

**PHYSIOLOGICAL BASIS
OF CROP GROWTH
AND DEVELOPMENT**

M. B. Tesar

Editor

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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.

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East Lansing, Michigan

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1 Crop Classification

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As the crop scientist looks into nature to appraise and evaluate the many thousands of different kinds of plants growing on this planet, he or she may feel frustrated by their large number and great diversity. However, crop plants can be systematically classified in various ways. Such classification makes for orderly and relevant approaches to the discussion of the many species and their uses.

There are many alternatives in classifying crop plants. Some of the more obvious routes of classification include 1) agronomic use, 2) special purpose, 3) growth habit, 4) leaf retention, 5) structure and form, 6) climatic adaptation, 7) usefulness, 8) photorespiration type, 9) photoperiod requirement, 10) temperature type, and 11) botanical. Each of these categories of classification is discussed in this chapter. Scientific names of crop plants discussed here, unless noted otherwise, are provided in Table 1.1.

AGRONOMIC USE

One of the more obvious ways to classify plants is to list them according to agronomic use (Table 1.1). What more meaningful way is there than to designate a crop for its uses as food, fuel, fiber, oil, or drugs? Therefore, we refer to grasses grown for their edible seeds as cereals. These include, especially, barley, grain sorghum, Job's-tears (*Coix lacryma-jobi* L.), corn (also called maize), oats, pearl and proso millets, rice, rye, teff [*Eragrostis*

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Table 1.1. Some important crop plants and their characteristics.†

Common name	Scientific name	Life cycle‡	Chromosome number§	Photo-periodic reaction¶	Photo-respiration type#	Temperature type††	Use (primary)
Alfalfa	<i>Medicago sativa</i> L.	P	16	L	C ₃	C	Forage
Barley	<i>Hordeum vulgare</i> L.	A;WA	7	L;N	C ₃	C	Food, feed, beer
Bean, field	<i>Phaseolus vulgaris</i> L.	A	11	S;N	C ₃	W	Food
Bean, lima	<i>Phaseolus lunatus</i> Macf.	P;A	11	S	C ₃	W	Food
Bean, mung	<i>Phaseolus aureus</i> Roxb.	A	11	S	C ₃	W	Food
Beet, sugar	<i>Beta vulgaris saccharifera</i> L.	B	9	L	C ₃	C	Sugar
Benigrass, creeping	<i>Agrostis palustris</i> Huds.	P	14	L	C ₄	C	Turf
Bermudagrass	<i>Cynodon dactylon</i> (L.) Pers.	P	15;18	—	C ₄	W	Forage, turf
Birdsfoot trefoil	<i>Lotus corniculatus</i> L.	P	12	L(?)	C ₃	C	Forage
Bluegrass, Kentucky	<i>Poa pratensis</i> L.	P	14;28;35	N	C ₃	C	Forage, turf
Bromegrass, smooth	<i>Bromus inermis</i> Leyss.	P	21;28;35	L	C ₃	C	Forage
Broomcorn	<i>Sorghum vulgare technicum</i> Pers.	A	10	S	C ₄	W	Brooms
Buckwheat, common	<i>Fagopyrum esculentum</i> Gaertn.	A	8	L;N	C ₃	W	Food, feed
Cassave	<i>Manihot utilissima</i> esculenta Pohl.	P	18;36	N	—	W	Food, forage
Castorbean	<i>Ricinus communis</i> L.	P;A	10	L	C ₃	W	Drug
Clover, alsike	<i>Trifolium hybridum</i> L.	P	8	L	C ₃	C	Forage
crimson	<i>Trifolium incarnatum</i> L.	WA	7;8	L	C ₃	C	Forage
ladino	<i>Trifolium repens</i> L.	P	8;12;14;16	L	C ₃	C	Forage
red	<i>Trifolium pratense</i> L.	P	7;14	L	C ₃	C	Forage
sweet, white	<i>Medicago alba</i> Med.	B	8	L	C ₃	C	Forage
sweet, yellow	<i>Medicago officinalis</i> Lam.	B	8	L	C ₃	C	Forage
white	<i>Trifolium repens</i> L.	P	8;12;14;16	L	C ₃	C	Forage
Corn or maize, dent	<i>Zea mays</i> L.	A	10	S	C ₄	W	Feed, food
Corn or maize, sweet	<i>Zea mays saccharum</i> L.	A	10	S	C ₄	W	Food

(continued on next page)

Table I.I. Continued.

