7th Edition

Forages

Volume I

an introduction to grassland agriculture

Under the editorial authorship of

Michael Collins
C. Jerry Nelson
Kenneth J. Moore
Robert F Barnes

With 22 contributing authors

WILEY

FORAGES

AN INTRODUCTION TO GRASSLAND AGRICULTURE

VOLUME I

7TH EDITION

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Millions of bison were present on the prairies of North America at the time of European settlement.

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Preface

The concept of grassland agriculture is based on the premise that pastures and fields comprised of forage plants that are grazed or harvested mechanically are integral parts of a sustainable agricultural system. Their roles in livestock systems, particularly ruminants, are well documented in terms of nutritional value, improvements in fertility and quality of soils, and erosion control to protect soil and water resources. Today, forages are expected to provide even more ecosystem services associated with nutrient management, winter cover crops, biofuel production, wildlife benefits, well-being of pollinators, mitigating global climate change, and even providing aesthetic value to the landscape. The social values of agricultural landscapes, including pastures and haylands, have become a major public priority.

The public is not well aware of these values of grasslands or how best to provide these multiple functions, yet is very concerned with the quality and safety of the food products from grasslands while preserving the environment and its many components. The public is aware that farmers and ranchers, as land managers, are major stewards of these resources, and that government programs are often used to encourage agriculturalists to meet these expectations. Furthermore, only about 1% of the US population is currently involved in production agriculture, and there has been a gradual shift from general support of the traditional family farms to concerns about large "corporate" or "industrialized" farms that may lack the core values expected from the stewards of these grassland resources. Often the corporate farm is considered to be closely linked to private industry, with an accompanying negative perception of the profit incentive and management strategies.

Therefore our goal is to provide an up-to-date textbook that introduces students and professionals to the concepts and practical ways in which pastures and haylands can contribute to sustainable land management by providing quality food and fiber products while protecting the environment and providing the expected ecosystem services. The seventh edition of *Forages* continues to serve as a textbook for undergraduate students (Volume I), and a more advanced and comprehensive treatment serves as a major reference (Volume II). Volume I of the seventh edition is a thorough update of the sixth edition, to add new dimensions and purposes of managing grasslands and haylands. The outcome is the most comprehensive text available for students of undergraduate courses over a broad geographic area.

In the seventh edition we provide students with a good balance of scientific principles, to aid them in integrating the basic concepts, along with practical information on plant identification, growth characteristics, management, and utilization of these resources that can be used by agricultural practitioners. Grassland ecosystems are extremely complex, and this includes the plant–animal interface and the soil–climate–forage interface, all of which must be considered when making management decisions that maintain the environment and are socially acceptable. The explanatory coverage of the science behind these plant characteristics and responses will make the book applicable to many parts of the world, while more focused, region-specific management information relates mainly to North America and areas with similar forage species, climates, and soils.

Revisions from the sixth edition are of two main types. First, we have focused on a more consistent writing style and academic level to make the book even more suitable for undergraduates with both rural and urban backgrounds. We have included one editor as a co-author on each of the 19 chapters, to enhance consistency. And we have added color throughout the book both to make it more interesting and to greatly enhance readability and comprehension. Some subject matter has been condensed and placed in a more appropriate location for better continuity. In other chapters, emphasis on certain topics has been either increased or decreased so as to be current and consistent with the amount of technical knowledge available.

Second, we have addressed emerging topics that were not emphasized in the sixth edition. During the 14 years since that edition was published there have been several important changes in technology and its adoption, which are now addressed. One example is the prominent role of herbaceous annual and perennial species, many of which are warm-season grasses, as potential sources of lignocellulosic biomass energy. Many species that are receiving attention as bioenergy crops have dual uses as forages and/or conservation crops, but there are unique considerations for bioenergy use that need to be addressed. Other species such as *Miscanthus* have limited forage or conservation value, but have significant potential as dedicated energy crops. Yet their management for yield and quality is based on principles of plant growth and development that are similar to those for forages.

Rapidly increasing national interest in sustainability of agriculture, including environmental factors such as water quality, global climate change, eutrophication in the Gulf, support of wildlife, and other relevant topics required greater coverage. Forage species play important roles in these topics because of their erosion-limiting and soil-improving characteristics that can contribute to carbon sequestration in the soil, and to reducing run-off and nutrient loss to groundwater, streams, and rivers, while also providing other environmental and social benefits. Several of these involve inputs and analyses of economists and other social scientists to evaluate efficient energy use, increased fertilizer cost, increased emphasis on reducing loss of mobile nutrients to surface and ground water, and many emerging regulatory issues associated with human and food safety, animal rights, and manure management. There is also renewed interest in cover crops as components of row cropping systems.

We recognize the large role that private industry has assumed in forage improvement and seed production, so information on these topics has been distributed within the species-related chapters. Information relating to the importance of seed quality has been incorporated into the chapter on forage establishment. Essential information on forbs has been incorporated into associated chapters based on their comparative growth, quality, and management considerations. Agricultural engineers have brought large changes in mechanization of harvesting, processing, and storage technology, which are covered in the appropriate chapters.

