CRC Handbook of Agricultural Productivity

Volume II Animal Productivity

Miloslav Rechcigl, Jr., Editor

CRC Handbook of Agricultural Productivity

Volume II Animal Productivity

Miloslav Rechcigl, Jr., Editor

Nutrition Advisor and Director
Interregional Research Staff
Agency for International Development
U.S. Department of State
Bethesda, Maryland

CRC Series in Nutrition and Food
Editor-in-Chief
Miloslav Rechcigl, Jr.

CRC Press, Inc.
Boca Raton, Florida

Library of Congress Cataloging in Publication Data

Main entry under title:

Handbook of agricultural productivity.

(CRC series in nutrition and food)
Bibliography: p.
Includes index.
CONTENTS: v. 1. Plant productivity.—v. 2. Animal productivity.
1. Agricultural productivity. 2. Agriculture.
I. Rechcigl, Miloslav. II. Series.
S494.5.P75H36 631.5 80-15628
ISBN 0-8493-3960-X (set)
ISBN 0-8493-3961-8 (v. 1)
ISBN 0-8493-3963-4 (v. 2)

Direct all inquiries to CRC Press, Inc., 2000 N.W. 24th Street, Boca Raton, Florida 33431.

International Standard Book Number 0-8493-3961-8 (Volume I)
International Standard Book Number 0-8493-3963-4 (Volume II)

Library of Congress Card Number 80-15628
Printed in the United States

PREFACE
CRC SERIES IN NUTRITION AND FOOD

Nutrition means different things to different people, and no other field of endeavor crosses the boundaries of so many different disciplines and abounds with such diverse dimensions. The growth of the field of nutrition, particularly in the last 2 decades, has been phenomenal, the nutritional data being scattered literally in thousands and thousands of not always accessible periodicals and monographs, many of which, furthermore, are not normally identified with nutrition.

To remedy this situation, we have undertaken an ambitious and monumental task of assembling in one publication all the critical data relevant in the field of nutrition.

The *CRC Series in Nutrition and Food* is intended to serve as a ready reference source of current information on experimental and applied human, animal, microbial, and plant nutrition presented in concise tabular, graphical, or narrative form and indexed for ease of use. It is hoped that this projected open-ended multivolume compendium will become for the nutritionist what the *CRC Handbook of Chemistry and Physics* has become for the chemist and physicist.

Apart from supplying specific data, the comprehensive, interdisciplinary, and comparative nature of the *CRC Series in Nutrition and Food* will provide the user with an easy overview of the state of the art, pinpointing the gaps in nutritional knowledge and providing a basis for further research. In addition, the series will enable the researcher to analyze the data in various living systems for commonality or basic differences. On the other hand, an applied scientist or technician will be afforded the opportunity of evaluating a given problem and its solutions from the broadest possible point of view, including the aspects of agronomy, crop science, animal husbandry, aquaculture and fisheries, veterinary medicine, clinical medicine, pathology, parasitology, toxicology, pharmacology, therapeutics, dietetics, food science and technology, physiology, zoology, botany, biochemistry, developmental and cell biology, microbiology, sanitation, pest control, economics, marketing, sociology, anthropology, natural resources, ecology, environmental science, population, law politics, nutritional and food methodology, and others.

To make more facile use of the series, the publication has been organized into separate handbooks of one or more volumes each. In this manner the particular sections of the series can be continuously updated by publishing additional volumes of new data as they become available.

The Editor wishes to thank the numerous contributors many of whom have undertaken their assignment in pioneering spirit, and the Advisory Board members for their continuous counsel and cooperation. Last but not least, he wishes to express his sincere appreciation to the members of the CRC editorial and production staffs, particularly President Bernard J. Starkoff, Earl Starkoff, Sandy Pearlman, Pamela Woodcock, Lisa Levine Eggenberger, John Hunter, and Amy G. Skallerup for their encouragement and support.

We invite comments and criticism regarding format and selection of subject matter, as well as specific suggestions for new data which might be included in subsequent editions. We should also appreciate it if the readers would bring to the attention of the Editor any errors or omissions that might appear in the publication.

