7th Edition

Forages

Volume II

The Science of Grassland Agriculture




Under the editorial authorship of

Kenneth J. Moore
Michael Collins
C. Jerry Nelson
Daren D. Redfearn

With 93 contributing authors

WILEY Blackwell

FORAGES

THE SCIENCE
OF GRASSLAND
AGRICULTURE

VOLUME II

7TH EDITION

FORAGES

THE SCIENCE OF GRASSLAND AGRICULTURE

VOLUME II

7TH EDITION

Edited by

Kenneth J. Moore
Michael Collins
C. Jerry Nelson
Daren D. Redfearn

With 93 contributing authors

WILEY Blackwell

This seventh edition first published 2020

Edition History

Registered Office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication data applied for

Hardback ISBN: 9781119436577

Cover Design: Wiley
Cover Image: © Pete Ryan/Getty Images
Inset Images: Courtesy of Mike Collins and Ken Moore

Set in 9/11pt AGaramondPro by SPi Global, Chennai, India

Printed and bound by CPI Group (UK) Ltd, Croydon, CR0 4YY

10 9 8 7 6 5 4 3 2 1

In Praise of Grass

Next in importance to the divine profusion of water, light, and air, those three great physical facts which render existence possible, may be reckoned the universal beneficence of grass.

Grass is the forgiveness of nature her constant benediction . . . . Forests decay, harvests perish, flowers vanish, but grass is immortal. It yields no fruit in earth or air, and yet should its harvest fail in a single year, famine would depopulate the earth.

Grass softens the rude outline of the world. Its tenacious fibers hold the earth in place. It invades the solitude of deserts, climbs the inaccessible slopes and forbidding pinnacles of mountains, modifies climates, and determines the history, character, and destiny of nations.

John James Ingalls
Kansas Magazine
1872

Grassland Science

Whoever could make . . . two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together.

Jonathan Swift
from Gulliver's travels, 1726

Contents

Preface

Forages in Transition

It is daunting to consider how to increase the food supply while conserving natural resources to feed the expected 10 billion people worldwide by 2050. This must occur with less land, less water, less fossil fuel, higher costs of labor, and will require more efficient use of inputs. And, it must be done while protecting the environment in the face of global climate change and greater public demand for sustainability. Forages and pastures will play a critical role by effectively using lower quality land resources, while simultaneously, supplying an adequate quantity of high-quality and safe products, especially animal products. Emphasis will increase for forages and pastures to contribute specific ecosystem services.

Much of the land resource of North America is occupied by grasslands and forages managed by ranchers and farmers for yield, quality and persistence. However, the social climate surrounding agriculture is rapidly changing as the public becomes more concerned and even distrustful about motives and priorities of land management for income over sustainability. How will research and technical advancement of forages and pastures address the non-production factors while moving the discipline forward?

Volume I of the 7th edition of Forages, an Introduction to Grassland Agriculture (2018), serves primarily as an undergraduate textbook. It emphasizes basic roles of the diverse array of forage plants, their adaptation, and principles of management practices used for efficient animal production that is sustainable. Volume II of the 7th edition of Forages, the Science of Grassland Agriculture (2020) gives more detail on how biological and physical processes in cells and tissues affect growth, forage quality and persistence of individual plants. We then integrate the basic knowledge about individual plants to their interaction in plant communities, whether harvested mechanically or grazed by animals, and how they contribute ecosystem services.

Forage yield in research plots has increased very little over the past half century. Relative focus is changing from increasing yield to reducing input costs and improving and retaining forage quality. New cultivars and strategies for disease and insect control help protect yield and improve both animal performance and stand persistence. New harvesting equipment improves leaf retention and shortens drying time to reduce weathering losses. Improved bale wrapping and silage preservation technologies further help retain digestible components. Global positioning and drones will find important uses for precision farming to increase management efficiency.

At the same time, the public desires increased emphasis on ecology, climate change, ecosystem services, animal welfare, and sustainable forage and pasture management. These concerns have led to stronger links among forage scientists, animal scientists, ecologists, climatologists and social scientists to form transdisciplinary foundations for managing forages and pastures. The broader role of forages and pastures will lead to new policies to provide quality animal products as well as valuable ecosystem services. New science will establish the best policies and practices.