The seventh edition has provided the opportunity to respond to the new technology and reflect the generational change that has taken place among forage scientists and teachers. We have added several new chapter authors who have become recognized leaders in the forage world. This will ensure that the book remains a contemporary and authoritative source that continues to be based on the cutting edge of scientific knowledge and its application in the field. We thank authors of a number of chapters in the fifth and sixth editions of *Forages: An Introduction to Grassland Agriculture* and *Forages: The Science of Grassland Agriculture* for their contributions.

Several prominent forage scientists reviewed and provided critical insights into the Compendium of Common Forages. In particular we would like to thank Drs. Don Ball (Auburn University), Gerald Evers (Texas A&M University), Al Frank (USDA Mandan, N.D.), John Jennings (University of Arkansas), and Chuck West (Texas Tech University) for their input on species adaptation, and Lynn Sollenberger (University of Florida) for his thorough and constructive review of the text.

On a sad note, we lost a critical member of our team when Dr. Robert F Barnes, known personally and professionally as "Bob", passed away in 2013. We have retained Bob as an editor since the four of us worked together in early discussions about how to revise the seventh edition, and many of his thoughts are incorporated in this volume. It was also appropriate due to the esteem in which he was held as a dedicated leader and scientist, and our genuine appreciation for the inspiration he provided for each of us personally. In addition, we wanted to honor his legacy for his long-term roles as a dedicated author and editor of *Forages*, beginning with the third edition, which was published in 1973. For these and other reasons, this volume is dedicated to his memory and expresses our gratitude for his mentoring and friendship.

As editors, we thank the authors who made Volume I of the seventh edition possible, many of them for the first time. Each has contributed new content and applications to their respective chapters. The change in authors also reflects the gradual turnover of scientific leaders in the discipline we know as grassland agriculture. Michael Collins carried administrative responsibilities. He or Jerry Nelson co-authored each chapter to maintain continuity and an appropriate level of coverage. Ken Moore contributed oversight to the content and had major responsibility for the appendix, glossary, and compendium. We hope that readers and students will find the subject to be interesting and helpful in their professional careers.

Michael Collins
C. Jerry Nelson
Kenneth J. Moore
Robert F Barnes

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In Memoriam

Dr. Robert F Barnes, 1933–2013

To honor the contributions to this and earlier editions of *Forages*, and his dedicated national and international leadership in grassland agriculture, we dedicate Volume I of the seventh edition to Dr. Robert F Barnes. "Bob", as he was affectionately known, was born in Estherville, IA on February 6, 1933 and passed away on April 27, 2013 in Madison, WI. He graduated from Estherville Junior College in 1953, served in the Army as an intelligence specialist for 2 years, and graduated in Agronomy from Iowa State University in 1957. He earned his M.S. in Farm Crops from Rutgers University in 1959, and his PhD in Agronomy from Purdue University in 1963.

Bob began his stellar research and service career working with the US Department of Agriculture (USDA) at Purdue University, where he pioneered work on methodologies for measuring forage quality. Thereafter, he continued his research as Director of the USDA Regional Pasture Research Laboratory at Pennsylvania State University. He then served on the USDA National Program Staff for Forages and Range in Washington, DC until 1986, and as Associate Regional Administrator for the Southern Region of the USDA in New Orleans, LA. In 1986 he became Executive Vice President of the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America until he retired in 1999.

For more than four decades the sequential editions of *Forages* were synonymous with Bob's perspectives as he provided administrative leadership and worked diligently to ensure the high quality of each volume. He was instrumental in changing the fifith edition by splitting it into two volumes, one focused on undergraduate education and the other providing a comprehensive reference book for scientists and technical workers. That change was continued in the sixth and seventh editions.

In addition to the *Forages* books, Bob authored or coauthored more than 100 scientific publications and provided vision and leadership for progress in forage and grassland science in North America. Coupled with his vision and encouragement of others he had a major influence on young scientists and the growth of the forage industry. He led the development of the first broadly accepted definition of sustainability of agriculture, and facilitated the movement towards use of near-infrared radiation to measure forage quality. He helped to build partnerships in animal sciences, crop sciences, soil sciences, and social sciences in order to broaden the roles of forage scientists. As Executive Vice President he assisted the development of several conferences and detailed monographs on topics related to forage. Based on the series of successful International Grassland Congresses, he supported and provided leadership to initiate the series of successful International Crop Science Congresses, the first of which was held at Iowa State University in 1992.

However, our appreciation extends much further, because Bob was a quiet motivator through his genuine concern and quality of mentorship for each of us and for scores of other forage workers. Few individuals have had such a profound influence on our professional lives and our profession. Bob's leadership in grasslands and forages was effective through his associations with the USDA, the series of International Grassland Congresses, and his role as Executive Vice President of the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America. Throughout he maintained his interest in forages and championed the roles of forages and grasslands in each of the societies, and he was highly respected by government leaders and agricultural scientists in North America and around the world.

Peers recognized Bob's professional contributions with numerous accolades and awards, including the prestigious Fellow Award from both the American Society of Agronomy (1973) and the Crop Science Society of America (1973). He served as President of the Crop Science Society in 1985. The American Forage and Grassland Council honored him with the Merit Award (1973) and its distinctive Grasslander Award (2001). Bob served on the Boards of the Agronomic Science Foundation and International Grassland Congress for several years.

