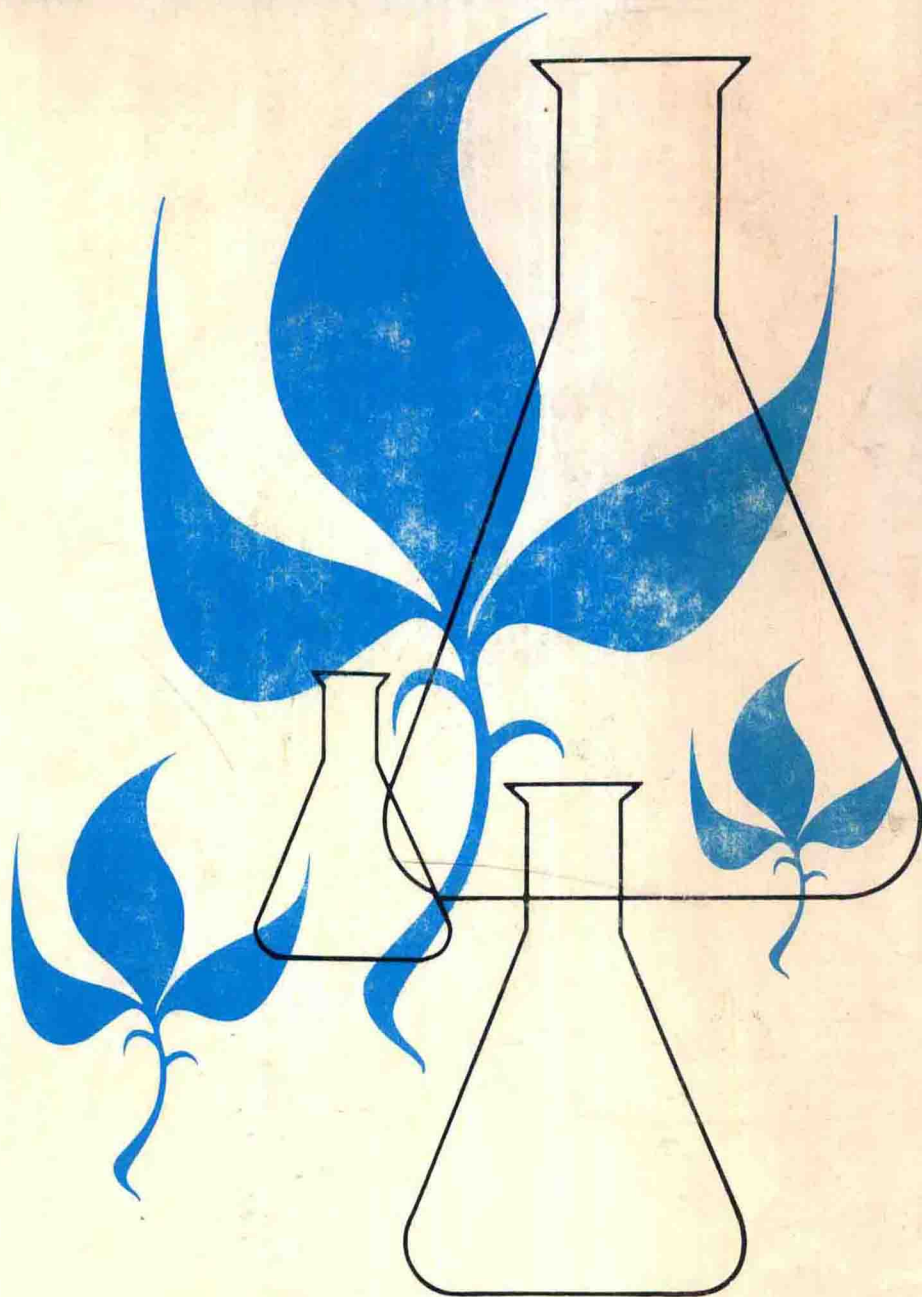


The Citrus Industry

VOLUME IV

DISEASES AND INJURIES; VIRUSES; REGISTRATION,
CERTIFICATION, INDEXING; REGULATORY MEASURES;
VERTEBRATE PESTS; BIOLOGICAL CONTROL OF INSECTS; NEMATODES



Edited by
WALTER REUTHER
E. CLAIR CALAVAN
GLENN E. CARMAN

THE CITRUS INDUSTRY

VOLUME IV

Crop Protection

EDITED BY:

Walter Reuther

E. Clair Calavan

Glenn E. Carman

Professor of Horticulture, Emeritus;
Professor of Plant Pathology; and
Professor of Entomology, respectively.
University of California, Riverside, California

WITH THE COLLABORATION OF:

Leo J. Klotz • James W. Wallace • E. Clair Calavan • Stanley M. Mather
E. H. McEachern • Dan Y. Rosenberg • F. Louis Blanc • Daniel W. Robinson
H. Len Foote • Maynard W. Cummings • Rex E. Marsh • C. P. Clausen
R. C. Baines • S. D. Van Gundy • E. P. DuCharme

Revised Edition

University of California

Division of Agricultural Sciences

1978

©1978 by The Regents of the University of California.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 67-63041
Printed in the United States of America

International Standard Book Number: 0-931876-24-9



DEDICATED TO
HOWARD SAMUEL FAWCETT
(1877-1948)

HOWARD SAMUEL FAWCETT
(1877-1948)

"Let us learn to dream, gentlemen; then perhaps we shall find the truth. . . . But let us beware of publishing our dreams before they have been put to proof by waking understanding."