Forages Need Innovation

Forages and pastures can effectively use land resources that do not compete directly with grain and oilseed crop production. Ruminants are critical since they have natural advantages in converting fibrous plant material into high nutritional value meat and milk products. Hundreds of plants could become significant forages in specific environments, and biotechnology will help improve species already used. Direct use of perennials for renewable energy sources can reduce dependence on fossil fuels. Forages will be more integral components of crop rotations, cover crops and vegetative waterways for feed sources and erosion control. Perennial legumes in crop rotations will protect the soil and support wildlife while providing fixed nitrogen for subsequent crops.

Fortunately, there are many new technologies in the pipeline such as global positioning systems, precision agriculture, drones, improved harvesting and packaging machinery, safer pesticides, improved efficiency of fertilizer use and many findings from biotechnology that are leading to major changes in plant and animal agriculture. Scientists are learning about managing marginal soils, how ecosystems work, how new technologies might be transferrable to other areas and how the benefits of plant diversity assist in maintaining ecosystem services. The private sector will continue to help by developing new cultivars, improved farm machinery, new research methodologies and instruments for monitoring hayfields, pastures and animal behavior.

Forages and the Role of Volume II

For Volume II of Forages, The Science of Grassland Agriculture, authors assembled a thorough review of relevant literature to glean, evaluate and integrate the most important factors for current and potential use. Unfortunately, the number of forage researchers in the US and Canada is decreasing, similar to trends in Europe, Australia, New Zealand and South America. This requires more use of international literature when the information is transferable or is validated or modified in the new environment. In addition, especially at basic levels, there is a need to use data and evaluations from non-forage species to provide insight to important features of forage and pasture plants. More transdisciplinary research with social and environmental scientists has aided evaluation of applications for economic viability and social acceptance.

As a first priority, authors considered how research improves adaptation, quality and persistence of forage and pasture plants. Second, authors evaluated technologies and management systems for sustainability within a field or pasture. In systems chapters, they considered forages and pastures as components when scaled to cropping or livestock systems within a larger area. Third, authors considered potential effects of resource limitations and pending climate change to support production and provide ecosystem services. Collectively, Volume II presents a comprehensive assessment of forages and their roles in agricultural systems that are changing in character and function.

Thanks to Contributors

The editors are very appreciative of the contributions of the 93 authors who delivered this work through their vision, commitment and knowledge. Their generosity, good will and talent made this 7th edition of Volume II possible. The completed edition also continues the tradition of providing the most comprehensive reference book available on forages and grasslands that is written by national leaders in their areas of education, extension, and research expertise.

In some chapters, concepts and descriptions include material from chapters on similar topics in earlier editions, especially the 5th and 6th editions. The current authors and editors are indebted to those authors who helped form the foundation and format for chapters in the 7th edition. With great respect, we thank those earlier authors for their efforts to advance the science of grassland agriculture and the roles of forages and pastures in dynamic ecosystems.

Ken Moore provided administrative leadership for the project and also edited and co-authored chapters. Michael Collins, Jerry Nelson, and Daren Redfearn shared in the editorial work and also co-authored chapters. We hope you can learn from and be reassured and stimulated by the publication. We welcome your responses about our collective effort, both negative and positive.

Kenneth J. Moore
Michael Collins
C. Jerry Nelson
Daren D. Redfearn

List of Contributors

Paul Adler
Research Agronomist,
Pasture Systems and Watershed Management Research Unit,
USDA-Agricultural Research Service,
University Park, PA, USA

Montgomery W. Alison
Extension Forage Specialist,
Louisiana State University Agricultural Center,
Winnsboro, LA, USA

L. Niel Allen
Associate Professor and Irrigation Specialist,
Utah State University,
Logan, UT, USA

David J. Barker
Professor of Horticulture and Crop Science,
The Ohio State University,
Columbus, OH, USA

Vern S. Baron
Research Scientist,
Agriculture and Agri-Food Canada,
Lacombe, AB, Canada

Gilles Bélanger
Research Scientist,
Agriculture and Agri-Food Canada,
Sainte-Foy, PQ, Canada

David P. Belesky
Clinical Associate Professor & Director Davis College Farm System,
West Virginia University,
Morgantown, WV, USA

Geoffrey E. Brink
Research Agronomist, USDA- Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Sylvie M. Brouder
Wickersham Chair of Excellence in Agricultural Research and Professor of Agronomy,
Purdue University,
West Lafayette, IN, USA

