PART I

CHARACTERISTICS OF FORAGE SPECIES

CHAPTER 1

Forages and Grasslands in a Changing World

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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.

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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

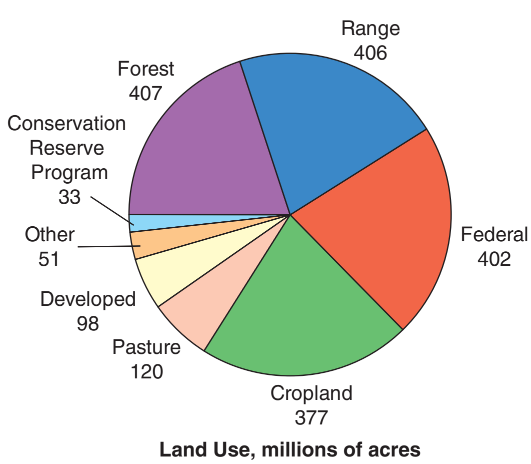

Fig. 1.1. Agricultural land use (million acres) in the contiguous USA. (Data from USDA Economic Information Bulletin No. 89, 2011.)

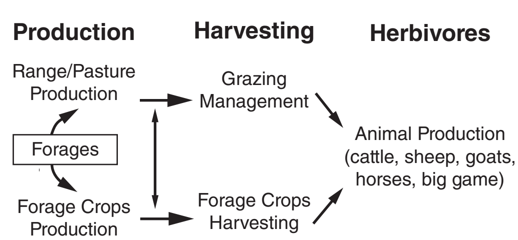

Fig. 1.2. The dual production-harvesting avenues that forage can follow during its harvest and conversion to useful products by herbivores. (Adapted from Vallentine, 2001.)

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

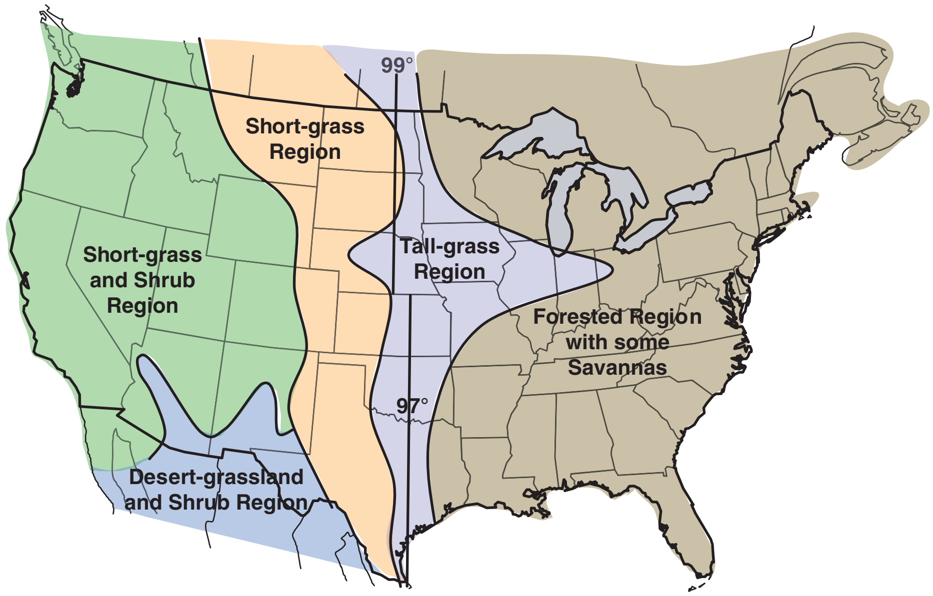

Fig. 1.3. Major grassland regions of the USA at present. Introduced species are dominant in northern areas along the West Coast and in areas of the east that were formerly wooded. Southern areas along the West Coast have primarily winter annuals in non-irrigated areas. (Adapted from Barnes, 1948.)