The Robert F Barnes Graduate Education Awards, begun in 2003, acknowledge his career and his vision to recognize graduate students who make outstanding paper presentations in the Forage and Grazinglands Division at the annual meetings of the Crop Science Society of America. These competitive awards recognize, encourage, and attract new educators, scientists, and practitioners to the division and its areas of study. They are funded largely by Dr. Barnes, and underscore his generosity and commitment to assisting others, especially young forage scientists, in their professional careers.

It is unfortunate that many younger scientists did not have the chance to experience the encouragement and friendly counsel we have received, or to see Bob's friendly smile and hear his characteristic chuckle. Our goal is to provide insight so that new students can be aware of this true gentleman and leader in forages. He was proud of the fact that his "middle name" was "F" and therefore did not need a period. His purpose was to live a life worthy of his calling as a Christian, husband, father, grandfather, professional colleague, and friend. He achieved these goals, in addition to his major scientific and professional contributions, by living humbly, rejecting passivity, accepting responsibility, listening carefully, and leading courageously.

Michael Collins
C. Jerry Nelson
Kenneth J. Moore

The Metric System

Base Units of the International System of Units

Measure	Base Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s

Prefixes Used with Units of the Metric System

Multiples and Submultiples	Prefix	Value	Symbol
$1{,}000{,}000{,}000 = 10^9$	giga	one billion times	G
$1{,}000{,}000 = 10^6$	mega	one million times	M
$1{,}000 = 10^3$	kilo	one thousand times	k
$100 = 10^2$	hecto	one hundred times	h
$10 = 10^1$	deca	ten times	da
$0.\,1 = 10^{-1}$	deci	one tenth of	d
$0.01 = 10^{-2}$	centi	one hundredth of	c
$0.001 = 10^{-3}$	milli	one thousandth of	m
$0.000{,}001 = 10^{-6}$	micro	one millionth of	µ
$0.000{,}000{,}001 = 10^{-9}$	nano	one billionth of	n

Metric to English Conversions

To convert metric to English multiply by	Metric unit	English unit	To convert English to metric multiply by
		Length	
0.621	kilometer (km)	mile (mi)	1.609
3.281	meter (m)	foot (ft)	0.305
0.394	centimeter (cm)	inch (in.)	2.54
0.0394	millimeter (mm)	inch (in.)	25.4
		Area	
0.386	kilometer^2(km^2)	mile^2 (mi^2)	2.590
2.471	hectare (ha)	acre (A)	0.405

	Volume		
35.316	meter^3 (m^3)	foot^3 (ft^3)	0.028
1.057	liter (L)	quart (US liq.) (qt)	0.946
	Mass		
1.102	ton (1000 kg) (mt)	ton (US t)	0.907
2.205	kilogram (kg)	pound (lb)	0.454
0.00221	gram (g)	pound (lb)	454
	Yield		
0.446	ton/hectare (mt/ha)	ton/acre	2.24
0.446	megagram/hectare (Mg/ha)	ton/acre	2.24
0.892	kilogram/hectare (kg/ha)	pound/acre	1.12
	Temperature		
1.8C + 32	Celsius (C)	Fahrenheit (F)	(F – 32)/1.8

The Last of the Virgin Sod

We broke today on the homestead
The last of the virgin sod,
And a haunting feeling oppressed me
That we'd marred a work of God.

A fragrance rose from the furrow,
A fragrance both fresh and old;
It was fresh with the dew of morning,
Yet aged with time untold.

The creak of leather and clevis,
The rip of the coulter blade,
And we wreck what God with the labor
Of a million years had made.

I thought, while laying the last land,
Of the tropical sun and rains,
Of the jungles, glaciers, and oceans
Which had helped to make these plains.

Of monsters, horrid and fearful,
Which reigned in the land we plow,
And it seemed to me so presumptuous
Of man to claim it now.

So when, today on the homestead,
We finished the virgin sod,
Is it strange I almost regretted
To have marred that work of God?

—Rudolf Ruste

Flesh is Grass

Grass is the forgiveness of nature—her constant benediction. Fields trampled with battle, saturated with blood, torn with the ruts of cannon, grow green again with grass, and carnage is forgotten. Streets abandoned by traffic become grass-grown like rural lanes, and are obliterated. Forests decay, harvests perish, flowers vanish, but grass is immortal.

Unobtrusive and patient, it has immortal vigor and aggression. Banished from the thoroughfare and the field, it bides its time to return, and when vigilance is relaxed, or the dynasty has perished, it silently resumes the throne from which it has been expelled, but which it never abdicates.

It bears no blazonry or bloom to charm the senses with fragrance or splendor, but its homely hue is more enchanting than the lily or the rose. It yields no fruit in earth or air, and yet should its harvest fail for a single year, famine would depopulate the world.

The primary form of food is grass. Grass feeds the ox: the ox nourishes man: man dies and goes to grass again; and so the tide of life, with everlasting repetition, in continuous circles, moves endlessly on and upward, and in more senses than one, all flesh is grass.