—AUGUST KEKULÉ

On the morning of May 15, 1933, Howard Samuel Fawcett stood beneath an orange tree in a grove affected with a mysterious disease that had baffled plant pathologists for decades. Suddenly a group of leaves hanging in just the right light against the sky caught his attention. Eleven years earlier, Fawcett had discovered a therapeutic treatment for the disease, but the cause still eluded him. Now he was "seized with a sensation as if the eyes of the scientific workers in this subject for the preceeding eleven years were looking through

mine." The illuminated flecked markings on the leaves broke upon Fawcett as a light of instantaneous understanding. Years later he could recall the exact instant—eight o'clock—that he reached a completely new hypothesis about the cause of psorosis. From that moment of prescience, he proceeded methodically to gather the data leading to the first discovery of a virus disease in citrus.

Sudden creative insights, always subject to rigid experimental scrutiny, were characteristic of Fawcett. He often spoke of the need for "constructive dreaming" in research, citing as an example August Kekulé, the organic chemist, who had formulated the benzene ring structure as the result of a dream. Fawcett's coworkers were continually amazed at how often his hunches directed him toward productive areas of investigation that other researchers had ignored. As a pioneer in citrus

pathology, Fawcett was one of those rare scientists most often found on the frontiers of a developing new discipline who blaze a path for other researchers to follow through every uncharted area on which their attention focuses. His discoveries far outweigh those of any other citrus pathologist of his era, and he was the founder of citrus virology. His contributions were surpassed only by the inspiration and stimulation he gave to colleagues throughout the world.

Of slight stature, quiet and soft spoken, he endeared himself to his colleagues by his good fellowship, enthusiasm, and willingness to help. The adjectives most often used by his friends in describing him were "kind," "patient," "fair," and "understanding." His surviving close associates in plant pathology pay lavish tribute to his genius as a scientist, and to the inspiration and leadership he gave to his discipline. They also delight in telling humorous anecdotes involving Fawcett's monumental absentmindedness; without doubt, many of these stories lose nothing in retelling over the years.

Howard Samuel Fawcett was born of Quaker parents on a farm near Salem, Ohio, on April 12, 1877. He completed the local high school curriculum and then attended a Friends' preparatory school in Westtown, Pennsylvania, graduating in 1899. After teaching science for a year in a preparatory school in Le Grande, Iowa, Fawcett enrolled at Iowa State College, where he majored in botany and received his B.S. degree in 1905.

Following graduation, Fawcett accepted a post as assistant in botany and horticulture at the University of Florida, where he carried out research in association with three distinguished pioneers in citrus investigation, Herbert John Webber, Walter T. Swingle, and P. H. Rolfs. He was appointed assistant plant pathologist in 1907 and plant pathologist in 1908. During seven years at the University of Florida, Fawcett made many significant contributions on scaly bark and gummosis diseases of citrus trees, on stem-end rot of citrus fruits, and on fungus diseases of citrus insects. While in Florida, Fawcett married T. Helen Tostenson in 1909. They had one daughter, Rosamond Annette Fawcett.

In 1912, Fawcett accepted an assignment with the California State Commission of Horticulture to investigate the brown rot gummosis which was ravaging the citrus trees of the state. In that same year, Herbert John Webber became the first

director of the University of California Citrus Experiment Station (now the Citrus Research Center and Agricultural Experiment Station) at Riverside, California. Webber immediately began building a staff of outstanding citrus scientists. The state agreed to release Fawcett to join Webber's staff with the understanding that his research on gummosis be continued. During the next three years, Fawcett single-handedly isolated the causal fungi, proved their relationship to the disease, and developed effective treatment methods.

For two years, beginning in 1916, Fawcett was on leave at John Hopkins University, where he received his Ph.D. in 1918. During that period he worked under Dr. Burton E. Livingston, investigating the temperature relations of certain fungi parasitic on citrus trees and pioneering development of temperature control apparatus for botanical studies.

From 1918 until his retirement in 1947, Fawcett was a professor of plant pathology for the University of California and a plant pathologist for the Citrus Experiment Station at Riverside. He also served as chairman of the department of plant pathology from 1920 until 1946, when he relinquished the post to devote full time to research.

From 1922 to 1923, Fawcett was on sabbatical leave with a mission sent by the American Friends Service Committee to assist the famine-stricken area of southeastern Russia. Throughout his life, he worked quietly and persistently in many ways for the advancement of peace and goodwill among men. His humanitarianism permeated his nonscientific writings, including an insightful publication that explores the workings of the scientific mind, *Adventures in the Plant-Disease World*, first presented as a Faculty Research Lecture in 1940 at the University of California, Los Angeles.

As a collaborator with the U. S. Department of Agriculture from 1929 to 1930, Fawcett studied citrus and date diseases in the Mediterranean countries, North Africa, and Palestine. In 1936-37, he investigated citrus problems in Brazil and Argentina. His findings during these travels appeared in technical papers and later in his authoritative textbook *Citrus Diseases and Their Control*. This landmark work, considered the classic reference on citrus diseases, first appeared in 1926 with Dr. H. A. Lee, who wrote several chapters, serving as junior author. Subsequently, it was greatly revised and expanded under the sole authorship of Fawcett in 1936 and 1947.

During his long career in plant pathology, Fawcett studied numerous citrus diseases and various diseases of walnuts, dates, cotton, and avocados. He contributed upwards of 300 articles to scientific and industrial journals and published two books. His second book, *Color Handbook of Citrus Diseases*, coauthored with L. J. Klotz, was a practical guide to identification and control of citrus diseases. His name was starred in the fifth edition of *American Men of Science* (1933), which meant that he was then considered one of the 250 leading scientists in the United States and one of twenty-five leading botanists.

