Grassland: Definition, Origins, Extent, and Future

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"Each rural landscape has its own set of characteristics. Any one may be just a little different from thousands of others, or very unlike any of them. Through science modern man tries to understand these landscapes—to unravel their many interlocking relationships—in order to discover the principles that can be used to guide the great producing powers of nature to his own ends." —C.E. Kellogg, in Stefferud, Grass: The 1948 Yearbook of Agriculture, p. 49

Grasslands sustain a tremendous diversity of life forms. Grasslands feed creatures as small as bacteria and larger than the North American bison. Grasslands provide environmental benefits by holding soil in place, filtering water, and cycling nutrients. Aesthetically, expanses of undulating, shimmering grassland plants please the eye. But what are grasslands? Are they defined by their use or what grows on them? How did the current lands we classify as grasslands come to be on a geologic time scale, how have humans transformed them, and what is their future?

These questions form the basis of this chapter. We define and describe U.S. grasslands on the basis of land type, land use, vegetation, distribution, and area. Then we take a long look back through geological time and discuss what we know about the distribution of grasslands and their species composition in North America. Last, we look ahead to consider the future of grasslands and their use in traditional ways, such as forage for livestock, and in new ways, such as bioenergy crops and as carbon sinks. We paint with broad brush strokes regarding these questions, issues, and topics to foreshadow the detailed chapters that follow.

WHAT ARE GRASSLANDS?

The term grassland may evoke an image of a flat treeless expanse covered by a canopy of wispy plants. It might even conjure up images of grazing animals, both native and domesticated, or of hazy summer days spent harvesting hay. Thus, there is a duality in how we define grasslands—either as a type of land covered by specific forms of vegetation, or as a use of land by humans (e.g., grazing, hay production; Barnes and Nelson, 2003).

Grassland as an ecological land type is defined as "land on which the vegetation is dominated by grasses" (Forage and Grazing Terminology Committee, 1991). The ecological basis for these land types
Of all the plants of the earth the grasses are of the greatest use to the human race” —A.S. Hitchcock (1950)

depends on climatic factors including temperature and soil moisture. Kinds of grasslands including meadows, prairies, rangeland, savannas, steppes, or tundra are often referred to as natural grasslands. Grazing-land as a type of grassland use is an all-inclusive term and refers to “any vegetated land that is grazed or has the potential to be grazed by animals” (Forage and Grazing Terminology Committee, 1991). Kinds of grazingland include pastureland, grazeable forest land, and rangeland. Kinds of natural grasslands and rangelands are discussed in more detail in Chapter 5 (Havstad et al., 2009, this volume). Other grasslands include those managed principally for agricultural production, such as pasture, silage, and hay, as well as some lands set aside for conservation, such as the acreage in the Conservation Reserve Program.

Pastureland is concentrated in the humid eastern half of the United States (Fig. 4–1). Pastures typically receive inputs of fertilizers and pesticides. The species present are most commonly introduced plant species, and pastures may be periodically renovated or replanted by a variety of techniques. Rangelands predominate in the drier western half of the United States with a few exceptions such as the flatwoods rangeland of Florida, longleaf pine (Pinus palustris) grassland in Alabama, and fragmented native grasslands in the eastern United States. Compared with pastureland, rangelands less frequently receive inputs of fertilizers, pesticides, and seeds. The vegetation is largely maintained by natural processes and grazing management. Native species are more common in rangelands, although introduced species are often present, and preventing the encroachment of weedy invasive species is a continual challenge.
GRASSLAND PLANTS

By definition, grasses dominate grassland vegetation. The subdominant species include legumes and other forbs (broadleaf herbaceous plants), trees, and shrubs depending on the climate, soils, and management of grasslands. The diversity of grassland plants can range from a few grasses and legumes in productive hayfields to dozens of native and introduced species in pastures and native grasslands. We cannot possibly describe the full range in morphology and physiology of all grassland plants here; thus, we describe the broad categories of grasses, legumes, and forbs.

GRASSES

With about 10,000 species worldwide, the grass family (Poaceae or Gramineae) is the fourth largest of the plant families. In the United States, taxonomists have described many species of grass ranging from the common lawn and pasture species Kentucky bluegrass (*Poa pratensis* L.; Fig. 4-2a) to the giant river cane (*Arundinaria gigantea* (Walt.) Muhl.) native to gulf coast marshes (Barnes and Nelson, 2003).