(*Excerpts from an address by John James Ingalls (1833–1900), Senator from Kansas from 1873 to 1891. Originally printed in the* Kansas Magazine *in 1872.*)

PART I

CHARACTERISTICS OF FORAGE SPECIES

Chapter 1

Forages and Grasslands in a Changing World

C. Jerry Nelson, Kenneth J. Moore, and Michael Collins

Welcome to forages and grassland agriculture. The roles and importance of forages and grasslands for mankind have a long history and continue to change as societies evolve and new technologies are developed for the plant and animal sciences. The foundational **grasses, legumes,** and other **forbs** observed today are the result of natural evolution for adaptation and resilience, often with the presence of grazing animals, for over 10,000 years with the advent of sedentary agriculture by humans. These plant resources are fragile; when they are managed or mismanaged beyond their limits, they deteriorate and can be lost.

The focus of this book is to understand and appreciate the plant characteristics and fundamental principles that provide diversity among the major forage and grassland species and to describe their use and optimal management. The goals of this chapter are to provide background and future perspectives for grasslands in the USA and North America.

Grassland Terminology

With any subject, it is important to know and understand the terminology. As with other subjects, the terms and definitions (see Glossary) for grassland agriculture overlap and are intertwined. The main land and plant resources are **forage, pasture, range,** and **grassland.** Forage is defined by the International Forage and Grazing Terminology Committee (Allen et al., 2011) as "edible parts of plants, other than separated grain, that provide feed for animals, or can be harvested for feeding." It includes **browse** (buds, leaves, and twigs of woody species), **herbage** (leaves, stems, roots, and seeds of non-woody species), and **mast** (nuts and seeds of woody species). Thus *forage* is an inclusive term for plants and plant parts that are consumed in many forms by domestic livestock, game animals, and a wide range of other animals, including insects. Furthermore, production of forage involves several types of land use and is subdivided using more specific terms.

The term *pasture* is derived from the Latin *pastus* and is defined by the International Forage and Grazing Terminology Committee (Allen et al., 2011) as "an area in which grass or other plants are grown for the feeding of grazing animals." This broad context includes **pasturage** that more accurately means "the vegetation which animals graze." Thus pasture refers to the land area or **grazing management unit,** rather than to what is consumed. *Pastureland* refers to land, usually in humid areas, devoted to the production of both **indigenous** (i.e., native to the area) and introduced forage species that are harvested primarily by grazing. *Permanent pasture* refers to pastureland composed of perennial or self-seeding annual plants that are grazed annually, generally for 10 or more successive years. In contrast, **rangeland** refers to land, usually in arid or semi-arid areas, consisting of tall-grass and short-grass prairies, desert grasslands and shrublands that are managed extensively and grazed by domestic animals and wildlife.

Cropland forage is land devoted to the production of a cultivated crop (e.g., corn or winter wheat) that is harvested for silage or hay. **Cropland pasture** is cropland that is grazed for part of the year, such as grazing corn stalks after the grain is harvested or grazing leaves of winter wheat during winter and early spring before reproductive growth

Forages: An Introduction to Grassland Agriculture, Seventh Edition. Edited by Michael Collins, C. Jerry Nelson, Kenneth J. Moore and Robert F Barnes.

begins. In addition to grazing, cropland pastures are useful in row crop rotations as winter cover crops to reduce soil erosion. **Cover crops** such as red clover or winter rye in the north or ryegrass and crimson clover in the south are seeded in fall primarily to provide protective ground cover over winter. The crop can be grazed, harvested, or tilled into the soil in spring. In addition to erosion control and protection of water quality, cover crops have favorable effects on soil fertility, soil quality, water quality, weeds, pests, diseases, and biodiversity and wildlife in an agroecosystem.

Rangeland is land on which the indigenous vegetation consists predominantly of grasses, grass-like plants, forbs, or **shrubs** and is managed as a natural ecosystem. When non-native plants are seeded into rangeland, they are managed as part of the vegetation mix as if they were native species. **Range** is a more collective term that includes grazeable **forestland** or **forest range** that produces, at least periodically, an understory of natural herbaceous or shrubby vegetation that can be grazed. This use has raised interest in **agroforestry,** namely the use of cropland agriculture among trees until the tree canopy causes shade. **Silvopasture** describes an agroforestry practice that combines managed pastureland with tree production.

Cropland, forestland, pastureland, and rangeland are also the basis for land-use mapping units (Fig. 1.1). Terms for grazing lands and grazing animals have been prepared by the International Forage and Grazing Terminology Committee (Allen et al., 2011); many of these are included in the Glossary.

Grassland Agriculture

Grassland includes pastureland, rangeland, and cover crops used for grazing, and thus in general denotes all plant communities on which animals are fed, with the exception of crops sown annually (such as wheat, corn, cotton, or sugar beets) that may also be used as forage. More commonly, *grassland* is any plant community, including harvested forages, in which grasses and/or small-seeded legumes make up the dominant vegetation.

The term **grassland agriculture** describes a farming system that emphasizes the importance of grasses and legumes in livestock and land management, including manure management. Farmers who integrate row crops with hayfields and pastures on their farm and manage livestock production around their grassland resources are grassland farmers.

