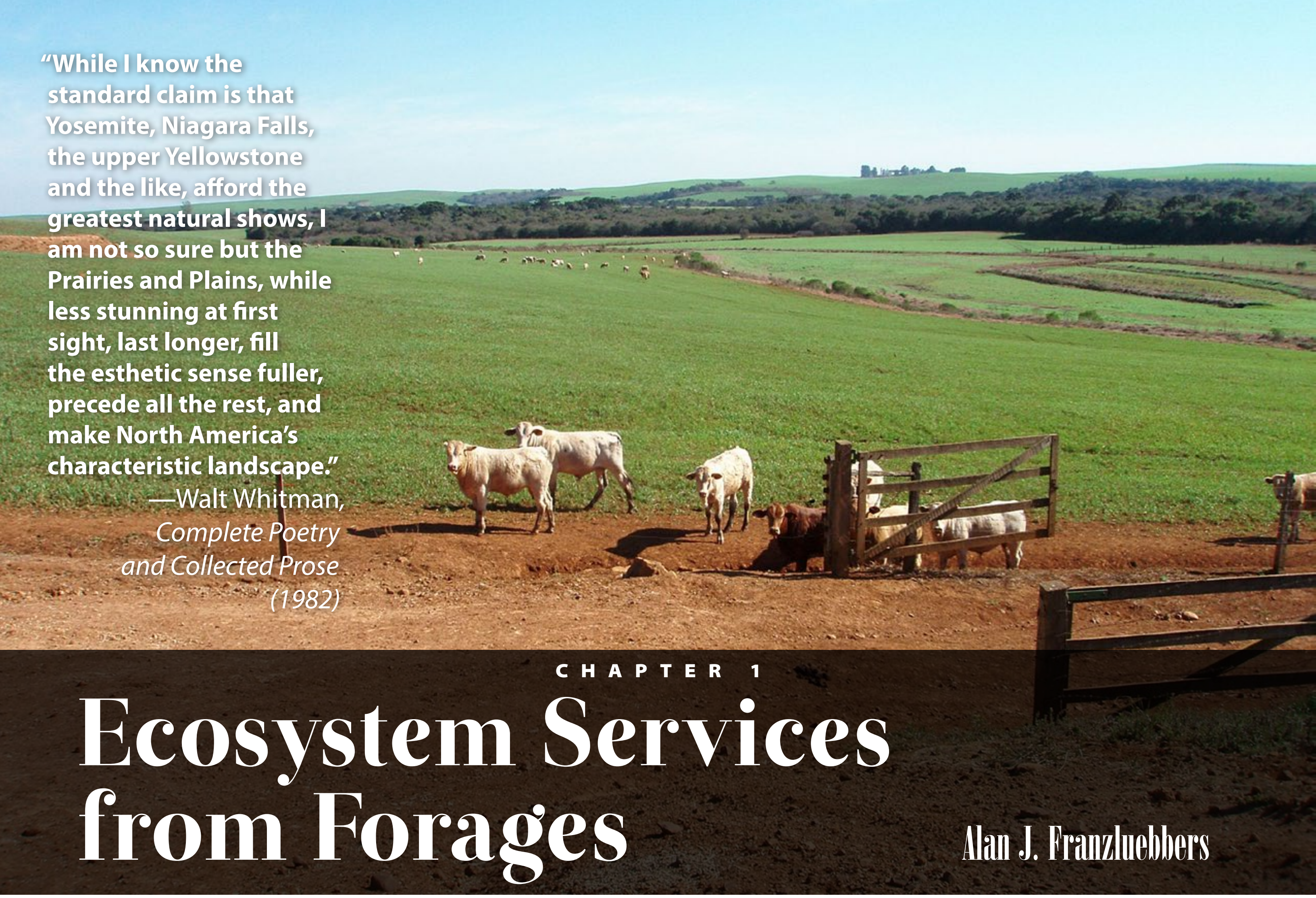

"While I know the standard claim is that Yosemite, Niagara Falls, the upper Yellowstone and the like, afford the greatest natural shows, I am not so sure but the Prairies and Plains, while less stunning at first sight, last longer, fill the esthetic sense fuller, precede all the rest, and make North America's characteristic landscape."

