

Published 1984

**PHYSIOLOGICAL BASIS OF CROP  
GROWTH AND DEVELOPMENT**

## **FOUNDATIONS FOR MODERN CROP SCIENCE SERIES**

- Crops and Man 1975  
*J. R. Harlan*
- Introduction to Crop Protection 1979  
*W. B. Ennis, Jr.*
- Crop Quality, Storage, and Utilization 1980  
*C. S. Hoveland*
- Crop Breeding 1983  
*D. R. Wood*
- Physiological Basis for Crop Growth and Development 1984  
*M. B. Tesar*
- Ecological Bases for Crop Growth and Development  
In preparation
- Propagation of Crops In preparation

# PHYSIOLOGICAL BASIS OF CROP GROWTH AND DEVELOPMENT

M. B. Tesar

*Editor*

American Society of Agronomy  
Crop Science Society of America  
Madison, Wisconsin  
1984

Domenic Fuccillo, *Managing Editor*  
Betty Les, *Manuscript Editor*  
Kristine E. Gates, final production  
Cover graphics prepared by Julia L. McDermott

Copyright © 1984 by the American Society of Agronomy, Inc., and the Crop Science Society of America, Inc.

ALL RIGHTS RESERVED UNDER THE U.S. COPYRIGHT LAW OF 1978 (P.L. 94-553). Any and all uses beyond the "fair use" provision of the law require written permission from the publishers and/or the authors; not applicable to contributions prepared by officers or employees of the U.S. Government as part of their official duties.

**Library of Congress Cataloging in Publication Data**

Library of Congress Catalog Card Number: 84-71222  
ISBN 0-89118-037-0

The American Society of Agronomy, Inc., and  
the Crop Science Society of America, Inc.  
677 S. Segoe Road, Madison, Wisconsin, USA 53711

Printed in the United States of America

# CONTENTS

<b>Foreword</b> .....	<b>ix</b>
<b>Preface</b> .....	<b>xi</b>
<b>Contributors</b> .....	<b>xiii</b>

## 1. CROP CLASSIFICATION

<i>A. W. Burger</i> .....	1
Agronomic Use .....	1
Special Purpose .....	6
Growth Habit or Life Cycle .....	7
Leaf Retention .....	8
Structure and Form .....	8
Climatic Adaptation .....	8
Usefulness.....	8
Photorespiration Type .....	9
Photoperiodic Reaction .....	9
Temperature Types .....	10
Botanical Classification .....	10
Suggested Reading.....	12

## 2. SEED DEVELOPMENT, METABOLISM, AND COMPOSITION

<i>L. H. Smith</i> .....	13
Development of Seed.....	14
Metabolism of Seeds .....	24
Seed Composition .....	28
Suggested Reading.....	52

## 3. SEED GERMINATION AND CROP PRODUCTION

<i>Vernon B. Cardwell</i> .....	53
Seed Quality .....	54
Regulation of Germination.....	63
Physiology of Germination .....	73
Factors Regulating Emergence and Seedling Establishment in the Field ..	78
Summary.....	90
References.....	91
Suggested Reading.....	92

## 4. SEEDLING GROWTH

<i>C. J. Nelson and K. L. Larson</i> .....	93
Structure and Growth of Cells .....	96
Growth .....	100
Cell Division and Vacuolation .....	102
Cell Wall Growth.....	103

Directional Control of Growth .....	105
Growth in the Natural State .....	108
Seedling Emergence.....	108
Root Development.....	112
Vegetative Shoot Development .....	114
Leaf Growth .....	115
Energy Sources.....	120
Environmental Influences on Emergence .....	122
References.....	128
Suggested Reading.....	129
<b>5. PHOTOSYNTHESIS, RESPIRATION, AND PHOTORESPIRATION IN HIGHER PLANTS</b>	
<i>Dale N. Moss</i> .....	131
Photosynthesis.....	132
The Biochemical Reactions of Photosynthesis.....	132
Environmental Responses of Photosynthesis.....	138
Respiration.....	147
Photorespiration .....	149
Concluding Statement.....	150
References.....	151
<b>6. GROWTH OF THE GREEN PLANT</b>	
<i>R. H. Brown</i> .....	153
Patterns of Growth .....	154
Growth Analysis .....	157
Partitioning of Photosynthetic Products .....	160
Photosynthate Translocation.....	164
Field Aspects of Growth.....	165
References.....	173
<b>7. NITROGEN AND MINERALS</b>	
<i>J. G. Streeter and A. L. Barta</i> .....	175
Nitrogen .....	176
Other Nutrients .....	190
References.....	199
Suggested Reading .....	200
<b>8. ENVIRONMENTAL STRESS INFLUENCES ON PLANT PERSISTENCE, PHYSIOLOGY, AND PRODUCTION</b>	
<i>Jerry D. Eastin and Charles Y. Sullivan</i> .....	201
Terminology.....	201
Stress Interactions .....	203
Temperature Stresses.....	205
Water Stress .....	214
Combined Stress Effects.....	223
Mineral Stress in Plants.....	227
Air Pollutants.....	228
Summary.....	230
Appendix: Water Potential Derivation .....	230
References.....	233

