BIOLOGICALLY EFFECTIVE MANAGEMENT OF GRAZINGLANDS

North Dakota State University
Dickinson Research Extension Center
2003

North Dakota State University *2003*
Dickinson Research Extension Center
Rangeland Research Extension Program 4005

Biologically Effective Management of Grazinglands

Llewellyn L. Manske PhD
Range Scientist

Project Assistants

Amy M. Kraus

Sheri A. Schneider

Lisa J. Vance

North Dakota State University
Dickinson Research Extension Center
1089 State Avenue
Dickinson, North Dakota 58601

Tel. (701) 483-2076
Fax. (701) 483-2073

North Dakota State University is an equal opportunity institute.

CONTENTS

Rangelands of the Northern Plains

Northern Plains Rangelands 1

Prehistorical Conditions of Rangelands 2

Seasonal Weather Patterns 7

Soil Formation 9

Landscape Site Management Units 11

Vegetation of the Northern Plains 15

Problems Inherent in Grasslands 16

Biology and Management of Grass Growth

Biological Requirements of Plants 19

Increasing Rhizosphere Fungi and Improving Soil Quality 34

Grass Growth in Height 40

Environmental Factors Affect Plant Growth 44

Grazing Starting Dates 49

Effects of Fall Grazing on Height 55

Effects from Long-Term Nongrazing 62

Effects of Grazing on Vegetation 70

Suppression of Grasshopper Population Numbers 76

Enhanced Biogeochemical Cycles and Improved Soil Structure 81

Herbage Quality and Range Cow Requirements

Annual Nutritional Quality Curves 83

Grass Tillers Crude Protein 97

Annual Mineral Quality Curves 98

Range Cow Nutrient Requirements 113

Mineral Requirements for Grazing Beef Cows 138

Twelve-Month Grazingland and Harvested Forage Management

Cow and Calf Performance on Grazing Strategies 151

Cow and Calf Performance on Fall Pastures 179

Costs-Returns on Grazing Strategies 193

Costs-Returns on Forage Strategies 228

RANGELANDS OF THE NORTHERN PLAINS

Northern Plains Rangelands

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Northern Plains rangelands are a valuable renewable natural resource that provides a multitude of benefits. Much of the region's economic base is dependent on rangelands, which are the principal land type for the area's recreation, wildlife, and tourism industries and provide the majority of the forage base for the livestock industry. The use of rangelands as grazinglands for domesticated livestock is the premier example of high-value-added sustainable agriculture with low energy input. The vegetation is self perpetuating, and the animals harvest their own forage. Grazing livestock on rangelands converts perennial vegetation that cannot be directly consumed by humans into a high-quality food and provides beneficial secondary products such as fibers, medicines, cosmetics, oils, glues, and base compounds. The vegetation on rangelands provides habitat for wildlife and scarce plants and animals and stabilizes the soil, protecting it from wind and water erosion. Through photosynthesis, the plants reduce the levels of carbon dioxide in the air and release clean oxygen into the atmosphere. Rangelands collect, filter, and store water in aquifers and small basins (pot holes), then slowly release it into streams and rivers by processes that reduce the damaging effects of fast runoff and floods. Rangelands provide clean water for plants, animals, and humans. The open spaces of rangelands are aesthetically appealing and offer opportunities for recreation and sightseeing.

Properly managed, rangelands can be maintained at high levels of production in perpetuity. Rangelands are managed with ecological principles, unlike cropland, which is managed with agronomic principles. Proper management of rangelands requires an understanding of the effects environmental forces have on plant growth and of the complex processes within the plants and ecosystems. Ecological and biological requirements of grass plants can be met by properly timed defoliation by grazing. Rangeland plants have become biologically adapted to grazing. The adaptations are expressed through resistance mechanisms plants have developed in response to the evolutionary selective forces of defoliation. To maintain adequate activity of these biological processes, healthy range plants require annual defoliation by grazing. Management that is focused on a single use and that does not include annual defoliation at the appropriate growth stages cannot sustain a healthy ecosystem over time. Management that places the biological requirements of the plants as the highest priority and facilitates the operation of ecosystem functions at potential levels will sustain healthy, productive rangelands that will remain a valuable renewable natural resource, providing forage for livestock, habitat for wildlife and plants, clean air, clean water, open spaces for recreation and sightseeing, and food, fiber, and energy for people. The greatest attribute of rangelands is that when managed properly, they can provide all of these valuable benefits at the same time.

Prehistorical Conditions of Rangelands in the Northern Plains

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

An accurate representation of the Northern Plains rangelands does not match the static romantic image of a vast, ageless, pristine grassland in excellent health, with large herds of free-roaming bison accompanied by elk, antelope, wolves, and grizzly bears in idealistic harmony. The present grassland assemblage of communities and ecosystems in the Northern Plains started to develop only about 5,000 years ago, and the plants that migrated into the region respond to environmental changes dynamically, with shifts in species composition and biological status. Populations of plants and animals in grassland ecosystems experience peaks and crashes in cycles of variable highs, lows, and duration, in response to the complex set of interrelated forces in the environment. Grassland ecosystems have never been static nor can they be managed to remain at an idealistic static goal. Most idealistic static management goals for grasslands are based on a perceived image of "presettlement conditions" that evokes strong nostalgia but does not provide a complete set of guidelines on which to base sound grassland management. To formulate an accurate representation of the integral parts of the Northern Plains grasslands and to develop an understanding of these interrelated processes we must look further back in time at the environmental forces and the processes within the plants and the ecosystems.

Climate

The climate of the Northern Plains has changed several times during geologic history. A major climate change resulted when the Rocky Mountains began to uplift about 70 to 80 million years ago, forming a barrier that prevented humid Pacific Ocean air masses from flowing eastward. The Plains became much drier. Two million years ago the climate became cooler and more humid, with several periods of glaciation. Glacial advances occurred during periods when the winter snow accumulation on top of the glacier was greater than the amount of ice melted during the summer. The periods of glacial advance were cool and humid, the interglacial periods warmer and drier.

The changes in climate since the last glaciation period, which occurred between 100,000 and 10,000 years ago, have strongly influenced the present conditions of the region. The last ice sheet reached its maximum advance between 14,000 and 12,000 years ago. About 10,000 years ago, a sudden change in the climate to drier and warmer summers but colder winters occurred. This major change accelerated the melting of the glacial ice. A spruce-aspen forest developed in the cool, moist conditions at the ice margin; this community graded into a deciduous forest, which graded into a grassland south of the Northern Plains. The climate was much drier and warmer for the period between 10,000 and 5,000 years ago. During the period between 8,500 and 4,500 years ago, the vegetation was a sage and short grass plant community similar to vegetation in parts of Wyoming, and the region experienced frequent summer droughts and extensive soil erosion from wind (Bluemle 1977, Bluemle 1991).

The climate changed about 5,000 years ago to conditions like those of the present, with cycles of wet and dry periods (Bluemle 1977, Bluemle 1991, Manske 1994). The wet periods have been cool and humid, with greater amounts of precipitation. A brief wet period occurred around 4,500 years ago. Relatively long periods of wet conditions occurred between 2,500 and 1,800 years ago and between 1,000 and 700 years ago. Recent short wet periods occurred from 1905 to 1916, 1939 to 1947, and 1962 to 1978. During the wet periods, the vegetation changed, with increases in taller grasses and deciduous woodlands. The dry periods have been warmer, with reduced precipitation and recurrent summer droughts. A widespread, long drought period occurred between 1270 and 1299, and more recent drought periods occurred in the 1860's and from 1895 to 1902, 1933 to 1938, and 1987 to 1992 (Manske 1994). During the dry periods, the vegetation changed, with decreases in woodlands and increases in grasslands, and the plant composition shifted from taller grass species to shorter grass species. This climatic pattern with cyclical changes in amounts of precipitation oscillating between wet and dry periods has caused noticeable changes in the plant species composition as it shifted from deciduous woodland species to tall grass, mixed grass, short grass, and desert shrub plant communities, then reversed the cycling process, returning to increases in taller grasses and woodland plants.

Vegetation

The plant species in this region originated in other areas and migrated into the Northern Plains by different mechanisms and at different times and rates. The present vegetation has plant species with affinities to the tall grass, mixed grass, and short grass prairies, deciduous and coniferous forests, and Rocky Mountain and desert shrub plant communities (Zaczkowski 1972). This wide mix of plant species in the Northern Plains formed from remnants of plant communities that reached periods of greater development during the periods of wet and dry cycles when conditions favored these various plant community types. The diversity of plant species in our native plant community permits it to respond dynamically to changes in climatic conditions by increasing the plant species favored by any set of conditions.

The grass plants that migrated into the Northern Plains had previously developed biological mechanisms to exist and thrive with defoliation by grazing herbivores. This evolutionary process started millions of years ago. The earliest grass fossils appeared in the late Tertiary Period during the time when the earth's climate was becoming cooler and drier as a result of the build up of an ice cap at the south pole on Antarctica. The earth's lush tropical and subtropical forests diminished and moved southward, and grasslands expanded and moved northward. Grass species evolved quickly during the lower Miocene Epoch, 20 million years ago, developing characteristics that are similar to those of present grasses and that identify these plants to modern genera.

Grass plants and grazing mammals evolved together (Manske 1994). During the period of coevolution with herbivores, grasses developed defoliation resistance mechanisms like hormonal growth regulation and symbiotic soil organism relationships as compensatory processes to grazing. Close cropping of plants by herbivores exerted selective pressure that improved the survival of grasses over that of other plants and promoted grassland expansion.

Herbivores

Grazing mammals appeared in the fossil record at about the same time as grass plants. The early grazing mammals had cecal fermentation digestive systems (small horses, rhinoceroses, tapirs, brontotheres, and chalicotheres) and primitive ruminant digestive systems (camels and oreodonts). Herbivore characteristics changed and improved in response to changing characteristics in grasses. Grass plants developed a complex chemical composition and deposited silicates in their tissue, rendering it tough and nearly indigestible. Herbivores developed deep, hard teeth with enamel ridges on the crowns and digestive systems with improved effectiveness. Increased predatory pressure on open grasslands led to herbivores' development of longer legs with horny hooves, and increases in overall body size. The latest and most successful group of herbivores to evolve during this coevolutionary process was the bovine (deer, sheep, cattle, and antelope), which have advanced true ruminant digestive systems, long legs, and hard, moon-shaped cusps on their teeth. Bison are an advanced bovine with a true ruminant digestive system, fast legs, and hard teeth. Early bison migrated to North America from Asia about a million years ago. The early populations remained small in response to competition. Bison have changed form several times, with a gradual decrease in body and horn size.

Several large mammals became extinct in North America between 10,000 and 8,000 years ago, after the sudden climatic change that set off ecological changes in the vegetation communities. Most paleontologists believe that these large mammals could have adjusted to the climate change had extra pressure from human hunters not altered the birth-death ratios and had increased competition for forage resources not disadvantaged territorial animals and given herding animals a survival advantage. The mastodon, mammoth, camel, tapir, sloth, horse, large long-horned bison, middle-sized bison, and dire wolf became extinct during this time. Caribou, musk oxen, and the small bison survived the climate change, hunting pressure, and forage competition. The dramatic success of the bison following this period resulted in part from the extermination of previous prairie competitors. The small bison was the dominant herbivore between 5,000 and 115 years ago (Manske 1994). Domestic cattle have been the dominant herbivore on Northern Plains rangelands for over one hundred years.

Humans

The early human inhabitants of the Northern Plains were descendants of Asian immigrants who moved across the Bering Land Bridge between 19,000 and 14,000 years ago (Snow 1989, Wormington 1957). They later moved into this region at the time of the retreating ice sheet. These people lived in small family groups, traveled and traded over long distances, and do not appear to have claimed territories. They had fire for warmth and cooking, used well-made stone-tipped spears to hunt

large game animals, and conducted hunting as an efficient, coordinated group activity. These people used fire intentionally as a hunting aid to change the vegetation to attract herds of game animals to a desired region (Bryan 1991, Holder 1970). During the early portion of human occupation in the Northern Plains, many types of large herbivores roamed the region and were used for food. Following a climate change about 10,000 years ago, the availability of game animals decreased for several thousand years, and the humans made a noticeable shift in their diet by increasing the use of plants. During this period, humans intentionally distributed seeds of food plants across the territory. Starting around 2,250 years ago, the inhabitants cultivated large plots of arable land for production of domesticated food plants (Manske 1994).

Conclusion

The rangelands of the Northern Plains are highly advanced, complex ecosystems that function similarly to living organisms, with response and feedback processes. Defoliation by herbivores is a process grass plants require at specific growth stages if healthy productive rangelands are to be maintained. Attempting to develop modern grazing management practices that emulate a perceived model of bison movement is naive. Grass plants developed their biological processes of defoliation resistance mechanisms 20 million years ago in areas outside the Northern Plains and in conjunction with early herbivores that are now extinct. Grass plants migrated from numerous types of environments into the Northern Plains and initiated development of dynamic plant communities only about 5,000 years ago, when the present climatic pattern started. The modern small bison did not coevolve with the grass species of the Northern Plains but migrated from Asia to North America about a million years ago. The large herds did not develop before 5,000 years ago. The bison has played a role in plant community dynamics and plant species composition, but it was not a part of the fauna when the grasses developed their biological mechanisms in resistance to defoliation. The 5000-year tenure of the bison on Northern Plains grasslands has the same relationship to the 20-million-year age of the grass plants as 6.8 days has to the age of a 75-year-old person. In order to be successful and maintain a healthy productive grassland ecosystem in the Northern Plains, modern grazing management practices must meet the grass plants' biological requirements as the first priority.

Management Implications

A. The present rangeland ecosystems have existed in the Northern Plains for only about 5,000 years, and the plant communities are still developing.

B. The normal Northern Plains climatic pattern is cyclical between wet and dry periods and causes changes in plant species composition, with periodic increases and decreases in woody plants and increases and decreases in taller and shorter grasses.

C. Plants on the Northern Plains rangelands originated elsewhere and migrated into the region, developing dynamic plant communities in place.

D. Plants developed defoliation resistance mechanisms during coevolution with herbivores prior to migration into the region and require defoliation at specific growth stages to remain healthy and productive.

E. The early herbivores that coevolved with grass plants in North America are extinct. All extant herbivores require control of grazing patterns so that plant requirements are met.

F. Humans lived in the Northern Plains prior to the development of the present rangeland ecosystems and have used various techniques and practices to manipulate herbivore movement and plant growth. The inhabitants distributed seeds of food plants across the region and cultivated arable land for food plant production from about 2,250 years ago.

Acknowledgment

I am grateful to Amy M. Kraus and Naomi J. Thorson for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

References

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Bluemle, J.P. 1977. The face of North Dakota, the geologic story. North Dakota Geological Survey. Ed. Series 11. 73p.

Bluemle, J.P. 1991. The face of North Dakota: revised edition. North Dakota Geological Survey. Ed. Series 21. 177p.

Branson, F.A. 1985. Vegetation changes on western rangelands. Society for Range Management. Denver, CO. 76p.

Bryan, L. 1991. The buffalo people. University of Alberta Press. Edmonton, Alberta. 215p.

Carstensen, V. (ed). 1968. The public lands, studies in the history of the public domain. University of Wisconsin Press. Madison, WI. 522p.

Dary, D.D. 1974. The buffalo book. Avon Books. New York, NY. 374p.

Daubenmire, R. 1968. Plant communities, A textbook of plant synecology. Harper and Row. New York, NY. 300p.

Daubenmire, R.F. 1974. Plants and environment, A textbook of plant autecology. John Wiley and Sons, New York, NY. 422p.

Davis, K.P. 1976. Land use. McGraw-Hill Book Co. New York, NY. 324p.

Dill, C.L. 1990. Early peoples of North Dakota. State Historical Society of North Dakota. Bismarck, ND. 63p.

Eyre, S.R. 1963. Vegetation and soils, a world picture. Aldine Publishing Co. Chicago, IL. 324p.

Fenneman, N.M. 1931. Physiography of western United States. McGraw-Hill Book Co. New York, NY. 534p.

Foster, J.E., D. Harrison, and I.S. MacLaren. 1992. Buffalo. University of Alberta Press. Edmonton, Alberta. 244p.

Gard, W. 1968. The great buffalo hunt. University of Nebraska Press. Lincoln, NE. 324p.

Gilmore, M.R. 1991. Uses of plants by the Indians of the Missouri River Region. University of Nebraska Press. Lincoln, NE. 125p.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas. Lawrence, KS. 1392p.

Heidenreich, V.L. (ed). 1990. The fur trade in North Dakota. State Historical Society of North Dakota. Bismarck, ND. 73p.

Hibbard, B.H. 1965. A history of the public land policies. University of Wisconsin Press. Madison, WI. 579p.

Holder, P. 1970. The hoe and the horse on the plains. University of Nebraska Press. Lincoln, NE. 176p.

Humphrey, R.R. 1962. Range ecology. The Ronald Press Co. New York, NY. 234p.

Hunt, C.B. 1974. Natural regions of the United States and Canada. W.H. Freeman and Co. San Francisco, CA. 725p.

Hyde, G.E. 1959. Indians of the high plains. University of Oklahoma Press. Norman, OK. 234p.

Lowie, R.H. 1963. Indians of the plains. Natural History Press. Garden City, NY. 258p.

MacNeish, R.S. 1973. Early man in America. W.H. Freeman and Co. San Francisco, CA. 93p.

Manske, L.L. 1994. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings-Leafy Spurge Strategic Planning Workshop. USDI National Park Service. Dickinson, ND. p. 3-16.

McHugh, T. 1972. The time of the buffalo. University of Nebraska Press. Lincoln, NE. 339p.

Morgan, L.H. 1993. The Indian journals, 1859-1862. Dover Publications Inc. New York, NY. 273p.

Quigg, J.M., and J.H. Brumley. 1984. Stone circles. State Historical Society of North Dakota. Bismarck, ND. 183p.

Ruhe, R.V. 1969. Quaternary landscapes in Iowa. Iowa State University Press. Ames, IA. 255p.

Sandoz, M. 1954. The buffalo hunters. University of Nebraska Press. Lincoln, NE. 372p.

Shiflet, T.N. (ed). 1994. Rangeland cover types. Society for Range Management. Denver, CO. 152p.

Snow, D.R. 1989. The archaeology of North America. Chelsea House Publishers. New York, NY. 143p.

Stevens, O.A. 1963. Handbook of North Dakota plants. North Dakota Institute for Regional Studies. 324p.

Stevens, O.A. 1965. Plants used by Indians in the Missouri River Area. North Dakota History 32:101-106.

Taylor, C.F., and W.C. Sturtevant (ed). 1991. The native Americans. Smithmark. New York, NY. 256p.

Thornbury, W.D. 1969. Principles of geomorphology. John Wiley and Sons. New York, NY. 594p.

Trimble, D.E. 1990. The geologic story of the great plains. Theodore Roosevelt Nature and History Association. Medora, ND. 54p.

Whittaker, R.H. 1962. Classification of natural communities. The Botanical Review. 28:1-239.

Whittaker, R.H. 1975. Communities and ecosystems. MacMillan Publishing Co. New York, NY. 385p.

Woodhead, H. (ed). 1992. The first Americans. Time Life Books. Alexandria, VA. 183p.

Wormington, H.M. 1957. Ancient man in North America. Denver Museum of Natural History. Denver, CO. 322p.

Zaczkowski, N.K. 1972. Vascular flora of Billings, Bowman, Golden Valley, and Slope Counties North Dakota. Ph.D. Thesis. North Dakota State University. Fargo, ND. 219p.

Seasonal Weather Patterns of the Northern Plains

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Precipitation Pattern

The current climate of the Northern Plains has existed for the past 5,000 years (Bluemle 1977, Bluemle 1991, Manske 1994, Bluemle 2000). The seasonal distribution of precipitation (figure) is classified as the Plains Precipitation Pattern (Humphrey 1962), in which most of the precipitation occurs during the growing season (85%) and the smallest amount occurs in winter (10%). Total precipitation for the 5-month nongrowing season of November through March averages less than 2.5 inches (63.5 mm) (15%) of precipitation. The greatest amount of precipitation occurs in spring and early summer (60%). The precipitation received in the 3-month period of May, June, and July accounts for over 50% of the annual precipitation, and June has the greatest monthly precipitation (22%).

Weather Air Mass Pattern

The weather of the Northern Plains is controlled by three major air masses that dominate at different times of the year (Redmann 1968). The Pacific air mass dominates the region from September through January, a period that is generally dry because the orographic effect of the Rocky Mountains causes a rain shadow as the air mass moves east. The mean monthly precipitation during this dry period is less than 1.0 inch (25.4 mm). The Polar air mass dominates the region from February through May, a period with mean monthly precipitation between 1.0 and 2.0 inches (25.4 mm and 50.8 mm). Throughout June, combinations of Gulf, Polar, and Pacific air masses mix and produce a relatively rainy period with a monthly precipitation average around 3.5 inches (88.9 mm). The summer months of July and August are dominated by the Gulf air mass, with little mixing of other air masses and a reduction of monthly precipitation to about 2.0 inches (50.8 mm), which comes generally in intermittent thunderstorms. The change from the dominance of one air mass to the next results in transition periods, which can vary annually. Differences in the transition periods contribute to the variation in conditions from year to year.

Literature Cited

Bluemle, J.P. 1977. The face of North Dakota: the geologic story. North Dakota Geological Survey. Ed. Series 11. 73p.

Bluemle, J.P. 1991. The face of North Dakota. Revised edition. North Dakota Geological Survey. Ed. Series 21. 177p.

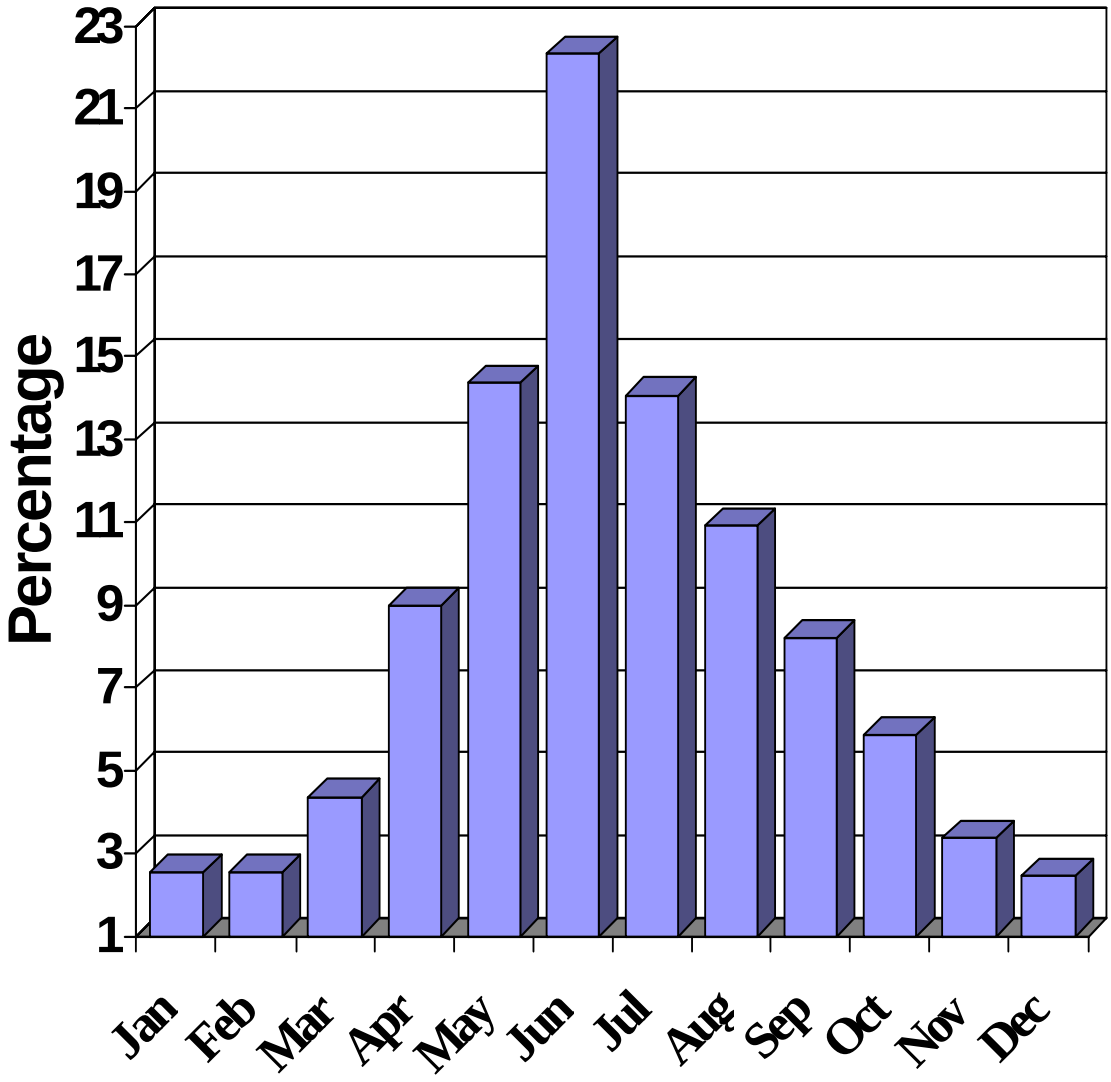
Bluemle, J.P. 2000. The face of North Dakota. 3rd edition. North Dakota Geological Survey. Ed. Series 26. 206p. 1pl.