—Walt Whitman, *Complete Poetry and Collected Prose* (1982)

CHAPTER 1

Ecosystem Services from Forages

Alan J. Franzluebbers

Perennial grasses, forbs and legumes have numerous ecological attributes to support robust and resilient ecosystems, whether these occur as native prairies, naturalized grasslands or managed forage systems. Some of these attributes are described in the following.

Native prairies are an historically sustainable and resilient land cover, rooted by a variety of vigorous grasses and forbs that provide essential ecosystem services of water cycling, nutrient cycling, gas exchange with the atmosphere, climate regulation, food and feed production, and aesthetic experience (Fig. 1). Whether naturally occurring or human planted, perennial grasses should be considered a vital ecosystem component – keeping the soil surface from being eroded away and allowing soil to maintain its functional capabilities over fields or ecoregions.

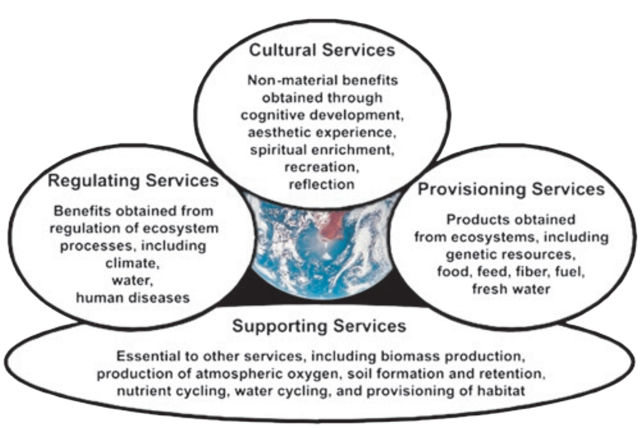

Figure 1. Categories of ecosystem services provided by nature, of which perennial grass systems are a key component. Adapted from Millennium Ecosystem Assessment 2005.

Obviously, the contribution of forages to ecosystem services is dependent on natural resource limitations of soil type, slope, aspect, precipitation and temperature patterns; and management approaches, including types of species present and whether they are annual or perennial, fertilizer and harvest practices and management of livestock. A number of these specific conditions can lead to a spectrum from fully enhanced environmental performance to severely compromised ecological condition. This narrative considers a typical, generalized, or mid-level response of ecosystem services to forage in the landscape.

Biomass production

Grasslands are highly effective in converting sunshine and carbon dioxide (CO_2) into stored energy in plant tissues, especially considering the relatively limited precipitation in typical grassland biomes. Biomass production in

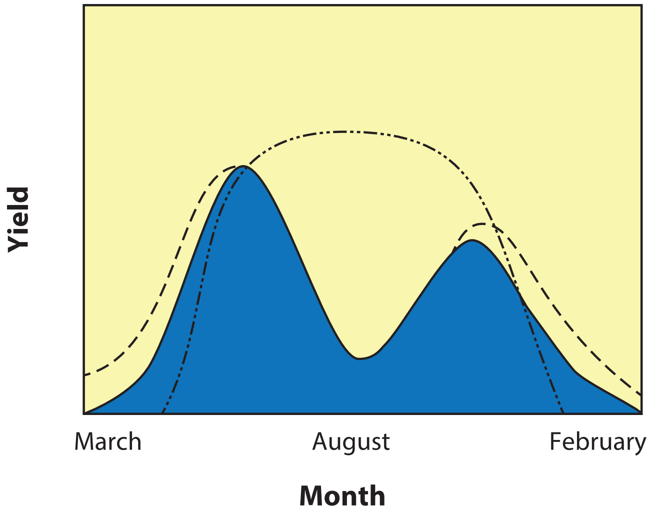

Figure 2. Typical forage growth curve of cool-season tall fescue (shaded area under solid line) and warm-season forage (e.g. bermudagrass with dot-dash line) in the southeastern USA. Earlier and later forage growth (dashed line) can be encouraged with N fertilizer, legume interseeding, and stock-piling. With permission from Tall Fescue Monograph (http://forages.oregonstate.edu/tallfescuemonograph/). *Online Tall Fescue Monograph*, Craig Roberts. Published by ASA-CSSA-SSSA, 2011.