<b>9. FLOWERING</b>	
<i>F. G. Dennis, Jr.</i> .....	237
Components of Yield .....	238
Developmental Stages .....	238
Control of Flowering .....	240
The Physiology of Flowering .....	253
Summary .....	262
References .....	263
Suggested Readings .....	264
<b>10. FRUIT DEVELOPMENT</b>	
<i>F. G. Dennis, Jr.</i> .....	265
Pollination .....	266
Environmental and Cultural Control of Fruit Set .....	268
Mechanisms Controlling Fruit Set .....	271
Fruit Growth .....	272
Mechanisms Controlling Fruit Growth .....	279
Ripening and Senescence .....	280
Mechanisms Controlling Ripening .....	285
Summary .....	286
References .....	287
Suggested Reading .....	288
<b>11. GENETICS AND USE OF PHYSIOLOGICAL VARIABILITY IN CROP BREEDING</b>	
<i>Donald C. Rasmusson and Burle G. Gengenbach</i> .....	291
Genes and Gene Functions .....	292
Breeding for Physiological Traits .....	298
Selection and Breeding Methods .....	302
Accomplishments in Breeding for Physiological Traits .....	305
Opportunities in Breeding for Physiological Traits .....	307
Summary .....	319
References .....	320
<b>INDEX</b> .....	323





# FOREWORD

The accelerated pace of research, augmented by sophisticated instrumentation and techniques, and new opinions, imparts to crop science a rapidly changing character as new discoveries replace and/or add to former concepts. New findings force us to reevaluate and often reconstruct the foundations on which crop science rests.

The Teaching Improvement Committee of the Crop Science Society of America identified the urgent need for developing contemporary reading materials aimed at upper level undergraduate college students. A current presentation of the dynamic state of modern crop science is a formidable challenge worthy of the best talents of eminent research and teaching personnel in the field. This task necessitates assembling the most capable representatives of the various disciplines within crop science and bringing them together in teams of writers to prepare a series of publications based on contemporary research. The Crop Science Society of America and the American Society of Agronomy have undertaken this large assignment by selecting more than 100 specialists who will contribute to making the Foundations of Modern Crop Science books a reality.

The authors and editors of this series believe that the new approach taken in organizing subject matter and relating it to current discoveries and new principles will stimulate the interest of students. A single book cannot fulfill the different and changing requirements that must be met in various programs and curricula within our junior and senior colleges. Conversely, the needs of the students and the prerogatives of teachers can be satisfied by well-written, well-illustrated, and relatively inexpensive books planned to encompass those areas that are vital and central to understanding the content, state, and direction of modern crop science. The Foundations for Modern Crop Science books represent the translation of this central theme into volumes that form an integrated series but can be used alone or in any combination desired in support of specific courses.

The most important thing about any book is its authorship. Each book and/or chapter in this series on Foundations for Modern Crop Science is written by a recognized specialist in his discipline. The Crop Science Society of America and the American Society of Agronomy join the Foundations for Modern Crop Science Book Writing Project Committee in extending special acknowledgement and gratitude to the many writers of these books. The series is a tribute to the devotion of many important contributors who, recognizing the need, approach this major project with enthusiasm.

A. W. Burger, chairman  
D. R. Buxton  
A. A. Hanson  
C. O. Qualset  
L. H. Smith



## PREFACE

This book is intended as a text or reference book for undergraduate students at the junior-senior level in the plant sciences, primarily in colleges of agriculture. The material in several of the chapters is comprehensive enough to meet the requirements of instruction at the graduate level.

The authors were selected from various disciplines within agronomy and horticulture from eight different universities. Each author is an authority in his field of research and teaching. Most of the authors are now actively engaged in teaching or have taught undergraduate students in various universities in the USA. Because of the wide diversity of authors, the reader will detect different styles of writing with a varying emphasis on citations or references in the written text. Some chapters have a group of references only at the end of the chapter; others may have citations referred to directly in the text. In either case, the material presented is very readable, understandable, and, I hope, stimulating enough to generate a further interest in a career in the plant sciences.

The information in the chapters should be self-explanatory but students may occasionally find the material complex—but interesting enough to warrant reading of the cited references.

All of the chapters, except Chapter 11, “Genetics and Use of Physiological Variability in Crop Breeding,” are primarily physiological in nature. Chapter 11 shows the importance of physiology in plant breeding and should provide a meaningful link between the physiology and genetics of plants. This chapter, prepared initially by two authors for this book, has been modified slightly and used as a chapter in Book IV, *Crop Breeding*, in this series.

I have enjoyed editing this book and hope the authors have enjoyed the important task of writing a chapter for a reference designed primarily for undergraduate students. Each author had to put teaching or research duties aside to complete the task and to each, I am most grateful. May your efforts be reflected in better-informed students who will help solve the urgent food problems of our world in the 21st century.

M. B. Tesar  
East Lansing, Michigan



## CONTRIBUTORS

Allan L. Barta, Professor, Department of Agronomy, The Ohio State University, Wooster, OH 44691.

R. H. Brown, Professor, Department of Agronomy, University of Georgia, Athens, GA 30602.

A. W. Burger, Professor, Department of Agronomy, University of Illinois, Urbana, IL 61801.

Vernon B. Cardwell, Professor, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108.

Frank G. Dennis, Jr., Professor, Department of Horticulture, Michigan State University, East Lansing, MI 48824.

Jerry D. Eastin, Professor of Crop Physiology, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0817.

Burle G. Gengenbach, Professor, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108.

Kenneth L. Larson, formerly Professor of Agronomy, College of Agriculture, University of Missouri, Columbia, MO 65211; now Associate Dean for Academic Programs, Iowa State University, Ames, IA 50011.

Dale N. Moss, Professor, Department of Crop Science, Oregon State University, Corvallis, OR 97331.

C. J. Nelson, Professor, Department of Agronomy, University of Missouri, Columbia, MO 65211.

Donald C. Rasmuson, Professor, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108.

John G. Streeter, Professor, Ohio Agricultural Research and Development Center, The Ohio State University, Wooster, OH 44691.

Charles Y. Sullivan, Research Plant Physiologist, Agricultural Research Service, U.S. Department of Agriculture, University of Nebraska, Lincoln, NE 68583-0817.