E. Charles Brummer
Professor,
University of California,
Davis, CA, USA

G. David Buntin
Professor of Entomology,
University of Georgia,
Griffin, GA, USA

Michael D. Casler
USDA-Agricultural Research Service, US Dairy Forage Research Center
Madison, WI, USA

Kimberly A. Cassida
Forage Extension Specialist, Michigan State University
East Lansing, MI, USA

Debbie J. Cherney
Professor of Animal Science,
Cornell University,
Ithaca, NY, USA

Jerome H. Cherney
Professor of Soil and Crop Sciences,
Cornell University,
Ithaca, NY, USA

Wayne K. Coblentz
Institute for Environmentally Integrated Dairy Management,
US Dairy Forage Research Center,
Marshfield, WI, USA

Robert C. Cochran
Professor, Kansas State University,
Manhattan, KS, USA

Michael Collins
Professor and Director Emeritus, Division of Plant Sciences,
University of Missouri,
Manchester, KY, USA

Steven W. Culman
Professor, School of Environment and Natural Resources,
The Ohio State University,
Columbus, OH, USA

Tim DelCurto
Professor and Nancy Cameron Chair,
Montana State University,
Bozeman, MT, USA

Matthew Digman
Assistant Professor of Agricultural Engineering,
University of Wisconsin,
River Falls, WI, USA

Gerald W. Evers
Professor Emeritus of Soil and Crop Sciences,
Texas A&M University,
Overton, TX, USA

Steven L. Fales
Emeritus Professor of Agronomy,
Iowa State University,
Ames, IA, USA

E. Scott Flynn
Agronomist, Corteva Agriscience,
Lees Summit, MO, USA

Jamie Foster
Associate Professor of Forage Agronomy, Texas A&M AgriLife Research,
Beeville, TX, USA

John A. Guretzky
Grassland Systems Ecologist,
University of Nebraska,
Lincoln, NE, USA

Richard J. Grant
President and Research Scientist,
The William H. Miner Agricultural Research Institute,
Chazy, NY, USA

Marvin H. Hall
Professor of Crop and Soil Sciences,
Pennsylvania State University
University Park, PA, USA

Mary Beth Hall
Research Animal Scientist, USDA-Agricultural Research Service,
US Dairy Forage Research Center
Madison, WI, USA

Dennis W. Hancock
Center Director, USDA-Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Keith R. Harmoney
Range Scientist, Kansas State University,
Hays, KS, USA

Ronald D. Hatfield
Research Plant Physiologist, USDA-Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

John R. Hendrickson
Research Rangeland Management Specialist, USDA-Agricultural Research Service
Mandan, ND, USA

Nicholas S. Hill
Professor of Crop and Soil Sciences,
The University of Georgia,
Athens, GA, USA

John Jennings
Professor of Animal Science-Forages,
University of Arkansas,
Little Rock, AR, USA

Jacob M. Jungers
Assistant Professor of Agronomy and Plant Genetics,
University of Minnesota,
St. Paul, MN, USA

Robert L. Kallenbach
Associate Dean, Agriculture and Environment Extension,
University of Missouri,
Columbia, MO, USA

Kenneth F. Kalscheur
Research Dairy Scientist, USDA- Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Douglas L. Karlen
Soil Scientist (Retired),
USDA-Agricultural Research Service,
Ames, IA, USA

Limin Kung, Jr.
Professor of Animal and Food Sciences,
University of Delaware,
Newark, DE, USA

William O. Lamp
Professor of Entomology,
University of Maryland,
College Park, MD, USA

Gregory Lardy
Department Head, Animal Sciences,
North Dakota State University,
Fargo, ND, USA

Karen L. Launchbaugh
Heady Professor of Rangeland Ecology,
University of Idaho,
Moscow, ID, USA

Andrew W. Lenssen
Professor of Agronomy,
Iowa State University,
Ames, IA, USA

Mark A. Liebig
Soil Scientist, USDA- Agricultural Research Service,
Northern Great Plains Research Laboratory,
Mandan, ND, USA

Jennifer W. MacAdam
Professor of Plants, Soils and Climate,
Utah State University,
Logan, UT, USA