Miloslav Rechcigl, Jr.
Editor-in-Chief

PREFACE

HANDBOOK OF AGRICULTURAL PRODUCTIVITY

The greatest challenge of our time is to produce sufficient food to keep pace with the rapidly growing population. In the opinion of experts, during the next 25 years there will be a need for as much food as was produced in the entire history of mankind to date. Of the various measures available, improvement in agricultural productivity is judged as the ultimate means of augmenting food production and supplies.

In this Handbook, an international team of experts consider the most important factors affecting production of both crops and livestock. This Handbook is intended as a scientific guide to practitioners and students, as well as to researchers, who should find here stimulating ideas for further exploration.

THE EDITOR

Miloslav Rechcigl, Jr. is a Nutrition Advisor and Chief of Research and Methodology Division in the Agency for International Development.

He has a B.S. in Biochemistry (1954), a Master of Nutritional Science degree (1955), and a Ph.D. in nutrition, biochemistry, and physiology (1958), all from Cornell University. He was formerly a Research Biochemist in the National Cancer Institute, National Institutes of Health and subsequently served as Special Assistant for Nutrition and Health in the Health Services and Mental Health Administration, U.S. Department of Health, Education and Welfare.

Dr. Rechcigl is a member of some 30 scientific and professional societies, including being a Fellow of the American Association for the Advancement of Science, Fellow of the Washington Academy of Sciences, Fellow of the American Institute of Chemists, and Fellow of the International College of Applied Nutrition. He holds membership in the Cosmos Club, the Honorary Society of Phi Kappa Pi, and the Society of Sigma Xi, and is recipient of numerous honors, including an honorary membership certificate from the International Social Science Honor Society Delta Tau Kappa. In 1969, he was a delegate to the White House Conference on Food, Nutrition, and Health and in 1975 a delegate to the ARPAC Conference on Research to Meet U.S. and World Food Needs. He served as President of the District of Columbia Institute of Chemists and Councillor of the American Institute of Chemists, and currently is a delegate to the Washington Academy of Sciences and a member of the Program Committee of the American Institute of Nutrition.

His bibliography extends over 100 publications including contributions to books, articles in periodicals, and monographs in the fields of nutrition, biochemistry, physiology, pathology, enzymology, molecular biology, agriculture, and international development. Most recently he authored and edited *Nutrition and the World Food Problem* (S. Karger, Basel, 1979), *World Food Problem: a Selective Bibliography of Reviews* (CRC Press, 1975), and *Man, Food and Nutrition: Strategies and Technological Measures for Alleviating the World Food Problem* (CRC Press, 1973) following his earlier pioneering treatise on *Enzyme Synthesis and Degradation in Mammalian Systems* (S. Karger, Basel, 1971), and that on *Microbodies and Related Particles, Morphology, Biochemistry and Physiology* (Academic Press, New York, 1969). Dr. Rechcigl also has initiated a new series on *Comparative Animal Nutrition* and was Associated Editor of *Nutrition Reports International.*

ADVISORY BOARD MEMBERS

ADVISORY BOARD MEMBERS (Continued)

Charity Waymouth
The Jackson Laboratory
Bar Harbor, Maine

E. M. Widdowson
Dunn Nutritional Laboratories
Cambridge, England

Dr. S. H. Wittower
Agricultural Experiment Station
Michigan State University
East Lansing, Michigan

CONTRIBUTORS

M. W. Adams, Ph.D.
Professor of Crop Sciences
Department of Crop and Soil Sciences
Michigan State University
East Lansing, Michigan

Rodney J. Arkley, Ph. D
Soil Morphologist and Lecturer
Department of Plant and Soil Biology
University of California
Berkeley, California

Billy J. Barfield, Ph.D.
Professor of Agricultural Engineering
Department of Agricultural Engineering
University of Kentucky
Lexington, Kentucky