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

The Resiliency of Nature

When cropland in the eastern USA is abandoned or pastureland is not managed, it is encroached, first with annual weeds and eventually with deciduous trees (Fig. 1.4). The ecosystem wants to regain balance with nature (i.e., to develop a mixture of plant species that coexist and are in long-term equilibrium with the environment). When land use by humans is far from this natural equilibrium, resources must be expended in terms of reseeding, fertilizing, controlling weeds and pests, and cutting or grazing management to keep the system as close as possible to the desired condition. The further that condition is from the natural equilibrium, the greater the management cost; "fighting nature" too far from the natural equilibrium becomes non-economic. Can you determine whether an abandoned cornfield in eastern Nebraska would revert to a more natural state as quickly as would one in central Pennsylvania? Would tree encroachment be a greater problem for a pasture site in western Missouri or in eastern Kentucky?

Fig. 1.4. Beef cattle grazing a managed pasture of smooth bromegrass and orchardgrass during autumn in Wisconsin. Note the deciduous hardwood trees in the background that provide shelter for the livestock and shade in summer, but the trees and shrubs would invade and dominate the ecosystem if the pasture was not managed correctly. (Photo courtesy of Michael Collins.)

of the 1930s. Vavra et al. (1993) conclude that "the westward expansion of the US was characterized by exploitation of natural resources." Interestingly, this exploitation was supported by the American public through federal legislation and policies. For example, the initial Homestead Act of 1862, followed by others in 1873 and 1877, encouraged westward expansion by allocating publicly owned grassland at very low cost for settlers for growing crops.

The influx of a farming population into the rangeland areas resulted in even greater demand for animal and meat production from the remaining rangeland. The public rangeland, which was in many respects a commons, was grazed by animals owned by nearby farmers and ranchers. In contrast with the culture and management of the Native Americans, there was little incentive to conserve the available forage and land for later use. This lack of property rights led to what Hardin (1968) called the "tragedy of the commons." The boon in unlimited livestock grazing lasted only 20 years, and by 1880 continued overstocking had reduced the carrying capacity of most of the western range. Dry summers coupled with severe winters resulted in the loss of 30–80% of the cattle in the Northern Plains during the winters of 1886 and 1887.

Soon thereafter the cattle industry in the Great Plains changed from an open-range, exclusive-use enterprise to a ranch-based industry that coexisted with cropland. The Taylor Grazing Act of 1934 began to control grazing on government-owned grasslands, and ended the series of Homestead Acts.

Although the interactions between livestock grazing and other elements of the Great Plains ecosystem are complex, research indicates that grazing of domestic livestock at conservative levels on sensitive western rangelands can be sustainable (Vavra et al., 1993), and that in most cases it is similar to grazing by buffalo. Sustainability must be the primary goal of any forage management plan, particularly for the Great Plains, where 63% of the area consists of grazing lands. At the same time, factors such as urbanization, climatic changes, reduction in the use of fire, increases in the number of woody species, introduction of alien plant species, and other human activities have had major influences on this natural resource.

Forage, Range, and Grasslands Today

Approximately 75 years ago there was an average of about 10 acres (4 ha) of cropland per person in the USA. By 30 years ago that figure had been reduced to about 5 acres (2 ha), and today it averages less than 2 acres (0.8 ha) per person. Meanwhile, average farm size increased, and the number of farms decreased from a peak of 6.8 million in 1935 to 2.1 million by 2012, and remains at approximately the same level today. About 8 million people were living on farms and ranches in 1978, but this figure had decreased to about 5 million by 1987, and to 3.2 million in 2012, as farm size gradually increased. As a result, the farm and ranch population today has declined to less than 1.2% of the total US population. However, forage and grazinglands remain an important part of US agriculture.

Currently, pasture and non-forested rangeland represent about 29% of the 2.3 billion acres (1.04 billion ha) of land area of the USA. The proportion of land used in agriculture has decreased from about 63% in 1950 to about 50% at the time of writing. Decreases occurred mainly in cropland, pastures, and range, especially grazed forestland. At the same time, non-agricultural uses increased to 49% of the total land base, primarily due to increases in national parks and national wilderness and wildlife areas, mainly in Alaska. In 2015, hay was produced on an estimated 56.2 million acres (22.8 million ha), of which about 32% was alfalfa and alfalfa mixtures. The average yield of alfalfa and alfalfa mixtures was 3.5 tons/acre (7.8 Mg/ha) whereas that for other hay was 2.1 tons/acre (4.7 Mg/ha). Corn and sorghum silage grown on over 7 million acres (2.8 million ha) added to the total value from forages.