Success in grassland farming depends on maintaining a healthy soil–plant–animal biological system. Land, or more specifically soil, is basic to plant production and hence to all of life. Simply stated, plants absorb from the soil the mineral elements that are required by animals and humans. Plants also combine the natural resources of solar energy, carbon dioxide (CO_2), and water to form carbohydrates and other carbon compounds. Plants then blend nitrogen (N) with appropriate carbon chains to produce amino acids and proteins. However, no single food plant contains the nutrients in the same proportions as are required by animals or humans.

Herbivores (animals that can digest the fibrous tissue of plants) subsist primarily on plants and plant materials, converting grassland products to high-quality meat and milk foods that complement the nutritive value of plant products for humans (Fig. 1.2). Ruminants and other herbivores contribute to human well-being by producing meat and milk products that are rich sources of proteins, fats, vitamins, and minerals. In addition, ruminants provide non-food products of value, such as:

- Hides, wool, and horns for clothing, implements, and adornments
- Power for draft work or transportation
- Manure for fertilizer and fuels
- Benefits to humans, such as the pleasure derived from keeping animals as pets, observing wild animals in their

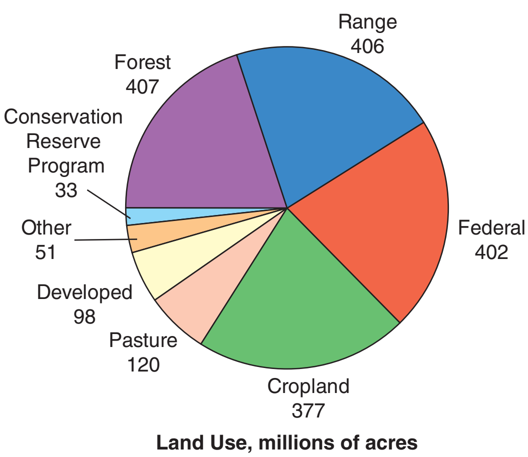

FIG. 1.1. Agricultural land use (million acres) in the contiguous USA. (Data from USDA Economic Information Bulletin No. 89, 2011.)

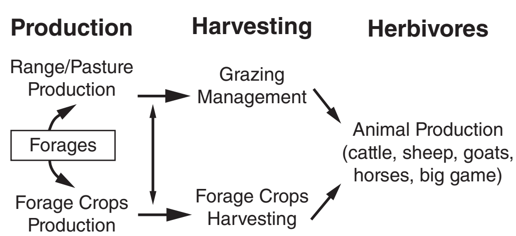

FIG. 1.2. The dual production-harvesting avenues that forage can follow during its harvest and conversion to useful products by herbivores. (Adapted from Vallentine, 2001.)

natural habitats, and using animals for competitive and sporting events, and hunting

- A biological means of harvesting desirable vegetation and removing unwanted vegetation.

Scientific Names of Forage Plants

Today grasslands and forage management are international in scope, and communication about forages occurs worldwide. The US Department of Agriculture (USDA) has active programs and strict regulations for evaluating introduced plants in regional testing sites that represent climatic areas. Seed of several grasses and legumes are produced in the USA and shipped to foreign markets. Similarly, the USA imports commercial seed of several forage species. These activities require accurate communication about forages based on universal terminology.

Most cultivated forages fit into two botanical families: the Poaceae (Gramineae), namely the grasses, and the **Fabaceae** (Leguminosae), namely the legumes. In addition, many other forbs, which are herbaceous (i.e., nonwoody) dicotyledonous plants (including legumes), and the leaves and buds of several trees and shrubs contribute to the nutritional requirements of ruminants. Each plant has its own scientific name. The binomial system of naming developed by the Swedish botanist Carl Linnaeus in the eighteenth century has been very effective, and is still the standard.

Each plant is known scientifically by its species name, which generally consists of two Latin words. The first word, the **genus,** always has a capitalized initial letter; the second word, the **species epithet,** is all lower case. The genus is similar to a surname and the species epithet to a first name. Thus, for example, *Medicago sativa* would be like Brown, John. The scientific name includes the authority, which is the abbreviated name of the person or persons who first classified the species. For example, *Medicago sativa* L. indicates that alfalfa was named by the Swedish botanist Linnaeus. If a plant is reclassified, the original authority is placed in parentheses, and the new authority follows it. For example, indiangrass, *Sorghastrum nutans* (L.) Nash, was first classified by Linnaeus and later reclassified by Nash.

Forage plants often have different common names in different regions of the USA and the world. For example, the name prairie beardgrass is occasionally used, but is not the approved common name for little bluestem *(Schizachyrium scoparium* [Michx.] Nash). Similarly, in the UK, alfalfa is called lucerne, and *Dactylis glomerata* L. is called cocksfoot instead of orchardgrass. The common and scientific names of many of the plants discussed in this book are listed in the Appendix.

The Early Role of Grasslands

Civilizations have had their origins on grasslands, and have vanished with its destruction. Grazing lands were vital to prehistoric nomadic peoples as hunting sites long before cattle and sheep were domesticated. Attempts to control the fate of humans by planting crops to provide for future needs, instead of remaining the victims of droughts or other calamities, must have taken place on grasslands, where the young calves, lambs, and kids that had been caught and tamed could find forage. After the nomads adopted a sedentary way of life and became food producers rather than food gatherers, the grasslands of these early peoples changed rapidly.