Fawcett's discovery of the psorosis virus opened up a new field of research in citrus diseases and placed the Citrus Experiment Station in the forefront of virology research. Shortly before his death in 1948, Fawcett demonstrated the virus origin of tristeza disease with J. M. Wallace, which

provided the key for dealing with a disease that threatened much of the world's citrus industry. Another major research contribution was his demonstration that stubborn disease was caused by a virus which could be transmitted by vegetative propagation. A review of early literature on citrus diseases clearly indicates the massive influence that Fawcett had on our knowledge of the cause, biology, and control of almost all of the major diseases affecting citrus.

Fawcett was a charter member of the American Phytopathological Society founded in 1909, and received its highest honor with his election to president of that national group in 1930. He was a member of Phi Beta Kappa, Sigma Xi, the Botanical Society of America, the Mycological Society of America, Societa Internazionale di Microbiologia (Milano), and a Fellow of the American Association for the Advancement of Science.

PREFACE

Since each volume of the revised and new edition of THE CITRUS INDUSTRY is complete in itself, the general plan of the work must be restated in each volume. The first volume of the revised edition, *History, World Distribution, Botany, and Varieties*, was published by the University of California Division of Agricultural Sciences in 1967. The second volume, *Anatomy, Physiology, Genetics, and Reproduction*, followed in 1968. These first two volumes covered much of the subject matter originally presented in Volume I of the first edition, plus some additional material. The third volume, *Production Technology*, published in 1973, encompasses orchard management portions of the subject matter originally covered in Volume II of the first edition. This fourth volume, *Crop Protection*, covers portions of Volume II of the first edition that were concerned with the biology and control of pests and diseases. Because many Crop Protection chapters exceeded original estimates of length, it was necessary to divide them into two volumes. Thus, a fifth volume, also concerned with crop protection, will appear soon. None of the chapters in these volumes are revisions of chapters in Volume II of the first edition; all are completely new treatments of the subject matter by a new generation of authors.

The first edition of *The Citrus Industry* served for more than two decades as the classic reference work on the biology and culture of citrus throughout the world. The first volume, *History, Botany, and Breeding*, edited by H. J. Webber and L. D. Batchelor, was published by the University of California Press in 1943, and was followed by two later reprintings. A larger printing of the second volume, *Production of the Crop*, edited by L. D. Batchelor and H. J. Webber, was published in 1948 by the University of California Press. In the decades following World War II, an increased tempo of citrus research has provided a much broader base of information and experience than was available to the original authors of the first

edition. Thus, the chapters presented in this and the other revised volumes reflect a substantial expansion of coverage and, thus, pages.

Most of the chapters in this volume were prepared by members of the staff of the University of California who are affiliated either with the Citrus Research Center and Agricultural Experiment Station (CRC-AES) at Riverside or with the University of California Agricultural Extension Service. Chapter 3 was prepared in collaboration with staff members of the State of California Department of Food and Agriculture, and Chapter 4 was written entirely by staff of this agency. Professor E. P. DuCharme of the University of Florida collaborated in the preparation of Chapter 7. Authors' treatment of subjects, therefore, tends to exhibit a regional perspective, although improved communications and transportation in the past few decades have made it possible for citrus researchers and specialists to be more cognizant of developments in other regions than was the case for contributors to the original volumes.

Taxonomic usage in this and other volumes of THE CITRUS INDUSTRY varies among chapters. No attempt was made to standardize the systematics since diversity in usage is common among technical citrus publications. A majority now accept W. T. Swingle's system, with seven species in the genus *Citrus*, for example, but some follow R. W. Hodgson, T. Tanaka, and others with many more species (see Volume I, Chapter 3 of THE CITRUS INDUSTRY, pp. 358-369).

The five volumes of the new revised and expanded edition of *The Citrus Industry* are intended to present a comprehensive view of all the production phases of the industry to a broad readership of researchers, administrators, advisors, teachers, students, and knowledgeable growers. An effort has been made to present all material clearly, yet scientifically, so that it might be understood by an intelligent and informed readership. The editors, however, considered it essential that scientific principles on which various practices are based also should be explained. Some parts of this volume, therefore, may present material of a highly technical nature best followed by specialists. Literature reviews for most chapters in the volume were completed with 1976 citations.

Tables for converting units of measurement from the English to the metric system and vice-versa are presented in Table I-1 of Appendix I.

Chapter 1, "Fungal, Bacterial, and Non-

papastic Diseases and Injuries Originating in the Seedbed, Nursery, and Orchard," by Leo J. Klotz, is a comprehensive review of the biology and control of the known diseases (except viruses) which afflict citrus seedlings as well as nursery and orchard trees. Also included are descriptions of various physiological and other nonparasitic disorders and injuries common in citrus orchards, together with the available preventative or therapeutic measures. This chapter is the most authoritative and up-to-date treatment of citrus diseases now available.

Chapter 2, "Virus and Viruslike Diseases" by James M. Wallace concerns the virus and viruslike diseases of citrus which have caused such serious losses to citrus growers throughout the world in the last half-century. The author, taking advantage of the great strides that have been made in the field of citrus virology in the past quarter century, provides a scholarly review of the subject. Included are descriptions of the symptoms, the nature of and structure of the organism when known, as well as modes of transmission, vector and host relations, rootstock-scion effects, detection methods, and avoidance procedures. Unfortunately, very little concerning practical therapeutic methods for infected orchard trees is included because of the lack of progress in field control methods for virus diseases of crop plants in general. This chapter is the first complete and up-to-date treatment to be written about this relatively new group of citrus diseases.