More than 40% of the rangeland, mainly in the far west, is owned by the US government, and much of it is grazed under contract with local ranchers. The amount needed, appropriate use, and management of these public lands continue to be debated.

Today, much of the woodland and forested area of the eastern USA has been cleared and is used for crop production. Except for a few pockets of native unplowed prairie, many of which are being preserved, the eastern half of the USA (east of 99° longitude) uses mainly introduced forage species for pasture and hay production (Fig. 1.5).

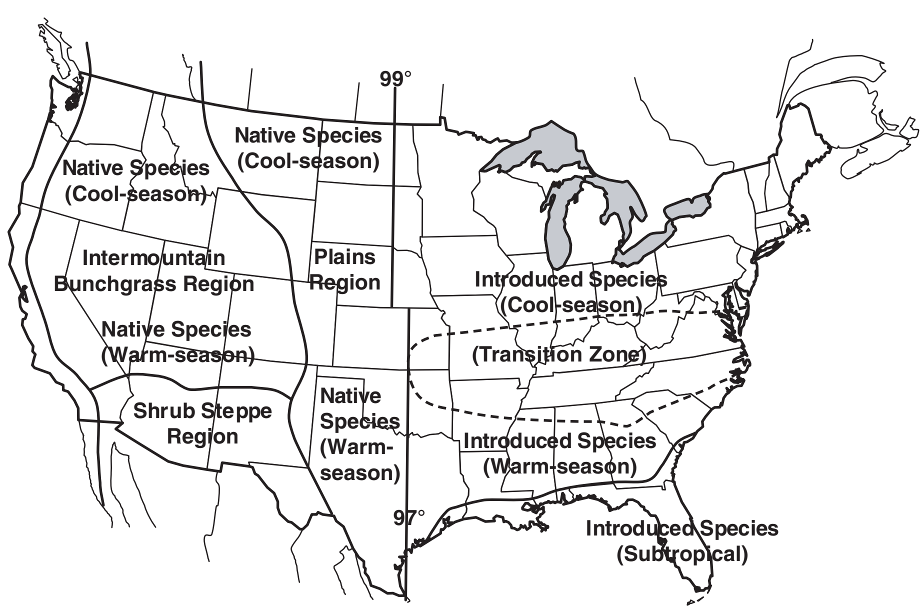

Fig. 1.5. Major grassland areas of the USA at present. Introduced species are dominant in northern areas along the West Coast and in areas of the east that were formerly wooded. Southern areas along the West Coast have primarily winter annuals in non-irrigated areas. (Constructed from authors' knowledge and Barnes, 1948.)

Fig. 1.6. Dairy cows utilizing a managed pasture of cool-season grasses and legumes in Wisconsin. The large barn includes the milking area and provides shelter during winter. The silos near the barn are for storing silage, mainly corn or grass silage, for winter feeding when pastures are not growing. Pasturing dairy cattle is a way to reduce the costs of harvesting, packaging, storing, and feeding forage. It also reduces problems with waste management because the manure is distributed on the pasture. (Photo courtesy of Michael Collins.)

Permanent pastures in the north central and northeastern regions are dominated by white clover and kentucky bluegrass, both of which are introduced species. Improved pastures (Fig. 1.6) include grasses such as timothy, orchardgrass, smooth bromegrass, perennial ryegrass, and reed canarygrass, and legumes such as red clover, white clover, birdsfoot trefoil, and alfalfa, all of which have been introduced. Each cool-season species has its optimum area of adaptation within the general region, depending on environmental stresses and the management system used.