temperate regions is often seasonally diverse, with both cool- and warm-season forages able to flourish under changing environmental conditions throughout the year (Fig. 2). Forage production is a keystone attribute for ruminant animal production and it allows land to be productive for both economic and ecological purposes. Therefore, meat and milk production transformed from animal intake of forage is an essential food production aspect derived from forages. The ability of ruminant animals to graze and digest forages is a naturalized biochemical conversion technology that has given value to grasslands for millennia. Forage production also serves to provide winter hay for livestock, bedding for sheltered livestock, heat and cooking sources in some cultures, raw materials for arts and crafts, construction materials, and feedstock for emerging industrial production of biofuels. The diversity of products from grasslands is often underappreciated.

While not the most productive of ecosystems, mixed-perennial grasslands are highly resilient to drought and flooding and produce a relatively stable supply of forage each year. The ability of robust managed forages and naturalized grasslands to withstand environmental perturbations give them ecological stability and resilience not typically offered by other agricultural management systems.

Air purification and climate regulation through greenhouse gas exchange

The ability of forages to fix CO_2 and emit oxygen (O_2) is one of the key ecosystem processes that sustain life on Earth. Grasslands contribute further to gas exchanges not only by drawing down CO_2 in the atmosphere via

Example of greenhouse gas (GHG) emissions from ruminant animals grazing forages in two different ecoregions.

Southeastern USA

If we assume that CH_4 emission from beef cattle is 0.15 ± 0.08 kg CH_4/head/day (Harper et al. 1999) and there are 19 million hectares (ha) of pasture land and 12 million head of cattle in southeastern USA (USDA-NASS, 1997), then this will equate to 0.63 head/ha emitting annually 16–53 kg CH_4/ha. With a global warming potential of CH_4 25 X that of CO_2 (Johnson et al. 2007), enteric CH_4 emission from beef cattle would be 400–1325 kg CO_2 equivalence/ha. Reported annual rates of soil organic carbon (SOC) sequestration during the first 10 to 20 years of grassland establishment in the southeastern USA are 2677–3483 kg CO_2 equivalence per ha (Franzluebbers et al. 2010). After 50 years, rates of SOC sequestration can be expected to decline to about 1/3 of the rate observed in the first decade (~800–1200 kg CO_2 equivalence /ha).

Great Plains USA

In a system-wide evaluation of three grazing systems in North Dakota, similar magnitudes of soil calculations were derived (Liebegetal 2010). Grazing management systems included two native vegetation pastures (moderately grazed and heavily grazed) and a heavily grazed crested wheatgrass [*Agropyron desertorum* (Fisch. ex. Link) Schult.] pasture. Global warming potential of GHGs: 1 for CO_2, 25 for CH_4, and 298 for N_2O. Intensity of GHG was calculated from net global warming potential divided by animal gain. Positive values are fluxes of GHGs to the atmosphere and negative values are removals of GHG from the atmosphere.

Variable	Crested wheatgrass	Heavily grazed	Moderately grazed
	kg $CO_{2\ equiv.}$/ha/yr		
N fertilizer	259 (0)a†	0b	0b
Enteric fermentation	563 (227)	484 (76)	176 (28)
CH_4 flux	-61 (4)‡	-62 (6)	-63 (9)
N_2O flux	1336 (260)a	477 (39)b	520 (85)b
SOC change	-1700 (114)	-1517 (187)	-1416(193)
Net GWP	397 (227)a	-618 (76)b	-783 (28)b
	kg $CO_{2\ equiv.}$/kg animal gain		
GHG Intensity	27 (17)b	-26 (9)b	-145 (38)a

† Values in parentheses reflect the standard error of the mean. Means in a row with unlike letters differ ($P \leq 0.05$).

‡ Negative values imply net CO_2 uptake.