Humphrey, R.R. 1962. Range ecology. The Ronald Press Company. New York, NY. 234p.

Manske, L.L. 1994. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings-Leafy spurge strategic planning workshop. USDI National Park Service. Dickinson, ND. p. 3-16.

Redmann, R.E. 1968. Productivity and distribution of grassland plant communities in western North Dakota. Ph.D. Thesis, University of Illinois. IL. 153p.

Seasonal Precipitation Distribution of the Plains Precipitation Pattern



Soil Formation in the Unglaciated Northern Plains

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Soil is the medium in which grassland plants grow. Major variations in soil properties result from differences in the type of parent material and in the soil developmental processes. Plant community dynamics and plant growth potentials are affected by the changing characteristics occurring during the continuous progression of soil formation, and soil, climate, and plants have complex cause-effect relationships regulating soil formation. Management practices affect these relationships and can enhance or impair soil developmental processes.

Parent Material from Sedimentary Deposits

The unglaciated region of the Northern Plains is part of a large geologic depression, which has been filled over a period of 515 million years with accumulations of sedimentary rocks deposited in off-shore shallow seas and in near-shore marine environments or by running water on floodplains or deltas. For about the last 5 million years, running water and wind have been eroding the generally flat-lying sedimentary deposits in the unglaciated region. These erosional forces have been selective in their action because hard, relatively resistant sandstone, limestone, scoria, chert, or other erosion-resistant materials were present in some of the sedimentary deposits and have remained as protective caps, while the soft, weakly consolidated, less resistant silt and clay layers have been easily washed or blown away. The landforms that have resulted from uneven sediment removal are gently rolling to hilly plains intermingled with buttes, which have flat tops and steep slopes. Over the last 600,000 years, badlands topography has developed near some streams and rivers from erosional forces that accelerated sediment removal when glacial ice blocked the northward flow of the drainage systems. The diverted routes to the east were shorter and steeper, and the water flowing in the drainage systems caused deep, rapid erosion that resulted in badlands landforms (Hunt 1974, Bluemle 1977, Trimble 1990, Bluemle 1991, Bluemle 2000).

Soil Development from Sedimentary Deposits

Soils in the unglaciated region have been developing from weathered sedimentary deposits of soft shale, siltstone, and sandstone. Soil formation is a long, slow, continuous process. Temperatures and precipitation levels of the area have been important in the development of the regional soils. The climate has determined the type of vegetation and the amount of annual growth, which, in turn, have influenced the amount of soil organic matter accumulated.

Temperature affects the rate of oxidation of organic matter. Higher temperatures promote rapid oxidation of organic matter, and soils in regions with long periods of high temperatures contain little organic matter. Little or no oxidation of organic matter occurs in frozen soil. Organic matter has accumulated in the soils in the Northern Plains because the climate has cold periods during which little chemical activity takes place. In most years, soils in the unglaciated region have frost penetration to a depth of 3 to 5 feet for a period of approximately 120 days (Larson et al. 1968), a condition that contributes to soil organic matter accumulation. The dark surface layer of most soils in the region has an accumulation of 2 to 5% organic matter (Larson et al. 1968, Wright et al. 1982).

Temperature and precipitation have influenced the amount and kinds of physical and chemical weathering of the region's parent material. High temperatures and high precipitation have encouraged rapid weathering and clay formation during the summer, while low temperatures during fall, winter, and early spring have caused cracks, fissures, and breaks in the parent material and developing soil as a result of the expansion and contraction forces of frost.

Precipitation level has influenced the amount of water in the soil. The amount of water that has entered the soil has not been the same as the precipitation level, and the amount of soil water has not been the same on all parts of the landscape. The amount of soil water has been less than the amount of precipitation received in areas that have had rain run off, and the amount of soil water has been greater than the amount of precipitation received in areas that have had rain run in. The amount of soil water present has affected the rate of leaching. The depth of the downward movement of the water has not been uniform for the soils on different topographic positions on the landscape.

Soil water has dissolved calcium carbonate (lime), soluble salts, exchangeable sodium, and clay particles from the upper horizons of the soil and moved them downward into a lower horizon. The amount of these dissolved materials in the soil profile has been dependent on the amount present in the weathered parent material. The depth to which they have been moved has varied with the amount of soil water. The layer where the dissolved material has accumulated indicates the approximate average depth of downward water movement. The depth of the accumulation layer decreases when the precipitation decreases. Soils with a high lime content have developed a layer of natural cement (hardpan) that restricts plant root penetration. Soils high in soluble salts and/or exchangeable sodium have developed accumulation layers containing sufficient amounts of these chemicals to impair plant growth. Soils high in soluble salts have developed into saline soils; soils high in exchangeable sodium have developed into sodic soils; and soils high in both have developed into saline-sodic soils (Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978).

Soil water has also dissolved clay particles and moved the clay downward. When the soil water with dissolved clay has hit areas of dry soil, the water has been withdrawn and the clay particles have been deposited. Over time this clay film layer has built up to form what is called an argillac horizon. Low amounts of argillac horizon in a soil can be beneficial because the clay helps increase the amount of water and nutrients stored in that zone; however, when the clay accumulation becomes great, the effects can be detrimental because water movement and plant root penetration are severely restricted. Soils that have a well-developed argillac horizon are called clay-pan soils (Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978).

The depth of the layer where the dissolved material accumulates is very important because it determines the thickness of the plant growth medium; the soil above the layer of accumulation holds the nutrients and soil water needed to sustain plant life. Shallow soils restrict plant growth. The depth of the accumulation layer decreases westward with the reduction in precipitation and ranges from 6 inches to 4 feet. Most soils in western North Dakota have formed the accumulation layer between 15 and 24 inches below the soil surface (Larson et al. 1968, Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978, Wright et al. 1982).

Literature Cited

Bluemle, J.P. 1977. The face of North Dakota: the geologic story. North Dakota Geological Survey. Ed. Series 11. 73p.

Bluemle, J.P. 1991. The face of North Dakota. Revised edition. North Dakota Geological Survey. Ed. Series 21. 177p.

Bluemle, J.P. 2000. The face of North Dakota. 3rd edition. North Dakota Geological Survey. Ed. Series 26. 206p. 1pl.

Foth, H.D. 1978. Fundamentals of soil science. John Wiley and Sons. New York, NY. 436p.

Hunt, C.B. 1974. Natural regions of the United States and Canada. W.H. Freeman and Company. San Francisco, CA. 725p.

Larson, K.E., A.F. Bahr, W. Freymiller, R. Kukowski, D. Opdahl, H. Stoner, P.K. Weiser, D. Patterson, and O. Olsen. 1968. Soil survey of Stark County, North Dakota. U.S. Government Printing Office. Washington, DC. 116p.+plates.

Omodt, H.W., G.A. Johnsgard, D.D. Patterson, and O.P. Olson. 1968. The major soils of North Dakota. Department of Soils. Bulletin No. 472. North Dakota State University. Fargo, ND. 60p.+map.

Soil Survey Staff. 1975. Soil Taxonomy. Agriculture Handbook No. 436. USDA Soil Conservation Service. U.S. Government Printing Office. Washington, DC. 754p.

Trimble, D.E. 1990. The geologic story of the Great Plains. Theodore Roosevelt Nature and History Association. Medora, ND. 54p.

Wright, M.R., J. Schaar, and S.J. Tillotson. 1982. Soil survey of Dunn County, North Dakota. U.S. Government Printing Office. Washington, DC. 235p.+plates.

Landscape Site Management Units

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Range site is the basic unit of rangeland with similar characteristics. Each named range site has similar soil characteristics, topographic position, environmental factors, and potential native vegetation composition. Range sites can be described and separated to a finer degree than is practical for application of specific management practices. Theoretically, enough differences exist among the range sites to warrant the use of different management and stocking rates for each range site. Such specific management would require that each range site be identified and considered separately.

This report attempts to simplify the process of range site identification by grouping categories of range sites into landscapes sites with similar management requirements and similar stocking rates. Two major differences among the landscape site management units are the type of soil parent material and the average annual precipitation. The average annual precipitation and the types of parent material from which soils have developed are variable across the Northern Plains and form four distinct physiographic regions: the Red River Valley, the Drift Prairie, the Missouri Coteau, and the West River Regions.

The **Red River Valley Region**, part of the Central Lowland Physiographic Province, is an exceptionally flat plain of glacial lake sedimentary deposits and is characterized by very gentle slopes over 95% of the area. The region has poorly developed stream systems. The range of average annual precipitation is 18 to 20 inches. The major native vegetation is the Bluestem, Switchgrass, and Indiangrass Type of the Tall Grass Prairie. Most of this region has been converted to cropland, and only fragments of tall grass prairie vegetation remain. Management considerations for this region are not included in this report.

The **Drift Prairie Region,** part of the Central Lowland Physiographic Province, is characterized by rolling, hummocky, or hilly glacial till deposits; gentle slopes of less than 8% on more than 80% of the area; and relief generally of less than 100 feet. The hills are closely spaced, with valleys containing numerous closed depressions called pot holes. The region has poorly developed stream systems. The range of average annual precipitation is 16 to 20 inches. The major vegetation is the Wheatgrass, Bluestem, and Needlegrass Type of the Mixed Grass Prairie. This region is considered the transition zone between the Tall Grass Prairie and the Mixed Grass Prairie.

The **Missouri Coteau Region,** part of the Great Plains Physiographic Province, is the glaciated portion of the Missouri Plateau. This region is a hummocky plain of terminal moraine and dead-ice moraine deposits and is characterized by gentle slopes of less than 8% on 50 to 80% of the area and relief generally of 100 to 300 feet. Some portions of the region are well drained with streams, and other portions have depressions containing closed basins with small bodies of water. The range of average annual precipitation is 14 to 18 inches. The major native vegetation is the Wheatgrass and Needlegrass Type of the Mixed Grass Prairie.

The **West River Region**, part of the Great Plains Physiographic Province, is the unglaciated portion of the Missouri Plateau. In this region sedimentary deposits have been eroded and formed into a rolling to hilly plain with large buttes. The region is characterized by gentle slopes of less than 8% on 50 to 80% of the area and relief generally of 300 to 500 feet. The region is well drained with a developed stream system. On an 8- to 25-mile-wide and nearly 200-mile-long strip along the Little Missouri River exists a subregion of badlands. This subregion is a rugged, deeply eroded, hilly area with gentle slopes of less than 8% on 20 to 50% of the area and relief commonly over 500 feet. The range of average annual precipitation is 13 to 16 inches for the region. The major native vegetation is the Wheatgrass and Needlegrass Type of the Mixed Grass Prairie.

The range sites within each of the different physiographic regions of the Northern Plains can be grouped into three landscape site categories based on the soil water holding capacity and the position of the water table. These three landscape site categories are easily identified and can be used during the planning of pasture and forage management strategies. The three landscape site categories are lowland, upland, and xeric sites. The lowland landscape sites have

high levels of soil water in the rooting zone of the soil for most of the year. Because of water run in, these sites receive greater amounts of water than the precipitation levels. The upland landscape sites have well-drained soils and are usually not at field capacity for much of the growing season. The xeric landscape sites have restricted water infiltration or water-holding capacity, and for much of the growing season, available soil water is below the potential to be gained from precipitation.

Among the physiographic regions, the characteristics of a landscape site type differ slightly. Therefore, management requirements and stocking rates differ slightly for areas of a particular landscape site type located in different physiographic regions.

Lowland Landscape Sites of the Drift Prairie Region

Topography is nearly level, low-lying swales, depressions, shallow basins, and drainageways. Slopes are less than 3%. Soils are deep and are poorly drained to moderately well drained. Permeability is very slow, slow, moderately slow, or moderate. Available water capacity is moderate, high, or very high. Lowland landscape sites receive additional amounts of water from run in from higher land, surface runoff, flooding, and/or underground seepage.

Upland Landscape Sites of the Drift Prairie Region

Topography is nearly level to rolling, with some areas gently sloping to moderately steep. Slopes are mostly 1 to 15%, with some 3 to 25%. Soils are deep to moderately deep; most are moderately well drained to well drained, and some are excessively well drained. Permeability is slow, moderate, moderately rapid, or rapid. Available water capacity is low, moderate, or high.

Xeric Landscape Sites of the Drift Prairie Region

Topography is nearly level, undulating, or gently sloping. Slopes are 1 to 6%. Soils are mostly very shallow or shallow; some are deep. Most are poorly drained or moderately well drained; some are excessively drained. Permeability is very slow, moderate, moderately rapid, or rapid. Available water capacity is very low, low, or moderate. Most xeric landscape sites have thin surface soils with an underlying hardpan that is nearly impervious to water.

Lowland Landscape Sites of the Missouri Coteau Region

Topography is nearly level swales, basins, and depressions, or nearly level and gently undulating low-lying bottomlands and stream terraces. Slopes are less than 3%. Soils are deep and poorly drained. Permeability is very slow to moderate. Available water capacity is moderate, high, or very high. Lowland landscape sites receive additional amounts of water from run in from higher land, surface runoff, flooding, and/or underground seepage. Lowland landscape sites are usually briefly flooded, with water standing over the surface for part of the growing season, and have a high water table for the majority of the growing season. Some lowland landscape sites have surface areas with salts, and some have sodium effects throughout the profile.

Upland Landscape Sites of the Missouri Coteau Region

Topography is nearly level, rolling, undulating, gently sloping, strongly sloping, or steep. Slopes are 1 to 35%. Soils are deep and moderately deep to shallow and are moderately well drained, well drained, or excessively drained. Permeability is slow, moderate, moderately rapid, or rapid. Available water capacity is low, moderate, or high. Upland landscape sites are usually underlain by sand, gravel, or weathered bedrock that restricts plant root penetration.

Xeric Landscape Sites of the Missouri Coteau Region

Topography is nearly level, undulating, gently sloping, or strongly sloping. Slopes are 1 to 9%. Soils are very shallow, shallow, or deep, and are well drained or excessively drained. Permeability is very slow, slow, moderate, or rapid. Available water capacity is low to moderate. Xeric landscape sites are usually underlain by sand or gravel or by hardpan that contains high accumulations of sodium and is nearly impervious to water.

Lowland Landscape Sites of the West River Region

Topography is slightly concave basins and depressions or nearly level low terraces and flood plains along streams and channels. Slopes are 1 to 3%. Soils are deep and are poorly drained to well drained. Permeability is very slow, slow, or moderate. Available water capacity is low, moderate, high, or very high. Lowland landscape sites receive

additional amounts of water from run in from higher land, surface runoff, flooding, and/or underground seepage. The water table is at the surface for the early part of the growing season and remains high for most of the growing season. Some lowland landscape sites are saline and/or alkaline and calcareous with salts at the surface and sodium effects throughout the profile.

Upland Landscape Sites of the West River Region

Topography is nearly level, undulating, rolling, gently sloping, or strongly sloping. Slopes are mostly 1 to 15% with some 25 to 50%. Soils are deep, moderately deep, or shallow, and are well drained to excessively drained. Permeability is moderately slow, moderate, moderately rapid, or rapid. Available water capacity is low, moderate, or high. Upland landscape sites are underlain by shale, siltstone, or sandstone that restricts root depth.

Xeric Landscape Sites of the West River Region

Topography is nearly level, undulating, gently sloping, moderately sloping, or steep plains. Slopes are mostly 1 to 9%, and some are 2 to 35%. Soils are very shallow or shallow. Permeability is moderate to very rapid near the surface and very slow to slow in the substratum. Available water capacity is very low, low, or moderate. Xeric landscape sites have thin surface soils underlain by coarse sand, gravel, weathered bedrock, scoria, or by a hardpan that has a high accumulation of sodium and is nearly impervious to water. These substratum materials restrict plant root depth.

Acknowledgment

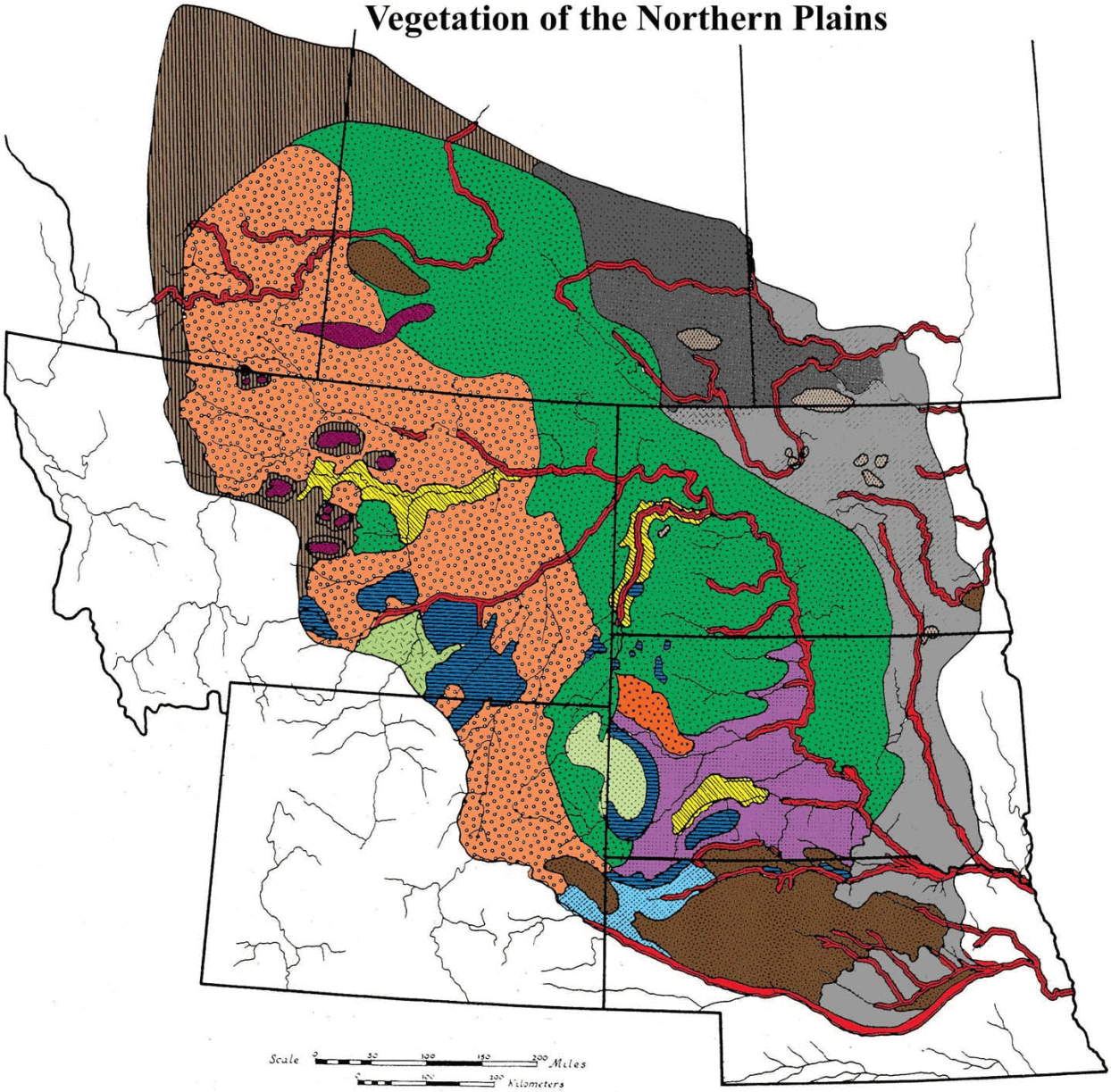
I am grateful to Amy M. Kraus for assistance in preparation of this manuscript.
I am grateful to Sheri Schneider for assistance in production of this manuscript.

Table 1. Range sites composing the landscape sites management units.