Chapter 3, "Registration, Certification, and Indexing of Citrus Trees" by E. Clair Calavan, Stanley M. Mather and E. H. McEachern, outlines the objectives of registration and certification programs and the historical evolution of the present day California program. Details of the legal basis, organization, and procedure used in California for ensuring the production of disease-free, true-to-name nursery stock are reviewed, along with description of programs in other states. Also, the methods used for virus and viruslike pathogen detection are described. This chapter will be of special interest not only to those interested in virus detection methodology, but also to regulatory people in other regions wishing to establish a citrus registration and certification program, or to improve an existing program.

Chapter 4, "Regulatory Measures For Pest and Disease Control" by Dan Y. Rosenberg, Eley

H. McEachern, F. Louis Blanc, Daniel W. Robinson, and H. Len Foote is concerned with the role of public regulatory agencies in pest and disease control in California and the United States. The philosophy, objectives, legal aspects, procedures and difficulties involved in quarantine, nursery inspection, pest and disease detection and eradication are discussed. Special emphasis is given to the problems of protecting the California citrus industry from the introduction of pests and diseases, and minimizing their spread within the state once they are established.

Chapter 5, "Vertebrate Pests of Citrus" by Maynard W. Cummings and Rex E. Marsh places greatest emphasis on the biology, damage, and control or management of the major vertebrate pest species. In the United States, rodents and lagomorphs (rabbits and hares) cause the most economic damage, while birds cause only minor economic losses. Also included are brief discussions of minor and potential pests. The depredations of birds, bats, and other pests in citrus orchards in some other citrus countries are discussed, but the information available is limited. Control measures are discussed from three viewpoints: (1) population reduction by use of lethal or sterilizing chemical agents, or by physical methods such as trapping or shooting; (2) habitat manipulation or modification to reduce orchard population by cultural practices and other means of altering the environment in a way unfavorable to the pests; and (3) behavioral manipulation by use of techniques which reduce damage by modifying or altering some behavior pattern, such as by use of chemical or physical repellents or barriers.

Chapter 6, "Biological Control of Citrus Insects" by C. P. Clausen is a basic treatment of the essentials of biological control of citrus pests throughout the world. Included are general discussions of the historical background, biotic control agents and procedures, biology of parasitic insects, microbial pathogens of insects, mass production of parasites, interactions with insecticides, and the time framework. The greater portion of the chapter is concerned with the biological control of specific insects parasitizing citrus.

Chapter 7, "Nematodes Attacking Citrus" by Richard C. Baines, Seymour D. Van Gundy, and Ernest P. DuCharme is a comprehensive treatment of the nematodes of citrus species. A majority of the chapter deals with the details of the

biology and control of specific nematode species which parasitize the roots of citrus species. Included are discussions of the influence of soil temperature and other soil factors, host plants, varietal tolerance, resistant strains, soil sterilization, and biological and chemical control measures.

The editors wish to express their deep appreciation to their colleagues too numerous to list

at Riverside and elsewhere around the world who so generously assisted by reviewing all or part of the text dealing with their particular fields of specialization.

WALTER REUTHER
Riverside, California
September 15, 1977

CONTENTS

CHAPTER 1. Fungal, Bacterial; and Nonparasitic Diseases and Injuries Originating in the Seedbed, Nursery, and Orchard	1
<i>Leo J. Klotz</i>	
Factors Affecting Incidence of Disease ...	2
The Major Bacterial and Fungal Diseases .	3
Seedbed Disorders	3
Damping-Off Disease	3
Albinism	5
Diseases and Injuries in the Nursery and Young Orchard	5
Diseases and Injuries of the Root System, Trunk and Scaffold Branches	9
Diseases Caused by <i>Phytophthora</i> spp. .	9
Bark Rots Caused by Other Fungi	15
Bark Blotch	15
Rio Grande Gummosis	15
Branch Wilt	18
Bark Rot	18
Diplodia Gummosis	18
Dothiorella Gummosis	18
Phomopsis Gummosis	18
Armillaria Root Rot	18
Rosellinia Root Rot	20
Phymatotrichum Root Rot	21
Hard Root Rot	22
Macrophomina Root Rot	22
Dry Root Rot	22
Wood Rots	24
Diseases and Injuries of Branches, Twigs, Leaves, and Preharvest Fruit	24
Pink Disease	24
Thread Blight	24
Areolate Spot or Mancha Areolada	25
Corticium Blight in Panama	26
Citrus Canker	26
Citrus Blast and Black Pit	28
Bacterial Spot of South Africa	28
Bacterial Leaf Spot of Sour Orange ...	28
Mal Secco	29
Citrus Blight	29
Diplodia Twig Blight	31
Sclerotinia Twig Blight	32
Botrytis Twig Blight	32
Fusarium Twig Disease	32
Citrus Scab	33
Melanose	33
Greasy Spot	35
Tar Spot	36
Phyllosticta Leaf Spots	36
Brown Rot and Phytophthora Blight ...	36
Various Leaf Spots	39
Sooty Mold	39
Smoky Blotch and Flyspeck	39
Powdery Mildew	39
Felt	40
Lichens	40
Alga Spot	40
Anthracnose (Including Withertip and Blossom Blight)	40
Septoria Spot	41
Black Spot	42
Citrus Knots, Galls, Witches'-Brooms ..	46
Parasitic Flowering Plants (Dodders, Mistletoes)	46
Leprosis	47
Mesophyll Collapse	48
Twig Dieback	48
June Drop of Fruitlets	49
Premature Fruit Drop	49
Fruit-Stem Die Back	49
Water Spot of Navel Oranges	49
Creasing of Orange Fruit	52
Endoxerosis	52
Peteca	52
Membranous Stain	53
Red Blotch	53
Albedo Browning	54
Stylar-End Rot	54
Granulation and Drying	54
Valencia Rind Spot	55
Rind Breakdown of Navel Oranges	55
Rind Stipple of Grapefruit	56
Gum Spot of Citrus Leaves	58
Lightning Injury	58
Hail and Snail Injury	58
Damage to Leaves and Fruit by Copper Sprays	58
Injury by Sulfur Fungicides-Insecticides	59
Injury by Plant Growth Regulators	61
Literature Cited	62