Common name	Scientific name	Life cycle†	Chromosome number§	Photo-periodic reaction¶	Photo-respiration type#	Temperature type**	Use (primary)
Cotton, upland	<i>Gossypium hirsutum</i> L.	P;A	26	N	C ₁	W	Fiber, feed, food
Cotton, Egyptian	<i>Gossypium barbadense</i> L.	P;A	26	N	C ₁	W	Fiber, feed, food
Cowpea	<i>Vigna sinensis</i> Endl.	A	12	S	C ₁	W	Forage, food
Crotalaria, showy	<i>Crotalaria spectabilis</i> Roth.	A	8	S	C ₁	W	Cover
Crownvetch	<i>Coronilla varia</i>	P	—	S	C ₁	—	Erosion control
Fescue, red	<i>Festuca rubra</i> L.	P	7;21;28;35	—	C ₁	C	Turf
Fescue, tall	<i>Festuca arundinacea</i> Schreb.	P	21	—	C ₁	C	Forage, turf
Field pea (see pea)							
Flax	<i>Linum usitatissimum</i> L.	A	15	L	C ₁	C	Fiber, food, paint
Guar	<i>Cyamopsis psoralides</i> DC.	A	7	—	—	W	Food, feed
Guayule	<i>Parthenium argentatum</i> Gray	P	—	W	—	—	Latex rubber
Hemp	<i>Cannabis sativa</i> L.	A	10	S	C ₁	C	Fiber
Hop	<i>Humulus lupulus</i> L.	P	10	L	C ₁	—	Beer
Kenaf	<i>Hibiscus cannabinus</i> L.	A	18	S	C ₁	W	Fiber
Kudzu	<i>Pueraria thunbergiana</i> Benth.	P	22 or 24	—	—	W	Forage
Lentil	<i>Lentilla lens</i>	A	7	L	C ₁	W	Food
Lespedeza, common	<i>Lespedeza striata</i> Hook & Arn	A	10	S	C ₁	W	Forage
Lespedeza, Korean	<i>Lespedeza stipulacea</i> Maxim	A	10	S	C ₁	W	Forage
Lespedeza, sericea	<i>Lespedeza cuneata</i> (Dum. de Cours) G. Don.	A	10	S	C ₁	W	Forage
Lupine, blue	<i>Lupinus angustifolius</i> L.	P	10	S	C ₁	W	Forage
Lupine, white	<i>Lupinus albus</i> L.	A	20;24	N;S	C ₁	—	Forage
Lupine, yellow	<i>Lupinus luteus</i> L.	A	ca. 20	N	C ₁	—	Forage
Maize (see corn)			ca. 23	N;L	C ₁	—	Forage
Millet, foxtail	<i>Setaria italica</i> (L.) Beauv.	A	9	S	C ₁	—	Food, feed
Millet, pearl	<i>Pennisetum glaucum</i> L.	A	7	S	C ₁	—	Forage, food
Millet, proso	<i>Panicum miliaceum</i> L.	A	18;21;36	S	C ₁	—	Food

(continued on next page)

Table 1.1. Continued.