Lowland Landscape Sites	**Upland Landscape Sites**	**Xeric Landscape Sites**
Wetland range site	Sands range site	Shallow to Gravel range site
Wet Meadow range site	Sandy range site	Shallow Clay range site
Subirrigated range site	Silty range site	Claypan range site
Overflow range site	Clayey range site	Thin Claypan range site
Closed Depression range site	Shallow range site	Very Shallow range site
Saline Lowland range site	Thin Upland range site	
	Thin Sands range site	

Table 2. Major grasses of landscape sites.					
Lowland Landscape Sites			**Upland Landscape Sites**		
	Western wheatgrass	*Agropyron smithii*		Western wheatgrass	*Agropyron smithii*
	Big bluestem	*Andropogon gerardi*		Sand bluestem	*Andropogon hallii*
	Northern reedgrass	*Calamagrostis stricta*		Sideoats grama	*Bouteloua curtipendula*
	Canada wildrye	*Elymus canadensis*		Blue grama	*Bouteloua gracilis*
	Switchgrass	*Panicum virgatum*		Plains reedgrass	*Calamagrostis montanensis*
	Reed canarygrass	*Phalaris arundinacea*		Prairie sandreed	*Calamovilfa longifolia*
	Sprangletop	*Scolochloa festucacea*		Prairie junegrass	*Koeleria pyramidata*
	Indiangrass	*Sorghastrum nutans*		Little bluestem	*Schizachyrium scoparium*
	Prairie cordgrass	*Spartina pectinata*		Sand dropseed	*Sporobolus cryptandrus*
	Slough sedge	*Carex atherodes*		Needle and thread	*Stipa comata*
	Wooly sedge	*Carex lanuginosa*		Porcupine grass	*Stipa spartea*
	Lowland sedges	*Carex spp.*		Green needlegrass	*Stipa viridula*
Saline Lowland Landscape Sites				Upland sedges	*Carex spp.*
	Inland saltgrass	*Distichlis spicata*	**Xeric Landscape Sites**		
	Foxtail barley	*Hordeum jubatum*		Western wheatgrass	*Agropyron smithii*
	Nuttall alkaligrass	*Puccinellia nuttalliana*		Blue grama	*Bouteloua gracilis*
	Tumblegrass	*Schedonnardus paniculatus*		Buffalograss	*Buchloe dactyloides*
	Squirreltail	*Sitanion hystrix*		Prairie junegrass	*Koeleria pyramidata*
	Alkali cordgrass	*Spartina gracilis*		Plains muhly	*Muhlenbergia cuspidata*
				Sandberg bluegrass	*Poa sandbergii*
				Little bluestem	*Schizachyrium scoparium*
				Needle and thread	*Stipa comata*
				Green needlegrass	*Stipa viridula*
				Upland sedges	*Carex spp.*

Vegetation of the Northern Plains



map from Barker and Whitman 1989

- Wheatgrass-Bluestem-Needlegrass
- Wheatgrass-Needlegrass
- Wheatgrass-Grama-Needlegrass
- Wheatgrass-Bluestem-Needlegrass (Rough-Fescue Mixed)
- Wheatgrass-Grama grass
- Wheatgrass
- Sandhills Prairie
- Grama-Buffalograss
- Foothills Prairie (Rough Fescue)
- Pacific Bunchgrass
- Badlands and River Breaks
- Pine Savanna
- Black Hills Pine Forest
- Montane Forest
- Upland Woodlands
- Riparian Woodlands

Range Management Practices Addressing Problems Inherent in the Northern Plains Grasslands

Llewellyn L. Manske PhD
Range Scientist,
North Dakota State University
Dickinson Research Extension Center

Range management practices that are biologically effective address the inherent problems and conditions of the geographic region in which the practices are implemented. In the Northern Plains grassland ecosystem, the vegetation is characterized by three major features that have implications for animal production: 1) plant growth is limited by several environmental factors, 2) ungrazed grasses are low in nutritional quality during the latter portion of the grazing season, and 3) plants grazed too early in the growing season or late in the growing season suffer negative effects. The twice-over rotation grazing system on native rangeland with complementary domesticated grass spring and fall pastures was developed with consideration of these features and has been successfully implementated on the Northern Plains.

In this region, the most important of the environmental factors limiting plant growth (Manske 1998) are moderate annual precipitation, limited distribution of precipitation during part of the growing season, cool temperatures in the spring and fall, and hot temperatures in summer. The seasonal precipitation pattern is characterized by a period of maximum precipitation in late spring and early summer, tapering off to a moderately light amount during fall and winter. Periods with precipitation levels sufficiently low to place plants under water stress and limit growth occur frequently. Herbage production within grassland communities is also limited by temperature. The frost-free period is usually short, from 120 to 130 days. Perennial grassland plants can sustain growth for longer than the frost-free period, but they require temperatures above the level that freezes water in plant tissue and soil. Plant growth is greatly limited by low air temperatures during the early and late portions of the growing season and by high temperatures, high evaporation, drying winds, and low precipitation during mid summer.

The growing season for perennial grasses covers about six months, from mid April to mid October. However, because favorable precipitation and temperature conditions occur during May, June, and July (Manske 1998), most plant growth in height is attained within this three-month period (Goetz 1963). Peak aboveground herbage biomass is usually reached during the last ten days of July. Herbage biomass of ungrazed plants increases in weight during May, June, and July; after the end of July the weight of the herbage biomass decreases because the rate of senescence (aging) of the grass leaves exceeds growth and the cell material in aboveground structures is being translocated to the belowground structures. This translocation causes a decrease in the nutritional quality of the aboveground structures. Ungrazed plants of the major upland sedges, cool-season grasses, and warm-season grasses drop below the 9.6% crude protein level around mid July (Whitman et al. 1951), as they attain maximum growth in height and weight.

The nutritional quality of the native vegetation during the latter portion of the grazing season is a limiting factor in animal performance. A 1000-pound lactating cow requires a crude protein level of at least 9.6% (NRC 1996). Most ruminant animals require a daily dry matter intake of about 2% (1.5-3.0%) of their body weight (Holechek et al. 1989). Cows may be able to compensate for lower-quality forage for a short time by increasing intake and/or selecting plant parts higher in nutritional quality than average plant parts. However, cows on seasonlong and deferred grazing systems lose weight from early or mid August to the end of the grazing season (Manske et al. 1988). The loss of weight does not hurt the animals but does cause decreased milk production (Landblom 1989) and a subsequent reduction in the daily gain of calves (Manske 1996).

The negative effects suffered by plants on a seasonlong system with grazing begun too early include great reductions in herbage biomass production, which cause reductions in stocking rates and animal production per acre. Data from three studies indicate that if seasonlong grazing is started in mid May on native rangeland, 45-60% of the potential peak herbage biomass will be lost and never be available for grazing livestock. If the starting date of seasonlong grazing is deferred until early or mid July, nearly all of the potential peak herbage biomass will grow and be available to the grazing livestock, but the nutritional quality of the available forage will be at or below the crude protein levels required by a

lactating cow. If the starting date is deferred until after mid July, less than peak herbage biomass will be available to grazing livestock because of senescence and the translocation of cell material to belowground parts (Campbell 1952, Rogler et al. 1962, Manske 1994a), and the crude protein levels of the available forage will be insufficient to meet the nutritional requirements of a lactating cow.

The phenological growth stage of the grass plants is the best indicator of appropriate grazing starting dates. Grazing plants before the third-leaf stage causes negative effects in grass growth, while starting grazing after the third-leaf stage stimulates tiller production, a process that leads to increased aboveground herbage biomass and increased nutritional quality of available herbage. Most native cool-season grasses reach the third-leaf stage around early June, and most native warm-season grasses reach the third-leaf stage around mid June. This phenological development indicates that within each management system, starting grazing on each pasture sometime between early June and early July would produce the fewest negative effects on herbage biomass production and nutritional quality of the available forage. Seasonlong grazing management systems on native rangeland should wait until mid June to begin grazing, but rotation grazing systems could start in early June.

Continuation of grazing late in the season can also produce detrimental effects on plants. Severe defoliation of grass plants during fall and winter reduces herbage production of the grasslands the following growing season. Late-stimulated tillers remain viable over winter and continue growth the following growing season. Cool-season species initiate tillers the previous fall and continue growth the following season. Defoliation of late-stimulated tillers and cool-season tillers during fall and winter reduces their contribution to the ecosystem the following season.

The twice-over rotation system on native rangeland with complementary domesticated grass spring and fall pastures times grazing to maximize vegetation and animal performance. In the twice-over rotation system a spring pasture of crested wheatgrass is grazed during May. A three- or four-pasture native rangeland rotation system is used from early June until mid October, with each pasture grazed for two periods. The first period occurs during the 45 days when grasses are between the third-leaf stage and flowering and can be stimulated to tiller, 1 June to 15 July. During this first period, each pasture is grazed for 15 days on a three-pasture system or for 11 days on a four-pasture system. During the second period, after mid July and before mid October, each pasture is grazed again for 30 days on a three-pasture system or for 22 days on a four-pasture system. A fall pasture of Altai wildrye is grazed by cows and calves from mid October until weaning in early or mid November.

The twice-over rotation system with complementary domesticated grass pastures has a grazing season of over 6.5 months, with the available forage above, at, or only slightly below the requirements for a lactating cow for nearly the entire grazing season. It requires fewer than 12 acres per cow-calf pair for the entire 6.5-month grazing season on grassland that when grazed for 6.0 months seasonlong requires 24 acres per cow-calf pair. The cow-calf weight performance on the twice-over rotation grazing system with complementary domesticated grass pastures is improved over the performance on other systems (Manske 1994b, Manske 1996).

It is possible that no range management practice can address all the problems inherent in an ecosystem, but successful practices will incorporate adjustment for the most serious problems. The twice-over rotation system with complementary domesticated grass pastures is one system that has been shown to be well adapted to the conditions of the Northern Plains grasslands and to produce positive results in vegetation and animal performance.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

Literature Cited

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Goetz, H. 1963. Growth and development of native range plants in the mixed grass prairie of western North Dakota. M.S. Thesis, NDSU. Fargo, ND. 165p.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1989. Range management principles and practices. Prentice Hall. NJ. 501p.

Landblom, D.G. 1989. Brood cow efficiency management study. 39th Livestock Research Roundup. Dickinson Research Center. Dickinson, ND. Sec.I. p. 20-34.

Manske, L.L. 1994a. Problems to consider when implementing grazing management practices in the Northern Great Plains. NDSU Dickinson Research Extension Center. Range Management Report DREC 94-1005. Dickinson, ND. 11p.

Manske, L.L. 1994b. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program, Regina, Saskatchewan, Canada.

Manske, L.L. 1996. Economic returns as affected by grazing strategies. p. 43-55. *in* Z. Abouguendia (ed.). Total Ranch Management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1998. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-1997. NDSU Dickinson Research Extension Center. Range Research Report DREC 98-1018. Dickinson, ND. 36p.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988. Cow and calf performance on seasonlong and twice over rotation grazing treatments in western North Dakota. Proceedings of the North Dakota Cow-Calf Conference. Bismarck, ND. p. 5-17.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th ed. National Academy Press. Washington, DC.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. N.D. Agr. Exp. Sta. Bul. 439. 15p.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. N.D. Agr. Exp. Sta. Bul. 370. 55p.

BIOLOGY AND MANAGEMENT OF GRASS GROWTH

Management of Northern Plains Prairie Based on Biological Requirements of the Plants

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

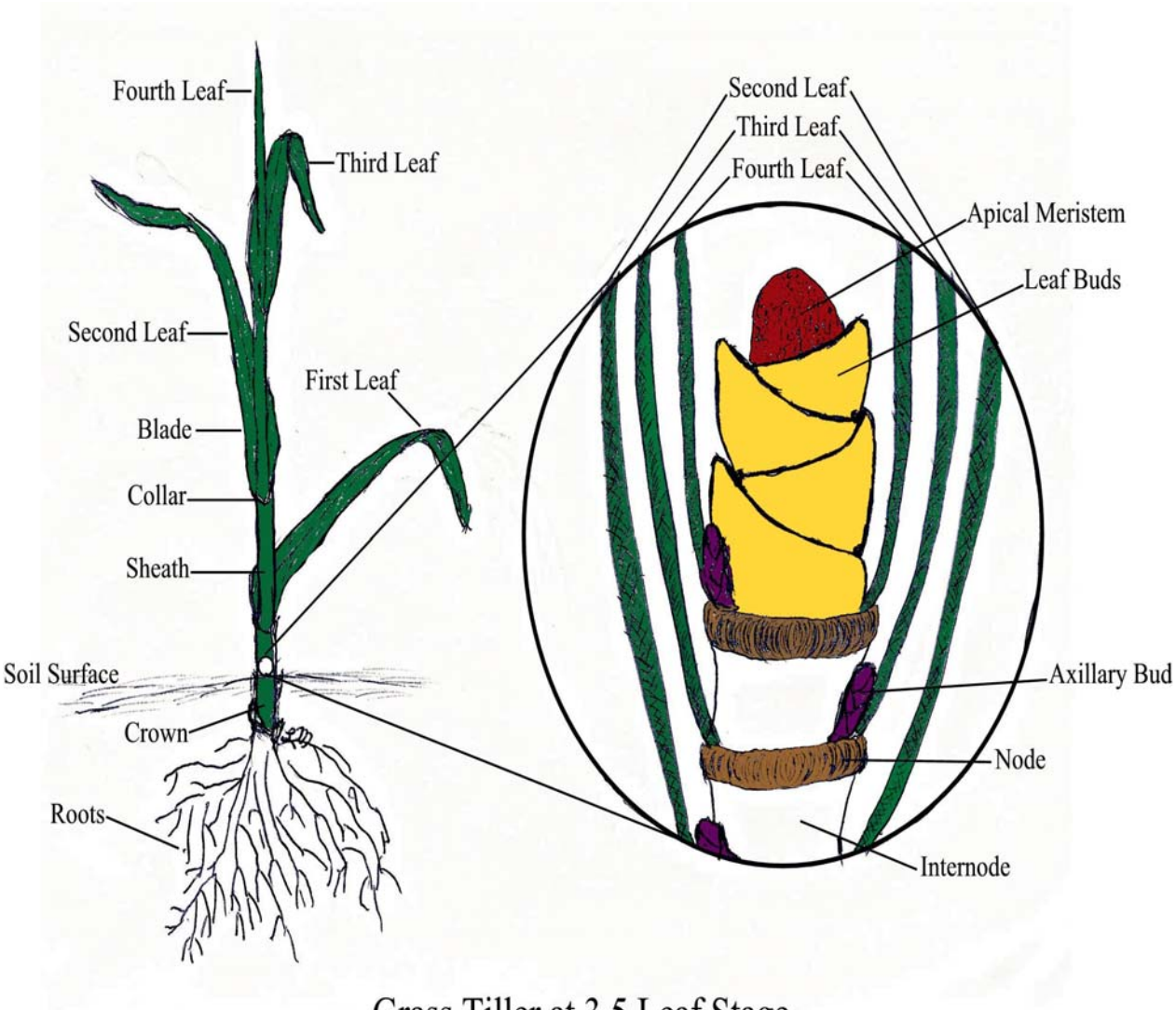
Properly managed prairie can provide a multitude of uses. Rangelands and grasslands provide forage for livestock, habitat for wildlife and plants, clean air, clean water, open spaces for recreation and sightseeing, and food, fiber, and energy for people. The unique attribute of healthy prairie ecosystems is that they can provide all these benefits simultaneously. However, if management practices are designed to enhance only a single use, a healthy, productive prairie ecosystem will not be maintained over time. Prairie ecosystem health and productivity can be sustained only when grass plant requirements and biological processes are given the highest priority in management strategies.

The key factor in meeting grass plant biological requirements is the proper timing of defoliation. The effect of defoliation is not simply the removal of herbage from grass plants (Langer 1972): defoliation also changes physiological processes in all parts of the plant; alters the plant community microclimate by changing light transmission, moisture relations, and temperature; and changes the soil environment, thereby affecting soil organism activity. Grass plants have developed defoliation resistance mechanisms in response to grazing during the long period of coevolution with herbivores and from the evolutionary selective forces of fire and drought. Grass plants developed these biological processes 20 million years ago in areas outside the Northern Plains and in conjunction with early herbivores that are now extinct. The biological processes within prairie plants are old, but the prairie plant communities in the Northern Plains and the interactions that affect plant growth and development are relatively young. Grass plants migrated from numerous types of environments into the region by different mechanisms and at different times and rates (Manske 1994b). Plants initiated development of the current dynamic plant communities only about 5,000 years ago when the climate of the Northern Plains changed to conditions like those of the present, with cycles of wet and dry periods (Bluemle 1977, Bluemle 1991, Manske 1994b). Plants that have developed adaptive biological processes, or resistance mechanisms, and have maintained a niche in a prairie community have the ability to thrive in a grazed plant community. Therefore, defoliation by livestock can be used to sustain healthy native prairie ecosystems when grazing is applied at phenological growth stages during which resistance mechanisms that beneficially manipulate grass growth and development can be stimulated.

Grass Leaf Development

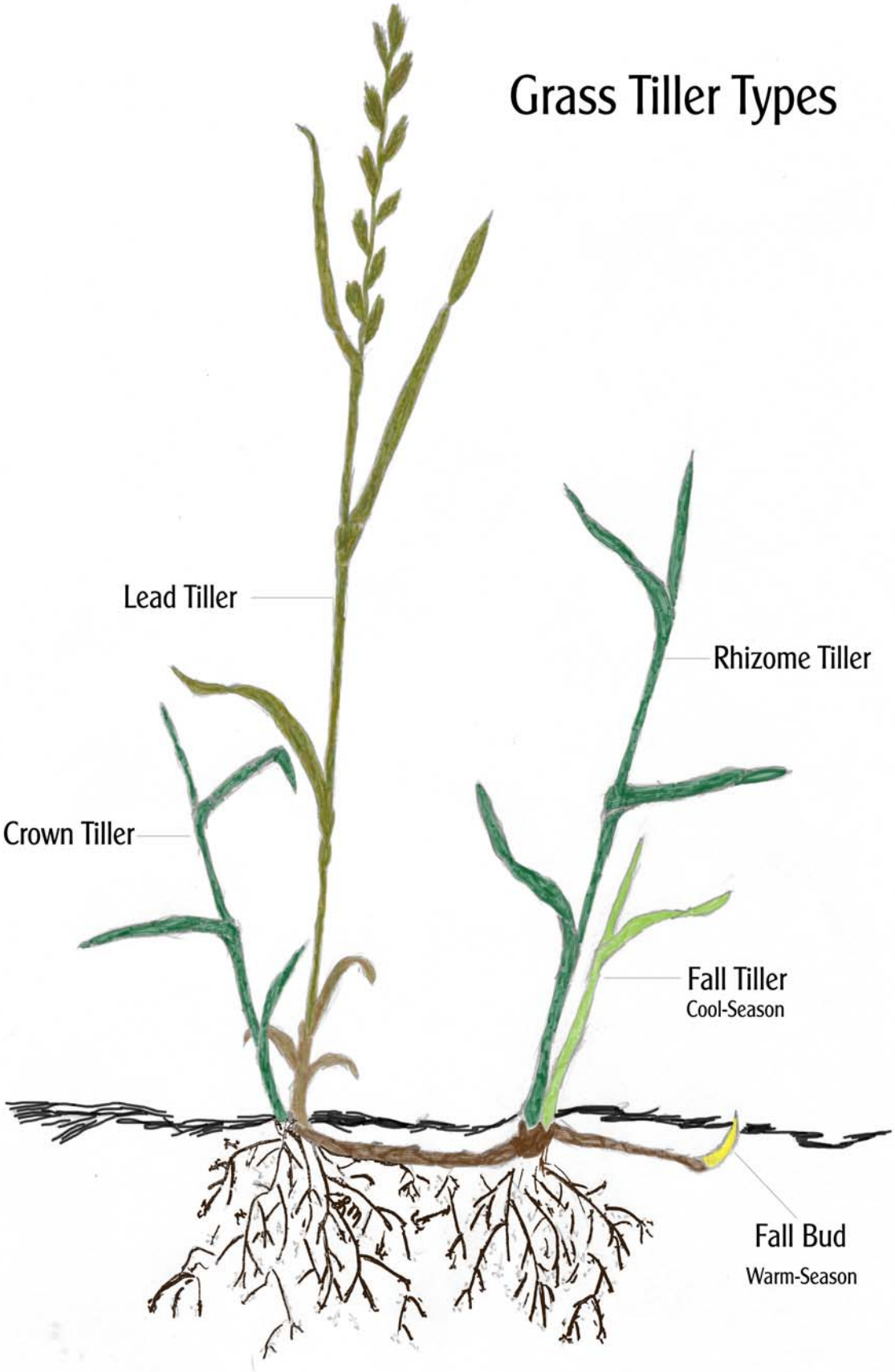
The grass shoot is made up of repeated structural units called phytomers (Beard 1973, Dahl 1995), each comprising four parts: 1) a leaf, consisting of a blade and sheath, with a collar separating the two structures; 2) a node, the location of leaf attachment to the stem; 3) an internode, the length of stem between two successive nodes; and 4) an axillary bud, the concentration of meristematic tissue capable of developing into a tiller (Hyder 1974, Dahl and Hyder 1977). Meristematic tissue is a collection of undifferentiated cells concentrated in growth point areas called meristem. A shoot generally has five or six phytomers but may have seven or more. Collectively the nodes and internodes of the phytomers are called the stem. The vegetative stem consists of a few to several nodes and unelongated internodes, with the apical meristem located at the highest node, at the top of the stem (Langer 1972). The crown of a grass plant is the lower portion of a shoot and has two or more nodes (Dahl 1995).

Young grass leaves develop from leaf bud primordia produced in the apical meristem. Almost all cells of the leaf are formed while the leaf is a minute bud (Langer 1972). Growth of the leaf results from expansion in cell size (Esau 1960, Dahl 1995) and increase in weight (Coyne et al. 1995). The new growing leaf draws carbohydrates from roots, stems, or older leaves until its maintenance and growth requirements can be met by assimilates produced by the new leaves (Langer 1972, Coyne et al. 1995). When the tiller is between the 3.0- and 3.5-leaf stage, the apical meristem ceases to produce leaf bud primordia and begins to produce flower bud primordia (Frank 1996, Frank et al. 1997). The previously formed leaf bud primordia continue to grow and develop (Esau 1960, Langer 1972), with the oldest cells at the tip (Langer 1972, Dahl 1995) and the oldest leaf outermost (Rechenthin 1956, Beard 1973). Defoliation of leaf material before the tiller has reached the third-leaf stage has the potential to



Grass Tiller at 3.5 Leaf Stage

Grass Tiller Types



disrupt the formation of leaf bud primordia for the tiller. However, defoliation of the tiller after the third-leaf stage functions beneficially, stimulating resistance mechanisms. In the Northern Plains, most native cool-season grasses reach the third-leaf stage around early June, and most native warm-season grasses reach the third-leaf stage around mid June. Many domesticated cool-season grasses reach the third-leaf stage around late April and early to mid May.

Defoliation Resistance Mechanisms

Defoliation resistance mechanisms are described in two categories. External mechanisms involve herbivore-induced environmental modifications (Briske and Richards 1995). Internal mechanisms are associated with herbivore-induced physiological processes (McNaughton 1979, McNaughton 1983) and are divided into two subcategories: tolerance mechanisms and avoidance mechanisms (Briske 1991). Defoliation tolerance mechanisms facilitate growth following grazing and include both increased activity within the plant meristem and compensatory physiological processes (Briske 1991). Defoliation avoidance mechanisms reduce the probability and severity of grazing and include the modification of anatomy and growth form. Grazing resistance in grass is maximized when the cost of resistance approximates the benefits. Plants do not become completely resistant to herbivores because the cost of resistance at some point exceeds the benefits derived from the resistance mechanisms (Pimentel 1988).

Internal Tolerance Mechanisms

Defoliation removes leaf area, immediately disrupting plant growth and photosynthesis. Defoliation by large herbivores triggers internal tolerance mechanisms that become engaged immediately following foliage removal and occur over a period of several days. The resulting increases in allocation of carbon and nitrogen, leaf photosynthetic capacity, and stimulated tiller development enable defoliated plants to compensate for foliage losses.

Carbon and nitrogen are necessary to many physiological processes within the plant. When a plant is defoliated, carbon and nitrogen levels decrease because the processes through which the plant normally acquires these elements are affected (Coyne et al. 1995). Carbon and nitrogen are then allocated from alternative sources to maintain the physiological functions of the plant. The compensatory growth process requires greater amounts of carbon and nitrogen. The carbon that may be utilized for compensatory shoot growth comes not from the roots but from the remaining leaf tissue, stems, and rhizomes and from alternative substrates, including hemicellulose, proteins, and organic acids (Richards and Caldwell 1985, Briske and Richards 1995). Current photosynthetic carbon from the remaining shoot is preferentially allocated to areas of active shoot meristematic tissue (Ryle and Powell 1975, Richards and Caldwell 1985, Briske and Richards 1995). Following defoliation, carbon allocation from undefoliated tillers to defoliated tillers increases until the defoliated tillers reestablish their own photosynthetic capacity (Welker et al. 1985, Briske and Richards 1995). Most of the nitrogen remobilized to support shoot growth following defoliation is allocated from remaining shoot tissue; a smaller portion is allocated from the root system (Briske and Richards 1995).