Keith C. Barrons, Ph.D.
Agricultural Consultant
Holmes Beach, Florida

A. Bondi, Ph.D.
Professor of Animal Nutrition and Biochemistry (Emeritus)
Faculty of Agriculture
Hebrew University of Jerusalem
Rehovot, Israel

Eileen Brennan, Ph.D.
Professor of Plant Pathology
Plant Pathology Department
Rutgens University
New Brunswick, New Jersey

M. J. Burridge, Ph.D.
Associate Professor of Epidemiology
College of Veterinary Medicine
University of Florida
Gainesville, Florida

Theodore C. Byerly, Ph.D.
Consultant, Winrock International Livestock Research and Training Center and
Adjunct Professor
University of Maryland
College Park, Maryland

David L. Carter, Ph.D.
Supervisory Soil Scientist
Snake River Conservation Research Center
Kimberly, Idaho

G. I. Christison, Ph.D.
Associate Professor
Department of Animal and Poultry Science
University of Saskatchewan
Saskatoon, Canada

Walter Couto, Ph.D.
Senior Soil Scientist
Tropical Pasture Program
Centro Internacional de Agricultura Tropical
Planaltina, Brazil

Robert J. Collier, Ph.D.
Assistant Professor
Dairy Science Department
University of Florida
Gainesville, Florida

S. H. Crowdy, Ph.D.
Professor
Department of Biology
The University
Southampton, England

S. E. Curtis, Ph.D.
Professor of Animal Science
College of Agriculture
University of Illinois
Urbana, Illinois

R. H. Daines, Ph.D.
Adjunct Professor
Department of Botany and Range Science
Brigham Young University
Provo, Utah

J. B. Derbyshire, Ph.D.
Chairman, Department of Veterinary Microbiology and Immunology
Ontario Veterinary College
University of Guelph
Ontario, Canada

V. Alejandro Deregibus, Ph.D.
Agronomic Engineer
Department of Ecology
Faculty of Agronomy
University of Buenos Aires
Argentina

J. G. Drummond, Ph.D.
Research Microbiologist
Life Sciences Research Division
IIT Research Institute
Chicago, Illinois

C. F. Eagles, Ph.D.
Principal Scientific Officer
Welsh Plant Breeding Station
University College of Wales
Plas Gogerddan near Aberystwyth
England

R. H. Ellis, Ph.D.
Research Fellow
Department of Agriculture and Horticulture
University of Reading
Reading, England

G. LeRoy Hahn
Agricultural Engineer and Technical Advisor for Livestock Environment Research
Roman L. Hruska U.S. Meat Animal Research Center
Science and Education Administration
U.S. Department of Agriculture
Clay Center, Nebraska

A. E. Hall, Ph.D.
Associate Professor of Plant Physiology
Department of Botany and Plant Sciences
University of California
Riverside, California

R. W. F. Hardy, Ph.D.
Director-Life Sciences
Central Research and Development Department
E. I. du Pont de Nemours & Co.
Experimental Station
Wilmington, Delaware

Henry Hellmers, Ph.D
Professor of Botany and Forestry
Department of Botany
Duke University
Durham, North Carolina

Rodney E. Henderson
Research Associate
Agronomy Department
Louisiana State University
Baton Rouge, Louisiana

Donald A. Jameson, Ph.D.
Professor of Range Science
Department of Range Science
Colorado State University
Fort Collins, Colorado

Harold D. Johnson, Ph.D.
Project Leader, Environmental Physiology
Dairy Science Department
University of Missouri-Columbia
Columbia, Missouri

Paul J. Kramer, Ph.D.
James B. Duke Professor of Botany, Emeritus
Department of Botany
Duke University
Durham, North Carolina

Ida Leone
Professor in Plant Pathology
Cook College, Rutgers University
New Brunswick, New Jersey

J. J. Lynch, Ph.D.
Principal Research Scientist
Division of Animal Production
Commonwealth Scientific Industrial Research Organization
Armidale, Australia

James D. McQuigg, Ph.D
McQuigg Consultants, Inc.
Columbia, Missouri

Henry Olivier, C.M.G., Ph.D.
Senior Partner-Consulting Engineer
Henry Olivier and Associates
Johannesburg
South Africa