Bisoondat Macoon
Research Professor,
Mississippi State University,
Raymond, MS, USA

Neal P. Martin
Director (Retired), USDA- Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Robert A. Masters
Rangeland Scientist (Retired),
Corteva Agriscience,
Indianapolis, IN, USA

Tim A. McAllister
Principal Research Scientist, Agricultural and Agri-Food Canada,
Lethbridge, AB, Canada

David R. Mertens
President, Mertens Innovation & Research LLC,
Belleville, WI, USA and
Research Dairy Scientist (Retired), USDA- Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Robert B. Mitchell
Research Agronomist, USDA-Agricultural Research Service,
Lincoln, NE, USA

Corey Moffet
Research Rangeland Management Specialist,
USDA-Agricultural Research Service,
Woodward, OK, USA

Kenneth J. Moore
Charles F. Curtiss Distinguished Professor in Agriculture and Life Sciences and Pioneer Hi-Bred Professor of Agronomy,
Iowa State University,
Ames, IA, USA

Richard E. Muck
Agricultural Engineer, USDA-Agricultural Research Service (Retired),
US Dairy Forage Research Center,
Madison, WI, USA

James P. Muir
Professor Grassland Ecology,
Texas A&M AgriLife Research & Extension Center,
Stephenville, TX, USA

C. Jerry Nelson
Professor Emeritus of Plant Sciences,
University of Missouri,
Columbia, MO, USA

Yoana C. Newman
Associate Professor of Plant and Earth Science,
University of Wisconsin,
River Falls, WI, USA

Renata N. Oakes
Assistant Professor of Forage Systems and Management,
University of Tennessee,
Spring Hill, TN, USA

John F. Obrycki
ORISE Fellow, USDA National Laboratory for Agriculture and the Environment,
Ames, IA, USA

David Parsons
Professor of Crop Science,
Swedish University of Agricultural Sciences (SLU)
Umeå, Sweden

Carlos G.S. Pedreira
Associate Professor of Animal Science,
University of São Paulo,
São Paulo, Brazil

Valentín D. Picasso Risso
Assistant Professor of Agronomy,
University of Wisconsin,
Madison, WI, USA

William D. Pitman
Professor,
Louisiana State University Agricultural Center,
Homer, LA, USA

Daniel H. Putnam
Forage Extension Specialist,
University of California,
Davis, CA, USA

Daren D. Redfearn
Associate Professor of Agronomy,
University of Nebraska,
Lincoln, NE, USA

Gabriel Ribeiro
Assistant Professor
Animal and Poultry Science,
University of Saskatchewan,
Saskatoon, SK, Canada

Esteban F. Rios
Assistant Professor of Agronomy,
University of Florida,
Gainesville, FL, USA

Craig A. Roberts
Professor of Agronomy,
University of Missouri,
Columbia, MO, USA

C. Alan Rotz
Agricultural Engineer, USDA-Agricultural Research Service,
US Dairy Forage Research Center,
Madison, WI, USA

Michael P. Russelle
Soil Scientist (Retired), USDA-Agricultural Research Service,
St. Paul, MN, USA

Matt A. Sanderson
Research Agronomist and Research Leader (Retired),
USDA-Agricultural Research Service,
State College, PA, USA

Craig C. Sheaffer
Professor of Agronomy and Plant Genetics,
University of Minnesota,
St. Paul, MN, USA

Kevin J. Shinners
Professor of Agricultural Engineering,
University of Wisconsin,
Madison, WI, USA

Byron B. Sleugh
Agronomist, Corteva Agriscience,
Indianapolis, IN, USA

Alexander J. Smart
Professor and Rangeland Management Specialist,
South Dakota State University,
Brookings, SD, USA

Lynn E. Sollenberger
Distinguished Professor of Agronomy,
University of Florida,
Gainesville, FL, USA

Tim L. Springer
Research Agronomist, USDA-Agricultural Research Service,
Woodward, OK, USA

Kim Stanford
Research Scientist, Alberta Agriculture and Forestry,
Lethbridge, AB, Canada

Jeffrey J. Steiner
Associate Director, Global Hemp Innovation Center,
Oregon State University,
Corvalis, OR, USA