CHAPTER 2. Virus and Viruslike Diseases 67

James M. Wallace

The Psorosis Diseases	69	Importance of Woody Gall	143
Importance and Distribution	70	Transmission of Causal Virus	144
Symptomatology	70	Control	144
Diseases of the Psorosis Group	72	Satsuma Dwarf	145
Relationships of Diseases in the		Symptomatology	145
Psorosis Group	80	Transmission and Spread	146
Transmission and Spread	84	Varietal Reaction to Satsuma Dwarf....	147
Control of Psorosis	85	Control	147
The Tristeza-Disease Complex	87	Citrus Tatter Leaf	147
Historical Developments	88	Symptomatology and Varieties Affected	147
Economic Importance	90	Citrange Stunt	149
Symptomatology	93	Separation and Identification of	
Transmission and Spread	103	Citrange-Stunt Virus	149
Host Range of Tristeza Virus Complex	104	Symptomatology	149
Control of Tristeza	104	Transmission and Spread	151
Exocortis	109	Importance	152
Symptomatology	109	Impietratura	153
Geographic Distribution and Host Range	111	Symptomatology and Varieties Affected	153
Importance of Exocortis	111	Transmission and Spread	154
Transmission and Spread	111	Control	155
Control	112	Citrus Ring Spot	155
Xyloporosis (Cachexia)	115	Symptomatology	156
Geographic Distribution, Host Range,		Transmission and Spread	156
and Economic Importance	115	Distribution and Importance	156
Symptomatology	116	Citrus Yellow Vein	156
Transmission and Spread	117	Symptomatology	157
Control	120	Transmission	158
Stubborn Disease	121	Interactions of Yellow Vein with	
Economic Importance	121	Other Citrus Viruses	158
Symptomatology	122	Importance	159
Nature of Causal Agent	126	Leaf Curl	160
Transmission and Spread	127	Transmission and Spread	160
Control or Prevention	129	Varietal Reaction	160
Greening Disease	131	Possible Relation to Other Citrus Viruses	161
Symptomatology	131	Importance	161
Nature, Transmission, and Spread	132	Cristacortis	161
Control	133	Symptomatology	162
Citrus Dieback Disease	135	Host Range and Importance	163
Nature and Symptomatology	135	Transmission and Control	164
Control	136	Gum-Pocket of <i>Poncirus trifoliata</i>	164
Leaf-Mottle-Yellows Disease	137	Symptomatology	164
Transmission and Nature of Disease	137	Distribution	164
Host Range	138	Possible Origin of the Disease	164
Control	139	Control	165
Likubin Disease	139	Multiple Sprouting Disease	165
Citrus Vein-Phloem Degeneration	140	Symptomatology	166
Vein Enation and Woody Gall	140	Experimental Transmission	166
Symptomatology and Host Range	141	Field Spread	167
Influence of Tissue Wounding on		Control	167
Gall Development	142	Tarocco Pit	168

Failure of Rangpur Lime on Sweet Orange	168
Gummy Bark of Sweet Orange	169
Bud-Union Crease	170
Some Apparently Inherited Disorders of Citrus	171

Future Outlook	172
Literature Cited	173

CHAPTER 3. Registration, Certification, and Indexing of Citrus Trees 185

E. Clair Calavan, Stanley M. Mather, and E. H. McEachern

California Registration and Certification		Propagation of Nursery Stock from	
Programs	185	Registered Trees	199
History	185	Budwood Foundation Grove	199
The Psorosis		Validation	199
(Interim) Program (1937-1973)	186	Seed-Source Trees	199
The Long-Range Program (1962-1973)	188	The Texas Program	199
The Combined Program (1974-present)	190	The Brazilian Programs	200
Citrus Seed Tree Program	195	The Rio Program	200
Improved Meyer Lemon Program	195	The São Paulo Program	200
Coordination and Development of		Other Programs	200
California Programs	195	Indexing	201
Legal Authority and Significance of		Chemical Indexing	201
California Program	196	Serology	201
Financing of California		Culturing	201
Programs	197	Electron Microscopy	202
The Florida Program	197	Tissue-Graft Indexing	203
Pre-registration Procedures	198	Indexing Procedures	208
Registration Procedures	198	Literature Cited	219
Scion Grove Trees	198		

CHAPTER 4. Regulatory Measures for Pest and Disease Control 223

*Dan. Y. Rosenberg, Eley H. McEachern, F. Louis Blanc,
Daniel W. Robinson, and H. Len Foote*

Quarantine	223	Manpower and Inspection	229
The Purpose of Plant Quarantine	224	Protective Methods	229
Principles and Limitations of Plant		Pest and Disease Detection	230
Quarantine	224	Purpose and Goals of Pest and	
Dispersal	224	Disease Detection	230
Conditions Necessary for Pest		Methods Used in Citrus Pest	
Species Establishment	225	and Disease Detection	231
Adherence to Quarantine Regulations	226	Planning for and Evaluating Detection	231
Methods of Enforcing Plant Quarantines	226	Evaluation of Detection	232
Current Quarantines Protecting the U.S.		The Future of Detection	232
Citrus Industry	227	Eradication of Introduced Pests and	
Nursery Inspection	228	Diseases	233
Importance and Purpose of Nursery		Purpose and Goals of Eradication	233
Inspection	228	Principles and Limitations of Eradication	233
Principles of Nursery Inspection	228	Citrus Disease Eradication Programs	235
Methods of Nursery Inspection	228	Literature Cited	236