R. A. Olson, Ph.D.
Professor of Agronomy
University of Nebraska-Lincoln
Lincoln, Nebraska

William H. Patrick, Jr., Ph.D.
Boyd Professor
Marine Sciences Department
Louisiana State University
Baton Rouge, Louisiana

Robert K. Ringer, Ph.D.
Professor of Physiology and Animal Science
Department of Animal Science
College of Agriculture and Natural Resources
Michigan State University
East Lansing, Michigan

E. H. Roberts, Ph.D.
Professor of Crop Production
Department of Agriculture and Horticulture
University of Reading
Reading, England

H. E. Smalley, D. V. M.
Consultant in Veterinary Toxicology
College Station, Texas

Arthur H. Smith
Department of Animal Physiology
University of California, Davis
Davis, California

B. C. Stenning, Esq.
Lecturer in Environmental Control
National College of Agricultural Engineering
Silsoe, Bedford
England

Donald R. Sumner, Ph.D.
Associate Professor of Plant Pathology
Department of Plant Pathology
University of Georgia
Coastal Plain Experimental Station
Tifton, Georgia

Howard M. Taylor, Ph.D.
Supervisory Soil Scientist
Soil and Water Conservation Research Unit
Agricultural Research, Science and Education Administration
U.S. Department of Agriculture
Ames, Iowa

Edward E. Terrell, Ph.D.
Botanist
Plant Taxonomy Laboratory
Plant Genetics and Germplasm Institute
Science and Educational Administration
U.S. Department of Agriculture
Beltsville, Maryland

William W. Thatcher, Ph.D.
Professor (Physiology)
Institute of Food and Agricultural Sciences
Dairy Science Department
University of Florida
Gainesville, Florida

Glover B. Triplett, Jr., Ph.D.
Professor of Agronomy
Ohio Agricultural Research and Development Center
Wooster, Ohio

M. J. Trlica
Associate Professor of Range Science
Range Science Department
Colorado State University
Fort Collins, Colorado

J. D. Turton, D.T.V.M.
Director, Commonwealth Bureau of Animal Breeding and Genetics
Edinburgh, Scotland

D. H. Wallace, Ph.D.
Professor
Department of Plant Breeding and Biometry and of Vegetable Crops
Cornell University
Ithaca, New York

Ian J. Warrington
Scientist
Department of Scientific and Industrial Research
Palmerston North
New Zealand

R. W. Willey, Ph.D.
Principal Agronomist
International Crop Research Institute for the Semi-Arid Tropics
Patancheru P.O.
India

C. M. Williams, Ph.D.
Professor and Head
Department of Animal and Poultry Science
University of Saskatchewan
Saskatoon, Canada

David Wilson, Ph.D.
Senior Principal Scientific Officer
Welsh Plant Breeding Station
University College of Wales
Plas Gogerddan near Aberystwyth
England

Mary Hotze Witt, Ph.D.
Associate Professor of Horticulture
Department of Horticulture and Landscape Architecture
University of Kentucky
Lexington, Kentucky

Richard W. Zobel, Ph.D.
Research Geneticist, USDA-SEA and Professor
Departments of Plant Breeding and of Agronomy
Cornell University
Ithaca, New York

TABLE OF CONTENTS

Volume I

PHYSICAL ENVIRONMENT

Climatic Variability and Plant Productivity 3
Temperature and Plant Productivity 11
Humidity and Plant Productivity 23
Water and Plant Productivity of Yield 41

SOIL ENVIRONMENT

Soil Aeration and Plant Productivity 51
Soil pH and Plant Productivity 71
Soil Fertility and Plant Productivity 85
Nitrogen Fixation and Crop Productivity 103
Salinity and Plant Productivity 117

CROP PHYSIOLOGY

The Biology of Crop Yield 137
Seed Storage, Loss of Viability, Genetic Damage, and Crop Yield 143
Plant Development and Crop Productivity 151
Rooting Pattern and Crop Productivity 185
Plant Population and Crop Yield 201
Transpiration and Productivity 209
Photosynthetic Efficiency and Plant Productivity 213