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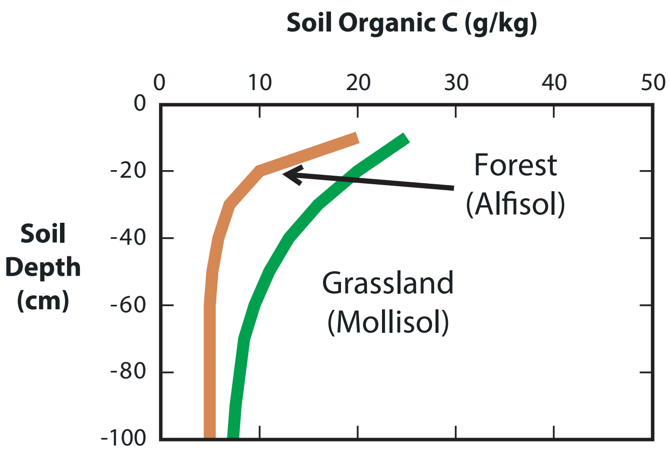

Figure 3. Typical depth distribution of soil organic carbon under native forest and grassland vegetation. Soil orders are typically Alfisol under forest due to higher precipitation and leaching and Mollisol under grassland due to accumulation of bases and thick upper horizon of organic matter accumulation.

photosynthesis, but also by storing some of the fixed carbon in the soil as organic matter. Grassland soils are well known for their abundant and deep storage of soil organic carbon (Fig. 3). In addition, the relatively low level of N fertilization of forages avoids emission of nitrous oxide (N_2O), a greenhouse gas that is 298 times more potent than CO_2. Another greenhouse gas of concern in grasslands is methane (CH_4). Ruminant animals belch CH_4 during digestion as a byproduct of anaerobic bacteria working in the rumen. The rate of enteric CH_4 eructation from ruminants can be controlled by the quality of forages — lower quality forages having greater CH_4 emissions than higher quality forages (Johnson et al. 2007). Emission of enteric CH_4 from cattle is of notable concern with regards to climate change issues, since enteric CH_4 emission may be of nearly the same magnitude of global warming potential as the carbon sequestered in soil organic matter under grassland (see sidebar on previous page).

Soil formation and retention

Soils are formed over millennia from recurring natural properties and processes – mainly <u>cl</u>imate, <u>o</u>rganisms, <u>r</u>elief, <u>p</u>arent materials, and <u>t</u>ime (Jenny 1941). Soils under Great Plains grasslands are often rich due to the parent materials, climate and vegetation that shaped them. Forages are beneficial to soil formation and retention in the short-term as well, because the dense canopy of forages (a) protects the soil from erosion by wind and water and (b) leaves behind abundant surface residues and root deposits (called rhizodeposits), which help build up soil organic matter and fertility. Root channels provide habitat for invertebrates to create stable aggregates and biopores, which contributes to a robust soil ecosystem that enhances further plant growth, cleanses water as it passes through the soil profile, and cycles nutrients through organic and inorganic phases.

The value of forages for reducing soil loss and preserving water quality (Fig. 4) cannot be overstated, yet the environmental protection role of forages is too often underappreciated in national policy debates on natural resource conservation.

Water cycling, quality and infiltration

Forages efficiently utilize water in the soil profile by growing rapidly following precipitation events, and otherwise capturing water deep in the soil profile through extensive root systems. The ability of forages to withstand drought, through termination of growth and senescence of older leaves, enables them to respond rapidly to intermittent precipitation events to produce biomass. This adaptation