The vegetative parts of grasses have a uniform structure across species (Fig. 4-3; Chase, 1948). The basic vegetative structure of all grasses includes a stem with solid nodes and a leaf at each node. The stem section between nodes is termed the internode. Leaves are normally arranged alternately on the stem. The entire leaf consists of the leaf blade and the leaf sheath. At the junction of the blade and sheath there is a collar, sometimes with two points called auri cles, and a thin...
Fig. 4-2. Grasses common in managed grasslands and native rangelands. (a) Kentucky bluegrass (*Poa pratensis* L.), a low-growing grass that spreads by rhizomes (underground stems), (b) Western wheatgrass (*Pascopyrum smithii* (Ryd.) A. Löve), a cool-season (*C₃*) native grass. (c) Cheatgrass (*Bromus tectorum* L.), an invasive annual species. (d) Buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), a native species that spreads by stolons (horizontal stems) and has separate male (bottom plant) and female (top plant) plants. Plant illustrations are adapted from the USDA-NRCS PLANTS database (http://plants.usda.gov); Hitchcock (1950).

Fig. 4-3. Orchardgrass plant illustrating the basic structural units of a grass. Orchardgrass is an introduced cool-season (*C₃*) bunch-type grass that does not spread by creeping roots or rhizomes. It is commonly used for hay and pasture. Plant illustration is adapted from the USDA-NRCS PLANTS database (http://plants.usda.gov); Britton and Brown (1913).
Panicle

Fig. 4-4. Switchgrass, a native warm-season (C₄) grass, illustrating some of the reproductive and underground structures of grasses. Switchgrass is a tall growing plant that spreads by short rhizomes. It is common to the tallgrass prairie region of the central Great Plains and is used for hay, grazing, and soil conservation purposes. It is also a model herbaceous energy crop species (Chapter 12 [Casler et al., 2009], this volume). Plant illustration is adapted from the USDA-NRCS PLANTS database (http://plants.usda.gov); Britton and Brown (1913).

papery structure on the inside called the ligule. Grass shoots are formed by repeating units (termed phytomers) of leaves, nodes, and internodes. Grasses spread by forming new shoots called tillers either from the base of the main plant stem or from lateral underground growth of stems, called rhizomes, or lateral growth aboveground of horizontal stems, called stolons.

The reproductive parts of grasses are highly varied and specialized. The seed head or inflorescence of a grass holds the inconspicuous flowers in units termed spikelets. Within the spikelet are the individual florets or flowers of the grass. Arrangements of spikelets on branches vary widely in grasses, giving rise to the variation in seed heads, from the dense compact head of timothy (Phleum pratense L.) to the splayed and highly branched panicle of switchgrass (Panicum virgatum L.) (Fig. 4-4).

Two broad groups of grasses are cool-season (C₃) and warm-season (C₄) species, classified according to their photosynthetic pathway. In cool-season grasses, the first compound formed from the photosynthetic fixation of carbon dioxide (CO₂) in the leaf contains three carbon atoms (hence C₃). Cool-season grasses typically do best in cool, moist climates. Warm-season grasses fix carbon into a four-carbon compound (hence C₄) via a unique cellular physiology and anatomy in the leaf that acts as a CO₂ “pump.” This mechanism concentrates carbon dioxide and facilitates its uptake at greater stomatal resistances brought about as stomata close down in response to higher temperatures, lower soil moisture, and greater light levels. The C₃ grasses cannot concentrate CO₂ in this manner, and so their growth is more severely restricted by heat and limited moisture.

LEGUMES

Legumes are in the pea family (Fabaceae or Leguminosae), which consists of about 18,000 species. Legumes include common herbaceous forages such as alfalfa (Medicago sativa L.) and white clover (Trifolium repens L.), along with native species such as Illinois bundleflower [Desmanthus ilinoensis (Michx.) MacM. ex B.L. Robins. & Fern.] and Carolina clover (Trifolium carolinianum Michx.) (Fig. 4-5). Legumes vary in life history including annuals, biennials, and perennials (Isely, 1998).
Mary Agnes Chase, author of “The Meek That Inherit the Earth” for the 1948 edition of Grass (Chase, 1948), was not as meek as her botanical subjects. A pioneering USDA agrostologist (a specialist in grasses), Chase spent 70 years exploring, describing, and classifying the grasses of North and South America. She collected 12,000 specimens for the Grass Herbarium at the Smithsonian Institution during field expeditions from the swamps of the southeastern United States to the jungles of Brazil.