Pastures in the southern part of this region are dominated by bermudagrass, dallisgrass, bahiagrass, and johnsongrass, all of which are introduced warm-season grasses (Fig. 1.5). Few perennial legumes show good adaptation to the South because of the long, warm summers, but white clover is widespread. Winter annuals such as crimson clover and several other clovers have also been introduced. In the subtropical areas of Florida and along the Gulf Coast there are many introduced species. In addition, in the southeast there are large areas of silvopasture where pine forests have an understory of grasses and legumes. These forages are usually burned on a regular basis to maintain productivity.

Tall fescue dominates in the region where the distributions of warm- and cool-season species overlap, creating what is known as the transition zone. Although tall fescue is physiologically a cool-season species, it evolved in North Africa and can survive the warm, dry summers and moderate winters of the area. In addition, an endophytic fungus lives in the sheaths of tall fescue leaves, enabling the plant to resist insects and enhancing its drought resistance and rooting capabilities. Chemicals produced as a result of the plant–fungus association also reduce the palatability to livestock, so plants are less likely to be severely defoliated. In southern areas, most of the tall fescue grown has the endophytic fungus. In the northern areas, where stresses are lower, endophyte-free cultivars are often used because they give better animal performance. In the transition zone there is interest in using various warm-season grasses, both native and introduced, to enhance summer production.

The plains grasslands west of 99° longitude, where rainfall is lower, are still dominated by a range of native short grasses, depending on their adaptation to cold. Species such as wheatgrasses and wildryes are common in the north. With good management and modest rainfall, the southern

Table 1.1. Numbers of ruminant livestock in the USA

Animal	1978	1987	1994	2002	2012
Cattle (million)	116.4	102.1	101.1	95.5	90.0
Beef cows (million)	38.7	33.8	34.6	33.4	29.0
Dairy cows (million)	10.9	10.5	9.5	9.1	9.2
Sheep (million)	12.4	10.7	9.8	6.3	5.4

Source: US Department of Agriculture, 2016.

areas have mainly native grasses such as blue grama and buffalograss.

The southwestern shrub-steppe region consists of grama grasses, some annuals, and shrubs. If there is poor grazing management the shrubs can become dominant.

Along the West Coast, especially in the south where climates are more Mediterranean, winter annuals predominate in non-irrigated areas. Along the northern coastline, the grasslands are mainly introduced cool-season species.

The intermountain bunchgrass region is located between the Cascade and Rocky Mountains. In northern areas where precipitation mainly falls as snow, the growing season is cool and short, and grasslands mainly consist of bluebunch wheatgrass and idaho fescue, both of which are native species, and numerous forbs. Downy bromegrass, a winter annual species, is an invader. Some of the northern areas have been cultivated from time to time. In the south, several native grasses predominate, but shrubs are primary invaders, especially in the absence of fire.

Forages in the National Economy

Grassland agriculture is highly dependent on a reliable source of forage as the primary feed base for ruminant livestock. Resource inputs used when raising cattle and sheep are widely scattered, both in location and in ownership, because livestock raising is a land-based, forage-utilizing enterprise. Cattle numbers in the USA peaked in 1975, with 135 million head, and then declined gradually (Table 1.1), mainly due to a reduction in the number of beef cattle as annual per-capita consumption of beef has decreased from 87 lb (40 kg) in 1978 to 57 lb (26 kg) in 2012. This occurred primarily due to higher costs and growing health concerns. Interestingly, the number of dairy cows has remained relatively steady, but production per cow has increased by about 13% over the past 10 years. Sheep numbers peaked in 1935 and then declined significantly, with a reduction of over 56% between 1978 and 2012. These numbers may increase somewhat in the future depending on the ethnic market that is developing. Overall, the total number of ruminant livestock has gradually declined, decreasing by about 25% between 1978 and 2012. During that same time period, annual per-capita consumption of pork remained relatively steady at about 46 lb (21 kg), whereas that of poultry increased from 54 lb (25 kg) to 98 lb (45 kg).