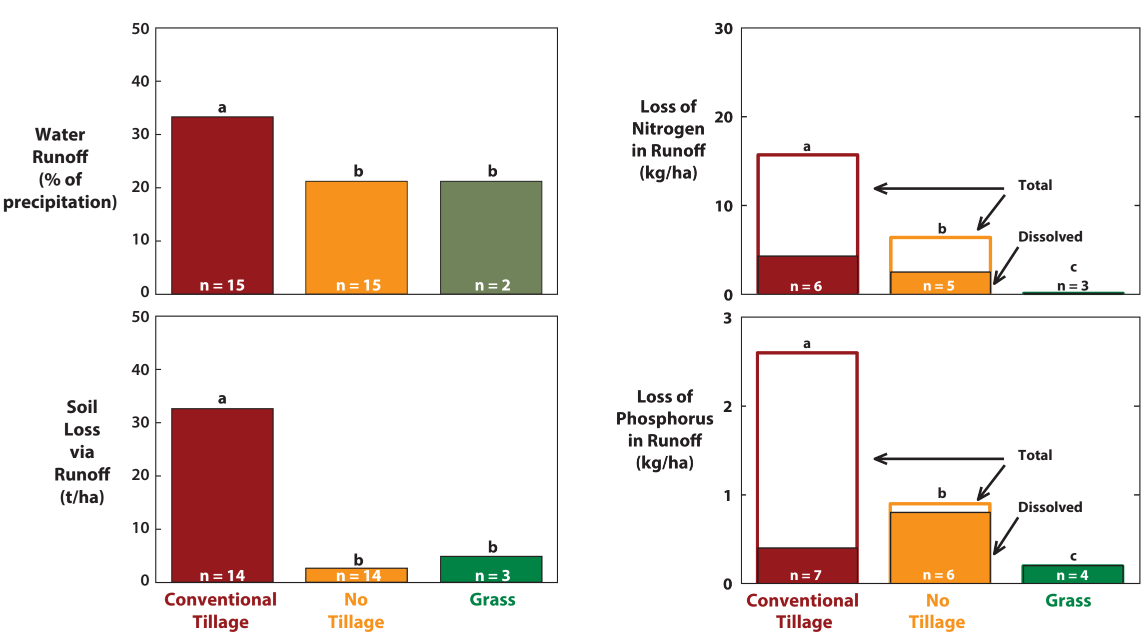

Figure 4. Land use effects on various aspects of water quality [conventional tillage cropland (red), no tillage cropland (orange), and perennial grassland (green)]. Upper left: water runoff as a percentage of precipitation. Lower left: soil loss in runoff. Upper right: loss of N in runoff. Lower right: loss of P in runoff. Data summarized from multiple studies in eastern USA (Franzluebbers 2008).

gives forages an advantage over many other agricultural crops in semi-arid and arid regions. Dense plant and surface residue cover of the soil helps create stable surface soil aggregates that withstand intense precipitation events and allow for rapid water entry into soil. Water percolation into the soil profile and its subsequent cleansing action yields abundant groundwater that contributes to surface water quality and a sustainable supply of freshwater for human and animal consumption. The value of vast grasslands in purifying groundwater needs to be more fully appreciated, especially as clean, fresh-water supplies become more limited with expected human population growth.

PHOTO–NRCS/USDA • LYNN BETTS

"The first experience of the plains, like the first sail with a "cap" full of wind, is apt to be sickening. This, once overcome, the nerves stiffen, the senses expand, and man begins to realize the magnificence of being."

—Richard Irving Dodge, *The Plains of the Great West (1877)*

The ability of forages to limit nutrient runoff compared with annual croplands has been well documented (Fig. 4) provided that excessive application of fertilizer or manures is avoided. Balanced nutrient management needs to be a priority in grasslands, just as in croplands.

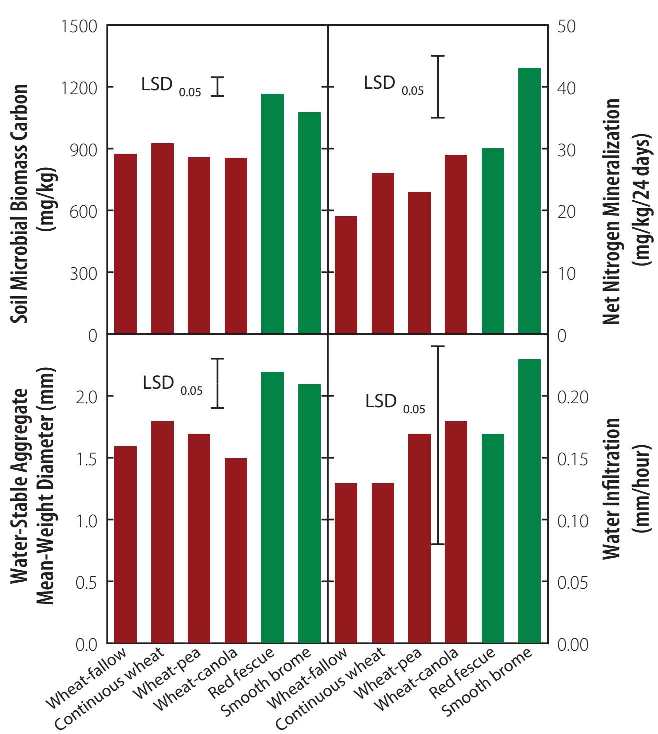

Figure 5. Biologically active fractions of soil organic matter and soil physical properties as affected by crop and forage management. Data from Arshad et al. 2004.