Agnes Chase (her maiden name was Meara, and there were several Marys in the family, so she went by Agnes) was born in Iroquois County, Illinois, in 1869. When she was two years old, her family moved to Chicago and changed their name to Merrill after the violent death of her father (he was lynched after brutally murdering his son). A self-educated botanist, she pursued a childhood fascination with plants, particularly grasses, as a hobbyist during the late 19th century. As a young woman, Chase worked as a proofreader for a newspaper at night and pursued her botanical hobby during the day. She married William Chase in 1888 but was widowed less than a year later. She began illustrating botanical specimens for a local collector, which in 1901 led to an unpaid position illustrating plants for the Field Museum of Natural History in Chicago. During this time, she also worked for the USDA at the Chicago stockyards inspecting meat for trichinæ and learning new skills with the microscope. Encouraged by family and friends to develop her botanical, collecting, and illustrating skills, she eventually landed a position in 1903 with the Bureau of Plant Industry, a part of the USDA, in Washington, DC. After promotion to scientific assistant in systematic agrostology in 1907, she began working for Dr. Albert Spear Hitchcock, and together they collected, described, and classified thousands of grass species during a 30-year professional collaboration. Hitchcock and Chase produced the landmark Manual of the Grasses of the United States in 1935 (one year before Hitchcock’s death), which Chase revised in 1950.

Chase retired from the USDA in 1939 but continued to work on her beloved grasses as a research associate at the National Herbarium of the Smithsonian Institution. Indeed, she spent most weekdays for the next 24 years tending her collection. Chase embarked on major collecting expeditions in Latin America during her career (she spent eight-month stints exploring Brazil in 1924 and 1929) and continued international collaboration and consult-
ing in her retirement. She advised the Ministry of Agriculture in Venezuela on agrostology and range management. She developed strong ties with several agrostologists internationally and trained and mentored many students from North and South America, China, and Asia, often boarding them in her home.

Chase was not a meek government scientist. Firmly committed to social justice, she was an active member of the NAACP, the Women’s Christian Temperance Union, and the Women’s Party. As a member of the radical Women’s Party, she picketed in Lafayette Park outside the White House to bring attention to the women’s suffrage movement. In 1918, her civil disobedience earned her and several other picketers a 5-day jail sentence, and she served another 10-day jail term for the same offense in 1919. During the latter jailing, she endured a hunger strike to the point of being force fed. Her social activism nearly cost her job; however, her scientific skills made her nearly indispensable at the USDA, and her immediate superiors held her in high regard and convinced the department to keep her employed.

Chase received honors from the Botanical Society of America, the Linnaean Society of London, and the Smithsonian. In 1958 at age 89, she received her only academic degree: an honorary doctorate from the University of Illinois.

Chase died in Bethesda, MD, in 1963 at age 94, just one day after entering a nursing home and one year after the publication of her magnum opus *Index to Grass Species*, a three-volume annotated index of the 80,000 card catalog of grass species she had identified and cataloged.

**ADDITIONAL READING**


The morphological structure of legumes is more highly varied than that of vegetative grasses. Like the grasses, legume leaves are arranged alternately on the stem and are attached at nodes. Legume leaves consist of a stipule, petiole, and leaflets (Fig. 4–6). There are typically three or more leaflets, which are arranged in different configurations depending on the species. The stem can be upright as in alfalfa, trailing as in birdsfoot trefoil (Lotus corniculatus L.), or creeping as in the stolons of white clover. The seed head of legumes varies in shape and size from the compact and rounded seed head of red clover to the elongated inflorescence of sweet clover. Legume flowers are small but not as inconspicuous as the grass flower. An individual flower has five petals, two of which are partly fused and form the keel, which encloses the stamens (anthers or male part) and the pistil (stigma, style, and ovary).