Common name	Scientific name	Life cycle†	Chromosome number§	Photo-periodic reaction¶	Photo-respiration type#	Temperature type††	Use (primary)
Mint (peppermint)	<i>Mentha piperita</i> L.	P	18	—	C ₁	—	Flavoring, drug
Mint (spearmint)	<i>Mentha spicata</i> L.	P	18	—	C ₁	—	Flavoring, drug
Oats, common	<i>Avena sativa</i> L.	A;WA	21	L;N	C ₁	—	Feed, food
Oats, red	<i>Avena byzantina</i> C. Koch	A;WA	21	L;N	C ₁	—	Feed, food
Orchardgrass	<i>Dactylis glomerata</i> L.	P	14	N;L	C ₁	C	Forage
Pea, field	<i>Pisum sativum</i> L.	A	7	L	C ₁	C	Forage
Peanut	<i>Arachis hypogaea</i> L.	A	20	S	C ₁	W	Feed, food
Potato	<i>Solanum tuberosum</i> L.	P;A	12;24	L;N	C ₁	C	Food
Ramie	<i>Boehmeria nivea</i> Gaud.	P	14	—	C ₁	—	Fiber
Rape, oilseed	<i>Brassica napus annua</i> Koch	A	19	L	C ₁	C	Lubrication
Rape, winter	<i>Brassica napus biennis</i> (Schubl. & Mart.)	B	19	—	C ₁	C	Forage
Redtop	<i>Agrostis alba</i> L.	P	14;21	—	C ₁	C	Forage, turf
Reed canarygrass	<i>Phalaris arundinacea</i> L.	P	14	L	C ₁	C	Forage
Rice	<i>Oryza sativa</i> L.	A	12	S	C ₁	W	Food
Rye	<i>Secale cereale</i> L.	A;WA	7	L;N	C ₁	C	Food, whiskey
Ryegrass, Italian	<i>Lolium multiflorum</i> Lam.	WA	7	L	C ₁	C	Forage, turf
Ryegrass, perennial	<i>Lolium perenne</i> L.	P	7	L	C ₁	C	Forage, turf
Safflower	<i>Carthamus tinctorius</i> L.	A	12	L;N	C ₁	—	Food, soap, paint
Sesame	<i>Sesamum indicum</i> L.	A	13;26	S	C ₁	W	Food
Sorghum (feterita)	<i>Sorghum bicolor</i> (L.) Moench	A	10	S	C ₁	W	Feed
Sorghum (hegari)	<i>Sorghum bicolor</i> (L.) Moench	A	10	S	C ₁	W	Feed
Sorghum (kafir)	<i>Sorghum bicolor</i> (L.) Moench	A	10	S	C ₁	W	Feed
Sorghum (milo)	<i>Sorghum bicolor</i> (L.) Moench	A	10	S	C ₁	W	Feed
Sorghum (sorgo)	<i>Sorghum bicolor</i> (L.) Moench	A	10	S	C ₁	W	Feed
Sorghum x sudangrass		A	10	S	C ₁	W	Forage

(continued on next page)

Table 1.1. Continued.

Common name	Scientific name	Life cycle†	Chromosome number§	Photo-periodic reaction¶	Photo-respiration type#	Temperature type††	Use (primary)
Soybean	<i>Glycine max</i> Merrill	A	20	S;N	C ₁	W	Food, feed
Sudangrass	<i>Sorghum bicolor drummondii</i>	A	10	S	C ₁	W	Forage
Sugar beet (see beet, sugar)							
Sugarcane	<i>Saccharum officinarum</i> L.	P	40	S	C ₁	W	Sugar, syrup
Sunflower	<i>Helianthus annuus</i> L.	A	17;34	N	C ₁	—	Feed, food
Sweet clover (see clover, sweet)							
Teosinte	<i>Euchlaena mexicana</i> Schrad.	A	10	—	C ₁	W	Feed, food
Timothy	<i>Phleum pratense</i> L.	P	7;21	L	C ₁	C	Forage
Tobacco	<i>Nicotiana tabacum</i> L.	A	24	N	C ₁	W	Drug (smoking)
Trefoil (see birdsfoot trefoil)							
Vetch, common	<i>Vicia sativa</i> L.	A;WA	6;7	L	C ₁	C	Forage
Vetch, hairy	<i>Vicia villosa</i> Roth	WA;B	7	L	C ₁	C	Forage
Wheat, common	<i>Triticum aestivum</i> L.	A;WA	21	L;N	C ₁	C	Food, feed
Wheat, durum	<i>Triticum turgidum</i> L.	A	14	L;N	C ₁	C	Food, feed
Wheatgrass, crested	<i>Agropyron cristatum</i> (L.) Gaertn.	P	7	—	C ₁	C	Forage
Wheatgrass, slender	<i>Agropyron trachycaulum</i> (Link) Malte	P	14	—	C ₁	C	Forage
Wheatgrass, western	<i>Agropyron smithii</i> Rydb.	P	21;28	L	C ₁	C	Forage

+ Dashes and question marks are used in the original tables. No explanation was given, but it is assumed that dashes (—) mean that the information is unknown and question marks (?) symbolize a conjectural classification. Adapted from Martin, John H., and Warren H. Leonard. 1967. Principles of Field Crop Production. The MacMillan Company, London, and Martin, John H., Warren H. Leonard and David L. Stamp. 1976. (same publication).