R. Mark Sulc
Professor of Horticulture and Crop Science,
The Ohio State University,
Columbus, OH, USA

Eric S. Vanzant
Associate Professor, University of Kentucky,
Lexington, KY, USA

Joáo M.B. Vendramini
Associate Professor of Agronomy, Range Cattle Research and Education Center,
University of Florida,
Ona, FL, USA

Kenneth P. Vogel
USDA-Agricultural Research Service (retired),
Lincoln, NE, USA

Jeffrey J. Volenec
Professor of Agronomy, Purdue University,
West Lafayette, IN, USA

John W. Walker
Professor and Resident Director of Research, Texas A&M AgriLife Research and Extension Center,
San Angelo, TX, USA

Yuxi Wang
Research Scientist, Agriculture and Agri-Food Canada,
Lethbridge, AB, Canada

Zeng-Yu Wang
Professor,
Qingdao Agricultural University,
Yantai, China

Marcelo O. Wallau
Assistant Professor of Agronomy,
University of Florida,
Gainesville, FL, USA

Richard Waterman
Research Animal Scientist, USDA- Agricultural Research Service, Fort Keogh Livestock and Range Research Laboratory,
Miles City, MT, USA

David A. Wedin
Professor,
School of Natural Resources,
University of Nebraska,
Lincoln, NE, USA

William P. Weiss
Professor of Animal Sciences,
Ohio Agricultural Research and Development Center,
The Ohio State University,
Wooster, OH, USA

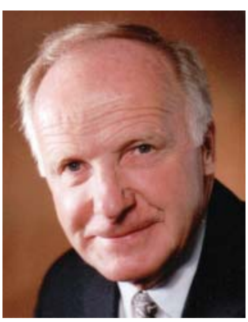
Jessica A. Williamson
Assistant Professor of Crop and Soil Sciences,
Pennsylvania State University,
University Park, PA, USA

Dedication

This volume is dedicated to the memory of Drs. Steven Louis Fales, Lowell E. Moser and Walter F. Wedin. Devoted and passionate grasslanders all, they were also highly productive researchers and enthusiastic educators. They inspired and trained many of the authors contributing to this volume. Their lives and careers crossed paths many times over the years and all three were contributors to earlier editions of Forages.

Steven L. Fales

Lowel E. Moser



Walter F. Wedin

Lowell edited several important books and monographs related to forages including ***Cool-Season Forage Grasses*** and ***Warm-Season (C4) Grasses***, both published by the Tri-Societies (ASA-CSSA-SSSA). Walt and Steve co-edited ***Grassland: Quietness and Strength for a New American Agriculture*** their homage to ***Grass, the 1948 Yearbook of Agriculture***.

This volume is also respectfully dedicated[1]:

To the Memory of Those gone on before, who, envisioning the needs of the future and the possibility of better things, lived purposively, giving of themselves.

In Recognition of Those of our own day, who, endowed with leadership ability in research and education, continue to stimulate us to more productive effort.

For the Inspiration of Those who today follow on, but who tomorrow, building upon established foundations, will be charged with the responsibility of solving problems with which those of their day will be confronted.

[1] From , Hughes, H.D., Heath, M.E., and Metcalfe, D.S. (eds.) (1951). *Forages: The Science of Grassland Agriculture*, 1e. Ames, IA: The Iowa State College Press.

Part I

FORAGE PLANTS

A mixed stand of alfalfa and timothy. Timothy mixtures with alfalfa in Kentucky provide mixed forage on the first cutting or grazing but nearly pure alfalfa through the remainder of the growing season. *Source:* Photo courtesy of Mike Collins.

Part I covers basic physiologic and physical properties of forage species at the cellular and whole-plant levels that guide genetic improvement and underscore management practices. The goals are to improve yield and quality of the biomass and resistance to biotic and abiotic stresses. These processes often have negative correlations that are species dependent, and responses of spaced-plants may not reflect their properties when grown in dense stands or mixtures. Critical topics such as photosynthesis, root growth, canopy architecture, lignification of cell walls and presence of antiquality factors such as alkaloids in leaves need to continue to be evaluated. Most perennial forage plants are polyploids and cross-pollinated, making it difficult to identify and transfer genes using biotechnology, but

Forages: The Science of Grassland Agriculture, Volume II, Seventh Edition.
Edited by Kenneth J. Moore, Michael Collins, C. Jerry Nelson and Daren D. Redfearn.