Legumes are unique in that they are able to obtain their nitrogen needs from the air via a symbiotic relationship with nitrogen-fixing bacteria that live in nodules on the roots. This ability to fix nitrogen makes legumes a perfect complement to grasses in forage and grassland systems.

OTHER PLANT SPECIES (NONLEGUMINOUS FORBS)

These plants include just about all the remaining herbaceous broadleaf species that are not legumes. In native rangelands, nonleguminous forbs provide a significant amount of forage to grazing and browsing animals, whereas in pastures and haylands, forbs are often considered weeds even though their nutritional value can be high and animals readily graze them. For example, chicory (Cichorium intybus L.) is a broadleaf plant used in grassland agriculture. Forbs also include many invasive species such as Canada thistle (Cirsium arvense L.) and spotted knapweed (Centaurea biebersteinii DC.) (Fig. 4–7).

The Wisconsin ecologist John T. Curtis (1959) joked that native grasslands such as the tallgrass prairie “should be called a daisyland rather than a grassland.” Although grasses make up the bulk of the biomass and plant population in native grasslands, Curtis found that grass species (members of the family Gramineae) accounted for only 12% of the hundreds of plant species found in native prairies of Wisconsin. The other most abundant plant families were the Asteraceae (the sunflower or composite family, 27% of the flora) and legumes (6.5%), with mints (Labiatae), lilies (Liliaceae), roses (Rosaceae), and milkweeds (Asclepiadaceae) together making up about 15% of the flora. About 14% of all U.S. flora are Asteraceae species (Stein et al., 2000).

ORIGINS OF NATURAL GRASSLANDS

Early European explorers encountered diverse grassland types across North America. These treeless regions included coastal sandplain grasslands on the Atlantic and Gulf coasts, scattered open meadows and prairies throughout the eastern forest region, midelevation parklands in the mountains of the arid West, intermontane grasslands of the Pacific and Great Basin states, and the Peace River parklands of northern Alberta. The prehistoric origins of these grasslands were also diverse, reflecting the influence of topography, climate, fire, grazing animals, and pre-European Native Americans. Experience with these regional grasslands left explorers unprepared, however, for what they found in the center of North America. The vast central grasslands included the Great Plains and much of the Midwest, stretching from patches of tallgrass prairie in Ohio west to the foothills of the Rockies. Explorer and artist George Catlin was not far off the mark in 1835 when he called this region a “wonderful anomaly of nature” (Evans, 1982). There were few natural regions on Earth where truly tree-free grasslands dominated such a vast region. This landscape, even after dramatic transformations by settlement and agriculture, still amazes modern explorers.

Our understanding of the origins and ecology of the central grasslands of North America have changed considerably since Grass was published in 1948 (Stefferud, 1948). In the 1940s, the ecological theories of F. E. Clements and his student, pioneering grassland ecologist J. E. Weaver, emphasized the age and stability of the North American prairie. Their view that “man alone can destroy the stability of the climax during the long period of control by its climate” (Weaver and Clements 1938) was evident in the influential 1936 Dust Bowl documentary The Plow That Broke the Plains (directed by Pare Lorentz). By the 1950s, however, geological, archaeological and paleoecological studies were beginning to tell a different story. In 1957, Great Plains geographer J.C. Malin (1957)
stated that “instead of the stability once thought to have prevailed in the Great Plains, the record has revealed great instability.”

Recent research on plant evolution, atmospheric CO₂ concentrations, and climate change has shed light on the origins of the great North American grasslands (Wedin 2004). While the fossil record of early grasses dates back roughly 30 million years, grasslands as a major ecosystem did not expand until 4 to 8 million years ago. The dramatic expansion of grasslands at this time in both the Old and New World appears to have been triggered by the evolution of warm-season grasses with the C₄ photosynthetic pathway.
Although the C₄ grasses have high water- and nitrogen-use efficiencies, and are generally tolerant of fire and grazers, another factor may have been critical in their sudden success. For much of Earth's history, atmospheric CO₂ concentrations varied between 800 and 2000 ppm. During the last 65 million years, however, atmospheric CO₂ began decreasing, dropping below 500 ppm roughly 10 million years ago. This decrease in atmospheric CO₂ was likely a major factor leading to the evolution and success of C₄ grasses (Cerling, 1999). The unique biochemistry of C₄ photosynthesis also means that C₄ plant tissues have a higher content of the stable heavy isotope of carbon (¹³C). The discovery of this natural tracer in the 1960s has provided new insights into the physiology and ecology of C₄ grasses and of the animals that depend on them. These animals included the first hominids, which evolved in grasslands and savannas around five million years ago (Cerling, 1999). Recent research thus confirms what the authors of *Grass* (Stefferud, 1948) intuitively knew—the connection between people and grass is ancient and profound.