† Life cycle: A = Annual; WA = Winter annual; B = Biennial; P = Perennial.

§ Chromosome number: reduced (gametic) number (N).

¶ Photo-periodic reaction: L = Long day; S = Short day; N = Day neutral or indeterminate.

Photo-respiration types: C₁ = Low net assimilation rate (high compensation point); C₂ = High net assimilation rate (low compensation point).

†† Temperature type: C = Cool-weather growth; W = Warm-weather growth.

tef (Zuccagni) Trotter], and wheat. Drug crops include mint (peppermint, spearmint), pyrethrum (*Chrysanthemum cinerariifolium* L. and *C. coccineum* L.), tobacco, and wormseed (*Chenopodium ambrosioides* L.). Many crops are grown for their fiber content. Fiber crops include abaca (*Musa textilis* Nee), broomcorn brush, cotton, flax, hemp, henequen (*Agave fourcroydes* Lem.), jute (*Corchorus capsularis* L.), kapok (*Ceiba pentandra* L.), kenaf, ramie, sansevieria (*Sansevieria* spp.), and sisal (*Agave sisalana* Perr.). Many animal feeds are derived from the vegetable matter (forage), either fresh or preserved, of various plants. Such crops are called forage crops and these include primarily grasses, legumes, and crucifers. Forage crops are used as pasture, silage, soilage, haylage, fodder, and hay. Certain legumes such as broadbean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.), cowpea, field bean and mung bean, field pea, lentil, peanut, pigeonpea [*Cajanus cajan* (L.) Huth], and soybean are grown for their edible seed. Root crops are those with swollen underground roots. These include cassava, carrot (*Daucus carota* L.), mangel and sugar beet, rutabaga [*Brassica napus* (L.) Napobrassica group], sweet potato [*Ipomoea batatas* (L.) Lam.], and turnip (*Brassica rapa* L.). In contrast, tuber crops such as potato and Jerusalem artichoke (*Helianthus tuberosus* L.) are grown for their enlarged underground stems. Sugar crops include primarily sugar beet and sugarcane. Sucrose is extracted and crystallized from these two species. You might also include as sugar crops sorghum and sugarcane, as sources of syrup, and corn, a source of dextrose. Many crops are grown for their oil, either edible or nonedible. These species, known as oil crops, include castorbean, corn, cotton, crambe (*Crambe abyssinica* Hochst. ex R. E. Fries), flax, peanut, perilla [*Perilla frutescens* (L.) Britt.], rape, safflower, sesame, soybean, and sunflower. Both guayule and kok-saghyz or Russian dandelion (*Taraxacum kok-saghyz* Roden) are grown for their latex and are referenced as rubber crops.

SPECIAL PURPOSE

Many agriculturists refer to different groups of crops by the specific purpose used. Thus, a catch crop is a substitute crop planted too late for a regular crop or after the regular crop has failed. Short season crops such as millet or sorghum \times sudangrass crosses are often used as catch crops. A companion crop, often referred to as a nurse crop, is one grown in association with another, sometimes for mutual benefit, and usually in order to get a return from the land in the first year of a new seeding. Thus, an oats companion to alfalfa ensures a grain or silage crop from the oats while the alfalfa crop is becoming established. The oats crop is a companion to the alfalfa and "nurses" the latter; i.e., the oats provide a soil-holding capacity while the slow-establishing alfalfa takes root. A cover crop is seeded to hold

the soil temporarily or during the winter months. Cover crops such as alfalfa, clovers, vetches, soybean, cowpea, rye, and buckwheat are usually plowed under for their fertility and/or tilth values to the succeeding crop. When such cover crops are turned under, they are referred to as green manure crops. Crops harvested and preserved in a succulent condition by partial fermentation and stored in an airtight receptacle are referred to as silage crops. Corn, sorghum, sorghum \times sudangrass crosses, forage grasses and forage legumes are some of the more important silage crops. Soiling crops are cut and fed green. Sorghum \times sudangrass crosses, field pea, and corn are good examples of soiling crops. Trap crops are seeded to attract certain insect parasites. Such crops are usually plowed under as a green manure crop after serving their purpose.