Early recognition of the value and fragilities of grass (i.e., forage resources) is noted in the Bible: "He makes *grass* grow for the cattle, and plants for man to cultivate—bringing forth food from earth" (Psalm 104:14). This is an early reference to the soil–plant–animal continuum to provide food, but it is unclear if the grass was managed. The close linkage between plants, animals, and humans is also referred to by Moses when he promised the Children of Israel that God "will provide *grass* in the fields for your cattle, and you will eat and be satisfied" (Deuteronomy 11:15). Psalm 103:15–16 compares grass to man and the transitory nature of human life: "As for man, his days are like *grass*, he flourishes like a flower of the field; the wind blows over it and it is gone, and its place remembers it no more." The shortage of grass was recognized as a symbol of desolation: "The waters … are dried up and the *grass* is withered; the vegetation is gone and nothing green is left" (Isaiah 15:6).

The theme of grass and grazing that runs throughout the Bible shows the early interrelationship of humans and nature, with the general view that nature was the major determinant of productivity. People knew little about how the grassland resource could be managed. As agriculture developed, populations of nomadic hunters and gatherers decreased, "apparently remaining only in areas where agriculture was unable to penetrate" (Harlan, 1975).

Early grassland management practices in Asia and Africa often consisted of communal grazing of livestock on large areas of native pastures. Such shared pastures were referred to as *commons*, a term generally used today for a public place for people. Commons were owned collectively, and one member could not exclude animals owned by another member. Consequently, overgrazing and conflict often resulted, leading to lower levels of animal production and subsequently to poorer human nutrition. At that time, cropland agriculture was becoming focused on planted monocultures with the expectation that farmers could overcome environmental and other constraints by management to increase yield.

The Evolution of Grassland Management

In Great Britain, the use of the scythe and the process of hay making date from 750 BC. The conversion of fresh green forage into dried hay, which could be stored with

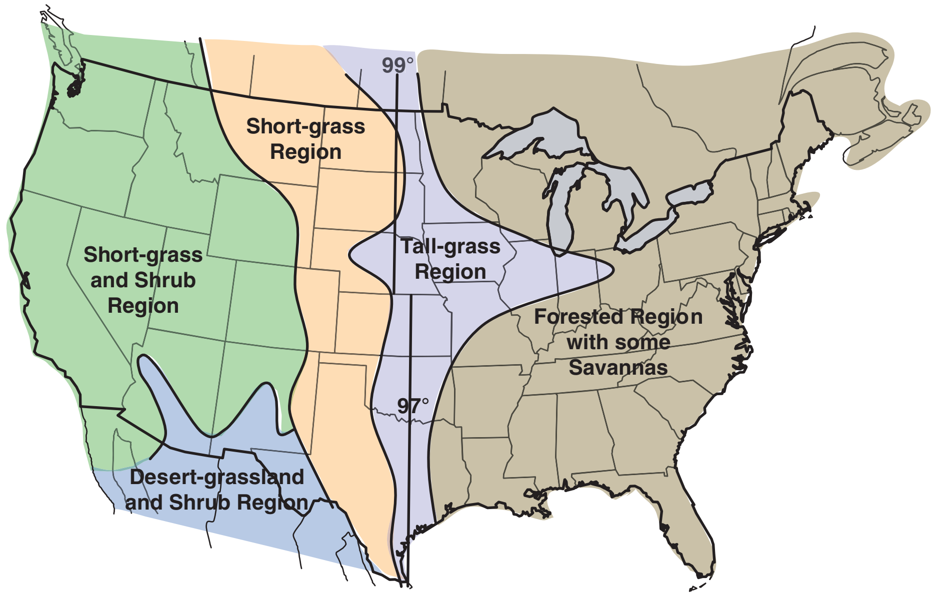

FIG. 1.3. Major grassland regions of the USA at present. Introduced species are dominant in northern areas along the West Coast and in areas of the east that were formerly wooded. Southern areas along the West Coast have primarily winter annuals in non-irrigated areas. (Adapted from Barnes, 1948.)

little change over time, was associated with a sedentary rather than nomadic agriculture. Winter survival of livestock depended on the success of the hay harvest. The growing of hay crops and the need for proper curing were described in detail by the Roman writer Columella in about AD 50.

The Anglo-Saxons began to enclose meadows in the Midlands of Great Britain around AD 800, probably using fences of stacked stones or hedges of thick or thorny plants. As early as 1165 the monks of Kelso were aware of the value of regular changes of pasture areas for the health of cattle and sheep. Around 1400, the monks of Couper were using crop rotations, alternating 2 years of wheat with 5 years of grass, a crop rotation practice that later came to be known as **ley** farming.

Red clover, which is a very important legume today, was cultivated in Italy as early as 1550, in western Europe somewhat later, in England by 1645, and in Massachusetts in 1747. Without knowing the causes, farmers recognized differences in value among the various forage species. We now know that red clover can fix nitrogen from the air, and that the addition of red clover or other legumes to the grass mixture increases both production and quality of the forage. The influence of red clover on civilization and European agriculture was probably greater than that of any other forage plant (Heath and Kaiser, 1985).