The Pleistocene (or ice) age, lasting from 1.8 million years ago until 10,000 years ago, saw the great grasslands and savannas of North America expand and contract many times. During periods of maximum glacial extent, global atmospheric CO₂ dropped as low as 180 ppm, favoring C₄ grasslands in competition with trees, shrubs, and other types of vegetation (Cerling, 1999). The diversity of large mammalian grazers and browsers was also remarkable in the Pleistocene, with many species, including the mammoth, going extinct in the last 15,000 years. One mammal in particular, however, influenced the structure of North America grasslands more than any other in this period. Archaeological evidence indicates that humans had entered North America by 12,000 years ago, possibly by 25,000 years ago. While much is unknown about these early Americans, they were without a doubt efficient hunters and masters of fire. They drove to extinction dozens of species of large grassland mammals, and they dramatically altered the fire frequency of North American ecosystems (Flannery, 2001). While early prairie ecologists such as Weaver and Clements (1938) saw the distribution of North American "climax" grasslands governed by climate, ecologists currently argue that the distribution and structure of our grasslands, particularly the relatively humid...
tallgrass prairie, are the result of 10,000 years of anthropogenic fire (Anderson 2006). Grassy mountain boulds, open woodlands, and meadows as far east as Cape Cod and Long Island were apparently maintained by Native American fires.

Change continued for the vast grasslands of central North America for much of the last 10,000 years. New techniques allow scientists to reconstruct climate through this period, and the story they see is one of frequent droughts and periodic "mega-droughts" (Miao et al., 2007), confirming Malin's 1957 assertion that the Dust Bowl of the 1930s was not unique in the history of the Great Plains. Change is forecast for North American grasslands (Wedin, 2004). Some argue that elevated atmospheric CO₂, together with decreased fire frequency, is causing the expansion of woody vegetation at the expense of native warm-season grasslands. Climate change may trigger new droughts and threaten Great Plains rangelands. Even nitrogen deposited through air pollution is affecting the ecology of native grasslands. The past, however, suggests that this will just be the next dynamic chapter in a six-million-year story of constant change for North America's grasslands.

20TH- AND 21ST-CENTURY TRENDS IN GRASSLAND EXTENT AND DISTRIBUTION

Most official statistics collected on grasslands classify them on the basis of land use (e.g., grazingland, hayland) rather than ecological...

"Prairies, like mountains, stagger the imagination most not in detail, but size. As a mountain is high, a prairie is wide; horizontal grandeur, not vertical. People neglect prairies as scenery because they require time and patience to comprehend. . . . Even in a car at 60 miles an hour it takes 3 days or more. Like a long symphony by Bruckner or Mahler, prairie unfolds gradually, reveals itself a mile at a time, and only when you finish crossing it do you have any idea of what you've seen." —Bill Holm (1965).
land type (e.g., savanna or prairie grasslands). In keeping with the original version of *Grass* (Stefflerud, 1948), we use the historical data on acreages and classification of grassland use from the USDA Economics Research Service (ERS) (Lubowski et al., 2006) to examine long-term trends. Hugh Wooten, principal author of "A Billion Acres of Grassland" in the 1948 edition of *Grass* (Wooten and Barnes, 1948), worked for a progenitor of the USDA-ERS and relied on the beginnings of the same dataset used by the USDA-ERS in subsequent reports. Other agencies, such as the USDA Natural Resources Conservation Service (NRCS), classify and inventory land cover and land use, but in slightly different ways. We use the land cover data of the USDA-NRCS to illustrate the current distribution of land types (rangeland and pastureland) in the United States (Fig. 4-1).