AGRONOMIC PRACTICES

Tillage and Crop Productivity 251
Irrigation and Crop Productivity 263
Crop Rotation and Plant Productivity 273
Organic Reserves in Herbage Plants: Their Relationship to Grassland Management 315

STRESS

Environmental Stress and Plant Productivity 347
Air Pollution Plant Response, and Productivity Air Pollution, Plant Response, and Productivity 375
Microbial Disease and Plant Productivity 401

INDEX 439

TABLE OF CONTENTS

Volume II

PHYSICAL FACTORS

Climate and Animal Productivity 3
Photoperiodism and Productivity of Domesticated Animals 55
Effects of Cold on Animal Production 69
Effect of Heat on Animal Productivity 77

Air Environment and Animal Performance 107
Gravity and Animal Productivity 119
Housing and Animal Productivity 135

PHYSIOLOGICAL FACTORS
Behavior of Livestock in Relation to Their Productivity 163
Nutrition and Animal Productivity 195
Castration and Animal Productivity 213

AGRICULTURAL PRACTICES
Agricultural Productivity: Potential and Constraints 265
Chemicals for Crop and Livestock Protection 305

STRESS
Effects of Disease on Animal Productivity 319
Microbial Disease and Animal Productivity 345
Effects of Pollution on Animal Productivity 353

INDEX 367

Physical Factors

CLIMATE AND ANIMAL PRODUCTIVITY*

H. D. Johnson and G. L. Hahn

INTRODUCTION

Climate, in the general context, includes physical factors such as temperature, humidity, wind, radiation, rainfall, and altitude; chemical factors such as air composition; and indirect factors such as quantity and quality of feed and water, disease, parasites, soil, and fertility. Animal management, shelter provisions, and the many factors associated with modern animal industry alter climatic influences of a temperate, arctic, or tropical environment.

All species of the plant and animal kingdom have an optimal environmental zone or set of conditions in which they function most productively and, usually, most efficiently. In this chapter, information on the environment is limited to primary climatic factors such as temperature, humidity, air velocity, radiation (when available and the effects these factors have on productivity of domestic animals. Data on domestic animals of major agricultural importance (cattle, sheep, poultry, and swine) are presented. Factors of productivity such as milk production, egg production, growth, reproduction, and associated physiological functions such as feed intake, body temperature, and heat balance are briefly categorized. Lactation of mammals and egg production of birds are productive functions that are dependent upon an optimal climate and environment for optimum growth, and time required for sexual maturity. The processes of lactation and ovulation are regulated by the neuroendocrine system, which in turn is strongly influenced directly and indirectly by climatic environmental factors. Reproduction and growth of birds and mammals are similarly influenced. Efficiency of all these productive functions is dependent upon availability and utilization of indirect factors of the environment such as quantity and quality of feed and water. The response to altered heat balance that operates to maintain homeothermy affects all of these as well as other animal functions described.

The climatic temperature for optimal productivity is summarized in Table 1; current recommended practices in the production of cattle, swine, and poultry are summarized in Table 2.[2]

Figure 1 is a generalized illustration of the productivity of pigs, laying hens, and dairy cows at temperatures ranging from 4.4 to 37.8°C.[3] Other environmental factors such as humidity, air flow, radiation, level of feeding, and breed and age differences modify these general curves. More specific information is presented in subsequent sections on growth, and egg and milk production.

Zones of thermoneutrality are similar to zones of optimal productivity for the various species and breeds and, of course, may vary due to many factors such as age, level of feed intake, physical activity, and acclimation. Data included in the section on heat production and heat loss substantiate the thermoneutral zone designations.

REPRODUCTION

Cattle

Seasonal variation in fertility occurs in both dairy and beef cattle. In the cool northern latitudes, fertility in the female is usually lowest during the winter months. In warm humid areas, however, cow fertility is lowest during late summer and fall. Semen quality and fertility in the male are depressed during the summer in most locations. Expo-

* Tables follow text, beginning on page 21.