CHAPTER 5. Vertebrate Pests of Citrus	237
<i>Maynard W. Cummings and Rex E. Marsh</i>	
Control of Vertebrates	238
Habitat Manipulation	238
Behavioral Manipulation	239
Population Reduction	239
Mammal Pests in the United States	241
Pocket Gophers	241
Meadow Mice	247
Ground Squirrels	252
Jack Rabbits	254
Cottontails	256
Tree Squirrels	257
Cotton Rats	258
Woodrats	258
Pine Mice	259
Roof Rats	259
Commensal Rats and House Mice	260
Raccoons	262
Opossums	262
Armadillos	262
Tortoises	262
Deer Mice	263
Moles	264
Bats	264
Deer	264
Avian Pests in Citrus	265
Parrots	266
Red-Whiskered Bulbuls	268
Woodpeckers	268
Crows	269
Miscellaneous Birds	269
Bird Control Methodology	269
Safety Precautions	270
Acknowledgments	271
Literature Cited	272
CHAPTER 6. Biological Control of Citrus Insects	274
<i>C. P. Clausen</i>	
Biotic Control Agents	276
The Historical Background of	
Biological Control	277
The Procedures in Biological Control	278
Progress in Control of Specific Pests	279
The Fluted Scales (Margarodidae)	280
Cottony-Cushion Scale, <i>Icerya purchasi</i>	
Mask	280
<i>Icerya seychellarum</i> (Westw.)	282
Other Fluted Scales	283
The Armored Scales (Diaspididae)	283
California Red Scale, <i>Aonidiella</i>	
<i>aurantii</i> (Mask.)	283
Yellow Scale, <i>Aonidiella citrina</i> (Coq.)	285
Florida Red Scale, <i>Chrysomphalus</i>	
<i>aonidum</i> (L.)	285
Purple Scale, <i>Lepidosaphes</i>	
<i>beckii</i> (Newm.)	286
Glover Scale, <i>Lepidosaphes</i>	
<i>gloveri</i> (Pack.)	287
Yanone Scale, <i>Unaspis yanonensis</i>	
(Kuw.)	288
The Unarmored or Soft Scales (Coccidae)	288
Black Scale, <i>Saissetia oleae</i> (Bern.)	288
Nigra Scale, <i>Saissetia nigra</i> (Nietn.)	290
Citricola Scale, <i>Coccus pseudo-</i>	
<i>magnoliarum</i> (Kuw.)	291
Brown Soft Scale, <i>Coccus hesperidum</i> L.	291
Red Wax Scale, <i>Ceroplastes rubens</i>	
(Mask.)	292
White Wax Scale, <i>Ceroplastes</i>	
<i>destructor</i> Newst	292
Green Shield Scale, <i>Pulvinaria</i>	
<i>psidii</i> Mask	292
The Mealybugs (Pseudococcidae)	293
Citrus Mealybug, <i>Planococcus</i>	
<i>citri</i> (Risso)	293
Citrophilus Mealybug, <i>Pseudococcus</i>	
<i>fragilis</i> Brain	294
Long-Tailed Mealybug, <i>Pseudococcus</i>	
<i>longispinus</i> (Targioni-Tazetti)	295
Green's Mealybug, <i>Pseudococcus</i>	
<i>citriculus</i> Green	296
Hibiscus Mealybug, <i>Maconellicoccus</i>	
<i>hirsutus</i> Green	296
<i>Rastrococcus</i> (<i>Phenacoccus</i>) <i>iceryoides</i>	
(Green)	296
The Whiteflies and Blackflies (Aleyrodidae)	297
Citrus Blackfly, <i>Aleurocanthus</i>	
<i>woglumi</i> (Asb.)	297
Spiny Blackfly, <i>Aleurocanthus spiniferus</i>	
(Quaint.)	299
Citrus Whitefly, <i>Dialeurodes citri</i>	
(Ashm.)	300
Woolly Whitefly, <i>Aleurothrixus floccosus</i>	
(Mask.)	301
The Fruit Flies (Tephritidae) and Other	
Fruit Feeders	302
Mediterranean Fruit Fly, <i>Ceratitis</i>	
<i>capitata</i> (Wied.)	302

Natal Fruit Fly, <i>Pterandus</i> <i>rosa</i> Karsch	303	Citrus Red Mite, <i>Panonychus citri</i> (McG.)	305
Oriental Fruit Fly, <i>Dacus dorsalis</i> Hendel	303	Biology of Parasitic Insects	306
Queensland Fruit Fly, <i>Dacus tryoni</i> (Frogg.)	304	Adaptive Races of Parasitic Insects	306
South American Fruit Fly, <i>Anastrepha fratercula</i> (Wied.)	304	Supersedence of Parasite Species	307
Mexican Fruit Fly, <i>Anastrepha ludens</i> (Loew)	305	Mass Production of Parasites and Predators	308
Southern Green Stink Bug, <i>Nezara viridula</i> (L.)	305	Effects of Insecticides Upon Biological Control	310
The Plant-Feeding Mites (Acarina)	305	Microbial Control	313
		The Time Required for Biological Control	315
		Ants in Relation to Biological Control	316
		Literature Cited	317