Defoliated plants increase photosynthetic rates of remaining foliage (Briske and Richards 1995). This compensatory photosynthesis can be induced by modifications of physiological functions and by changes in light intensity and quality that result from grazing modifications to the microhabitat (Briske and Richards 1995). Through these changes, the photosynthetic apparatus is rejuvenated, the rate of leaf senescence is inhibited or reduced, and the life span of the leaf is increased (Briske and Richards 1995). Remaining mature leaves on defoliated plants frequently develop increased leaf mass per unit area within one to fourteen days after defoliation (Briske and Richards 1995). Leaves exhibiting compensatory photosynthesis after defoliation may have higher rates of dark respiration, a characteristic which is exhibited by leaves with higher protein content (Atkinson 1986) and which therefore suggests that foliage at the same growth stage is higher in protein content and nutritional quality on defoliated plants than on undefoliated plants.

The growth rate of replacement leaves and shoots increases following defoliation. Expanding leaves tend to grow longer on defoliated plants than on undefoliated plants (Langer 1972), and the photosynthetic rate of the regrowth leaves is higher than that of same-age foliage on undefoliated plants (Briske and Richards 1995). Enhanced leaf and tiller growth rates usually persist for only a few weeks following defoliation and are not consistently expressed in all environmental conditions or phenological stages within the growing season.

Partial defoliation of young grass leaf material at the appropriate phenological growth stages can stimulate tillering by reducing the

influence of apical dominance, the physiological process by which the apical meristem of a lead tiller exerts hormonal control over the growth of axillary buds and inhibits axillary buds from developing into tillers (Briske and Richards 1994, Briske and Richards 1995). Partial defoliation of the lead tiller at an early phenological growth stage reduces the hormonal effects of apical dominance asserted by that tiller and allows some secondary tillers to develop from the previous year's axillary buds. Without defoliation manipulation, secondary tillers can develop after the lead tiller has reached flowering phenophase, but usually only one secondary tiller develops from the potential of five to eight buds because this secondary tiller asserts apical dominance and hormonally suppresses additional axillary bud development. When the lead tiller is partially defoliated at an early phenological growth stage, several axillary buds can develop subsequently into secondary tillers. Apparently, no single secondary tiller is capable of developing complete hormonal apical dominance following early partial defoliation of the lead tiller. Defoliation that removes the apical meristem, previously the only process known to influence apical dominance, has been shown to increase tillering in several warm-season grasses and some cool-season grasses (Richards et al. 1988, Murphy and Briske 1992) and not to stimulate tillering in some other cool-season grasses (Branson 1956, Richards et al. 1988).

Stimulation of tillering by defoliation is not consistent throughout the growing season and varies with stage of phenological development, environmental condition, and frequency and intensity of defoliation. Influence of the physiological stage of plant development at the time of defoliation is not completely understood; however, some studies have reported effects of defoliation at several phenological stages. Defoliation during early spring, before plants have reached the third-leaf stage, exerts a negligible stimulatory effect on tillering (Olson and Richards 1988, Vogel and Bjugstad 1968) and negatively affects potential peak herbage biomass production (Campbell 1952, Rogler et al. 1962, Manske 1994c). In some grasses, defoliation during later vegetative growth promotes tiller recruitment to a greater extent than does defoliation during any other phenological stage (Briske and Richards 1995). Defoliation during stem elongation but prior to the emergence of the inflorescence stimulates tillering in several grass species (Olson and Richards 1988). Some warm-season grasses are stimulated to tiller by defoliation applied at the inflorescence emergence stage (Vogel and Bjugstad 1968). Defoliation alters the timing or seasonality of tiller recruitment. Severe fall or winter defoliation has the potential to reduce grass density and production greatly the following year because late-stimulated tillers remain viable over the winter and cool-season species initiate tillers the previous fall. Defoliation of these tillers reduces their contribution to the ecosystem the following summer.

Tiller development decreases with increasing frequency and intensity of defoliation. Low levels of grazing also reduce tiller densities by decreasing tiller development and increasing tiller mortality through shading (Grant et al. 1983). Grazing decreases individual plant basal area and increases total plant density of some native bunch grass populations (Butler and Briske 1988). However, severe grazing may reduce total basal area and tiller numbers (Olson and Richards 1988). The optimal defoliation intensity varies with species, stage of phenological development, and associated environmental conditions (Langer 1963). Partial defoliation of lead tillers between the third-leaf stage and flowering can beneficially stimulate vegetative reproduction through an increase in tiller development from axillary buds.

Internal Avoidance Mechanisms

Internal avoidance mechanisms reduce plant tissue accessibility to herbivores by changing the morphology of a plant, producing secondary compounds for chemical defense, and depositing mineral silica in epidermal cells. Grass plants exhibit two strategies of stem elongation: short shoots and long shoots. In plants with short shoots, the apical meristem remains below cutting or grazing height during vegetative growth, continuing to produce new leaves until the stem enters the reproductive phase and the flower stalk elongates (Dahl 1995). In plants with long shoots, the apical meristem is elevated while the tiller is still in the vegetative phase (Dahl 1995). Both heavy grazing and frequent mowing can exert selective pressure on grass plant morphology, causing forms to change and plants to grow low and close to the ground. This genetically based change in growth form can occur in less than 25 years (Briske and Anderson 1992). The grazing-induced growth forms are characterized by a large number of small tillers with reduced leaf numbers and blade area (Briske and Richards 1995). This growth form is better able to avoid grazing because less biomass is removed and a greater number of meristem remain to facilitate growth. Many grass species with long shoots are stimulated to increase tiller production by moderate defoliation prior to flowering (Richards et al. 1988). Plants with long shoots are nearly always decreased in pastures that are heavily grazed continuously (Branson 1953).

External Resistance Mechanisms

External mechanisms contribute to compensatory grass growth following defoliation. In ungrazed areas, shading from upper leaves reduces the intensity of light reaching the lower leaves and causes a change in growth form. Grass leaves become long and thin, and lower in weight. Shading also causes reduced root growth (Langer 1972). Grazing removes some aboveground herbage and increases the amount of solar radiation that reaches remaining tissue. Defoliation improves plant water status as the result of a higher root-shoot ratio and reduced transpiration surface. The higher root-shoot ratio also results in increased nutrient supply to remaining tissue.

An important external resistance mechanism stimulated by defoliation of grassland plants is manipulation of the activity of symbiotic soil organisms within the rhizosphere, the narrow zone of soil surrounding the living roots of perennial grassland plants (Manske 1996a). The exudation of organic substances from grass plant roots affects microorganism activity (Curl and Truelove 1986, Whipps 1990, Campbell and Greaves 1990). Under conditions with no defoliation, rhizosphere microorganisms are limited by access to simple carbon chains (Curl and Truelove 1986). At early phenological growth stages, defoliation stimulates the roots of the grass plant to exude carbon into the rhizosphere. The elevated carbon level leads to increased activity of the soil microorganisms (Elliott 1978, Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990) and to the acceleration of the overall nutrient cycling process (Coleman et al. 1983), thereby increasing the amount of nitrogen available for plant growth (Ingham et al. 1985a, Ingham et al. 1985b, Clarholm 1985, Allen and Allen 1990). Defoliation during the middle and late portions of the grazing season produces less beneficial results in the rhizosphere. During this period, when grass plants have entered the middle and late phenological stages, defoliation stimulates the release of very little or no carbon into the rhizosphere. Moreover, the general decreases in soil water level typical of this time also limit rhizosphere organism activity (Curl and Truelove 1986, Bazin et al. 1990).

Stimulation of Resistance Mechanisms

The 3.0- to 3.5-leaf phenological growth stage is the best indicator of grass plant grazing readiness. Grazing grass plants prior to the third-leaf stage negatively affects grass growth. Starting grazing after the third-leaf stage allows plants to establish sufficient leaf area to produce adequate photosynthetic assimilate to meet leaf growth requirements and allows leaf bud primordia in the apical meristem to develop completely.

Partial defoliation between the third-leaf stage and flowering phenophase stimulates defoliation resistance mechanisms. The two mechanisms of primary concern to grassland managers are vegetative reproduction by secondary tiller development from axillary buds and increased symbiotic soil organism activity in the rhizosphere. Little evidence has been found to suggest that defoliation at other stages has beneficial stimulatory effects on grass growth.

Along with properly timed defoliation, periods with no defoliation should be provided to allow defoliated plants to complete the entire resistance mechanism process before successive defoliation events are permitted. Because the carbon and most of the nitrogen for recovery from defoliation are allocated not from the roots but from remaining shoot tissue, each defoliation event should be regulated to ensure that plants retain sufficient leaf surface to provide adequate assimilates for regrowth. Grass plants subjected to continuous severe defoliation do not completely recover and cannot produce at their potential levels.

Grazing before Third-Leaf Stage

Cool-season grasses initiate lead tiller growth during the fall and resume active growth the next spring. Spring growth of cool-season grass leaves depends both on carbohydrate reserves and on photosynthetic products from the portions of fall-initiated tiller leaves that have overwintered and regreened. Spring growth of warm-season grass leaves depends initially on carbohydrate reserves and later both on carbohydrate reserves and on photosynthetic product from young leaves. Grass plant growth and development depend on adequate carbohydrate reserves in early spring because the amount of photosynthetic product synthesized by early growing leaves is insufficient to meet the requirements for leaf growth (Heady 1975, Coyne et al. 1995). Grass growth also requires that the plant have adequate leaf area to provide photosynthetic product for early growing leaves. The total nonstructural carbohydrates of a grass plant are at low levels following the reduction of reserves during the winter respiration period, and the carbohydrate reserves remaining in the roots and stems are needed for both root growth and initial leaf growth during early spring. The low quantity of reserve carbohydrates may not be adequate to supply the entire amount required to support root growth and

also support leaf growth until sufficient leaf area is produced to provide the photosynthetic assimilates required for plant growth and other processes (Coyne et al. 1995). Removal of aboveground material deprives plants of foliage needed for photosynthesis and increases the demand upon already low levels of carbohydrate reserves when sequential leaves grow. The quantity of herbage produced by a grass plant after it has been grazed is dependent on the levels of carbohydrates present in the remaining herbage at the time of defoliation (Coyne et al. 1995). Defoliation of the tiller before the third-leaf stage, when the plant is low in carbohydrates, results in reduced growth rates of herbage production (Coyne et al. 1995) and negatively affects peak herbage biomass production later in the year (Manske 1994c).

Grazing after Third-Leaf Stage

Defoliation of leaf material after the third-leaf stage affects herbage biomass production in relation to the amount of leaf material removed. The amount of leaf area remaining after defoliation and capable of conducting photosynthesis is an important factor affecting the quantity of herbage produced by grazed grass plants. Replacement of leaf tissue from current assimilates has a lower cost to the plant than growth from stored carbohydrates and results in higher growth rates and increased production of herbage biomass (Coyne et al. 1995). Plants with sufficient leaf area remaining after defoliation utilize some stored carbohydrates for development of new leaf tissue (Briske and Richards 1995, Coyne et al. 1995), but the source of carbohydrates for most new growth is current photosynthates, which are preferentially allocated to areas of active shoot growth (Richards and Caldwell 1985, Briske and Richards 1995). Severely defoliated plants depend upon stored carbohydrates for new plant growth (Briske and Richards 1995), and dependence on stored carbohydrate for replacement of the photosynthetic system occurs at an additional cost to the plant. This implied reduction in efficiency results in low growth rates and reduced production of herbage biomass (Coyne et al. 1995). Additional restrictions inhibit herbage production when the stored carbohydrates are at low levels (Coyne et al. 1995).

Defoliation after the third-leaf stage stimulates vegetative reproduction from axillary buds by reducing apical dominance (Manske 1998). Partial defoliation of grass plants between the third-leaf and flowering stages stimulates growth of secondary tillers and stimulates rhizosphere organism activity (Manske 1998). The presence of higher levels of carbohydrate reserves before defoliation increases the number of stimulated tillers that grow (Coyne et al. 1995), and the resulting development of secondary tillers increases herbage biomass. Rate of growth of secondary tillers is variable depending on the growing-season period during which axillary bud growth is stimulated. Early stimulated secondary tillers require less time to reach the third-leaf stage than do late-stimulated tillers. Grazing periods should be synchronized with the growth rate of the stimulated secondary tillers so that defoliation is applied only after they reach the third-leaf stage.

Grazing during Late Season

In the fall, cool-season grass species initiate lead tillers that overwinter. The following spring, the tiller leaf cells with intact cell walls regreen, resume active growth, and provide photosynthetic product for new leaf growth (Briske and Richards 1995, Manske 1998). Late-stimulated secondary tillers that start development during late June or early July usually do not produce flower heads and also frequently overwinter, resuming active growth the subsequent growing season (Briske and Richards 1995, Manske 1998). Therefore, secondary tillers should be allowed to reach the third-leaf stage before they are grazed. Late-stimulated secondary tillers and fall-initiated lead tillers should be managed in the fall so that they retain adequate leaf material to produce sufficient carbohydrate reserves. Selective severe fall and winter defoliation of late-stimulated secondary tillers and cool-season fall-initiated lead tillers reduces their contribution to the ecosystem and results in greatly reduced grass density and herbage production the following year (Manske 1998) because with late-season defoliation, plants are unable to replenish sufficient reserve carbohydrates to support active growth (Coyne et al. 1995).

Deferred Grazing after Seed Development

The concept of deferring the start of grazing on a pasture until after seed production was developed shortly after 1900. The intended goal was to increase grass density by promoting seedling development from increased seed stalk development and using trampling of the livestock to scatter and plant the resulting seeds. However, Sarvis (1941) was not able to determine any benefit from reseeding of the grasses after 23 years of grazing treatment on a three-pasture, once-over, deferred rotation system. Through three years of research Manske et al. (1988a) found that after only one year, the total basal cover and the basal cover of warm-season grasses showed significant negative effects from the three-pasture, once-over, deferred treatments compared to ungrazed treatments. The basal cover of cool-season

grasses and upland sedges showed trends of reductions after one year of deferred treatments. Kentucky bluegrass showed a trend of increased basal cover on the deferred treatments.

Plant populations persist through both asexual reproduction and sexual reproduction (Briske and Richards 1995). Sexual reproduction is necessary for a population to maintain genetic diversity to withstand large-scale changes (Briske and Richards 1995). However, production of viable seed each year is not necessary for perpetuation of a healthy grassland. Reproductive shoots are adapted for seed production rather than for tolerance to defoliation (Hyder 1972). Grass species that produce a high proportion of reproductive shoots are less resistant to grazing than are those species in which a high proportion of shoots remain vegetative (Branson 1953). The frequency of true seedlings is low in functioning grasslands, and establishment of seedlings occurs only during years with favorable moisture and temperature conditions (Wilson and Briske 1979, Briske and Richards 1995), in areas of reduced competition from older tillers, and when resources are readily available to the growing seedling. Vegetative growth is the dominant form of reproduction in semiarid and mesic grasslands (Belsky 1992, Chapman and Peat 1992, Chapman 1996), including the tallgrass, midgrass, and shortgrass prairies of North America (Briske and Richards 1995).

Since seedlings contribute very little to plant production, defoliation management designed to enhance sexual reproduction through seed production, like the deferred grazing system or full season rest system, does not improve the prairie ecosystem. The energy and resources used in seed production could be manipulated into vegetative tiller production through more effective grazing management.

Short-Term Severe Defoliation

Short-term severe defoliation results from practices that remove a high proportion of leaf material during a relatively short period (one to a few days). Such practices include fire, flash grazing, or mowing close to the ground. If the plants are healthy and have relatively high levels of stored carbohydrates, prairie ecosystems can tolerate periodic short-term severe defoliation events. The interval between short-term severe defoliation events and the seasonal periods during which they are effective require additional research. Current guidelines for determining the seasonal periods and the interval between severe defoliation events are based on interpretation of historical information. The interval between short-term severe defoliation events was extrapolated from the fire return interval, which is 3 to 4 years for tallgrass prairie, 5 to 10 years for moist mixed grass prairie, and up to 25 years for dry mixed grass prairie (Wright and Bailey 1982, Bragg 1995). The seasonal period when short-term severe defoliation occurred was interpreted from historical grassland fire information about Indian- and lightning-set fires (Higgins 1986). The Indian-set fires occurred primarily during two periods, March through May, with a peak in April, and July through early November, with a peak in October; the probable practice was burning the mixed grass prairie in late summer and fall and the tallgrass prairie in spring. Lightning-set fires occurred during summer and early fall, with 73% occurring in July and August.

Healthy vigorous plants will be able to recover from short-term severe defoliation in a relatively short period, one to a few years. Severely defoliated plants have little or no leaf area capable of conducting photosynthesis and will depend on stored carbohydrates for new growth, an inefficient process that results in reduced herbage production. Some plants that are not vigorous will undergo greater stress from severe defoliation and require several years to recover. The additional stress from severe defoliation will cause serious damage from which plants previously stressed by small leaf area, low carbohydrate reserves, and/or water stress may not recover.

Mowing close to the ground is short-term severe defoliation because a high proportion of the leaf area is removed. Mowing height, however, can be adjusted. The severity of mowing decreases when a greater amount of leaf area remains after defoliation. Mowing at a moderate height that leaves adequate leaf area capable of conducting photosynthesis and that is performed during the period between the third-leaf stage and flowering phenological growth stage can be used to stimulate resistance mechanisms.

Short-term severe defoliation can have beneficial effects. Conducted at a seasonal period when undesirable species are experiencing greater levels of stress than desirable species, the practice can selectively modify plant species composition. Management practices that result in short-term severe defoliation can also be used in grassland ecosystems to alleviate the ecological problems of slowed nutrient cycling processes and inhibited herbage production that are caused by excessive litter accumulation. Even though short-term severe defoliation practices can increase nutrient cycling, it

is doubtful that healthy prairie ecosystems can be sustained over time with only short-term severe defoliation management. Severe defoliation stresses plants by draining carbohydrate reserves; even healthy plants require a few to several years to recover from this practice. Consequently, grassland ecosystems without excess accumulated litter are not benefited ecologically from short-term severe defoliation practices.

Long-Term Severe Defoliation

Long-term severe defoliation is continued heavy defoliation that exceeds the recovery capacity of the plants. Prolonged severe defoliation that results in biological damage to plants is technically overgrazing. Overgrazing reduces the total leaf area and photosynthetic capacity so that the affected grassland has reduced potential herbage yield, reduced plant root systems, distorted plant growth patterns with decumbent forms, delayed growth response, and reduced plant vigor causing death to some plants and resulting in a shift in plant species composition to a deteriorated range condition. When these conditions start to occur, a change in management practices is in order. These problems could result from excessively high stocking rates, but they also could result from defoliation during periods that plants are at or near stressful stages of development; from defoliation that is too severe and removes too much leaf area, forcing plants to use the limited stored carbohydrates for new growth; or from defoliation too frequent to allow plants adequate recovery time between defoliation events.

Application of the term “overgrazed” to pasture conditions that may be below an arbitrary critical standard but that have not been damaged biologically is incorrect. The assumption that overgrazing is caused only by overstocking is also incorrect. The term “overgrazed” correctly refers to the status of the plants managed over a period of time with defoliation practices that have caused biological damage to those plants. Stocking rate may not be the cause of the problems. Proper stocking levels for a parcel of land are variable with different grazing systems. Grazing systems based on plant requirements and coordinated with plant phenological growth stages can be properly stocked at levels that would be considered overstocked on a given parcel of land managed with another type of grazing system.

Long-Term Non-Defoliation

Long-term non-defoliation (idle) management is a management choice that withholds defoliation from a grassland for a considerable length of time. Non-defoliation treatments increase the level of shading in a grassland ecosystem and thereby reduce the intensity of the light that reaches the leaves. Long-term ungrazed grass plants shift to erect growth forms with a small number of larger tillers because the shading from other plants reduces the light intensity reaching the lower leaves of an individual plant (Briske and Richards 1995). Grass leaves grown under shaded conditions become longer but narrower, thinner, (Langer 1972, Weier et al. 1974) and lower in weight (Langer 1972) than leaves in sunlight. Shaded leaves have a reduced rate of photosynthesis, which decreases the carbohydrate supply and causes a reduction in growth rate of leaves and roots (Langer 1972). Root growth is reduced because roots are very sensitive to reductions in light intensity reaching the leaves. Shading increases the rate of senescence in the lower older leaves.

Decomposition of leaf material through microbial activity can take place only after the leaves have made contact with the soil. Standing dead material not in contact with the soil does not decompose but breaks down slowly as a result of leaching and weathering. Accumulation of standing dead leaves reduces availability of carbon and nitrogen. Under ungrazed treatments dead leaves remain standing for several years. Increased mulch biomass resulting from long-term non-defoliation (Brand and Goetz 1986, Manske 1995d) negatively affects the soil. Excessive mulch reduces water infiltration and early season soil temperatures, causing reduced soil bacterial activity in the top 12 inches of soil. Excess mulch accumulation also causes conditions that decrease mycorrhizal fungi and rhizosphere organism activity, slow nutrient cycles, and reduce available nutrients. Standing dead leaves shade early leaf growth in spring, slowing the rate of growth, reducing the leaf area, and causing a reduction in the net primary productivity. Long-term effects of shading in ungrazed grasslands include reduced total plant densities and native grass species composition (Manske 1995d) and increased composition of shade-tolerant or shade-adapted replacement species like smooth bromegrass and Kentucky bluegrass.

Management Implications

Defoliation by herbivores has the greatest beneficial effect if planned to stimulate two mechanisms: vegetative tillering from axillary buds and activity of symbiotic soil organisms. The phenological growth stages during which these two mechanisms can be manipulated are the same, between the third-leaf stage and flowering phenophase.

The twice-over rotation system was developed for use in the Northern Plains and was designed to manipulate processes that result in beneficial changes to the prairie ecosystem. The twice-over rotation system on native rangeland with complementary domesticated grass spring and fall pastures coordinates defoliation with grass phenological growth stages to maximize vegetation and animal performance. In the twice-over rotation system, a spring pasture of crested wheatgrass or other early growing domesticated cool-season grass is grazed during the month of May. A three- or four-pasture native range rotation system is used from early June until mid October, with each pasture grazed for two periods. The first period occurs during the 45 days when grasses are between the third-leaf stage and flowering and can be stimulated to tiller, 1 June to 15 July. During this first period, each pasture is grazed for 15 days on a three-pasture system or for 11 days on a four-pasture system. During the second period, after mid July and before mid October, each pasture is grazed again for 30 days on a three-pasture system or for 22 days on a four-pasture system. A fall pasture of Altai wildrye or other type of wildrye is grazed by cows and calves from mid October until weaning in early or mid November.

The twice-over rotation grazing management system with complementary domesticated grass pastures has a grazing season of over 6.5 months, with the available forage above, at, or only slightly below the requirements for a lactating cow for nearly the entire grazing season. This system requires fewer than 12 acres per cow-calf pair for the entire 6.5-month grazing season on grassland that when grazed for 6.0 months seasonlong requires 24 acres per cow-calf pair. The cow-calf weight performance on the twice-over rotation grazing system with complementary domesticated grass pastures is improved over the performance on other systems (Manske 1994a, Manske 1996b).