CRISPR-Cas9 and other new technologies are opening new ways to supplement traditional breeding methods.

Genetic potential for growth and persistence set the upper limits for yield. Management strategies utilize resources efficiently to achieve the actual annual yield, but it rarely nears the genetic potential. Reducing the yield gap by more intense management may not be economically feasible or environmentally friendly. Thus, increasing efficiency of energy, radiation, nutrient, water and other natural resources are objectives. These processes are integrated to understand and optimize plant growth, flowering and seed development. The integrated system is what the manager must understand to achieve the desired objective in a way that is sustainable for now and the future.

CHAPTER

1

Perspectives, Terminology, and Classification

C. Jerry Nelson, Professor Emeritus, *Plant Sciences, University of Missouri, Columbia, MO, USA*
Kenneth J. Moore, Distinguished Professor, *Agronomy, Iowa State University, Ames, IA, USA*
Michael Collins, Professor Emeritus, *Plant Sciences, University of Missouri, Columbia, MO, USA*
Daren D. Redfearn, Associate Professor, *Agronomy, University of Nebraska, Lincoln, NE, USA*

As it has for millennia, the earth is changing physically, especially during the past few decades, while human population is growing very rapidly. Forage management has advanced to help meet the expanding needs for ruminant animal products, nitrogen acquisition, fuel resources and environmental stewardship. However, changes in climate, conflicts and shortages of water supplies, increased public emphasis on ecosystem management, and the challenges of world hunger and energy remain in the news almost daily. Other concerns include food safety, food quality and animal welfare. Each raises questions about how to deal with hunger, the environment and quality of human life; especially how management of pastures, forage fields and the products they support can help provide solutions.

Need for Consistent Terminology

Clear communication depends on terminology that is common among the individuals involved. Many terms are common to production of all crops and animals. In this book, however, emphasis is on those terms unique to forage crops, pastures, range, and livestock that describe their underlying science and practical use. Terms in bold face are defined in a comprehensive glossary in the appendix.

While many terms have a history of usage, they can be confusing when moved from one culture or location to another. New terms appear regularly along with new technologies, and need to be clear and used correctly. For example, a few years ago, a drone would have referred to a male bee, which it still does, but with the advent of precision agriculture, a drone is also now an unmanned aircraft guided by remote control or onboard computers using global positioning systems (GPSs). Drones can carry instruments that measure plant health, forage quality, forage production and monitor animal behavior in a pasture. Many other applications will soon follow.

Most definitions are written for the practitioner and may not be fully understood by the general public or policy makers. Practitioners are more aware than the public or legislators about the intrinsic values of forages

Forages: The Science of Grassland Agriculture, Volume II, Seventh Edition.
Edited by Kenneth J. Moore, Michael Collins, C. Jerry Nelson and Daren D. Redfearn.

and grasslands. They have a vested interest in technical and economic aspects that help them be better managers or marketers. Some specific or technical terms for communication among researchers are in the glossary for use by practitioners involved with technical communications. Scientists, extension specialists, consultants, and journalists need to be aware of differences in knowledge levels between practitioners and the public, especially in urban areas.

Terms in Grassland Management

Professionals in forages and grasslands have responsibility to develop consistency of definitions so communication is clear. Endophyte-free or E^- tall fescue, glandular-haired alfalfa, and no-till seeding are terms that are becoming common. Conversely, there is debate as to what constitutes animal rights, labor laws, use of water, and others, including how to measure these factors and assign or estimate economic values.

When allowed to develop unabated, local, and generic terms take on a local meaning. For example, the public may observe a pasture that is "rundown" or "overgrazed." The practitioner might suggest the pasture was "grazed heavily," whereas the scientist might say an inappropriate **stocking rate**, **stocking density**, or **grazing pressure**, respectively, was the cause. Each scientific term has some features in common with the more general descriptor, but focuses on a more specific factor to add clarity using biological reasons for the pasture condition. For example, overgrazing could be due to poor plant growth, having too many animals, or retaining them on the pasture too long, all with the result of leaving too little residual **forage mass**.

"Grazing heavily" suggests too many animals for the forage available such that too much forage was removed. The scientist would use terms such as **stocking rate** (number of animals per unit land area for a period of time) and **grazing pressure** (mass of forage available per animal at a given time) to understand the situation in quantifiable terms.