![Pie chart for 1948 and 2002 land use](image)

**Fig. 4-8.** Major land use areas (millions of acres [ha]) in the 48 contiguous states in 1948 (top) and 2002 (bottom). Source: Lubowski et al. (2006).
Wooten and Barnes (1948) classified land use in the United States into several categories, which we have summarized into hayland, grassland, cropland, woodland and forest, and other land (including urban land) (Fig. 4-8). Thus, grasslands, hayland, and forested rangeland accounted for 1130 million acres (457 million ha) or 60% of the total 769 million ha (1900 million acres) of land in the 48 contiguous United States in 1948. At that time, these lands provided half of the feed for all livestock in the United States. By 2002, those same land categories had changed considerably. Grassland acreage declined to 844 million acres (342 million ha) (44% of land in the 48 contiguous states), whereas woodlands, forests, urban, and other lands increased by 284 million acres (115 million ha). All cropland decreased by 13 million acres (5.3 million ha) in the same time. Alaska and Hawaii, not yet states in 1948, contributed a total of 2.7 million acres (1.1 million ha) of grassland in 2002.

The long-term trends in grassland acreages reflect a general decline in all grasslands and a substantial decline in grazed forest land (Fig. 4-9). The USDA-ERS explained the decline in grazed forest land as the result of fewer farms and less total farmland, increased density of forest stands (precluding grazing), and improvements in livestock and forest management. Broad national trends, however, can mask regional or local trends, which are detailed in other chapters (see Chapters 5 and 6 [Havstad et al., 2009; Sheaffer et al., 2009], this volume). Regardless, grassland remains the single largest land type and land use in the United States. In broader terms of grasslands and grazing lands, however, these official figures do not include such land uses as crops grazed in fall or winter or land types such as tundra in Alaska.

The USDA-ERS and NRCS databases do not address the status of North America’s remaining native grasslands, their biodiversity, and their conservation status. This perspective is certainly a new development since the 1948 assessment by Wooten and Barnes. The most recent national grassland inventory with a conservation perspective was completed by the Natural Heritage program, a project sponsored by the Nature Conservancy and numerous state and federal agencies (Stein et al., 2000). They found 27 critically endangered ecosystem types in the United States that had lost more than 98% of their original distribution (Noss et al., 1995). Thirteen of these 27 ecosystem types were grasslands and savannas such as tallgrass prairie east of the Missouri River, the palouse prairie of the Northwest, and Louisiana coastal prairies. Even though public awareness of grassland conservation has increased dramatically in recent decades, native grasslands continue to be lost to development, encroachment of woody vegetation, and agriculture. Federal conservation programs such as the NRCS, protection by conservation groups such as the Nature Conservancy, and conservation easements on private land are all approaches being used today to protect remaining native grasslands. In areas where native grasslands have been lost, public agencies, private groups, and individual landowners are replanting and restoring native grassland.
species. In 1948, the only native grassland "restorations" in the United States were plots established by Aldo Leopold, Curtis, Henry Greene, and other pioneering ecologists at the University of Wisconsin's Arboretum in Madison. Two prominent prairie restoration projects since then have been the 1000+ acre (405+ ha) restoration within the accelerator ring at the Fermilab (USDA) in Illinois and the 8600-acre (3480-ha) Walnut Creek National Wildlife Refuge in Iowa. Today, there are thousands of grassland restoration projects across the United States planted and nurtured by professionals and volunteers passionate about native grasslands.

**GRASSLAND MULTIFUNCTIONALITY FOR FUTURE ECOSYSTEM SERVICES**

Grasslands are truly multifunctional. Not only do they produce food and fiber for humans, but they also provide many ecosystem services on which humans depend. Such ecosystem services include soil erosion control, soil fertility improvement, water conservation and protection, wildlife habitat, pollution buffers, recreational uses, biofuel production, and an agricultural system termed grassland agriculture (Nelson and Burns, 2006; Havstad et al., 2009, this volume).

Managing grassland multifunctionality will become increasingly important in the future because of a growing population, environmental concerns, and ever-tightening energy supplies. It is clear that society as a whole will have a much greater say in agricultural production and land management in the United States in the future. In this section, we summarize some existing and emerging issues in grasslands management.

**GRASSLAND AGRICULTURE AND THE CONSUMER**

In coming years, we will continue to see an increasing demand for animal products produced in ways perceived as more humane and less damaging to the environment. The demand for organic and grass-fed or pasture-raised animal products is a rapidly growing part of the agricultural sector. Sales of organic products have increased about 20% each year since 1990 and reached a value of $13.8 billion in 2005.