The twice-over rotation grazing management system applies defoliation treatment to grass plants at the appropriate phenological growth stages to stimulate the defoliation resistance mechanisms and the activity of the symbiotic rhizosphere microorganisms. This stimulation increases both secondary tiller development of grasses and nutrient flow in the rhizosphere, resulting in increased plant basal cover and aboveground herbage biomass and improved nutritional quality of forage. The increase in quantity and quality of herbage permits an increase in stocking rate levels, improves individual animal performance, increases total accumulated weight gain, reduces acreage required to carry a cow-calf pair for the season, improves net return per cow-calf pair, and improves net return per acre (Manske et al. 1984, Manske and Conlon 1986, Manske et al. 1988b, Manske 1994a, Biondini and Manske 1996, Manske 1996b, Manske and Sedivec 1999). The increase in basal cover and herbage biomass reduces the number and size of bare soil areas and increases the quantity of residual vegetation. These changes in vegetation produce conditions favorable to the limitation of grasshopper pest species populations (Manske 1995a, 1995b; Manske and Onsager 1997; Onsager 1998). The increase in plant density, herbage production, residual vegetation, and ecosystem health improves the habitat for prairie grouse, ducks, and other waterfowl and ground nesting birds (Manske and Barker 1981a, 1981b, 1988; Manske et al. 1988a; Sedivec et al. 1990, Manske 1995c). These beneficial effects of improved vegetation condition, livestock performance, wildlife habitat, and grasshopper control demonstrate the potential of the twice-over rotation grazing system for successful implementation in this region.

Acknowledgment

I am grateful to Amy M. Kraus and Naomi J. Thorson for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

Literature Cited

Allen, E.B., and M.F. Allen. 1990. The mediation of competition by mycorrhizae in successional and patchy environments. p. 307-389. *in* J.B. Grace and D. Tilman (eds.). Perspectives on plant competition. Academic Press Inc., San Diego, CA.

Anderson, R.V., D.C. Coleman, C.V. Cole, and E.T. Elliott. 1981. Effect of nematodes *Acrobeloides sp.* and *Mesodiploqaster lheritieri* on substrate utilization and nitrogen and phosphorus mineralization. Ecology 2:549-555.

Atkinson, C.J. 1986. The effect of clipping on net photosynthesis and dark respiration rates of plants from an upland grassland, with reference to carbon partitioning in *Festuca ovina*. Annals of Botany 58:61-72.

Bazin, M.J., P. Markham, E.M. Scott, and J.M. Lynch. 1990. Population dynamics and rhizosphere interactions. p. 99-127. *in* J.M. Lynch (ed.). The rhizosphere. John Wiley and Sons, New York, NY.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Belsky, A.J. 1992. Effects of grazing competition, disturbance and fire on species composition and diversity in grassland communities. Journal of Vegetation Science 3:187-200.

Biondini, M.E., and L.L. Manske. 1996. Grazing frequency and ecosystem processes in a northern mixed prairie, USA. Ecological Applications 6(1):239-256.

Bluemle, J.P. 1977. The face of North Dakota: the geologic story. North Dakota Geological Survey. Ed. Series 11. 73p.

Bluemle, J.P. 1991. The face of North Dakota: revised edition. North Dakota Geological Survey. Ed. Series 21. 177p.

Bragg, T.B. 1995. The physical environment of North American grasslands. *in* K. Keeler and A. Joern (eds.). The changing prairie. Oxford University Press, New York, NY.

Brand, M.D., and H. Goetz. 1986. Vegetation of exclosures in southwestern North Dakota. Journal of Range Management 39:434-437.

Branson, F.A. 1953. Two new factors affecting resistance of grasses to grazing. Journal of Range Management 6:165-171.

Branson, F.A. 1956. Quantitative effects of clipping treatments on five range grasses. Journal of Range Management 9:86-88.

Briske, D.D., and V.J. Anderson. 1992. Competitive ability of the bunchgrass *Schizachyrium scoparium* as affected by grazing history and defoliation. Vegetatio 103:41-49.

Briske, D.D., and J.H. Richards. 1994. Physiological responses of individual plants to grazing: current status and ecological significance. p. 147-176. *in* M. Vavra, W.A. Laycock, and R.D. Pieper (eds.). Ecological implications of livestock herbivory in the west. Society for Range Management, Denver, CO.

Briske, D.D., and J.H. Richards. 1995. Plant responses to defoliation: a physiological, morphological and demographic evaluation. p. 635-710. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Briske, D.D. 1991. Developmental morphology and physiology of grasses. p. 85-108. *in* R.K. Heitschmidt and J. W. Stuth (eds.). Grazing management: an ecological perspective. Timber Press, Portland, OR.

Butler, J.L., and D.D. Briske. 1988. Population structure and tiller demography of the bunch grass *Schizachyrium scoparium* in response to herbivory. Oikos 51:306-312.

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Campbell, R., and M.P. Greaves. 1990. Anatomy and community structure of the rhizosphere. p. 11-34. *in* J.M. Lynch (ed.). The rhizosphere. John Wiley and Sons, New York, NY.

Chapman, G.P., and W.E. Peat. 1992. An introduction to the grasses. C.A.B. International, Wallingford, UK. 111p.

Chapman, G.P. 1996. The biology of grasses. C.A.B. International, Wallingford, UK. 273p.

Clarholm, M. 1985. Interactions of bacteria, protozoa and plants leading to mineralization of soil nitrogen. Soil Biology and Biochemistry 17:181-187.

Coleman, C.D., C.P.P. Reid, and C.V. Cole. 1983. Biological strategies of nutrient cycling in soil ecosystems. Advances in Ecological Research 13:1-55.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Curl, E.A., and B. Truelove. 1986. The rhizosphere. Springer-Verlag, New York, NY.

Dahl, B.E., and D.N. Hyder. 1977. Developmental morphology and management implications. p. 257-290. *in* R.E. Sosebee (ed.). Rangeland plant physiology. Range Science Series No. 4. Society for Range Management, Denver, CO.

Dahl, B.E. 1995. Developmental morphology of plants. p. 22-58. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Elliot, E.T. 1978. Carbon, nitrogen and phosphorus transformations in gnotobiotic soil microcosms. M.S. Thesis, Department of Agronomy, Colorado State University, Ft. Collins, CO.

Esau, K. 1960. Anatomy of seed plants. Wiley and Sons, New York, NY.

Frank, A.B., J.D. Berdahl, and J.F. Karn. 1997. Phyllochron development in cool-season grasses. XVIII International Grassland Congress Poster.

Frank, A.B. 1996. Evaluating grass development for grazing management. Rangelands 18:106-109.

Grant, S.A., G.T. Barthram, L. Torvell, J. King, and H.K. Smith. 1983. Sward management, lamina turnover and tiller population density in continuously stocked *Lolium perenne*-dominated swards. Grass and Forage Science 38:333-344.

Heady, H.F. 1975. Rangeland management. McGraw-Hill Book Company, New York, NY.

Higgins, K.F. 1986. Interpretation and compendium of historical fire accounts in the Northern Great Plains. US Fish and Wildlife Service. Resource Publication 161. 39p.

Hyder, D.N. 1972. Defoliation in relation to vegetative growth. p. 302-317. *in* V.B. Youngner and C.M. McKell (eds.). The biology and utilization of grasses. Academic Press, New York, NY.

Hyder, D.N. 1974. Morphogenesis and management of perennial grasses in the U.S. p. 89-98. *in* Plant morphogenesis as the basis for scientific management for range resources. USDA Misc. Publ. 1271.

Ingham, R.E., D.A. Klein, and M.J. Trlica. 1985a. Response of microbial components of the rhizosphere to plant management strategies in semiarid rangelands. Plant and Soil 85:65-76.

Ingham, R.E., J.A. Trofymow, E.R. Ingham, and D.C. Coleman. 1985b. Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. Ecological Monographs 55:119-140.

Langer, R.H.M. 1963. Tillering in herbage grasses. Herbage Abstracts 33:141-148.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold, London, Great Britain. 60p.

Manske, L.L., and W.T. Barker. 1981a. Prairie chicken habitat use on the Sheyenne National Grasslands, North Dakota. Proc. North Dakota Academy of Science 35:2.

Manske, L.L., and W.T. Barker. 1981b. The prairie grouse on the Sheyenne National Grasslands, North Dakota. Research Report. NDSU. Fargo, ND. 238p.

Manske, L.L., and W.T. Barker. 1988. Habitat usage by prairie grouse on the Sheyenne National Grasslands. U.S.D.A. Forest Service. General Technical Report RM-159. p. 8-20.

Manske, L.L., W.T. Barker, and M.E. Biondini. 1988a. Effects of grazing management treatments on grassland plant communities and prairie grouse habitat. U.S.D.A. Forest Service. General Technical Report RM-159. p. 58-72.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988b. Cow and calf performance on seasonlong and twice over rotation grazing treatments in western North Dakota. Proceedings of the North Dakota Cow-Calf Conference. Bismarck, ND. p. 5-17.

Manske, L.L., and T.J. Conlon. 1986. Complementary rotation grazing system in western North Dakota. North Dakota Farm Research 44:6-10.

Manske, L.L., J.L. Nelson, P.E. Nyren, D.G. Landblom, and T.J. Conlon. 1984. Complementary grazing system, 1978-1982. p. 37-50. *in* Proceedings North Dakota Chapter of the Society for Range Management, 1983. Dickinson, ND.

Manske, L.L., and J.A. Onsager. 1997. Cultural management practices as tools to help reduce grasshopper populations. Proceedings of the National Grasshopper Management Board 1997 Annual Meeting. Rapid City, SD. p. 10-11.

Manske, L.L., and K.K. Sedivec. 1999. Early grazing strategies. North Dakota State University Extension Service. Circular R-1167.

Manske, L.L. 1994a. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program, Regina, Saskatchewan, Canada.

Manske, L.L. 1994b. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings-Leafy Spurge Strategic Planning Workshop. USDI National Park Service, Dickinson, ND. p. 3-16.

Manske, L.L. 1994c. Problems to consider when implementing grazing management practices in the Northern Great Plains. NDSU Dickinson Research Extension Center. Range Management Report DREC 94-1005. Dickinson, ND. 11p.

Manske, L.L. 1995a. Modification to native range vegetation by grazing management to affect grasshopper populations, 1993-1994. NDSU Dickinson Research Extension Center. Range Research Report DREC 95-1006. Dickinson, ND. 12p.

Manske, L.L. 1995b. Modification to crested wheatgrass vegetation by grazing and mowing management to affect grasshopper populations, 1993-1994. NDSU Dickinson Research Extension Center. Range Research Report DREC 95-1007. Dickinson, ND. 8p.

Manske, L.L. 1995c. Habitat management for the prairie grouse on the Sheyenne National Grasslands. NDSU Dickinson Research Extension Center. Range Management Report DREC 95-1009. Dickinson, ND. 30p.

Manske, L.L. 1995d. Rangeland reference areas in western North Dakota. NDSU Dickinson Research Extension Center. Range Management Report DREC 95-1011. Dickinson, ND. 7p.

Manske, L.L. 1996a. Adaptive tolerance mechanisms in grass plants. p. 97-99. *in* Z. Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1996b. Economic returns as affected by grazing strategies. p. 43-55. *in* Z. Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1998. General description of grass growth and development and defoliation resistance mechanisms. NDSU Dickinson Research Extension Center. Range Management Report DREC 98-1022. Dickinson, ND. 12p.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. American Naturalist 113:691-703.

McNaughton, S.J. 1983. Compensatory plant growth as a response to herbivory. Oikos 40:329-336.

Murphy, J.S., and D.D. Briske. 1992. Regulation of tillering by apical dominance: chronology, interpretive value, and current perspectives. Journal of Range Management 45:419-429.

Olson, B.E., and J.H. Richards. 1988. Spatial arrangement of tiller replacement in *Agropyron desertorum* following grazing. Oecologia 76:7-10.

Onsager, J.A. 1998. Theoretical benefits of modifying grasshopper life history parameters. Proceedings of the 1998 Annual Meeting of the National Grasshopper Management Board, Denver, CO. p. 3-4.

Pimentel, D. 1988. Herbivore population feeding pressure on plant hosts: feedback evolution and host conservation. Oikos 53:289-302.

Rechenthin, C.A. 1956. Elementary morphology of grass growth and how it affects utilization. Journal of Range Management 9:167-170.

Richards, J.H., and M.M. Caldwell. 1985. Soluble carbohydrates, concurrent photosynthesis and efficiency in regrowth following defoliation: a field study with *Agropyron* species. Journal of Applied Ecology 22:907-920.

Richards, J.H., R.J. Mueller, and J.J. Mott. 1988. Tillering in tussock grasses in relation to defoliation and apical bud removal. Annals of Botany 62:173-179.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. North Dakota Agricultural Experiment Station. Bulletin 439. 15p.

Ryle, G.J., and C.E. Powell. 1975. Defoliation and regrowth in the graminaceous plant: the role of current assimilate. Annals of Botany 39:297-310.

Sarvis, J.T. 1941. Grazing investigations on the Northern Great Plains. North Dakota Agricultural Experiment Station. Bulletin 308. Fargo, ND. 110p.

Sedivec, K.K., T.A. Messmer, W.T. Barker, K.F. Higgins, and D.R. Hertel. 1990. Nesting success of upland nesting waterfowl and sharp-tailed grouse in specialized grazing systems in southcentral North Dakota. U.S.D.A. Forest Service. General Technical Report RM-194. p. 71-92.

Vogel, W.G., and A.J. Bjugstad. 1968. Effects of clipping on yield and tillering of little bluestem, big bluestem, and Indiangrass. Journal of Range Management 21:136-140.

Weier, T.E., C.R. Stocking, and M.G. Barbour. 1974. Botany: an introduction to plant biology. John Wiley and Sons, New York, NY.

Welker, J.M., E.J. Rykiel, Jr., D.D. Briske, and J.D. Goeschl. 1985. Carbon import among vegetative tillers within two bunchgrasses: assessment with carbon-11 labelling. Oecologia 67:209-212.

Whipps, J.M. 1990. Carbon economy. p. 59-97. *in* J.M. Lynch (ed.). The rhizosphere. John Wiley and Sons, New York, NY.

Wilson, A.M., and D.D. Briske. 1979. Seminal and adventitious root growth of blue grama seedlings on the central plains. Journal of Range Management 32:209-213.

Wright, H.A., and A.W. Bailey. 1982. Fire ecology. John Wiley and Sons, New York, NY. 501p.

Increasing Rhizosphere Fungi and Improving Soil Quality with Biologically Effective Grazing Management

Llewellyn L. Manske PhD[1] and TheCan Caesar-TonThat PhD[2]
[1]North Dakota State University, Dickinson Research Extension Center, Dickinson, ND
[2]United States Department of Agriculture, Agricultural Research Service, Sidney, MT

Abstract

This report compares the effects of grazing management strategies on livestock performance, herbage biomass, and rhizosphere fungal populations on Northern Plains native rangeland. Compared to traditional grazing management strategies, the biologically effective twice-over rotation grazing management strategy improves cow and calf weight performance, yields greater herbage biomass production, stimulates rhizosphere organism activity, and enhances activity levels of ectomycorrhizal fungi with the ability to aggregate and stabilize soil particles and improve soil quality.

Introduction

Biologically effective defoliation management places priorities on meeting grass plant biological requirements and enhancing beneficial ecological processes performed by soil microorganisms in grassland ecosystems. Grass plants, grazing mammals, and grassland ecosystem processes have evolved together. During the long period of coevolution, grass plants developed both internal and external biological processes as defoliation resistance mechanisms. A complex system of symbiotic organisms that has numerous trophic levels and is critical for ecosystem functions and for energy and nutrient flow through the ecosystem developed in conjunction with the evolution of plants. The relationships among the grass plants, the soil organisms in the rhizosphere, and the grazing mammals are not completely understood. The objective of this study was to help clarify these complex relationships by evaluating defoliation treatments for differences in 1) livestock performance, 2) herbage biomass production, and 3) rhizosphere microbial populations, including ectomycorrhizal fungi involved in aggregating and stabilizing soil.

Procedure

The study site is on the Dickinson Research Extension Center ranch, operated by North Dakota State University and located 20 miles north of Dickinson in southwestern North Dakota, U.S.A. (47°14'N.lat., 102°50'W.long.). Mean annual temperature is 42.2°F (5.7°C). Long-term annual precipitation is 16.57 inches (420.90 mm). The growing-season precipitation (April to October) is 14.04 inches (356.73 mm), 85.0% of the annual precipitation (Manske 2003a). The vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie.

Commercial crossbred cattle were weighed on and off each treatment and on each rotation date. Live-weight performance of weight gain per day and weight gain per acre for cows and calves was used to evaluate each treatment. Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986) on both grazed and ungrazed quadrats from April to November. Differences between means of livestock weights and differences between means of herbage weight were analyzed by a standard paired-plot t-test (Mosteller and Rourke 1973). Field samples of soil with plants and roots were collected on the grazing management treatments. The enzyme-linked immunosorbent assay (ELISA) technique (Caesar-TonThat et al. 2001a) was used on the water-stable rhizosphere soil to detect specific basidiomycete fungi. Results were statistically analyzed using ANOVA models.

Grazing Management Treatments

The grazing treatments and a nongrazed control were organized as a paired-plot design. The nongrazed control, 4.5-month twice-over rotation treatment, and 6.0-month seasonlong treatment had two replications. The 4.5-month seasonlong treatment had three replications. The long-term nongrazed treatments had not been grazed, mowed, or burned for more than 30 years prior to the start of data collection. The 4.5-month twice-over rotation (4.5 TOR) management treatment began in early June. The livestock followed a rotation sequence through three native rangeland pastures for 135 days, until mid October. Each pasture was grazed for two periods, one period of 15 days between 1 June and 15 July (from the third-leaf stage to anthesis phenophase), followed by a second period of 30 days after 15 July and prior to mid October. The first pasture grazed in the sequence was the last pasture grazed the previous year. The 4.5-month seasonlong (4.5 SL) management treatment began in early June, with livestock grazing one native rangeland pasture.

The livestock remained on this pasture for 135 days, until mid October. The 6.0-month seasonlong (6.0 SL) management treatment began in mid May, with grazing on one native rangeland pasture. The livestock remained on this pasture for 183 days, until mid November.

Results

Livestock weight performance was greatest on the twice-over rotation treatment (Manske et al. 1988, Manske 1996a, 2001, 2003b). Cow and calf weight gain per acre was significantly greater on the twice-over rotation treatment than on the seasonlong treatments. Cow weight gain per day on the twice-over rotation treatment was 82% greater than that on the 4.5-month seasonlong and 417% greater than that on the 6.0-month seasonlong treatments. Cow weight gain per acre on the twice-over rotation treatment was 157% greater than that on the 4.5-month seasonlong and 937% greater than that on the 6.0-month seasonlong treatments. Calf weight gain per day on the twice-over rotation treatment was 6% greater than that on the 4.5-month seasonlong and 23% greater than that on the 6.0-month seasonlong treatments. Calf weight gain per acre on the twice-over rotation treatment was 49% greater than that on the 4.5-month seasonlong and 115% greater than that on the 6.0-month seasonlong treatments.

Herbage biomass production was greatest on the twice-over rotation treatment (Manske 1994, 2003c). An average of 15% more herbage remained standing after each grazing period on the twice-over rotation treatment than the amount that grew on the long-term nongrazed treatment. The amount of herbage remaining standing after grazing during July, August, and September was significantly greater on the twice-over rotation treatment than on the seasonlong treatment. The seasonlong treatment averaged 8% less herbage standing after grazing than the nongrazed treatment and 29% less than the rotation treatment. The amount of herbage remaining standing at the end of the grazing season was significantly greater on the twice-over rotation treatment than the amount of herbage remaining on the nongrazed and seasonlong treatments. The measurements of the amount of herbage standing after each grazing period do not include the amount of vegetation removed by livestock during the grazing period.

Grassland ecosystem productivity is variable and depends on the degree of success of the mutually beneficial relationships among large herbivores, grass plants, and rhizosphere organisms. The rhizosphere is the narrow zone of soil surrounding living roots of perennial grassland plants where the symbiotic soil organisms--bacteria, protozoa, nematodes, mites, small insects, and fungi (primarily vesicular-arbuscular mycorrhizae)--interact as a complex trophic web that is critical for energy and nutrient flow in grassland ecosystems. Rhizosphere microorganism activity is affected by levels of root exudation. As the amount of root exudate increases, so do the biomass and the activity of beneficial rhizosphere organisms. Increases in carbon allocation from the crown and aboveground portions of the plant to roots of grasses under some grazing treatments result in an increase of carbon exuded from the grass plant roots compared to the amount exuded from the roots of ungrazed grasses (Holland et al. 1996). The amount of root exudate is higher on the twice-over rotation treatment, and this greater influx of carbon influences the quantity of fungi in the rhizosphere. As a result of the increased activity of rhizosphere fungi, grass plant rhizospheres are more robust and soil aggregates adhere more securely to root surfaces of grasses on the twice-over rotation treatment than on traditional grazing management treatments in the Northern Plains.

An immunological assay (ELISA) was developed for the detection and quantification of specific basidiomycete fungi that have the ability to aggregate and stabilize soil particles by forming water-stable aggregates in soil (Caesar-TonThat et al. 2000, 2001a). Water-stable rhizosphere soil samples collected during the field seasons of 1999 and 2000 were analyzed by the ELISA techniques. Absorbance readings (Caesar-TonThat et al. 2001b) for the detection of antigens in the rhizosphere soil of grasses from 3 soil layers of twice-over rotation and 6.0-month seasonlong grazing treatments indicated that in sandy soil and in silty soil layer 2, the amount of these fungi in the rhizosphere of grasses was significantly greater on the twice-over rotation treatment than on the seasonlong treatment, but a significant difference was not detected in layers 1 and 3 of the silty soil samples. The rhizosphere fungi detected during this study are ectomycorrhizal basidiomycete fungi from the Homobasidiomycete class and the Russuloid clade; they stabilize soil by forming water-stable soil aggregates near the rhizosphere of grasses (CaesarTonThat et al. 2001b).

Discussion

The twice-over rotation grazing management strategy on native rangeland was developed for the Northern Plains and designed to improve vegetation and livestock performances compared to those of traditional grazing management treatments (Manske et al. 1988, Manske 1999, 2001, 2003b). The

biologically effective twice-over rotation treatment coordinates defoliation periods with grass phenological growth stages in order to manipulate the defoliation resistance mechanisms developed by grass plants during the long period of coevolution with herbivores. Two mechanisms that can be manipulated by defoliation of grasses between the third-leaf stage and flowering phenophase stimulate both vegetative tillering from axillary buds and activity of symbiotic soil organisms in the rhizosphere (Manske 1999, 2000).

The increased livestock weight performance on the twice-over rotation system over that on the traditional grazing management treatments results from the greater herbage production on the biologically effective grazing management system (Manske et al. 1988, Manske 1996a, 2001, 2003b).

The higher plant biomass measured on the twice-over rotation treatment compared to that on seasonlong grazing treatments and the ungrazed control (Manske 1994, 2003c) may be attributed to the beneficial results of applying a defoliation treatment to grass plants that are between the third-leaf stage and the flowering stage. The timed grazing of the twice-over system allows plants to retain sufficient leaf surface to recover from defoliation. Grass plants subjected to continuous, severe defoliation on seasonlong treatments do not completely recover and cannot produce at their potential levels (Manske 1999, 2000). Long-term seasonlong grazing causes superficial root system development and reduced root biomass (Chaieb et al. 1996, McNaughton et al. 1983, Mawdsley and Bardgett 1997), resulting in reduced production of aboveground herbage biomass. Grazing plants that are between the third-leaf and the flowering stages not only improves grass plant health but also leads to herbage biomass increases through beneficial changes in grass plant growth. The photosynthetic rate of the regrowth leaves is higher than that of the same-age foliage on undefoliated plants (Briske and Richards 1995), and expanding leaves tend to grow longer on defoliated plants (Langer 1972). The timed defoliation of the twice-over rotation treatment also stimulates vegetative tillering from axillary buds.