GROWTH HABIT OR LIFE CYCLE

It is often convenient to refer to plants as summer annuals, winter annuals, biennials, and perennials, depending on their life cycles (Table 1.1). The principal food crop plants of the world are annuals, including wheat, rye, oats, barley, rice, millet, bean, soybean, pea (*Pisum* spp.), and corn. Some of these are classified as summer annuals, others as winter annuals. Thus, spring wheat, which is grown in the Dakotas, Montana, and Canada, is sown in the spring and completes its life cycle by fall. This is a summer annual. In contrast, the winter wheats, grown primarily in Kansas, Nebraska, Oklahoma, Illinois, Indiana, Ohio, Michigan, New York, Oregon, and Washington, are sown in the late summer and early fall and complete their life cycle during the following spring and summer. These wheats are winter annuals. In any case, an annual plant completes its life cycle in 1 year and perpetuates itself by seed. Biennial crop plants require 2 years to complete their growth cycle. Generally, biennials accumulate food reserves in underground storage organs during the first year and produce reproductive flowers and seed during the second year. Good examples of biennials include both white and yellow biennial sweet clover, beet, carrot, parsnip (*Pastinaca sativa* L.), onion (*Allium* spp.), cabbage (*Brassica oleracea* L.), and hollyhock (*Althea rosea* Cav.). Perennials complete their life cycle in more than 2 years and may grow indefinitely. Most forage grasses and legumes die back to the ground each year but recover during the next growing season from the crown and/or storage organs, such as rhizomes or stolons, of the previous year's growth. In this category are well known legumes such as alfalfa, red clover, birdsfoot trefoil, sericean lespedeza, and such well-known grasses as smooth brome grass, tall fescue, orchardgrass, reed canarygrass, timothy, and bermudagrass. Some plants that are annuals in a temperate climate may perform as perennials in a tropical climate. Cotton and sorghums are good examples.

LEAF RETENTION

While not common in field crop plants, leaf drop is routine during the winter in most hardwood trees, which are said to be deciduous in contrast to evergreen, which refers to needle trees such as spruce (*Picea* spp.) or pine (*Pinus* spp.). You should remember that even evergreens have leaf drop and renewal, but they are, nevertheless, green the year around.

STRUCTURE AND FORM

Most of our field crop plants are herbaceous—soft and succulent with little or no secondary tissue. Woody plants are those that develop secondary stem tissue and considerable xylem. We think of forest trees and fruit trees as woody plants. Vines do appear in the field crop kingdom, but rather rarely. Herbaceous field crop vines include field pea, vetch, kudzu, and cowpea.

CLIMATIC ADAPTATION

Most of the crop plants in the USA are adapted to a temperate climate, which means they grow in places with a marked winter season. However, in the southern latitudes we encounter a warm climate where freezing rarely, if ever, occurs and tropical plants dominate. Tropical plants, in general, shed their leaves once a year in response to a changing season. However, they are essentially green the year around. Crop plants growing in the area between temperate and tropical climate are often termed subtropical. We often speak of hardy or tender plants, depending on their capacity to tolerate climatic extremes. For example, winter hardy alfalfas grow in the northern USA climates while the winter tender types will not survive in this northern temperate climate.

USEFULNESS

I have already discussed the agronomic use category of field crop plants. However, plants may also be classified as useful, useless, and harmful. For example, a weed is a plant out of place or a plant growing where it is not wanted. It is harmful to field crop plants because it competes for all factors of the environment, including light, nutrients, and water, and thus weakens the production potential of the crop plant. Weeds may be harmful, e.g., Canada thistle [*Cirsium arvense* (L.) Scop.] and cocklebur (*Xanthium pensylvanicum* Wallr.), because of the physical harm they may inflict, or