In the United States, the beef production system includes cow–calf operations, stocker operations, and a finishing phase in feedlots. Cow–calf farms and stocker operations rely almost entirely on pasture, forage, and rangeland for feed. Most U.S. beef production comes from animals finished on a high-grain diet in large feedlots. Conventional dairy systems often rely on confinement systems in which cows are fed in production groups and receive a diet of roughly 60% forage (e.g., hay, haylage, or silage) and 40% concentrate (e.g., grain, protein supplement). Some dairy producers have converted to pasture-based systems to reduce costs or for personal lifestyle reasons. Estimates of the number of pasture-based dairy systems in the United States range from 10 to 30% of all dairy operations and vary by state.

Producing livestock exclusively on grassland poses significant challenges for farmers—especially those in more northern states. With beef and dairy cattle, productivity on a grassland-only system may be lower than in a system that includes grain and concentrates for high milk production or in the traditional beef feedlot finishing system. In this situation, net profit must be increased by other components within the system such as savings on purchased feed and higher prices received for valued-added products. When these factors are taken into account, profitability in pasture-raised livestock systems can be significant and sometimes surpass conventional systems.

Recent evidence suggests that livestock grown predominantly on grassland provide health benefits for both animals and humans (Chapter 11 [Karsten and Baer, 2009], this volume). Meat and milk from animals fed mainly on grassland usually have lower levels of saturated fat and higher levels of omega-3 fatty acids and conjugated linoleic acid (CLA) than that from grain-fed animals. These compounds, sometimes termed healthy fats, have shown anticancer properties in laboratory studies. The link between consumption of animal products from grassland systems and improved human health is not conclusive. If this link is established, it will undoubtedly increase demand for these products. Thus, there is a need to identify plant species and management strategies that will produce optimal fat composition in animal products from different regions in the United States.
Moreover, significant environmental benefits may accrue from a livestock production system based on grasslands. Sound science is needed to inform farmers and policy makers of human-health and environmental consequences of adopting grassland-based livestock systems (Chapter 14 [Undersander et al, 2009], this volume).

PUBLIC LAND USE

Despite the favorable perception of grassland-based agriculture by some in a highly urbanized United States, there are others who view traditional uses of public lands (e.g., grazing, timber production) as harmful to the ecosystem. Concern centers on potential destruction of wildlife habitat and degradation of soil and water resources. These perceptions will have important implications for the future of western rangelands (see Chapter 5 [Havstad et al., 2009], this volume). These perceptions stem from historical land practices that severely degraded rangelands at the beginning of the 20th century. Society has changed since the early 1900s, and so have livestock production methods. As our understanding of the ecological interactions among grazing animals, plants, soils, and other organisms has grown, range-land ecological status has improved. To maintain this progress, land managers will need new tools and technology (i) to identify lands at risk of degradation, (ii) to forecast and communicate early warnings of potential problems, and (iii) to prescribe treatments or management practices needed to protect natural resources while maintaining an economically sustainable grassland production.

“Grassland agriculture is a farming system that emphasizes the importance of grasses and legumes in livestock and land management. Farmers who plan row crops and livestock production around their grassland acres are grassland farmers. The main feature of grassland agriculture is dependence on herbaceous plants such as grasses, legumes, and forbs, and, in many range situations, on the leaves, buds, and stem tips of shrubs and woody vegetation.”—R.F Barnes, and T.H. Taylor (1985).
A new trend in public land use is the establishment of open space and natural areas near cities for outdoor recreation, to check urban growth, and to safeguard natural resources. Local governments are including "working landscapes," or areas that allow traditional uses, such as ranching and grassland agriculture, thus protecting these lands from loss.

**GRASSLANDS FOR ENERGY**

In response to rising fossil fuel prices, potential energy shortages, and concerns about greenhouse gas emissions, grasslands in the future may be used for biomass or bioenergy production and manufacture of bio-based products (see Chapter 12 [Casler et al., 2009] and Chapter 13 [Weimer and Morris, 2009], this volume). Extensive conversion of grassland to bioenergy production presents some challenges that must be addressed if we are to preserve ecosystem services in the future. A major issue is how to manage the tradeoff between food and energy production to meet the needs of a growing population. Because grasslands will receive increased attention for cellulosic ethanol the food-vs.-energy dilemma must be resolved before extensive land conversion to biomass production occurs.