The twice-over rotation treatment further enhances the growth of secondary tillers and of remaining foliage on defoliated tillers by increasing rhizosphere organism activity beneficial to grass plants. The stimulated organisms include rhizosphere fungi, which are primarily vesicular-arbuscular mycorrhizae (taxonomically in the class Phycomycetes and the family Endogonaceae) that form endomycorrhiza in which the vesicles, arbuscules, and hyphae of the fungus enter the cells and tissue of the host plant (Harley and Smith 1983). The symbiotic function of endomycorrhizal fungi in grassland plant rhizospheres is the nitrification of ammonia and the enhancement of plants' absorption of phosphorus, other mineral nutrients, and water (Moorman and Reeves 1979, Harley and Smith 1983, Allen and Allen 1990, Box and Hammond 1990, Marschner 1992, Manske 1996b).

The twice-over rotation system also strengthens grass plant growth and grassland ecosystem health by increasing activity of ectomycorrhizal fungi in the Homobasidiomycetes class and the Russuloid clade (Caesar-TonThat et al. 2001b). Rhizosphere fungi of this type form ectomycorrhizae; the hyphae do not enter tissue of the host plant but develop a sheath around the root (Harley and Smith 1983). Russuloid homobasidiomycete ectomycorrhizal fungi form water-stable aggregates in soil and stabilize soil particles around the rhizosphere by excreting large amounts of insoluble extracellular polysaccharides that have adhesive qualities. These substances can act as binding agents of soil particles, causing aggregation of soil around fungal structures (Caesar-TonThat 2002). Increases in soil aggregation and stabilization are an indication of soil quality improvement that causes increases in soil oxygenation, increases in water infiltration, and decreases in erodibility (Caesar-TonThat et al. 2001a).

The detection of these fungi is an important scientific discovery. Finding ectomycorrhizal basidiomycete fungi in the rhizosphere of grass plants in the mixed grass prairie is unusual. Ectomycorrhizal fungi are slow growing and are limited almost exclusively to associations with woody plants. Very few herbaceous species are known to form ectomycorrhiza on their roots (Harley and Smith 1983). The factors and conditions that enhance the development of these ectomycorrhizal fungi in the rhizosphere of grass plants managed with the twice-over rotation grazing system are not completely understood. The capacity of this grazing management practice to enhance the activity levels of rhizosphere fungi with the ability to aggregate and stabilize soil particles and thereby improve the quality of soil in grassland ecosystems is of considerable significance for the development of biologically effective grazing management treatments.

Acknowledgment

The authors are grateful to Sheri Schneider for assistance in production of this manuscript and to Amy M. Kraus for assistance in preparation of this manuscript.

Literature Cited

Allen, E.B., and M.F. Allen. 1990. The mediation of competition by mycorrhizae in successional and patchy environments. p. 307-389. *in* J.B. Grace and D. Tilman (eds.). Perspectives on plant competition. Academic Press Inc., San Diego, CA.

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Box, J.E., and L.C. Hammond. 1990. Rhizosphere dynamics. Westview Press, Boulder, CO.

Briske, D.D., and J.H. Richards. 1995. Plant response to defoliation: a physiological, morphological and demographic evaluation. p. 635-710. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Caesar-TonThat, T.C., and V. Cochran. 2000. Soil aggregate stabilization by a saprophytic lignin-decomposing basidiomycete fungus. I. Microbiological aspects. Biology and Fertility of Soils 32:374-380.

Caesar-TonThat, T.C., W. Shelver, R.G. Thorn, and V.L. Cochran. 2001a. Generation of antibodies for soil-aggregating basidiomycete detection to determine soil quality. Applied Soil Ecology 18:99-116.

Caesar-TonThat, T.C., D.H. Branson, J.D. Reeder, and L.L. Manske. 2001b. Soil-aggregating basidiomycetes in the rhizosphere of grasses under two grazing management systems. Poster. American Society of Agronomy Annual Meeting. Charlotte, NC.

Caesar-TonThat, T.C. 2002. Soil binding properties of mucilage produced by a basidiomycete fungus in a model system. Mycological Research 106:930-937.

Chaieb, M., B. Henchi, and M. Boukhris. 1996. Impact of clipping of root systems of three grasses species in Tunisia. Journal of Range Management 49:336-339.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Harley, J.L., and S.E. Smith. 1983. Mycorrhizal symbiosis. Academic Press, New York, NY.

Holland, J.N., W. Cheng, and D.A. Crossley, Jr. 1996. Herbivore-induced changes in plant carbon allocation: assessment of below-ground C fluxes using carbon-14. Oecologia 107:87-94.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold Ltd., London, U.K.

Manske, L.L. 1994. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program, Regina, Saskatchewan, Canada.

Manske, L.L. 1996a. Economic returns as affected by grazing strategies. p. 43-55. *in Z.* Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1996b. Adaptive tolerance mechanisms in grass plants. p. 97-99. *in Z.* Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1999. Can native prairie be sustained under livestock grazing? p. 99-108. *in* J. Thorpe, T.A. Steeves, and M. Gollop (eds.). Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, Alberta.

Manske, L.L. 2000. Management of prairie in the Northern Great Plains based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 12p.

Manske, L.L. 2001. Biological effectiveness of grazing strategies. 2001 NDSU Beef Cattle Report. North Dakota State University. Fargo, ND. p. 37-42.

Manske, L.L. 2003a. Ombrothermic interpretation of range plant water deficiency from temperature and precipitation data collected at the Ranch Headquarters of the Dickinson Research Extension Center in western North Dakota, 1982-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1019f. Dickinson, ND. 17p.

Manske, L.L. 2003b. Cow and calf performance as affected by grazing management. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1052. Dickinson, ND. 28p.

Manske, L.L. 2003c. Effects of grazing management treatments on rangeland vegetation. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 03-3027. Dickinson, ND. 6p.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988. Cow and calf performance on seasonlong and twice-over rotation grazing treatments in western North Dakota. Proceedings of the North Dakota Cow-Calf Conference. Bismarck, ND. p. 39-43.

Marschner, H. 1992. Nutrient dynamics at the soil-root interface (Rhizosphere). p. 3-12. *in* D.J. Read, D.H. Lewis, A.H. Fitter, and I.J. Alexander (eds.). Mycorrhizas in ecosystems. C.A.B. International, Wallingford, U.K.

Mawdsley, J.L., and R.D. Bardgett. 1997. Continuous defoliation of perennial ryegrass (Lolium perenne) and white clover (Trifolium repens) and associated changes in the microbial population of an upland grassland soil. Biology and Fertility of Soils 24:52-58.

McNaughton, S.J., L.L. Wallace, and M.B. Coughenour. 1983. Plant adaptation in an ecosystem context: effects of defoliation, nitrogen, and water on growth of an African C4 sedge. Ecology 64:307-318.

Moorman, T., and F.B. Reeves. 1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. II. A bioassay to determine the effect of land disturbance on endomycorrhizal populations. American Journal of Botany 66:14-18.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Grass Growth in Height

Llewellyn L. Manske, Ph.D.
Range Scientist
North Dakota State University
Dickinson Research Extension Center

The mixed grass prairie consists of an assemblage of mid grasses, short grasses, and sedges. Each species exhibits a characteristic growth pattern during its seasonal development from active vegetative growth in spring through the stages of flower stalk growth.

An understanding of the growth patterns of grassland plants is essential for development of proper management practices for grassland ecosystems. At the Dickinson Experiment Station, Dr. Warren C. Whitman and Dr. Harold Goetz conducted an 8-year study designed to collect quantitative data on the seasonal progress in height growth of leaves and flower stalks of major species in the mixed grass prairie of western North Dakota. A summary of some of their data is included in this report.

Procedures

From 1955 through 1962, Whitman and Goetz collected leaf and stalk height measurements for major graminoids. Plant heights were determined by measuring leaves and flower stalks of an average of 10 ungrazed lead tillers of each species to the nearest 1 cm. Measurements were collected at approximately 7- to 10-day intervals from early April to mid September. Leaf heights were measured from the ground to the tips of extended leaves. Flower stalk heights were measured from the ground to the tips of the inflorescences.

Grass Height Growth

Goetz (1963) reported the average percentage of growth completed at sequential intervals. These percentages were based on the average maximum leaf and flower stalk heights. A summary of these data is shown in tables 1 and 2 and figure 1. Upland sedges complete 100% of their growth in leaf and flower stalk height by 30 June. Cool-season grasses complete 100% of their growth in leaf and flower stalk height by 30 July. Warm-season grasses complete 100% of their growth in leaf height and 91% of their growth in flower stalk height by 30 July. In warm-season grasses, a small amount of flower stalk elongation occurs after 30 July.

Herbage Biomass

Peak aboveground herbage biomass is usually reached during the last 10 days of July. Herbage weight of ungrazed plants increases during May, June, and July. After the end of July, herbage weight decreases because the rate of senescence of the grass leaves exceeds the rate of growth. During senescence, cell material from the aboveground structures is translocated to the belowground structures; this movement results in a reduction in weight of aboveground structures.

Precipitation Pattern

The seasonal distribution of northern mixed grass prairie precipitation occurs in the Plains Precipitation Pattern (Humphrey 1962), with most of it occurring during the growing season (85%) and the greatest amounts occurring in spring and early summer. The precipitation received during May, June, and July accounts for 51% of the annual precipitation (Manske 2000).

Conclusion

The primary period of growth in graminoid leaf and flower stalk height and of accumulation in aboveground herbage weight occurs during the remarkably short period of May, June, and July, which coincides with the period of greatest precipitation.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider and Lisa Vance for assistance in production of this manuscript.

Table 1. Mean percent growth in leaf height completed by sample date for ungrazed plants of major graminoid species from western North Dakota mixed grass prairie.

	15 May	**30 May**	**30 Jun**	**30 Jul**	**30 Aug**	**30 Sep**
UPLAND SEDGES	**75**	**93**	**100**	**-**	**-**	**-**
Western Wheatgrass	54	69	92	100	-	-
Needleandthread	40	62	97	100	-	-
Prairie Junegrass	72	84	93	100	-	-
Plains Reedgrass	68	78	95	100	-	-
COOL SEASON GRASSES	**59**	**73**	**94**	**100**	**-**	**-**
Blue Grama	34	48	82	100	-	-
Prairie Sandreed	16	39	88	100	-	-
WARM SEASON GRASSES	**25**	**44**	**85**	**100**	**-**	**-**

Goetz. 1963. MS Thesis. NDSU

Table 2. Mean percent growth in flower stalk height completed by sample date for ungrazed plants of major graminoid species from western North Dakota mixed grass prairie.

	15 May	**30 May**	**30 Jun**	**30 Jul**	**30 Aug**	**30 Sep**
UPLAND SEDGES	**66**	**82**	**100**	**-**	**-**	**-**
Western Wheatgrass	0	0	91	100	-	-
Needleandthread	0	39	85	100	-	-
Prairie Junegrass	0	42	100	-	-	-
Plains Reedgrass	0	0	100	-	-	-
COOL SEASON GRASSES	**0**	**20**	**94**	**100**	**-**	**-**
Blue Grama	0	0	68	94	100	-
Prairie Sandreed	0	0	0	88	100	-
WARM SEASON GRASSES	**0**	**0**	**34**	**91**	**100**	**-**

Goetz. 1963. MS Thesis. NDSU

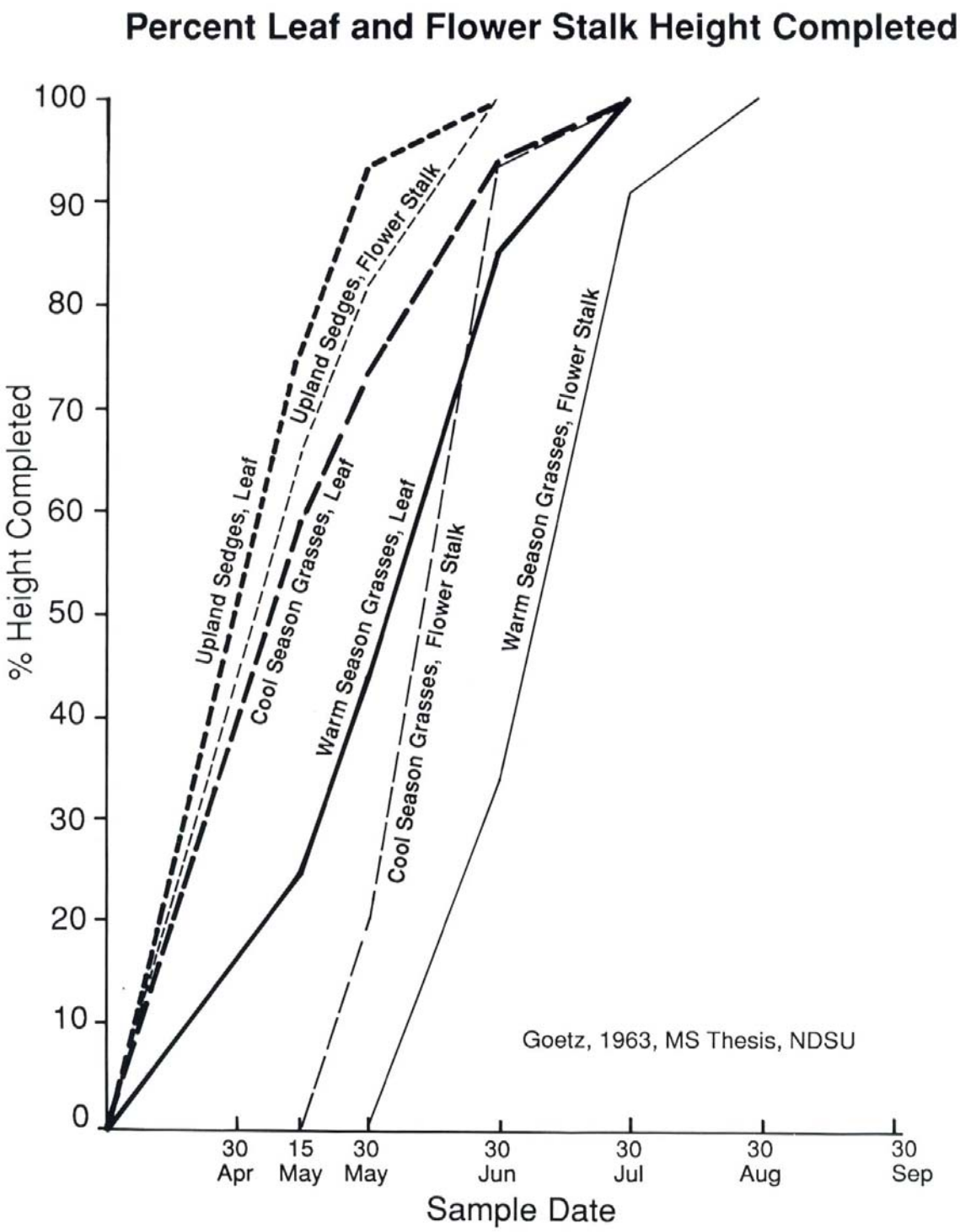


Fig 1. Mean percent growth in leaf and flower stalk height completed by sample date from ungrazed plants of three categories of graminoids from western North Dakota mixed grass prairie.

Literature Cited

Goetz, H. 1963. Growth and development of native range plants in the mixed prairie of western North Dakota. M. S. Thesis, North Dakota State University, Fargo, ND. 165p.

Humphrey, R. R. 1962. Range ecology. The Ronald Press Company, New York, NY. 234p.

Manske, L. L. 2000. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-1999. NDSU Dickinson Research Extension Center. Range Research Report DREC 00-1018c. Dickinson, ND. 36p.

Range Plant Growth and Development Are Affected by Environmental Factors

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Range plant growth and development are controlled by internal regulators that are modified according to environmental conditions. The long-term climatic conditions for a region determine the type of vegetation in that region, and regional environmental factors affect growth and development of the plants. The three most ecologically important environmental factors affecting rangeland plant growth are temperature, water (precipitation), and light. These factors require consideration during the development of long-term rangeland management strategies (Manske 2000).

Temperature

Temperature, an approximate measurement of the heat energy available from solar radiation, is an important factor because most plant biological activity and growth occur within only a narrow range of temperatures, between 32°F (0°C) and 122°F (50°C) (Barbour et al. 1987). High temperatures limit biological reactions because the complex structures of proteins are disrupted or denatured. Although respiration and photosynthesis can continue slowly at temperatures well below 32°F if plants are physiologically "hardened", low temperatures limit biological reactions because water becomes unavailable when it is frozen and because available energy is inadequate.

Low temperatures define the length of the active growing season. The growing season for annually seeded plants corresponds approximately to the frost-free period, the number of days between the last day with minimum temperatures below 32°F (0°C) in the spring and the first day with minimum temperatures below 32°F (0°C) in the fall (Ramirez 1972). Perennial plants maintain physiological processes throughout the year. Winter dormancy in perennial plants is not total inactivity but reduced activity (Leopold and Kriedemann 1975). Perennial grassland plants can grow actively beyond the frost-free period if temperatures are above the level that freezes water in plant tissue and soil. Perennial plants begin active growth more than 30 days before the last frost in spring and continue growth after the first frost in fall; the growing season for perennial plants is considered to be between the first 5 consecutive days in spring and the last 5 consecutive days in fall with a mean daily temperature at or above 32°F (0°C), generally from mid April through mid October. Low air temperature during the early and late portions of the growing season and high temperatures after mid summer greatly limit plant growth (Jensen 1972).

Different plant species have different optimum temperature ranges. Cool-season plants, which are C_3 photosynthetic pathway plants, have an optimum temperature range of 50° to 77°F (10° to 25°C). Warm-season plants, which are C_4 photosynthetic pathway plants, have an optimum temperature range of 86° to 105°F (30° to 40°C) (Coyne et al. 1995).

Large fluctuations in seasonal and daily air temperature occur in the Northern Plains. The large diurnal change in temperature during the growing season, which has warm days and cool nights, is beneficial for plant growth because warm days increase the photosynthetic rate and cool nights reduce the respiration rate (Leopold and Kriedemann 1975).

Water (Precipitation)

Water, an integral part of living systems, is ecologically important because it is a major force in shaping climatic patterns and biochemically important because it is a necessary component in physiological processes (Brown 1995). Water is the principal constituent of plant cells, usually composing over 80% of the fresh weight of herbaceous plants. Water is the primary solvent in physiological processes by which gases, minerals, and other materials enter plant cells and by which these materials are translocated to various parts of the plant. Water is the substance in which processes such as photosynthesis and other biochemical reactions occur and a structural component of proteins and nucleic acids. Water is also essential for the maintenance of the rigidity of plant tissue and for cell enlargement and growth in plants (Brown 1977, Brown 1995).

Water Deficiency

The climatic conditions in the Northern Plains cause frequent periods when plants experience water stress. Rain deficiency periods in which 75% or less of the long-term mean precipitation is received are called droughts. Periods of drought conditions can last for a full year or a complete growing season, but water deficiency periods of one month are long enough to limit herbage production greatly. Water deficiency conditions during May, June, and July are not frequent. These months constitute the primary period of production for range plant communities. August, September, and October experience water deficiency conditions more than half the time and are not dependable for positive water relations. The water relations during this latter portion of the growing season limit range plant growth and herbage biomass accumulation (Manske 2000). Frequent late-season water deficiency limits shrub and tree growth more than grass growth.

Water Stress

Temperature and precipitation act together to affect the physiological and ecological status of range plants. The balance between rainfall and potential evapotranspiration determines a plant's biological situation. Precipitation-evapotranspiration levels interact and influence the rates of the carbon and nitrogen cycles. Evaporation rates are dependent on temperature: as average temperature decreases, evaporation rate decreases; as temperature increases, evaporation rate increases. The mixed grass prairie region has greater evapotranspiration demand than precipitation. The tall grass prairie region has greater precipitation than evapotranspiration demand.

The native vegetation in the Northern Plains comprises a mixture of cool-season and warm-season species. The relationship between temperature and evaporation levels affects the ratio of cool-season to warm-season grasses in the plant species composition. The northern portion of the region has lower average temperature and lower evaporation rate; these conditions result in a higher percentage of cool-season species. The southern portion of the region has higher average temperature and greater evaporation rate; these conditions result in a higher percentage of warm-season species. A mixture of cool- and warm-season species is highly desirable because the herbage biomass production remains more stable over wide variations in seasonal temperature, precipitation, and evaporation levels.

During periods when rainfall is lower than evapotranspiration demand, a water deficiency exists. Under water deficiency conditions, the rate of water loss from transpiration exceeds the rate of water absorption by the roots, and plants undergo water stress. Water stress can vary from a small decrease in water potential (as in midday wilting on warm clear days) to the lethal limit of dessication. Although range plants have mechanisms that help reduce damage from water stress, water deficiency conditions lasting a month cause plants to experience water stress severe enough to reduce herbage production (Brown 1977, Brown 1995). The annual variation in temperature, precipitation, and evaporation affects the severity and duration of water deficiency, which in turn affect the levels of water stress.

Plant Water Stress

Plants experiencing water stress conditions respond at different inhibitory levels in relationship to the severity of the water deficiency. Early stages of water stress slow shoot and leaf growth. Leaves show signs of wilting, folding, and discoloration. Tillering and new shoot development are reduced, but root production may be increased. Senescence of older leaves is accelerated. Cell wall formation, cell division, and protein synthesis are reduced. As water stress increases, enzyme activity declines and the formation of necessary compounds slows or ceases. The stomata begin to close, and rates of transpiration and photosynthesis decrease. Respiration and translocation are substantially reduced as water stress increases. When water stress becomes severe, most functions nearly or completely cease and severe damage occurs. Leaf and root mortality induced by water stress progresses from the tips to the crown, its rate increasing with increasing stress. If water stress is prolonged or becomes more severe, the condition can be lethal. Plant death occurs when the meristems become dehydrated beyond the limits required to maintain cell turgidity and biochemical activity (Brown 1995).

Plants in water stress have limited growth and reduced photosynthetic activity. Plant vigor is decreased, carbohydrate storage is reduced, and root biomass is reduced. Plant height and herbage biomass accumulation are reduced. Leaf senescence increases and, as a result, nutritional quality of forage decreases. The rate of sexual reproduction is diminished as a result of a decrease in seed stalk numbers and height and a reduction in numbers of seeds in the seed heads. Rate of vegetative reproduction is reduced because the number of axillary buds and the number of secondary tillers decrease.

Basal cover is reduced because of mortality of entire plants or portions of plants, and open spaces

in the plant community increase because of a decrease in plant numbers. The species composition shifts to an increase in species with advanced water-stress resistance mechanisms and a decrease in drought-susceptible species. Occurrence of some forbs and weedy species increases because of their ability to exploit the open spaces. Quantity and quality of wildlife habitat diminish. Livestock performance decreases because of the reductions in the quantity and quality of available forage, which in turn cause a reduction in milk production and a corresponding reduction in calf rate of gain and weaning weight. During extended periods of water stress, stocking rates generally need to be reduced.