Native Grasslands of North America

Before colonization and the introduction of cattle, sheep, and goats by European settlers, heavy forest covered much of the eastern USA; about 40% of the total land area in the contiguous USA was grassland (Fig. 1.3). Around the year 1500 there were nearly 700 million acres (284 million ha) of grass-covered native prairie stretching from Ohio westward. In general, the most fertile, deep, rich, black soils developed under the vegetative growth of the prairies. The tall-grass prairies of the central and Great Lakes states were dominated by native grasses such as big bluestem, indiangrass, and switchgrass, which grew tall and dense. These prairie grass sods were so tough and thick that some farmers preferred not to plow them until the stand had been weakened for a few years by **overgrazing** and repeated mowing. Today, the Flint Hills area of eastern Kansas and the Osage Hills of Oklahoma are the only extensive areas of undisturbed native tall-grass prairie.

Further west, the shortgrass prairie originally extended from Mexico and Texas north into Canada, and east from the Rocky Mountains to mid-Kansas, Nebraska, and the Dakotas. Native short grasses such as wheatgrasses in the north and buffalograss and grama grasses in the south were in greatest abundance. Some tall grasses were intermixed in the region of transition and predominated toward the eastern margin, especially in sites with higher soil moisture levels.

The areas of grassland gradually changed several times over geological time, ranging in character from woodlands and forest during moist, cool eras to grasslands during more arid periods. For example, it is known that between 4000 and 8000 years ago a drying trend extended the arm of tall-grass prairie between the Ohio River and the Great Lakes all the way to the Appalachian Mountains. As less arid times returned, the forest encroached again and the prairie retreated westward, leaving behind soils of grassland origin and patches of relic prairie communities that still exist in New York and Pennsylvania.

The vast native grasslands of the USA were referred to as range and rangelands soon after the turn of the twentieth century. English settlers on the Atlantic Coast brought with them their term **meadow** for native grassland that was suitable for mowing. The French in Canada used the term prairie for similar grassland, and the Spanish in Florida used the word savanna. These various names for native grassland in North America have become a part of the American vocabulary, with each term having its own meaning.

Native Americans and Forages

A unique feature of the management of the vast grasslands of North America was the use of fire. References to burning of grasslands by Native Americans are found in the journals of many early explorers and settlers in the western USA. Early on, the range was shrubbier and had intermittent grasses. It is likely that Native Americans noted the effects of natural fires caused by lightning in summer when the soil and plants were dry, and then tried burning the overwintering residue earlier in the year. Today we know that the burning of grasslands in spring, as the plants are just beginning to grow, contributes to the abundance of productive grasses by removing old ungrazed forage, recycling minerals, and reducing the numbers of weeds and shrubs. The improved grassland led to increased numbers of American bison *(Bison bison* L.), also known as buffalo. Native Americans selectively burned large areas in order to entice the herds of buffalo and other wildlife to the improved areas, where they could be more easily hunted.

Fire Cleanses and Rejuvenates

The word *fire* conjures up thoughts of heat, tragedy, smoke, and dirty ashes. However, many native grasslands benefit from the burning of old stubble and residue in spring. A “good” fire is hot enough to burn the residue completely, but moves across the ground quickly so that the temperature of the soil and the meristematic regions of grasses at soil level remains low. Unless they are protected by thick bark, herbaceous plants, young shrubs, and young trees with meristems higher in the air are destroyed. The life cycles of insects and many pathogens are disrupted. Ashes on the soil surface absorb solar energy, which warms the soil and thus stimulates early growth of the surviving grasses. Plant minerals in the ashes are available to support new growth that is of very high quality. Researchers are still learning about the value of fire.

The relationship between soil, grass, fire, buffalo, and Native Americans developed over several thousand years, as a result of which these native grasslands provided great wealth. About 200 years ago the prairies supported 60 million buffalo, 40 million whitetailed deer, 40 million pronghorn antelope, 10 million elk, and hundreds of millions of prairie dogs, jackrabbits, and cottontail rabbits—all forage consumers. Grasslands were essential for buffalo, on which Native Americans depended for their existence. After the buffalo herds were destroyed by hunting on a massive scale in the 1800s, the prairie and Native Americans were subdued.

Forages in American Colonial Times

The first English settlers in the American Colonies found that their method of farming and producing food crops in the New World was minimally successful. The East Coast was covered with forests with little open grassland (Fig. 1.3). The few domestic animals that survived the long ocean voyage grazed the small pockets of native grasses, where they did well during the summer, but required shelters and supplemental harvested forage to survive the long, hard winters. As the number of livestock increased, the limited acreage of native pastureland and production of poor-quality hay made it difficult to carry animals through the winter. Gradually, the year-on-year grazing without rest weakened the tall-growing native species. This led to the introduction of short-growing grasses and clovers used previously in England. The introduced species had a longer growing season, were more productive, especially during the cool seasons of spring and fall, and were better adapted to close and repeated grazing.