Data on the use of feedstuffs for livestock and poultry in the USA allow the proportion of the diet provided by forage for various classes of livestock to be calculated (Table 1.2). Ruminant animals depend on forage as the basic feed source, but very little forage is fed to poultry, and minimal amounts are fed to swine. However, for beef cattle, before being fed out on high-concentrate rations, about 96% of the feed is in the form of forages. In general, dairy cattle use a lower proportion of forages in the diet than do beef cattle, mainly because dairy cattle need large amounts of concentrate to produce milk for several years, compared with a period of only a few months when beef cattle are finished on a high-concentrate diet.

Table 1.2. Use of concentrates and forages in livestock and poultry rations in the USA

	Proportion of ration (%)		Proportion of total concentrate (%)	Proportion of total feed (%)
	Concentrate	Forages		
All livestock and poultry	36	63	100.0	100.0
All dairy cattle	39	61	16.6	16.0
All beef cattle	17	83	25.8	56.9
Beef cattle on feed	72	28	20.7	10.7
Other beef cattle	4	96	5.1	46.2
Sheep and goats	9	91	0.4	1.9
Hens and pullets	100	0	12.4	4.6
Turkeys	100	0	3.3	1.3
Broilers	100	0	9.3	3.5
Swine	85	15	30.0	13.2
Horses and mules	28	72	2.2	2.9

Source: Adapted from Council for Agricultural Science and Technology, 1980.

Table 1.3. Estimated value of forages consumed by ruminant livestock

Animals	Receipt as feed costs[a] (%)	Feed units as forage[b] (%)	Cash receipts as forage value[c]	1996 Cash receipts[d] (US$ million)	Forage value[e] (US$ million)
Beef cattle	70	83	0.581	36,094	20,971
Sheep and wool	70	91	0.637	680	433
Dairy cattle (milk)	50	61	0.305	20,997	6404
Total forage value					27,808

[a]From Hodgson, 1974.
[b]From Council for Agricultural Science and Technology, 1980.
[c]Obtained by multiplying column 2 (receipt as feed costs) by column 3 (feed units as forage).
[d]Reported in US Department of Agriculture, 1999.
[e]Obtained by multiplying column 4 (cash receipts as forage value) by column 5 (1996 cash receipts).

Hodgson (1974) calculated the value of forage based on proportional feed costs for each class of livestock (Table 1.3). Using estimated feed costs for livestock production, rather than feed value, underestimates the true value of forages. Using feed costs based on cash receipts for 1998 (US Department of Agriculture, 1999), the total value of forages of US$ 27.8 billion (Table 1.3) exceeded the cash value of other crops. About 75% of the total value of forages was for beef cattle and 23% was for dairy cattle. The value of hay alone in 2014 was US$ 19.1 billion (US$ 10.6 billion for alfalfa and US$ 8.5 billion for other hay), which was exceeded only by corn and soybeans, which were valued at US$ 53.0 billion and US$ 39.5 billion, respectively (US Department of Agriculture, 2016). Unfortunately, no data are available for annual values of pasture and rangeland.

Sustainable Pastures and Hayfields

The number of farms and the number of people farming are gradually declining, while at the same time the challenge of providing adequate supplies of safe and wholesome food and other **ecosystem services** for an ever-expanding population is increasing. Large-scale farming, often termed "corporate" or "industrial" farming, has raised genuine suspicion and mistrust about a food system that appears to be being driven by large companies and its stockholders, not by local farmers. The need for sustainability of agriculture is a high priority involving the agricultural community, the public, and focused government programs to ensure that resources are conserved in order to be available for and meet the needs of subsequent generations. Most farmers and ranchers are aware of the basic issues, and the need to adopt practices that contribute to sustainability. Yet the public, which is geographically and historically removed from agriculture, is concerned and often reacts in ways that are based on emotion or hearsay, and with little scientific background. New technologies and the growing role of industry in marketing seed, chemical fertilizers, pesticides, and genetically modified crops have heightened public awareness and the need for regulations.