Light

Light is the ultimate source of energy and the most important ecological factor affecting plant growth. Variations in quality, intensity, and duration of light affect plant growth. Light is necessary for photosynthesis, the process that converts light energy into chemical energy. The rate of photosynthesis varies with different wavelengths, but the quality (wavelength) of sunlight does not vary enough in a given region to have an important differential effect on the rate of photosynthesis. The intensity of sunlight (measurable energy) and duration of sunlight (length of day or photoperiod), however, do vary sufficiently to affect plant growth. Light intensity varies greatly with season and time of day because of changes in the angle of incidence of the sun's rays and the distance light travels through the atmosphere. Light intensity also varies with the amount of humidity and cloud cover because atmospheric moisture absorbs and scatters light rays. However, the greatest variation in intensity of light received by range plants results from the various degrees of shading from other plants. Because most range plants require full sunlight or very high levels of sunlight for best growth, shading can reduce or limit growth of range plants. Duration of sunlight (day-length period or photoperiod) is one of the most dependable cues by which plants time their activities in temperate zones. The buds or leaves of a plant contain sensory receptors, specially pigmented areas that detect day length and night length and can activate one or more hormone and enzyme systems that bring about physiological responses. The phenological development of rangeland plants is triggered primarily by changes in the length of daylight, although other environmental factors produce secondary effects and may cause slight variations in the pattern of phenological development. The tilt of the earth's axis in conjunction with the earth's annual revolution around the sun produces the seasons and changes the length of daylight, which increases from the beginning of the growing season until mid June then decreases to the end of the growing season. Photoperiod (day-length period) for a given date and locality remains the same from year to year (Odum 1971, Daubenmire 1974, Barbour et al. 1987).

Changes in day length (photoperiod) function as the timer and trigger that activates or stops physiological processes initiating growth and flowering and activates the process of hardening for resistance to low temperatures in the fall and winter. Vegetative growth is triggered by photoperiod and temperature (Langer 1972, Dahl 1995), and reproductive initiation is triggered primarily by photoperiod (Roberts 1939, Leopold and Kriedemann 1975, Dahl 1995) but can be slightly modified by temperature and precipitation (McMillian 1957, Leopold and Kriedemann 1975, Dahl and Hyder 1977, Dahl 1995). Cool- and warm-season plants respond to changes in photoperiod differently. Generally, most cool-season plants are long-day plants, and most warm-season plants are short-day plants. Long-day plants reach the flowering stage after exposure to a critical photoperiod and during the period of increasing daylight between the beginning of active growth and mid June, usually flowering before 21 June. Short-day plants are induced into flowering by day lengths that are shorter than a critical length and that occur during the period of decreasing day length after mid June, usually flowering after 21 June. Short-day plants are technically responding to the increase in the length of the night period rather than to the decrease in the day length (Weier et al. 1974, Leopold and Kriedemann 1975).

Management Implications

The combined influences of light, temperature, and precipitation affect the quantity and quality of plant growth in the Northern Plains and can limit livestock production if not considered during the planning of long-term grazing management strategies. Strategies based on phenological growth stages of the major grasses can be planned by calendar date after the relationships between growth stage of the grasses and date have been determined with consideration of a possible variation of about ± 7 days to accommodate annual potential modification from temperature and precipitation (Manske 1980). Implementation of such strategies has the potential to maintain the stability of the grassland ecosystem, enhance quantity and quality of herbage, and sustain livestock production.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

Literature Cited

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial plant ecology. The Benjamin/Cummings Publishing Co., Menlo Park, CA. 634p.

Brown, R.W. 1977. Water relations of range plants. p. 97-140. *in* R.E. Sosebee (ed.). Rangeland plant physiology. Range Science Series No. 4. Society for Range Management. Denver, CO.

Brown, R.W. 1995. The water relations of range plants: adaptations of water deficits. p. 291-413. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Dahl, B.E., and D.N. Hyder. 1977. Developmental morphology and management implications. p. 257-290. *in* R.E. Sosebee (ed.). Rangeland plant physiology. Range Science Series No. 4. Society for Range Management. Denver, CO.

Dahl, B.E. 1995. Developmental morphology of plants. p. 22-58. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Daubenmire, R.F. 1974. Plants and Environment. John Wiley and Sons, New York, NY. 422p.

Jensen, R.E. 1972. Climate of North Dakota. National Weather Service, North Dakota State University, Fargo, ND. 48p.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold, London, Great Britain. 60p.

Leopold, A.C., and P.E. Kriedemann. 1975. Plant growth and development. McGraw-Hill Book Co., New York, NY. 545p.

Manske, L.L. 1980. Habitat, phenology, and growth of selected sandhills range plants, Ph.D. Thesis, North Dakota State University, Fargo, ND. 154p.

Manske, L.L. 2000. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-1999. NDSU Dickinson Research Extension Center. Range Research Report DREC 00-1018c. Dickinson, ND. 36p.

McMillan, C. 1957. Nature of the plant community. III. Flowering behavior within two grassland communities under reciprocal transplanting. American Journal of Botany 44(2):144-153.

Odum, E.P. 1971. Fundamentals of ecology. W.B. Saunders Company. Philadelphia, PA. 574p.

Ramirez, J.M. 1972. The agroclimatology of North Dakota, Part 1. Air temperature and growing degree days. Extension Bulletin No. 15. North Dakota State University, Fargo, ND. 44p.

Roberts, R.M. 1939. Further studies of the effects of temperature and other environmental factors upon the photoperiodic response of plants. Journal of Agricultural Research 59(9):699-709.

Weier, T.E., C.R. Stocking, and M.G. Barbour. 1974. Botany: an introduction to plant biology. John Wiley and Sons, New York, NY. 693p.

Grazing Starting Dates

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Grassland herbage production can be sustained at relatively high levels only when grass plants retain adequate leaf area. Heavy grazing of native rangeland pastures that repeatedly removes a great proportion of the leaf area has long been known to cause reductions in grassland herbage production. Grazing during early spring prior to range readiness also deprives grass plants of needed leaf area and results in reductions in grass growth, herbage production, and economic returns. The reductions in herbage production and in economic returns vary with grazing starting date and grazing strategies. These reductions in herbage production and economic returns are quantified in this report.

Methods

Data reported by Campbell (1952) from a four-year grazing study conducted at Swift Current, Saskatchewan, and data reported by Rogler et al. (1962) and Lorenz (per. com.) from a four-year clipping study conducted at Mandan, North Dakota, were summarized, and the amounts of herbage produced on treatments with defoliation starting at various dates were compared to the potential aboveground herbage biomass. Data collected during grazing studies conducted from 1982 to 1987 at Dickinson, North Dakota, were used to compare herbage production, animal performance, and economic net returns (gross minus pasture and forage costs) for three grazing strategies: 1) a seasonlong treatment with grazing starting 15 May, 2) a seasonlong treatment with grazing starting 15 June, and 3) a three-pasture twice-over rotation grazing system with grazing starting 1 June.

Results

Percent reductions from the potential herbage biomass that are caused by defoliation treatments with different starting dates are shown in table 1 and figure 1. The percentages of the reductions in herbage biomass at Swift Current, Mandan, and Dickinson are quite similar for the various defoliation starting dates. These reductions in herbage biomass show that when grazing on native rangeland is started in early May, more than 75% of potential herbage biomass will not be produced. When grazing is started in mid May, 45% to 60% of the potential herbage biomass will not be produced and will not be available for grazing livestock. When the starting date of grazing is between early June and early July, the reductions from potential herbage biomass are not great. When the starting date of grazing is delayed until early July, nearly all of the potential herbage biomass will grow and be available to grazing livestock, but the nutritional quality of the herbage will be at or below crude protein levels required for lactating cows (Whitman et al. 1951, Manske 1999b). When the starting date is deferred until mid July, after plants have produced seed, less than potential herbage biomass will be available to grazing livestock because of senescence and the translocation of cell material to belowground plant structures. The nutritional quality of the herbage on deferred grazing strategies will be below the crude protein requirements for lactating cows (Whitman et al. 1951, Manske 1999b), individual cow and calf performance will be reduced (Manske 1994), and net return per cow-calf pair will be 15% lower than net return per cow-calf pair on the seasonlong treatment with grazing starting 15 June, after the third-leaf stage (Manske 1996). The major long-term problem with a deferred management strategy that starts grazing after grass seed development is the reduction in native-grass basal cover (Sarvis 1941, Manske et al. 1988). Data from these native rangeland defoliation studies indicate that starting grazing between early June and early July causes the least reduction in herbage production, herbage nutritional quality, and grass plant density.

The phenological growth stage of grass plants can be used as an indicator of when grazing can be started without detriment to plant health and herbage production. Grass plants are physiologically capable of tolerating grazing pressure after they have reached the 3.0- or 3.5-leaf stage (Manske 1999a). Grazing grass plants that have not reached the third-leaf stage negatively affects grass growth. Grazing grass plants after they have reached the third-leaf stage and before they have reached the flowering stage stimulates vegetative tiller production from axillary buds and subsequently increases herbage biomass production (Manske 1994). Most native cool-season grasses reach the third-leaf stage around early June, and most native warm-season grasses reach the third-leaf stage around mid June (Manske 1999a). Seasonlong grazing management strategies on native rangeland should delay grazing until mid

June, but rotation grazing systems that are based on grass biological requirements and that stimulate tiller growth from axillary buds could start grazing in early June.

Starting grazing before the third-leaf stage, as does the seasonlong treatment with grazing starting 15 May, causes a reduction in herbage biomass production (-45% (table 1)), which causes reductions in stocking rate (-29%), calf average daily gain (ADG) (-14%), and calf gain per acre (-40%) compared to stocking rate, calf average daily gain, and calf gain per acre on the seasonlong treatment with grazing starting after the third-leaf stage (table 2). This reduction in animal performance causes a decrease in net returns (gross minus pasture and forage costs) per cow-calf pair (-80%) and per acre (-89%) compared to net returns per cow-calf pair and per acre on the seasonlong treatment with grazing starting after the third-leaf stage (table 2). The seasonlong treatment with grazing starting after the third-leaf stage has greater animal performance and higher economic returns than does the seasonlong treatment with grazing starting before the third-leaf stage, because starting grazing after the third-leaf stage results in less damage to grass plants and allows greater production of herbage biomass (-21% (table 1)). The seasonlong treatment with grazing starting after the third-leaf stage has reductions in stocking rate (-29%), calf average daily gain (-6%), calf gain per acre (-33%), net returns per cow-calf pair (-33%), and net returns per acre (-53%) compared to stocking rate, calf average daily gain, calf gain per acre, and net returns per cow-calf pair and per acre on the twice-over rotation treatment with grazing starting after the third-leaf stage (table 2). The twice-over rotation system with grazing starting after the third-leaf stage also has grazing periods designed to coordinate with grass phenological development and to meet the biological requirements of grass plants (Manske 1999a) and grazing animals (Manske 1994). The twice-over rotation system has increased stocking rate (+49%, +29%), calf average daily gain (+19%, +6%), calf gain per acre (+60%, +33%), net returns per cow-calf pair (+86%, +33%), and net returns per acre (+95%, +53%) compared to stocking rate, calf average daily gain, calf gain per acre, and net returns per cow-calf pair and per acre on the seasonlong treatments with grazing starting before and after the third-leaf stage, respectively (table 2). Grazing systems designed to meet the requirements of plants and animals have greater herbage biomass production and better animal performance than other systems. Grazing systems that rotate livestock in an arbitrary sequence that is not coordinated with grass plant phenological development and that does not meet the biological requirements of the plants and animals do not produce satisfactory results.

Table 1. Percent reduction from potential aboveground herbage biomass on defoliation treatments with different starting dates.

Starting dates of defoliation	Swift Current[a] grazing data	Mandan[b] clipping data	Dickinson grazing data
1 May	-78%	-76%	-
15 May	-46%	-57%	-45%
1-5 Jun	-13%	-43%	-
15-20 Jun	-7%	-33%	-21%
1-5 Jul	0%	-8%	-
15-20 Jul	-18%	0%	0%
1 Aug	-	-13%	-

[a]Campbell 1952
[b]Rogler et al. 1962
[b]Lorenz (per. com.)

Table 2. Comparisons of costs, production, and net returns on native rangeland managed by seasonlong and twice-over rotation grazing systems with grazing starting before and after the 3rd leaf stage.

		Seasonlong starting before 3rd leaf	Seasonlong starting after 3rd leaf	Twice-over Rotation starting after 3rd leaf
Stocking rate (acres/AUM)	(ac)	4.04	2.86	2.04
Calf ADG	(lb)	1.80	2.09	2.21
Calf gain/acre	(lb)	13.59	22.55	33.64
Pasture cost/cow/calf pr				
@$8.76/ac	($)	212.34	111.25	78.84
Cost/lb calf gain	($)	0.64	0.39	0.26
Net return/cow/calf pr				
@$0.70/lb	($)	18.24	89.18	133.10
Net return/acre@$0.70/lb	($)	0.75	7.02	14.79

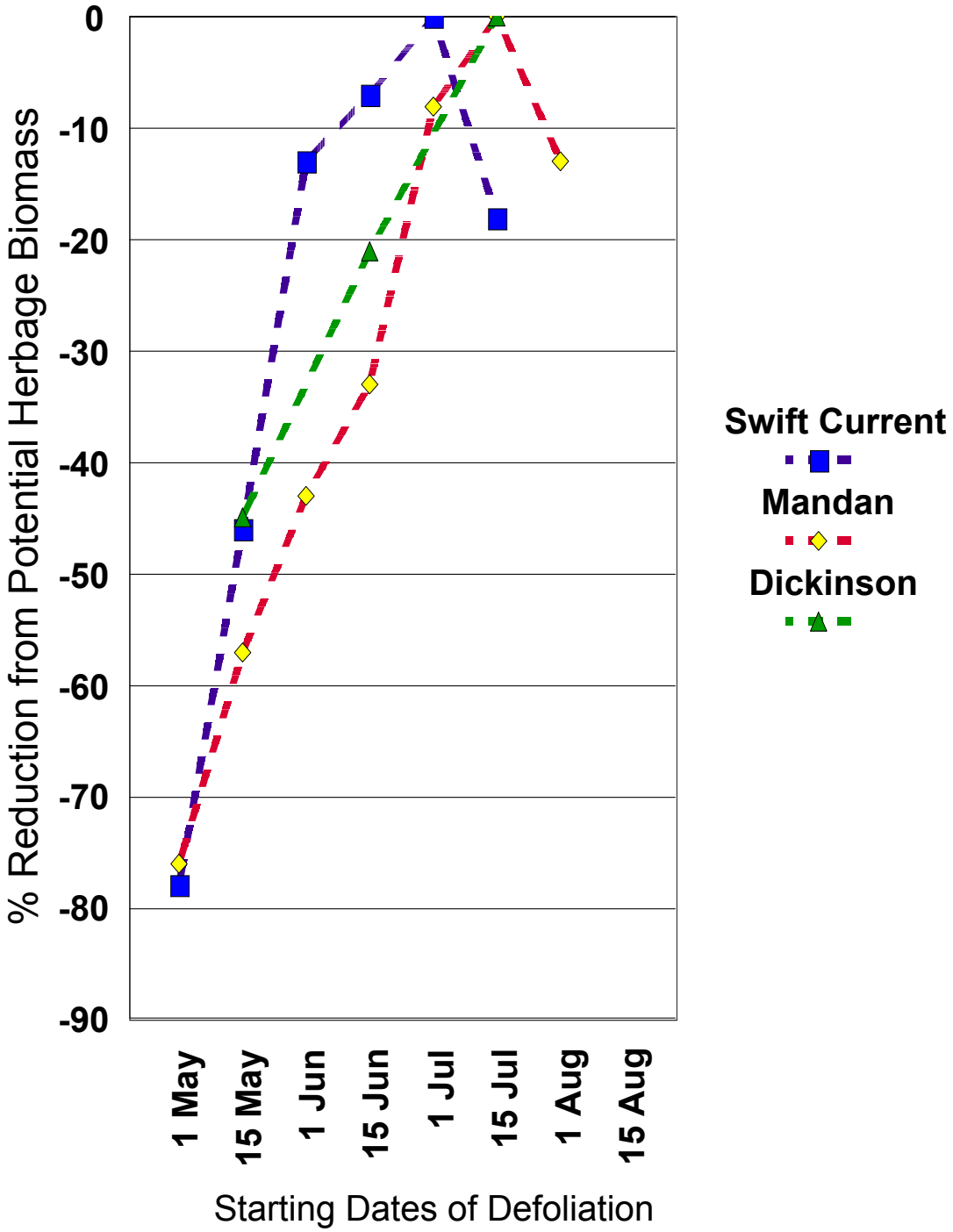


Fig. 1. Percent reduction from potential aboveground herbage biomass on defoliation treatments with different starting dates.

Discussion

The amount of herbage biomass produced on grasslands decreases when plants are defoliated before the third-leaf stage. The earlier defoliation is started, the greater the decrease in herbage production. Early spring growth depends both on carbohydrate reserves and on photosynthetic products from the active leaf area of the tiller. Before the third-leaf stage, the plant has little leaf area and low carbohydrate levels. Defoliation of the plant at this time results in reduced rates of herbage production (Coyne et al. 1995) because the plant produces little photosynthetic product and must depend upon stored carbohydrates, which are usually not adequate for complete recovery of growth. This early spring damage causes a reduction in herbage biomass production for the entire growing season. The reduction in herbage biomass reduces stocking rate and animal performance and results in lower economic returns per cow-calf pair and per acre.

Sustaining high levels of herbage production on grasslands requires that grazing not begin before the plants have reached the 3.0- or 3.5-leaf stage. Delaying grazing on native rangeland until 1 June, when cool-season grasses reach the third-leaf stage, requires that another type of forage be available for grazing earlier. Some domesticated perennial cool-season grasses reach the third-leaf stage three to five weeks earlier than native cool-season grasses and can be grazed as complementary spring pastures before native rangeland reaches grazing readiness. Domesticated cool-season grass pastures like crested wheatgrass or smooth bromegrass can be grazed from early May, after they have reached the third-leaf stage, to early June, when native cool-season grasses reach the third-leaf stage. Like native rangeland, complementary spring domesticated grass pastures should be grazed only after plants have reached the third-leaf stage. The start of the grazing season on domesticated grass pastures is restricted to very late April or early May, because no perennial grasses in the Northern Plains reach the third-leaf stage before late April.

Summary

Grazing native rangeland before the grass plants reach the third-leaf stage causes reductions in herbage biomass production and subsequent reductions in stocking rate and animal performance. These reductions result in lower economic returns for a livestock operation. Herbage biomass production can be increased, along with stocking rate, animal performance, and net returns, when grazing is started after the third-leaf stage. Herbage production can be further increased when grazing started after the third-leaf stage is coordinated with grass phenological growth to meet the biological requirements of the grass plants. With such management, stocking rate, calf average daily gain, calf gain per acre, net returns per cow-calf pair, and net returns per acre will also increase.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the figure and tables.

Literature Cited

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Manske, L.L., W.T. Barker, and M.E. Biondini. 1988. Effects of grazing management treatments on grassland plant communities and prairie grouse habitat. USDA. Forest Service. General Technical Report RM-159. p. 58-72.

Manske, L.L. 1994. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program. Regina, Saskatchewan.

Manske, L.L. 1996. Economic returns as affected by grazing strategies. p. 43-55. *in* Z. Abouguendia (ed.). Total Ranch Management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan.

Manske, L.L. 1999a. Can native prairie be sustained under livestock grazing? p. 99-108. *in* J. Thorpe, T.A. Steeves, and M. Gollop (eds.). Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, Alberta.

Manske, L.L. 1999b. Annual nutritional quality curves for graminoids in the Northern Great Plains. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 99-3014. Dickinson, ND. 14p.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. North Dakota Agricultural Experiment Station. Bulletin 439. Fargo, ND. 15p.

Sarvis, J.T. 1941. Grazing investigations on the Northern Great Plains. North Dakota Agricultural Experiment Station. Bulletin 308. Fargo, ND. 110p.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Effects of Fall Grazing on Grass-Leaf Height

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Grazing beef cattle on native rangeland during the fall season is an optional management practice that has been followed in the Northern Plains. Fall occurs between the autumnal equinox (22 September) and the winter solstice (21 December) and includes October, November, and December. The practice of grazing during these months, frequently incorrectly referred to as "winter grazing", persists in part because of the common belief that grazing after frost in the fall does not harm perennial plants. A search of the pertinent scientific literature does not produce data to support the belief that native grasses are unaffected by late-season grazing. In fact, results of a study conducted from 1958 to 1962 at the Dickinson Research Extension Center indicates that fall grazing is detrimental to perennial grasses, greatly reducing leaf height of graminoid plants the following growing season.

Methods

Following World War II, the beef herd at the Dickinson Experiment Station was managed with a contemporary repeated spring, summer, and fall seasonal pasture grazing schedule. During the growing season, the 40-acre fall pasture was used as a native-grass study area on which basic plant growth data were collected for numerous range-related investigations. An exclosure (A) was constructed on the fall pasture during the spring of 1958, and a second exclosure (B) was constructed during late summer of 1961. From 1958 to 1962, Dr. Warren C. Whitman and Dr. Harold Goetz conducted a study designed to evaluate the effects fall grazing had on the height of grass leaves during the following growing season. Data from that study were reported by Goetz (1963).

Plant heights were determined by measuring leaves of an average of ten ungrazed lead tillers of each species to the nearest 1 cm during the growing seasons following fall treatments. Measurements were collected at approximately 7- to 10-day intervals from early April to mid September. Leaf heights were measured from the ground to the tips of extended leaves. Leaf-height measurements for needleleaf sedge (*Carex eleocharis*), needle and thread (*Stipa comata*), western wheatgrass (*Agropyron smithii*), and blue grama (*Bouteloua gracilis*) were collected in the fall-grazed pasture and in exclosures A and B, which were not grazed in the fall. A summary of these data and their interpretation is the primary subject of this report.

Growing-season conditions affect range plant growth (Manske 1998) and are a factor to be considered in the assessment of grass and sedge growth. The average monthly temperature and monthly precipitation data for 1958 to 1962 from the Dickinson Research Extension Center (Manske 2000) were used to characterize growing-season conditions as normal, drought, and wet.

Results

Goetz (1963) reported maximum leaf heights (table 1) of ungrazed lead tillers of needleleaf sedge, needle and thread, western wheatgrass, and blue grama measured from 1958 though 1962. Goetz (1963) stated that the data show that leaf heights for the four species of grasses and sedge were greater inside the exclosures than outside on the fall-grazed rangeland, irrespective of moisture conditions. Goetz (1963) concluded that the results of the study indicate a great reduction in maximum leaf height because of decreased vigor of the plants on rangeland subjected to fall grazing.

Maximum leaf heights of major graminoids on rangeland grazed during the fall were reduced 23.0%, 17.3%, 30.4%, and 43.0% for needleleaf sedge, needle and thread, western wheatgrass, and blue grama, respectively, compared to maximum leaf heights on treatments not fall grazed (table 2). Fall grazing reduced maximum leaf height of major graminoids 28.4% during the succeeding growing season.

Maximum leaf heights of the major graminoid species were affected by growing-season weather conditions in addition to the fall grazing treatments. The weather conditions of the growing seasons from 1958 to 1962 are summarized in table 3. The growing-season conditions of 1959 and 1961 were normal, the growing seasons of 1958 and 1960 had drought conditions with average precipitation levels 8.8% below normal, and the growing-season conditions of 1962 were wet, with precipitation levels 21% above the long-term mean.