CHAPTER 7. Nematodes Attacking Citrus..... 321

*R. C. Baines, S. D. Van Gundy, and
E. P. DuCharme*

The Citrus Nematode	321	Spreading Decline	331
Nematodes and Mineral Nutrition	322	Control of Burrowing Nematode	336
Nematodes and Soil Types	326	Other Nematodes Pathogenic on Citrus	337
Nematodes, Soil Moisture, and Oxygen Supply	327	Literature Cited	342
Effect of Soil Temperature on Infection and Survival.....	327	Appendix I. Conversion Tables for Temperature, Area, Length, Weight, Yield, Volume, and Tree Spacing	347
The Nematode's Life Cycle	327	Index	353
Nematode Hosts	328		
Nematode Control	329		

CHAPTER 1

Fungal, Bacterial, and Nonparasitic Diseases and Injuries Originating in the Seedbed, Nursery, and Orchard

LEO J. KLOTZ

THE CITRUS NURSERYMAN, grower, and packinghouse manager are, of necessity, greatly concerned with the prevention and control of maladies to which citrus is subject. If the grower had to combat all the numerous disorders of the world's citrus, he would soon be discouraged. Fortunately, however, only a few diseases in any citrus-growing locality are sufficiently important to require drastic control measures. Quarantine vigilance and local or worldwide differences in climate and soil conditions largely determine which disorders are present in a citrus area. For example, the dry climates of California, Arizona, and North Africa are unfavorable for citrus canker, scab, and melanose diseases which thrive near the equator and in environments such as those of Florida, Japan, and the West Indies. Septoria spot, brown rot, and water spot of citrus fruit, which cause great losses in California, are of minor or no significance in Florida. Northern California navel orchards suffer from blast, a disease which is of very minor importance in southern California.

In its broadest sense, plant disease is a deviation from the normal, healthy condition of a plant that threatens its usefulness or well being.

Any one of many agencies can cause disease: (1) parasitic higher plants, algae, fungi, and bacteria; (2) nonparasitic factors such as malnutrition, physical condition of environment, and inherited genetic weaknesses; (3) animal organisms, such as higher animals, insects, mites, and nematodes; and the very important group of agencies, including (4) viruses, mycoplasma-like and viroid organisms (Semancik and Weathers, 1971). This chapter, with minor exceptions, deals with diseases and injuries of citrus under the first two categories. Other chapters in this volume, in Volumes 2 and 3, and in Volume 5 (in press) discuss virus, mycoplasma-like, viroid, and postharvest diseases, nutritional deficiencies and excesses, and injury by insects, nematodes, rodents, and adverse climatic factors.

In general, the discussions of this chapter are arranged in groups corresponding to the parts of the citrus tree affected: (1) soil-borne diseases of roots and rootstocks; (2) diseases of trunk and scaffold branches; and (3) diseases of small branches, twigs, leaves, and fruit in the orchard.

In the prevention and treatment of diseases, three factors must always be considered: effectiveness of the methods of treatment, cost of

treatments, and possible injury to the plants. Obviously, the cost of control measures used must be less than the losses the disease could cause. In the control of diseases caused by parasitic organisms, various means are employed: (1) removing or restricting the sources of infections; (2) avoiding or decreasing the effects of conditions that promote the infection; (3) preventing entrance of the parasite by treating susceptible parts of plants with fungicides or disinfectants; (4) using resistant species and varieties; and (5) when the disease has not yet appeared or become established, excluding parasites from the orchard, locality, or even the entire country by quarantine measures.

Limitations of space for this chapter require that emphasis be given to brief descriptions of the diseases and means for control. More detailed discussion of history, geographic distribution, and the nature of causes of citrus diseases, and conditions contributing to their occurrence, together with literature references, have been presented in earlier publications.

The first edition of the classic publication *Citrus Diseases and Their Control* was written by Howard S. Fawcett and H. Atherton Lee (1926). The second edition with Dr. Fawcett (1936) as sole author recorded results of experiments and observations on citrus diseases up to 1936. Material up to 1948 was collected by H. S. Fawcett and L. J. Klotz (1948) in Chapter XI of Volume 2 of *The Citrus Industry*. The University of California Press in 1941 and 1948 published the first and second (revised) editions of a *Color Handbook of Citrus Diseases*, which by color photographs and descriptions gave the essential symptoms or means of recognizing all the diseases, injuries, and nutritional troubles of citrus considered important at that time. Control measures were also presented. The Division of Agricultural Sciences of the University of California published the third revised and enlarged edition of the handbook in 1961. Since 1948, many investigators have entered the field and made valuable contributions to our knowledge of citrus maladies caused by fungi, viruses, and unfavorable environmental conditions. Much of their material was abstracted and used in the fourth revised and enlarged edition of the color handbook (Klotz, 1973). Other useful compilations on citrus diseases have been published by Bondar (1929); Rhoads and DeBusk (1931); Rose *et al.* (1943); Suit (1949); Knorr, Suit, and DuCharme (1957); Pratt (1958); Chapot and Delucchi (1964);

Scaramuzzi (1965); Del Rosario (1968); and Knorr (1965, 1973).

FACTORS AFFECTING INCIDENCE OF DISEASE

Although conditions and operations influencing the occurrence and severity of diseases in seedbed, nursery, and orchard are discussed in more detail in later sections, a general statement may be made concerning such factors. Assuming first of all that a grower has secured trees free of diseases and pests and suitable to climatic and other conditions of his locale, there are several factors that can be controlled to keep his orchard healthy and productive. Soils and water with excessive or toxic salts or which harbor parasites of citrus obviously will be detrimental to the health and growth of trees. Excessive watering and poor drainage will promote root rot at all stages of growth. Crowding of seedlings and nursery and orchard trees will increase humidity in orchards and favor development and rapid spread of diseases such as damping-off, fruit and leaf spots, and decays. Injury from cold, even when tissues are not directly killed, provides conditions for bark- and wood-rotting fungi and weak parasites which ordinarily do not attack sound fruit or other parts of a tree. Damage by wind, hail, and lightning (see p. 58) also provides openings for disease-producing fungi and bacteria.