Public concerns have caused regulations to be put in place by the US Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA) to ensure that the food, water, and air are tested and determined to be safe. There was a strong need for clarity about sustainable agriculture so that rational and clear communication could be used. Sustainable agriculture was legally defined in U.S. Code Title 7, Section 3103 (US Government Publishing Office, 2006, p. 1406) as "an integrated system of plant and animal production practices having a site-specific application that will over the long term:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource base upon which the agricultural economy depends
- Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls
- Sustain the economic viability of farm operations
- Enhance the quality of life for farmers and society as a whole."

In summary, the basic goals of sustainable agriculture are economic profitability, environmental preservation, and social responsibility, each of which has intrinsic or inherent value (Fig. 1.7). Although the terms are valid, it is unclear what approach should be used to measure and then determine whether a farm is sustainable. As well as serving as the major source of feed nutrients for wild and domestic animals, grassland agriculture provides many complementary benefits for the environment and helps to gain social acceptance of farming practices. In addition to food, it is well known that forages and grasslands contribute to human well-being by:

- Providing raw materials for clothing and other textiles
- Soil erosion control

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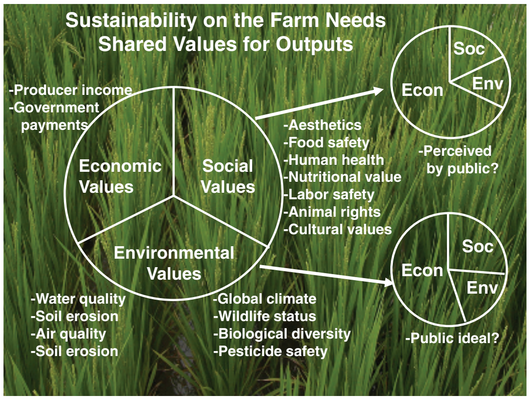

Fig. 1.7. Sustainable agriculture involves economic return to the farmer and environmental preservation that are achieved in ways which are socially acceptable. The left portion gives each component equal emphasis, but that probably does not reflect reality. The public believes that farmers are less concerned about environmental and social values than they are about economic values. However, the ideal is site specific and unknown. (Adapted from Nelson, 2007.)

- Improvement of soil structure and fertility of arable lands
- Water conservation and protection
- Providing habitat for biologically diverse plants and wildlife
- Protecting the environment from pollutants such as sediment, windblown soil, municipal and farm wastes, and some toxic substances
- Providing a source of outdoor recreation and pleasure
- Providing biomass for conversion to energy as a renewable resource
- Providing feedstocks for manufacturing products.

Economic return is relatively easy to define in monetary units that are used for farm management. Everyone wants clean water, but each person will differ with regard to what they perceive to be its "value." Everyone wants farmers to have a clean and safe working environment and to treat animals humanely, but how are those factors described and valued? Environmental factors are difficult to quantify and value. Social values differ markedly among people, and vary depending on culture, age, and economic status. It is easy to envision how they differ among rural and urban residents. The conclusions drawn by activists and others about sustainability are frequently based on valid concerns (e.g., animal rights), but often are not defined or supported by scientific research. This leads to mistrust and conflict.

In the USA, farm and ranch sizes are increasing due to mechanization and the known increase in efficiency associated with size. This often develops into a "business style" in which the owner or manager makes the decision while the employees do the work. The farms are usually focused on production of one or only a few commodities on large fields of monocultures with little diversity. This contrasts markedly with the smaller "family farm", where there is diversity of crops and animals on each farm, use of pastures and hayfields in rotations, and labor and decision making undertaken by the farmer and family members. Many researchers in social and agricultural sciences are investigating the values of the various environmental and social factors involved in order to compare the various scenarios with regard to sustainability.

Sustainability of agriculture tends to be addressed differently by individuals and their governments. Countries with high incomes, such as Germany, Switzerland, and other European countries, restrict the amalgamation of land and subsidize the high proportion of small landowners (farmers) in order to maintain a good income from diversity of crops and livestock on a small land area. Conversely, Canada, Australia, and Brazil, which have very large farms, have policies more similar to those of the USA. Other countries, such as some African and Asian countries, have low personal incomes, and agriculture production is prioritized in the short term to feed the people even though the conditions are not sustainable. Gradually as incomes increase there is an increased public emphasis on environmental factors. As incomes rise further, other sustainability concerns are added sequentially, such as food safety, followed by taste and nutritional value, and eventually animal rights and biodiversity, including wildlife. Thus the concept of sustainability changes as a function of both measurable outcomes and individual perspectives.