Sometimes a term used routinely needs to be modified to lead to change. "Intensive grazing management" was commonly used for decades and generally connoted the use of management practices involving "rotational grazing," now called **rotational stocking**, but it also implied that the "grazing intensity," now called **stocking rate**, was managed. Earlier interpretations could involve rotating periods of grazing and rest, or encouraging faster bite rate or larger bite size of animals, i.e. "grazing with intensity."

Research on the technologies introduced new terms that helped increase producer interest in pasture management. The need to be biologically accurate, and consistent with other terminology regarding grazing methods, led professionals to shift the term from intensive grazing management to **management-intensive grazing** (Nation 2004). This focuses properly on the grazing method that is managed intensively based on knowledge about plants, animals, fencing, water supplies, and other technologies used as inputs (Gerrish 2004).

In another case, professionals early on used accumulated forage for **deferred grazing**; meaning the forage that accumulated during active growth was allowed to stand until needed for grazing. Yet, practitioners and technology transfer specialists also coined the terms "stockpiling" and "grazing on-the-stump," neither of which was functionally descriptive of forage accumulated during active growth, usually during fall, and subsequently grazed in winter when growth was slow or had stopped. Even so, the term **stockpiling** was gradually accepted, clearly defined and is now widely adopted (Figure 1.1).

Terms for Soil and Its Functions

Soil has long been defined as "unconsolidated mineral or organic material on the immediate surface of the earth that serves as the natural medium for the growth of land plants." However, this definition raised concerns among soil scientists that soils are not limited to earth, some parts of soil may be rocks or other consolidated material, soils contain liquids, gases and biological organisms, including plants, and that soils are dynamic due to soil-forming factors that differ depending on their use and management (van Es 2017).

Under leadership by the Soil Science Society of America, ideas and concepts were coalesced to a new definition: **Soil** is now "the layer(s) of generally loose mineral and/or organic material that are affected by physical, chemical, and/or biological processes at or near the planetary surface and usually holds liquids, gases and biota and support plants" (van Es 2017). The new definition clearly places more emphasis on the physical makeup of the soil and broadens the definition and uses beyond agriculture, i.e. more than just supporting plants.

Soil Quality

A number of years ago, the term soil quality was introduced and considered as "the capacity (of soil) to function" (Karlen et al. 2003). Soil quality depends on physical, chemical, and biological features of upper layers, and how they interact to provide a given function, be it for road construction, crop production or a home lawn. A change in one feature results in a different soil. Scientists are developing methods to assess the indicators, and then use mathematical equations to combine several physical, chemical, and biological features, including organic matter that changes with human activity, into a numeric index (Friedman et al. 2001). The desired numeric index based on physical, chemical, and biological properties would vary depending on the purpose, e.g. agriculture or civil engineering.

Fig. 1.1. Beef cattle in Saskatchewan extending the grazing season by using accumulated forage. *Source:* Photo courtesy of Vern Baron.

Understanding how the components of the soil quality index interact, while being a noble goal, has been difficult to measure and interpret over a range of soil types and topographies (Laishram et al. 2012). This led to interest in soil health, a simpler concept for evaluating "soil value" that is related more directly to content of organic matter (Doran and Zeiss 2000). This seemed more practical for agricultural uses, especially in the short term, since organic matter is responsive to management and affects the structure of the soil and its capacity for holding water and nutrients.

Soil Health

Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. The term may be more useful than soil quality to describe the "health state" of a soil in terms of its productivity and roles in environmental conservation and the many ecosystem services of pastures and forages since it is based mainly on organic matter content that is relatively easy to measure and quantify. Many practitioners and the USDA Natural Resources Conservation Services have adopted the term soil health using organic matter as the main component for evaluating soil conditions associated with crop and forage management. Soil health and its emphasis on organic matter is the term championed by organic agriculturalists.

Sustainability of Grassland Agriculture

Sustainability of agriculture has been a critical issue for farmers and ranchers for generations, but in the 1960's public concern grew about the increased emphasis on primary production of food and fiber based on use of chemical fertilizers and pesticides. Agriculture was perceived as mining natural resources for economic benefit with little concern for short- and long-term sustainability based on health and well-being of consumers and the environment. The public raised real concerns about government regulations and management practices for use of chemicals on farms.