Nutrient cycling

Forages are diverse in nutrient requirements, and therefore, are diverse in their capacities for recycling of nutrients. With N being the most limiting nutrient in most soils, legumes have an ecological advantage in grasslands by virtue of their symbiotic association with N-fixing bacteria. However, since P is often the next most limiting nutrient and legumes having a relatively high demand for P, legumes do not dominate grasslands due to persistence issues and competition with more vigorous grass roots. In mixed stands, forages have a high affinity for accumulating nutrients into above-ground biomass that can be subsequently either harvested by grazing ruminant animals or mechanically for hay, as well as returned to the soil in plant residues to enrich soil organic matter. Cycling of nutrients under perennial forages is often characterized by a high proportion of nutrients in organic form, as compared with annual grain crops, in which a lower proportion of nutrients are in organic form. Nutrients bound to organic matter are more protected from losses via (a) leaching through soil (e.g. nitrate loss), (b) dissolved fractions in surface runoff (e.g. P loss in runoff), and (c) volatile loss to the atmosphere of ammonia or conversion of nitrate to N_2 or N_2O through denitrification.

Biologically active fractions of organic matter accumulate under forages, because soil organic matter supports a plethora of microbial and faunal life. Soil microbial biomass and N mineralization potential under perennial grasses can be significantly greater than under adjacent fields of annual grain crops (Fig. 5). In addition, the biologically active soil under forages helps support soil pore development and soil structural integrity, which leads to an improved soil physical condition that supports more efficient nutrient cycling.

Habitat provision

With soil under grasslands becoming enriched in organic nutrients, soil organic matter content, aggregate stability and biopore development, it provides abundant habitat for

"The plain gives man new and novel sensations of elation, of vastness, of romance, of awe, and often nauseating loneliness."

—Walter Prescott Webb,
The Great Plains (1931)

bacterial, fungal, and faunal diversity. Spatial and temporal rooting diversity and depth distribution help to feed soil organisms, as the breakdown of roots provides energy for these decomposing organisms. Forage crown development and surface residue accumulation also concentrate organic substrates as a source of habitat for ground-dwelling insects, spiders, small animals and birds. Forage seeds further concentrate nutrients as sources of food for roaming wildlife.

Grassland habitats are certainly diverse, and native prairies and naturalized perennial pastures can be considered excellent habitat for a wide diversity of above-ground and below-ground organisms. Deer, rabbit, quail, pheasants, doves, etc. are wildlife game species that have particular preference for mixed grassland swards.

Aesthetic experience

The beauty of native, naturalized and agriculturally managed grasslands is personal, like all works of art, yet like all natural resources exposed for our viewing pleasure, grasslands are unique in their grandeur and simple features. Forage and grazing lands somehow persuade patient observers with varied senses of serenity, of hidden natural treasures, of buzzing and frolicking insects searching for place, of peaceful cattle lowing, of grass being ripped from its stout base to serve the needs of its subjugator…

Recreation

Terrestrial space, abundant with life so near the ground, gives grasslands a unique characteristic appreciated by all who have that curious spirit of roaming – perhaps a unique feature of North American people's sense of enduring freedom. Space provided by forage and grazing lands allows the peaceful co-existence of livestock, wildlife, humans, clean water flowing over the land, fresh air and so much more. When we were young and the wind was blowing, where did we find the space to fly our kites? When we were looking for solitude, where did we go to find the warmth of the sun while on a walk in the countryside? Rivers passing through fields of forages, where could we find clean water and plenty of good fishing? Looking for fields to ride our horses, we could always rely on lush pastures to appease our trusted steed to carry us into a world of relaxing Sunday afternoons!

References available online at www.farmwest.com

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Reflection

PHOTO BY DAVID HARTNETT

"There was something about the prairie for me—it wasn't where I had come from, but when I moved there it just took me in and I knew I couldn't ever stop living under that big sky."

—Pam Houston,
Cowboys are My Weakness (1992)

"A world of grass and flowers stretched around me, rising and falling in gentle undulations, as if an enchanter had struck the ocean swell, and it was at rest forever…"

—Eliza Steele,
Summer Journey in the West (1840)