As the world population continues to grow from today to more than 9 billion by 2050, there is a need for an increase in food production of about 70%. Many areas of the world are arid, and for other reasons related to soil or climate are not suitable for crop production, but can support ruminant livestock for meat, milk, and animal fiber production. A sound national grassland philosophy must be goal oriented and supported by government policies. As any nation becomes self-sufficient in diet, first in plant-based products and then in animal-based products, the public's demands for protection of the environment, for landscapes with enhanced aesthetic value, and for easy access for leisure and recreation will increase. Meeting these needs for sustainability requires producers to develop management practices that emphasize and balance the multiple uses of the grassland resource.

Adjusting to Climate Change

It is clear that climate change is related to the total increase in greenhouse gases such as carbon dioxide (CO_2) (77% of the total), methane (CH_4) (14% of the total), and nitrous oxide (N_2O) (8% of the total). About 14% of the total emission worldwide is from all aspects of agriculture and 17% is from deforestation. Forages and pastures make some contribution to the 14% from agriculture, but much less per acre than crops. Even so, they should be part of the solution.

The atmospheric CO_2 concentration increased rapidly from about 290 parts per million (ppm) in 1900 to nearly 400 ppm in 2015, largely as a result of the burning of fossil fuels (57%) and the reduction of forests (17%) that normally use CO_2 and store carbon as wood. The atmospheric concentration of CH_4 from ruminant animals and wetlands also increased rapidly from about 800 parts per billion (ppb) in 1900 to more than 2000 ppb in 2015, and the atmospheric concentration of N_2O, lost mainly from chemical fertilizers, increased from about 1000 ppb in 1900 to around 1300 ppb in 2015. Although CO_2 receives the most attention, a molecule of CH_4 is about 25 times stronger and a molecule of N_2O is about 300 times stronger as a greenhouse gas than a molecule of CO_2. Methane is probably the major factor for forages and pastures, as N_2O levels are decreased when legumes are used, and CH_4 levels can be reduced if ruminants have higher-quality diets.

Greenhouse gases are expected to cause an increase in air temperature, mainly night temperature, of 3°F (2°C) near the equator and up to 9°F (5°C) nearer the poles. Projections are that the growing season will be longer and that annual precipitation will be similar to current levels, but more precipitation will occur as severe storms with longer dry periods between storms. It is expected that there will be more droughts, more floods, and more inundation of shorelines with the melting of polar ice. Thus plants and animals will be exposed to more heat and drought stress, and will face more challenges with regard to insects (and pollinators) and diseases. The timing of field operations and effective storage and preservation of quality products will be more critical.

Management of pastures, livestock, and hayland production will need to adjust to the changes in both the short and long term. Seeding can be done using minimal tillage and less use of fossil fuels. Cultivars with improved drought and flood tolerance will help during drought and storms. Using appropriate mixtures of grasses and legumes will reduce erosion and will cause less N_2O release, as legumes fix nitrogen. Ruminants should have high-quality diets that reduce methane production in the rumen. The grazing season will need to be extended to reduce dependence on harvested and stored forage, but requirements for shade and clean water for livestock in the pastures will increase. With incentives, some managers will focus on increasing **soil organic matter** content as a way to sequester CO_2 to reduce atmospheric concentration, especially with long-term rotations and permanent grasslands.