The Delaney amendment in 1958 prohibited any compound in feeds or foods that caused cancer in animals or humans. To help meet these concerns, the government developed stricter regulations on use of chemical fertilizers and especially pesticides based on better diagnostic procedures. This was coupled with increased public interest in organic agriculture that prohibits use of chemical inputs. To address the growing concerns, the concept of sustainable agriculture emerged and, early on, was somewhat linked to the use of organic practices.

Roles of the Public

The public was concerned about sustainability even though it was clear organic agriculture alone could not meet the total food needs then (Pesek et al. 1993) or later (Reganold and Wachter 2016). Soon a more holistic perspective of sustainable agriculture emerged that involved more than food production and was defined based on three major components: (i) the economic return to the producer, (ii) the conservation of the environment, and (iii) use of practices that are accepted socially (American Society of Agronomy 1989).

Federal and state governments began cost-share programs to encourage and reward producers who adopted management practices to reduce soil erosion, maintain water quality, increase plant diversity, enhance wildlife and reduce negative effects of chemical nutrients and pesticides. Industry also accepted the challenges by working on the broader issues before submitting chemicals for registration.

Today, there is growing concern about social aspects like animal rights, worker safety, food safety and labeling of contents in food as components of sustainability. In many cases today, the consumer can get some reassurance by purchasing food directly from Farmer's Markets or track products back to the farm or ranch from which it was produced.

Consideration of Ecosystem Services

After a detailed international analysis (Millennium Ecosystem Assessment 2005), sustainability of agriculture today also includes providing a wide range of **ecosystem services**, a more inclusive and more comprehensive set of ecosystem components and interactions affecting human well-being. This four-part framework, led mainly by ecologists and social scientists, consisted of four outputs or services from the land (Figure 1.2).

The desired outputs, all expected from agriculture, include (i) Supporting services like primary production, nutrient cycling and soil formation; (ii) Provisioning services like food, fresh water, wood, and fuel; (iii) Regulating services like influences on climate, quantity and quality of water, and diseases of plants and animals; and (iv) Cultural services like spiritual issues, education, and esthetics. Currently, a major goal for scientists is to learn the breadth and determine values of individual ecosystem services and their interrelationships.

The millennium report on sustainable agriculture is gradually being accepted internationally as a goal, while more sub-components are added on a regular basis. Costanza et al. (2017) reported on the explosion of research by ecologists and economists wanting to assign values to ecosystems, encourage policies and document applications of the ideas. Sustainability now extends beyond the farm gate to the entire food chain and includes a myriad of environmental, social, and cultural issues rarely considered a few decades ago. Agricultural scientists need to continue to be involved in all aspects.

Unfortunately, agricultural science has often not kept up to provide a scientific basis for leadership to make good policy decisions. The public is now the major player, often without scientific evidence, in decisions and regulations for the entire food system and the preservation of natural resources.

Assessing and understanding the complexity involved with agricultural sustainability will likely require mathematical modeling and transdisciplinary approaches in research. Forage and pasture management and animal welfare issues need science-based cooperation with social scientists and practitioners to understand relationships, provide education and satisfy public demands for sustainability.

Industrialization of agriculture via new technologies from both the public and private sectors has raised concerns about ethical and economic motivation among the players. The question arises; are commercial motives parallel with those of the public, and based on science? Scientists are in the early stages of establishing an index that includes measurable variables associated with the Millennium Assessment to achieve sustainability in ways that are socially acceptable. As incomes increase in developed countries, demands for fresh and safe foods with good taste will continue to rise. Many will believe, with little or no scientific evidence, that organically produced foods are safer, healthier, and taste better. The balance between organic and other production systems will evolve (Tillman et al. 2002).

The Role of Organic Agriculture

Organic foods and beverages are a small, but rapidly growing market segment in the global food industry including meat and milk products, primarily due to health and nutrition concerns. A recent study analyzed 40 years of science comparing organic and conventional agriculture across the four goals of sustainability, productivity, environmental impact, economic viability, and social well-being (Crowder and Reganold 2015). In summary, organic systems produced lower yields compared with conventional agriculture, yet it was more profitable because consumers pay 12–50% more for the products.

Overall, organic farms tend to store more soil carbon, have better soil quality, and reduced soil erosion. Initial evidence indicates that organic agricultural systems deliver greater ecosystem services and social benefits.