By the early 1700s, the acreage of introduced grasses, somewhat open woodlands, and enclosed meadows was not keeping pace with the need for meat and milk. Croplands worn out by excessive tillage and then abandoned to weed fallow made poor pasture. Farmers continued to cut hay chiefly from natural meadows and marshy areas.

In England, between 1780 and 1820, many crude research trials on various grasses and legumes grown in small plots were conducted. Yield and nutritive value were determined, and the findings were published as a book that made its way to the USA, where these results were used for about 50 years.

In 1850, haying tools consisted of the scythe, a crude hay rake, and the pitchfork. Mechanization began with the sicklebar mower, followed by a harpoon-type fork for unloading hay from a wagon into the barn (1864), the hay loader for moving hay from a swath onto a wagon (1874), and the side-delivery rake to make a windrow from the swath (1893). However, hay making was still a difficult and time-consuming job. The baler with a pickup attachment (developed in the 1940s) made it easier to collect the dried hay and form a dense rectangular package that could be moved and stored efficiently. The big round baler (developed in the early 1970s) further reduced labor needs. Today, the use of dense, compact, rectangular bales weighing from 500 lb (225 kg) to over 1 ton (450 kg) are used for commercial sales and international trade. Later advances in electric fencing and watering systems facilitated the use of intensive grazing systems. Today, new technologies continue to shift and improve the nature of forage management and use.

Silage production, which is a process of fermenting plants in anaerobic conditions to preserve them with a high moisture content, was carried out in a crude form by the Egyptians and Greeks. They placed wet forage into a vertical structure (silo) made of stones or a covered pit, and packed it to reduce the oxygen content. Natural microorganisms used up the remaining oxygen to form organic acids that lowered the pH to prevent other organisms from rotting the material. Ensiling the wet forage sooner, before it was dry enough to store as hay, reduced the potential for weather damage and harvest losses in the field that decrease forage yield and quality. The modern era of ensiling crops began in the mid-1800s in Germany, perhaps due to the common practice of making sauerkraut to preserve cabbage. By 1900, silage making was being promoted in the USA, facilitated by improved storage structures, mechanization for harvest, and chopping the plant material into small pieces for improved ensiling.

The Merging of Grassland Cultures

The culture of grass in the USA evolved as a product of the Native American and European farming systems that produced the beginnings of American agriculture (Edwards, 1940). As the pioneer farmers began to push westward from New England in the late 1700s, they needed to clear heavy forest before crops and the introduced forage species could be grown. Interestingly, it was generally thought that land which supported only grass was inferior to that which supported tree growth. As settlers entered Ohio and western areas where there was a choice between forest and prairie, forest-covered soils were favored. Forest also provided security for the pioneer farmers; it sheltered the game that was a major source of meat, and it supplied timber for cabins, stock shelters, fuel, and fences.

Fencing materials were important to the settlers, and fences on the prairies were not practicable until the invention of barbed wire in 1867 and its rapid introduction into US agriculture. The pioneers hesitated to migrate onto the large prairies of seemingly endless tall grass. The vastness was overwhelming and left the impression that it could not be subdued. Low-cost fencing and the steel moldboard plow opened up new opportunities. Meanwhile, settlers of Spanish origin were entering the south-west from Mexico.

George Stewart's chapter in Senate Document No. 199 provides a classic historical documentation of range resources in the USA (Stewart, 1936, p. 2):

> The western range is largely open and unfenced, with control of stock by herding; when fenced, relatively large units are enclosed. It supports with few exceptions only native grasses and other forage plants, is never fertilized or cultivated, and can in the main be restored and maintained only through control of grazing. It consists almost exclusively of land which, because of relatively meager precipitation and other adverse climatic conditions, or rough topography or lack of water for irrigation, cannot successfully be used for any other form of agriculture. In contrast, the improved pastures of the East and Middlewest receive an abundant precipitation, are ordinarily fenced, utilize introduced forage species, … cultivation for other crops, and are often fertilized to increase productivity, and are renewed following deterioration.

The impression of early explorers was that the growth of grasses on these vast prairie areas would endlessly support countless herds and flocks. However, two factors eventually upset the resilience of this grassland resource: first, the Spanish heritage of rearing cattle in large herds, and second, the increased demand for meat after the discovery of gold in California in 1848. Livestock on the prairies had previously been raised largely for hides, tallow, and wool, but that changed with the rapid migration of people to the West. After 1870 the number of large herds of cattle increased rapidly from central Texas northward and westward (Edwards, 1940). The influence of the colonial Spanish on the use of grasslands of the southwestern USA is best summarized by Stewart (1936, p. 122):

> The tremendous growth in range cattle, however, carried with it a weakness that in the end proved fatal. It was based on a husbandry transplanted from Mexico, which brought to English-speaking people for the first time in history the practice of rearing cattle in great droves without fences, corrals, or feed. … Cattle instead of grass came to be regarded as the raw resource, and the neglected forage began to give way before the heavy and unmanaged use to which it was subjected.

The steel moldboard plow and the tractor spread the development of agriculture, particularly in the Midwest and tall-grass prairie region. However, this led to widespread conversion of grassland, with its rich soils, to cropland even in dry areas, and eventually to the Dust Bowl