In the longer term, water will be more restricted and this will eventually reduce irrigation of cropland and forages such as alfalfa. Large aquifers such as the Ogallala that extend underground from South Dakota to Texas are gradually decreasing due to crop irrigation, and that land area may revert back to grasslands to restore soil carbon, and provide feed for ruminant livestock and biofuel for energy. More beef and milk production will be based on high-quality pastures to reduce methane production from livestock and fossil fuel use for harvest and preservation. Marginal land sites for crops will be shifted to forages to prevent erosion, improve water quality, and provide wildlife habitat. There will be economic incentives to enhance the organic matter content of the soil, and use of minimal tillage to save energy and reduce losses of greenhouse gases from the soil.

Grasslands and Energy Issues

Grasslands can contribute to energy needs. Switchgrass has demonstrated potential for producing large amounts of plant **biomass**, a raw agricultural commodity of above-ground growth that can be processed into a solid or liquid fuel and other organic feedstocks to offset the use of fossil fuels. Biomass crops are a source of renewable energy, as they recycle CO_2 from the environment to offset that produced by burning the fuel. Most of these biofuel crops are efficient, as they are perennial and provide ground cover to reduce soil loss. Many industries are restricted with regard to the amounts of gaseous emissions that they can release, and know their "carbon footprint", which is the net amount of CO_2 emitted. Industries that produce high levels of CO_2 can offset these emissions by contracting with landowners who manage crops and grassland to sequester the CO_2 to gain the benefits of additional carbon incorporated into soil organic matter. Due to their perennial nature, forage-based systems can be managed for livestock production and increased carbon sequestration in the soil (Council for Agricultural Science and Technology, 2000).

The Need for Knowledge-Based Management

Regardless of the situations that develop, there will be a continued need for forages and grasslands, since in many ways this form of land use is the best alternative. However, the management of the soil–land–animal resources will continue to be economically productive while conserving the environment, in both cases in a socially acceptable way. New technologies such as drones, genetically modified plants and animals, and improved pesticides will be available. However, the fundamental decisions will require a strong basic understanding of the principles of soils, plants, ruminant livestock, and economics, and that is the main purpose of this book.

As time passes, the value of forages and grassland resources to the world and to national and individual well-being will be defined and redirected based on new technologies and alterations in human needs and expectations as changes occur in the physical and social climate. The future of forages and grasslands will be knowledge based and will require continued changes in management and attitudes. Our goal for this book is to provide a technical foundation for sound and rational decision making both now and in the future.

Summary

Since the beginning of sedentary agriculture, forages and grazinglands have contributed to the food supply for domesticated animals and wildlife that are used for human diets or serve as draft animals. In addition to supplying meat, milk, and power, these animals contribute manures and nitrogen to improve the soil resource for annual grain crops in rotations. The early Northern European immigrants to the eastern areas used fenced pastures and harvest strategies for feed supplies over winter. The western areas, influenced by the Spanish, used large herds of animals owned by several ranchers who moved the cattle and sheep over large land areas.

Forage and pasture contribute about 61% of the diet for dairy cattle, 83% for beef cattle, and 91% for sheep and goats, being supplemented by grains to increase production. Forages improve soil properties, maintain water quality, and protect the environment and wildlife. Future emphasis will be on providing environmental services together with use as biofuels. Populations in less developed countries will continue to demand more animal protein in their diets. However, since crop plants will compete for the best soils, the animal products will be produced on lower-productivity soils and with lower inputs. New technologies and forage species are needed to manage forages and livestock to effectively support the demand for animal products and conservation of resources.

Questions

1. Discuss some early forage practices in Europe, including Great Britain, that were transferred to America by the colonists.
2. Discuss the role of native grasslands in the development of the western USA, and its implications for modern grassland agriculture.
3. Discuss three primary factors that have contributed to the prominence of introduced forage species in the eastern area of the USA.
4. What constitutes sustainability of a pasture? Would the answer be the same for a nearby hayfield?
5. Explain the importance of the soil–plant–animal biological system and its significance to sustainability.
6. Explain how global change will affect forage and grasslands in your state.
7. What is the role of forages as an overall source of feed for livestock?
8. List and discuss at least five trends related to forage and pasture production that have occurred, that are occurring, or that will occur.
9. Why are forages undervalued in the overall food system?
10. Why is the Latin name important when communicating about forage plants?

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