Avoidance or control of these unfavorable factors is the objective of the successful orchardist. Injuries to roots resulting from deep cultivation and concentrated fertilizers can be minimized by careful cultivation methods or the so-called noncultivation method and uniform application of recommended amounts of fertilizers. Quality of soil and water is a primary consideration. Soils and water harboring citrus parasites can be disinfested by treatment with certain chemicals. By close attention to irrigation, which should be guided by tensiometers, damage from overwatering can be avoided. Approved seeding and planting distances and pruning obviate dangers from overcrowding. Severe injury by cold weather usually can be avoided or lessened by careful selection of the orchard site to provide good air drainage and by use of heaters, air mixers, and certain plant-growth regulators. Again, it must be emphasized that since parasitism of citrus by several fungi is favored by cold injury, protection of trees from frost is also important in avoiding disease. The trees,

moreover, can be protected from many maladies by timely application of fungicides.

THE MAJOR BACTERIAL AND FUNGAL DISEASES

The four most important bacterial and fungal diseases in world citrus orchards both in terms of destructiveness and difficulty or expense in achieving control, are citrus canker, mal secco, black spot, and infections caused by *Phytophthora* spp. In certain areas, various other diseases, such as *Armillaria* root rot, blast, and scab are extremely serious, but the first four diseases mentioned are generally the most destructive.

The only successful method for control of citrus canker, a bacterial disease, is a campaign of thorough eradication, which involves the expense of frequent surveys, the use of a large amount of labor, and the destruction of affected trees. Mal secco is most severe in lemon orchards of the Mediterranean basin. This fungal disease requires almost daily observance and control measures by orchardists to remove affected parts of trees. Black spot is most damaging to the fruit of lemons and Valencia oranges in South Africa, Australia, and the Far East, requiring three or four well-timed sprays per crop to reduce enormous losses from fruit spoilage. *Phytophthora* spp. attack all organs of citrus trees and can destroy them at any growth stage. Great losses are caused, particularly through fruit decay.

It is evident that control measures in the orchard, including avoidance of mechanical injuries due to chemical and climatic factors are required not only for protection of trees and fruit but also for many of the fruit maladies that may develop after harvest.

SEEDBED DISORDERS

Damping-Off Disease

The general occurrence and seriousness of the damping-off disease of citrus seedlings (figs. 1-1 and 1-2) make it an important concern of nurserymen and growers. The disease wreaks havoc in seedbeds where excessive soil moisture accompanies favorable temperatures for the causal fungi (Klotz *et al.*, 1966).

Symptoms.—Two phases of the disorder are recognized: (1) the pre-emergence phase, during which the fungi attack the young embryo before it reaches the soil surface; and (2) the post-emergence phase, in which fungi attack the seedling stem at ground level. The former results in a sparse stand and the latter in many toppled seedlings.

A soil-borne fungus, *Rhizoctonia solani* Kuhn, is the principal cause of this malady with citrus seedlings. *Pythium aphanidermatum* (Eds.) Fitz. and other *Pythium* spp. may occasionally cause some damage (DeWolfe, Calavan, and Sufficool, 1954). Where present, *Phytophthora citrophthora* (Sm. & Sm.) Leonian and *P. nicotianae*

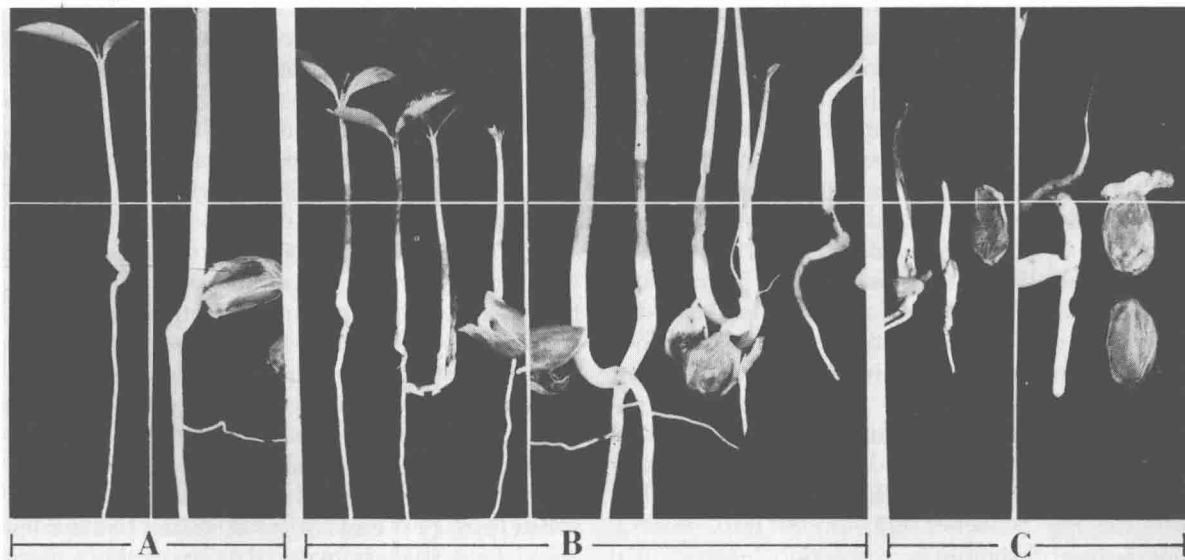


Fig. 1-1. Damping-off disease of citrus seedlings. A, healthy seedlings. B, post emergence damping off. C, preemergence damping off. White line indicates soil surface. (Photos courtesy of T. A. DeWolfe).