There are several promising perennial grasses, such as switchgrass, that will likely play a major role in future biomass production for energy. The use of legumes in a dual-product system—producing biomass for energy and leaf meal for livestock protein—has also been proposed. Planting vast expanses of perennial monocultures for biomass may not be wise from an ecological standpoint or necessary from a management standpoint. Like annual crops, perennial monocultures planted on vast acreages could become increasingly susceptible to disease and insect pressure and be less resilient to regional climate fluctuations. An alternative is mixed-species grasslands grown on marginal lands as a biomass source. Conceptually, highly diverse grasslands may avoid the potential instability of monocultures, promote native biodiversity, and reduce the need for expensive inputs. The economics of the high-diversity, low-input (and low-yielding) approach must be evaluated to ensure an economically sustainable solution. Inputs may need to be tailored for the characteristics of each grassland resource.

One indirect effect of increased biomass production for energy may be conversion of grasslands to annual cropland—especially to corn (*Zea mays* L.) for ethanol production. As the demand for corn ethanol increases along with rising corn prices, we may see increased pressure to convert Conservation Reserve Program (CRP) grasslands into corn or other crop production. The CRP was started in 1985 to reduce soil erosion by establishing perennial vegetation on highly sensitive lands (see Chapter 14 [Undersander et al., 2009], this volume). These grasslands are useful examples of how ecosystems can recover from long-term cultivation. Conversion of CRP land or other grasslands to intensive annual crop production could be ecologically disastrous in terms of biodiversity reduction and lost carbon sequestration potential. Increased research and education is essential to ensure that such land use changes do not result in negative impacts on a large scale.

**GRASSLANDS AND CLIMATE CHANGE**

Global surface temperatures have increased by 0.6 ± 0.2°C during the 20th century and are projected to increase by 1.5 to 5.8°C by the end of the 21st century (Intergovernmental Panel on Climate Change, 2007). Regardless of the potential causes of this warming, an increase in surface temperature will almost certainly influence regional precipitation patterns. Many climate-change predictions suggest that periodic droughts will become more common and extreme rainfall events more frequent. A combination of increased dry periods interspersed with larger individual rainfall events will result in extended periods of soil moisture deficit and greater variability in soil water content. Such a change may have important consequences for grasslands. For example, the timing of rainfall events may be more important than changes in rainfall amount in affecting important ecosystem properties like CO₂ uptake and forage productivity (Intergovernmental Panel on Climate Change, 2007).

To maintain productive grassland systems in the face of more extreme climate fluctuations, farmers will need to manage flexible systems and adjust quickly to environmental fluctuation. Volatile weather conditions would make it increasingly difficult to sustain cropping systems...
with limited diversity. In this context, grasslands may become even more important as a way to diversify farming systems. Such systems may include complementary grazing systems using both cool- and warm-season species, greater reliance on annual cover crops to help fill seasonal niches, and direct integration of livestock and crop production (Sulc and Tracy, 2007). If farming systems can be structured to be less energy intensive, more resilient in an unstable climate, and more productive than monocultures by virtue of their multispecies output, farmers will adopt them for economic reasons (Kirschenmann, 2007). Integration of grasslands into conventional farming systems will aid this transition.

**ECOSYSTEM SERVICES AND RESOURCE CONSERVATION**

Recognition of ecosystem services that grasslands provide (e.g., soil and water conservation, carbon sequestration, wildlife habitat) will likely increase. It will require innovative management to balance the preservation of these services with the demands of a growing population seeking a diet rich in animal products. Management practices that reduce the productive potential of grassland soils and thus undermine our ability to provide food and fiber for an expanding population must be avoided. New knowledge is needed to balance management intensification with preservation of grassland ecosystem services.

Increased use of grassland-based agriculture in the United States makes sense from both economic and environmental perspectives. To ensure that we achieve a balance of productive use and preservation from grassland resources, we must invest in research and training to educate future students, producers, and the general public about the multifunctional nature of grasslands and the services they provide. By taking this approach now, we can better prepare for the management challenges that will face grasslands in the next 60 years.

**REFERENCES**


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