Maximum leaf heights were shorter under drought growing-season conditions than under normal growing-season conditions for major graminoids on the treatments not fall grazed (table 4). During growing seasons with drought conditions, maximum leaf heights decreased 25.8%, 14.0%, and 11.8% for needleleaf sedge, needle and thread, and blue grama, respectively, from maximum leaf heights during growing seasons with normal conditions. During the study conducted by Whitman and Goetz, maximum leaf height of western wheatgrass was 8.0% greater during growing seasons with drought conditions than during growing seasons with normal conditions (table 4). This inconsistency can be explained by the precipitation patterns of the drought and normal growing seasons of 1958 to 1961 (table 3). Western wheatgrass completes most of its growth during May and June. Precipitation levels for June were greater than three inches in each of the two years with drought-condition growing seasons, 1958 and 1960. During the two years in which growing-season conditions were normal, 1959 and 1961, precipitation levels were greater than three inches during June only in 1959. These differences between the precipitation patterns of the drought and normal growing seasons can cause the observed differences in leaf heights of western wheatgrass. Precipitation occurring during important growth periods can greatly benefit single grass species even during growing seasons with generally stressful conditions. Maximum leaf height of major graminoids was reduced 11% in growing seasons with drought conditions.

Maximum leaf heights were greater under wet growing-season conditions than under normal growing-season conditions for major graminoids on the treatments not fall grazed (table 4). During the growing season with wet conditions, maximum leaf heights were 22.5%, 46.6%, 69.7%, and 65.4% greater for needleleaf sedge, needle and thread, western wheatgrass, and blue grama, respectively, than maximum leaf heights attained during growing seasons with normal conditions. Maximum leaf height of major graminoids increased 51% in the growing season with wet conditions.

In 1959 and 1961, when the growing season conditions were normal, leaf heights (table 5) of the major species on the treatments not fall grazed were greater than leaf heights of the plants on the treatments grazed the previous fall. Fall grazing reduced maximum leaf height of major graminoids 20.8% during the growing seasons with normal conditions.

In 1958 and 1960, when the growing seasons had drought conditions, leaf heights (table 5) of the major species on the treatments not fall grazed were not much greater than leaf heights of the plants on the treatments grazed the previous fall. Leaf heights of needleleaf sedge and needle and thread on treatments not grazed in the fall did not differ from leaf heights on the fall-grazed treatments (table 5). Fall grazing reduced maximum leaf height of major graminoids 9.4% during the growing seasons with drought conditions.

In 1962, when the growing season conditions were wet, leaf heights (table 5) of all the major species on the treatments not fall grazed were considerably greater than leaf heights of the plants on the treatments grazed the previous fall. Leaf height of blue grama on exclosure A was more than twice the leaf height of the fall-grazed plants (table 5). Fall grazing reduced maximum leaf height of major graminoids 31.2% during the growing season with wet conditions.

Upland sedges attained an average maximum leaf height of 12.0 cm (4.7 in) in early to mid June during growing seasons with normal conditions. Leaf height of upland sedges was reduced 26% under drought conditions and increased 23% under wet conditions. Fall grazing reduced maximum leaf height of upland sedges 23%.

Needle and thread attained an average maximum leaf height of 19.3 cm (7.6 in) in late June to early July during growing seasons with normal conditions. Drought conditions reduced leaf height 14% from leaf height during normal conditions, and wet conditions increased leaf height 47% over leaf height during normal conditions. Fall grazing reduced maximum leaf height of needle and thread 17%.

Western wheatgrass attained an average maximum leaf height of 23.8 cm (9.4 in) by mid July during growing seasons with normal conditions. Wet conditions increased leaf height 70%. In growing seasons with drought conditions but with greater than three inches of precipitation in June, leaf height for western wheatgrass was not reduced. Drought conditions with below-normal precipitation in June would cause a reduction in maximum leaf height for western wheatgrass. Fall grazing reduced maximum leaf height of western wheatgrass 30%.

Blue grama attained an average maximum leaf height of 12.7 cm (5.0 in) in early to mid July during growing seasons with normal conditions. Under drought conditions, leaf height decreased 12%,

and under wet conditions leaf height increased 65%. Fall grazing reduced maximum leaf height of blue grama 43%.

Growth in height of the major graminoid species of the mixed prairie in the Northern Plains was affected by grazing during the fall as well as by precipitation patterns and moisture conditions during the growing season. Fall grazing damaged perennial grasses and reduced grass growth in leaf height during normal, drought, and wet growing-season conditions.

Discussion

Data collected by Whitman and Goetz during their study clearly show that fall grazing on native rangeland damages range plants and reduces leaf height by diminishing the vigor of the plants. The range condition of pastures that have a history of being grazed during the fall season can be improved if the fall grazing location is changed from the native range pasture to pastures of an alternative forage type like a variety of perennial wildrye (Altai, Russian, basin) or to a spring-seeded winter cereal pasture. The data from Goetz (1963) can be used to help predict the levels of improvement in the major species after the fall grazing practice has been changed. The average maximum leaf height of the major native range graminoids could be expected to increase 17.2% during the first year if the growing season had normal conditions and 33.3% if the first growing season had wet conditions. An increase of 42.5% in leaf height could be expected within four years of a change from grazing native rangelands in the fall.

Conclusion

The scientific results from the five-year research project Dr. Whitman and Dr. Goetz conducted at the Dickinson Research Extension Center provide evidence that fall grazing of native rangeland causes biological damage to the major rangeland species. Leaf heights of the major graminoids of the mixed grass prairie are affected by the grazing management practices used during the previous fall season and by the precipitation pattern and moisture conditions of the growing season. Not the benign practice it is commonly believed to be, fall grazing of rangeland causes a decrease in plant vigor and a great reduction in leaf height (28%) of the major graminoids during the succeeding growing season, regardless of the growing-season moisture conditions.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables.

Table 1. Maximum leaf height [centimeters (cm) and inches (in)] of ungrazed lead tillers measured during growing seasons following treatments fall grazed or not fall grazed (1958-1962), data from Goetz (1963).

Year	Upland sedge		Needle and thread		Western wheatgrass		Blue grama	
Treatment	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)
1958								
Initial	9.0	3.5	16.7	6.6	23.0	9.1	9.7	3.8
1959								
Exclosure A (1 yr)	10.7	4.2	20.0	7.9	22.3	8.8	12.0	4.7
Fall Grazed	9.0	3.5	19.0	7.5	20.0	7.9	9.0	3.5
1960								
Exclosure A (2 yr)	8.7	3.4	16.5	6.5	28.3	11.1	12.7	5.0
Fall Grazed	9.0	3.5	17.0	6.7	19.0	7.5	8.0	3.1
1961								
Exclosure A (3 yr)	13.3	5.2	18.6	7.3	25.3	10.0	13.3	5.2
Fall Grazed	9.0	3.5	16.0	6.3	22.0	8.7	7.0	2.8
1962								
Exclosure A (4 yr)	16.3	6.4	29.5	11.6	41.7	16.4	25.0	9.8
Exclosure B (1 yr)	13.0	5.1	27.0	10.6	39.0	15.4	17.0	6.7
Fall Grazed	11.0	4.3	23.0	9.1	26.0	10.2	11.5	4.5

Table 2. Average maximum leaf height [centimeters (cm) and inches (in)] of ungrazed lead tillers measured during growing seasons following treatments fall grazed or not fall grazed (mean of 1958-1962), summary of data from Goetz (1963).

Treatments		Exclosure	Fall grazed	Percent difference from treatments not fall grazed (%)
Upland sedge	(cm)	12.6	9.7	-23.0
	(in)	5.0	3.8	
Needle and thread	(cm)	23.1	19.1	-17.3
	(in)	9.1	7.5	
Western wheatgrass	(cm)	32.6	22.7	-30.4
	(in)	12.8	8.9	
Blue grama	(cm)	16.5	9.4	-43.0
	(in)	6.5	3.7	

Table 3. Summary of weather conditions during study of fall grazing effects on leaf height (1958-1962).

Year		1958	1959	1960	1961	1962
Growing-season precipitation	(in)	9.42	11.56	8.54	12.65	16.41
Percent of long-term mean precipitation	(%)	69.44	85.21	62.95	93.25	120.96
Months with water stress		May, Aug, Sep	Apr, Jul, Aug	Apr, Jul, Sep, Oct	Jul, Aug, Oct	Sep, Oct
Percent growing-season months with water stress	(%)	50	42	50	42	25
Months with > 3" precip.		Jun, Jul	Jun, Sep	Jun	Sep	May, Jul
Spring conditions		Dry	Dry	Dry	Normal	Wet
Fall conditions		Dry	Wet	Dry	Normal	Dry
Growing-season conditions		Drought	Normal	Drought	Normal	Wet

Data from Manske 2000

Table 4. Average maximum leaf height [centimeters (cm) and inches (in)] of ungrazed lead tillers measured during three growing-season conditions on treatments not fall grazed (1958-1962), summary of data from Goetz (1963).

Growing-season conditions		Normal	Drought		Wet	
Treatments		Exclosure	Exclosure	% Difference from Normal (%)	Exclosure	% Difference from Normal (%)
Upland sedge	(cm)	12.0	8.9	-25.8	14.7	+22.5
	(in)	4.7	3.5		5.8	
Needle and thread	(cm)	19.3	16.6	-14.0	28.3	+46.6
	(in)	7.6	6.5		11.1	
Western wheatgrass	(cm)	23.8	25.7	+8.0	40.4	+69.7
	(in)	9.4	10.1		15.9	
Blue grama	(cm)	12.7	11.2	-11.8	21.0	+65.4
	(in)	5.0	4.4		8.3	

Table 5. Maximum leaf height [centimeters (cm) and inches (in)] of ungrazed lead tillers measured during three growing-season conditions following treatments fall grazed or not fall grazed (1958-1962), summary of data from Goetz (1963).

Growing-season conditions		Normal		Drought		Wet		
Years		1959 & 1961		1958 & 1960		1962		
Treatments		Exclosure A	Fall grazed	Exclosure A	Fall grazed	Exclosure A	Exclosure B	Fall Grazed
Upland sedge	(cm)	12.0	9.0	8.9	9.0	16.3	13.0	11.0
	(in)	4.7	3.5	3.5	3.5	6.4	5.1	4.3
Needle and thread	(cm)	19.3	17.5	16.6	16.8	29.5	27.0	23.0
	(in)	7.6	6.9	6.5	6.6	11.6	10.6	9.1
Western wheatgrass	(cm)	23.8	21.0	25.7	21.0	41.7	39.0	26.0
	(in)	9.4	8.3	10.1	8.3	16.4	15.4	10.2
Blue grama	(cm)	12.7	8.0	11.2	8.8	25.0	17.0	11.5
	(in)	5.0	3.1	4.4	3.5	9.8	6.7	4.5

Literature Cited

Goetz, H. 1963. Growth and development of native range plants in the mixed prairie of western North Dakota. M.S. Thesis, North Dakota State University, Fargo, ND. 165p.

Manske, L.L. 1998. Environmental factors' effect on range plants. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 98-3006. Dickinson, ND. 3p.

Manske, L.L. 2000. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-1999. NDSU Dickinson Research Extension Center. Range Research Report DREC 00-1018c. Dickinson, ND. 36p.

Effects from Long-Term Nongrazing

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Long-term rangeland reference areas are important contributors to the understanding of the dynamics of rangeland ecosystems. Reference areas are intended to allow natural biological and physical processes to occur unhindered. The primary biological and physical forces affecting rangeland ecosystems are geologic material, topography, soil parent material, climate (precipitation, temperature, wind, and sunlight), seasonal precipitation patterns, fire, plant competition, and herbivory (from mammals, birds, insects, and microorganisms). These biological and physical forces act together on rangeland ecosystems over the long term and determine the structure and functions of a stable ecosystem. Long-term reference areas represent the stable rangeland ecosystem for a region with a specific set of biological and physical forces.

Rangeland reference areas can be used to evaluate the effects of mammalian herbivores on the ecosystem if a portion of the reference area is fenced with an exclosure. The exclosure can be designed to exclude all mammals, just large mammals, or just livestock. Reference areas that have a livestock exclosure and a similar area exposed to grazing are categorized as "two-way" reference areas. These "two-way" rangeland reference areas are designed to show the dynamics of both a stable rangeland ecosystem with all the biological and physical forces except livestock grazing and a stable rangeland ecosystem with all the biological and physical forces including livestock grazing.

Rangeland Reference Areas

Western North Dakota has four "two-way" rangeland reference areas. These reference areas were established by Dr. Warren C. Whitman in the Pyramid Park Region on the eastern edge of the breaks of the Little Missouri River Badlands in 1936-1938. The sites were selected to represent four of the major grassland types of the region (Hanson and Whitman 1938); grassland types would be labeled as range sites in today's terminology. All four sites are located in Billings County, south of the city of Medora.

The Sandy Upland Rangeland Reference Area was classified as the Sandgrass grassland type (Sandy range site), with prairie sandreed *(Calamovilfa longifolia*) as the dominant grass. The reference area is located in Section 15, T138N, R102W, has slopes of 2% east, northeast, and west, has an exclosure of 6.3 acres, and was established in 1938.

The Badlands Upland Rangeland Reference Area was classified as the Grama-needlegrass-sedge grassland type (Shallow range site), with blue grama (*Bouteloua gracilis*), needleandthread (*Stipa comata*), and upland sedges (*Carex filifolia* and *C. heliophila*) as the dominant grasses. The reference area is located in Section 5, T138N, R101W, has a slope of 3% north, has an exclosure of 6.2 acres in two parts, and was established in 1937.

The Badlands Slope Rangeland Reference Area was classified as the Western wheatgrass-grama-sedge grassland type (Silty range site), with blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and upland sedge (*Carex filifolia*) as the dominant grasses. The reference area is located in Section 3, T138N, R101W, has a slope of 3% south, has an exclosure of 14 acres, and was established in 1937.

The Sagebrush Flat Rangeland Reference Area was classified as the Sagebrush type (Overflow range site), with silver sage (*Artemisia cana*) as the dominant shrub and western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and green needlegrass (*Stipa viridula*) as the dominant grasses. The reference area is located in Section 11, T138N, R101W, has a slope of less than 1%, has an exclosure of 4.2 acres, and was established in 1937.

Whitman (1953) reported that these four rangeland reference areas were established in 1936 by an informal agreement with the United States Department of Agriculture Resettlement Administration. When the USDA Soil Conservation Service took over the administration of the Land Utilization Project, a formal lease agreement was signed in 1939 by the North Dakota Agricultural Experiment Station and Soil Conservation Service. The lease agreement was for 50 years, and it was

automatically renewable every eight years. When the USDA Forest Service took over the administration of the Little Missouri National Grassland, the agency honored the previous lease agreement and issued an Occupancy Permit in 1955. This Terminable Permit was annually renewable as long as the requirements and conditions were met. In 1987, the USDA Forest Service issued a Special Use Permit to North Dakota State University Agricultural Experiment Station for scientific study of the four Grassland Ecosystem Reference Areas. This special use permit is valid until 31 December 2004 and is assumed to be renewable if the requirements and conditions of the permit are met.

The four rangeland reference areas in Pyramid Park are the oldest and best scientifically documented reference areas in North Dakota and possibly in the Northern Plains. Dr. Whitman established these rangeland reference areas for the purpose of studying the long-term effects of grazing on four typical grassland ecosystems by monitoring changes in herbage production, plant species composition, and soil characteristics. Eight years of data were collected by Dr. Whitman during the years following establishment on locations within the exclosures and similar areas outside the exclosures that were exposed to grazing. Six years of additional data were collected by Dr. Whitman after 1952, but this data collection was not as intensive as the data collection before World War II.

Dr. Michael Brand continued this project with intensive research data collection at these sites from 1976 through 1978 to document the changes in vegetation and soils of the exclosures and adjacent grazed areas after 40 years. A summary of Dr. Brand's data reported in Brand 1980 and Brand and Goetz 1986 is included in this report.

Methods and Treatments

Dr. Brand collected data on aboveground herbaceous production, belowground biomass, and plant species composition. The aboveground herbaceous production was sampled by clipping ten $0.5m^2$ quadrats per plot per year to ground level in August, 1976-1978. Species categories were separated on one quadrat and estimated on nine quadrats. Belowground biomass was sampled with 20 soil cores, 2.1 cm in diameter, per plot to a depth of 4 feet in August 1978. Plant species composition was sampled using the 10-pin point frame with 3000 points per plot per year in June and July, 1976-1978 (Brand 1980, Brand and Goetz 1986).

The barbed wire fence on the exclosures has stayed intact fairly well over the years. There have been a few brief periods with broken wire permitting cattle to enter the exclosures. These incidents have been so infrequent that it is assumed that no changes to the range ecosystem have been made as a result of livestock within the exclosures. All exclosure fences had major replacement and repair work done in 1987 and 1988 and are in good condition. The Badlands Slope exclosure was observed to have a patch of leafy spurge (*Euphorbia esula*) in 1982; it was sprayed several times with Tordon 22K until 1987, when the stem density was determined to be 90 to 95% reduced. This patch has again increased in recent years. The portion of the reference areas within the exclosures represents stable rangeland ecosystems for western North Dakota with all the biological and physical forces except large grazing herbivores.

The portions of the reference areas that are outside the exclosures have been annually exposed to seasonlong grazing by livestock, primarily cow-calf pairs. The grazing treatments are part of larger grazing units that are allotments in the Little Missouri National Grassland, administered by USDA Forest Service and managed in cooperation with North Dakota Grazing Associations. Grazing permits for these allotments run from 1 May through 31 December, but in most years the grazing season has been shortened to seven months because of inclement weather conditions. The average utilization of the vegetation at these reference areas was determined by Dr. Whitman with Ocular Estimates to be 40 to 50% from 1952 through 1978. The portion of the reference areas outside the exclosures represents stable rangeland ecosystems for western North Dakota with all the biological and physical forces including large grazing herbivores. This portion of the reference areas was managed with moderate, 7- to 8-month seasonlong grazing treatments.

Discussion

Dr. Brand's data show that the aboveground herbage biomass was not very different between the exclosure and grazed treatments at each reference area (table 1) except that the exclosure at the silty range site had greater graminoid herbage production primarily because of an increase in Kentucky bluegrass (*Poa pratensis*) and the exclosure at the shallow range site had a greater graminoid herbage production primarily because of an increase in upland sedges. The mulch biomass on each exclosure was significantly greater than the mulch biomass on the grazed treatments (table 1) and was an accumulation of four or five years of herbage production. This mulch ties up some of the nutrients required for new

plant growth and reduces the amount of sunlight reaching the soil surface.

The belowground biomass, which can have portions with variable ages from current year to about five years old, was generally greater on the grazed treatments of each reference area (table 2) except on the shallow range site, which had belowground biomass about the same on each plot. Whitman (1974) found that the belowground biomass was consistently greater on the grazed treatments than on the exclosures during his microclimate studies in western North Dakota.

Shortgrasses made up a greater percentage of the aboveground biomass on all the grazed plots than on the exclosures (table 3). Sedges made up a greater percentage of the aboveground biomass on the exclosures than on the grazed plots (table 3) except on the overflow range site. Mid and tall grasses made up a greater percentage of the aboveground biomass on the grazed plots of the sandy range site and shallow range site than on the exclosures (table 3). Mid and tall grasses made up a greater percentage of the aboveground biomass on the exclosure of the silty range site than on the grazed plot (table 3). This increase in biomass in the silty range site exclosure was primarily from Kentucky bluegrass. Aboveground biomass of mid and tall grasses on the overflow range site was about the same on the grazed plot and exclosure (table 3).

Basal cover of short grasses was greater on the grazed plots of all four reference areas than on the exclosures (table 4). Basal cover of upland sedges was greater on the exclosures than on the grazed plots on all reference areas except the overflow range site, which did not have upland sedge (table 4). Basal cover of mid and tall grasses was about the same on the grazed plots and exclosures of the sandy range site and overflow range site (table 4). Basal cover of mid and tall grasses was greater on the grazed plot on the shallow range site and greater on the exclosure on the silty range site (table 4).

Basal cover of total graminoids and total herbaceous plants was greater on the grazed plots of all the reference areas than on the exclosures (table 5). Blue grama basal cover was greater on the grazed plots of all the reference areas, and upland sedge basal cover was greater on the exclosures of all the reference areas (table 5) except the overflow range site, which did not have upland sedge. Kentucky bluegrass basal cover was greater on the exclosure of the silty range site, and prairie sandreed basal cover was greater on the exclosure of the sandy range site (table 5). Western wheatgrass showed a tendency to have greater basal cover on the grazed plots of all the reference areas (table 5). Plains reedgrass showed a tendency to have greater basal cover on the grazed plots (table 5) except on the overflow range site. Needleandthread showed a tendency to have greater basal cover on the grazed treatments of the shallow and overflow range sites (table 5) and a tendency to have greater herbage production on the grazed treatments of the silty and overflow range sites (Brand and Goetz 1986). The basal cover and herbage production for needleandthread were about the same on each plot of the sandy range site (table 5, Brand and Goetz 1986).

Summary

These four reference areas show the differences in rangeland ecosystems on sandy, shallow, silty, and overflow range sites after 40 years without livestock grazing and 40 years of 7 to 8 months of moderate seasonlong grazing. Generally, the aboveground herbage production was about the same for most categories on the grazed plots and exclosures; the exceptions were Kentucky bluegrass production and upland sedge production, which were great enough on the exclosures of the silty range site and shallow range site, respectively, to show an increase in total graminoid production on the respective exclosures. Mulch biomass was greater on all exclosures than on grazed plots. Belowground biomass was greater on grazed plots except on the shallow range site which had about the same biomass as the exclosure. Graminoid and total herbaceous plant basal cover was greater on all grazed plots of the reference areas. Blue grama basal cover was greater on the grazed plots. Upland sedge basal cover was greater on the exclosures. Kentucky bluegrass basal cover and prairie sandreed basal cover were greater on the exclosures of the silty and sandy range sites, respectively.

Moderate 7- to 8-month seasonlong grazing management is generally considered by most range managers not to be beneficial to the rangeland ecosystem, and several other grazing management practices have been found to be improvements over this type of seasonlong grazing practice (Sarvis 1941, Manske et al. 1988, Manske 1994). Forty years of 7- to 8-months of moderate seasonlong grazing at these reference areas has not reduced the aboveground herbage production as would be expected. The reference areas under this grazing treatment have greater belowground biomass and graminoid basal cover than the ecosystems inside the exclosures. The exclosures at the reference areas have eliminated one important biological force from the rangeland

ecosystem--the large grazing herbivore. Most rangeland plants have evolved mechanisms that permit the plants to coexist and thrive with grazing herbivores (Manske 1994). Large grazing herbivores have been an integral part of the rangeland ecosystem for 20 million years and need to continue to be a part of the rangeland ecosystem.

Conclusions

The 7- to 8-month seasonlong grazing management treatment is generally considered to be inferior to many other grazing management practices, but Dr. Brand's data point out that even with this type of grazing treatment, the rangeland ecosystems with large grazing herbivores show ecological benefits over ecosystems that have eliminated the large grazing herbivores. When improved grazing management practices are used to manage the grazing herbivores, the ecological benefits to the rangeland ecosystems are even greater than those of 8-month seasonlong grazing treatment. Management practices and recommendations that eliminate the large grazing herbivores will develop ecosystems that are not as ecologically healthy over the long term as rangeland ecosystems that include large grazing herbivores. Rangeland management practices must be ecologically beneficial to the ecosystem to be sustainable for the long term.

Table 1. Mean aboveground herbage biomass in lbs/acre, 1976-1978.

	Sandy Upland		**Badlands Upland**		**Badlands Slope**		**Sagebrush Flat**	
	Sandy Range Site		Shallow Range Site		Silty Range Site		Overflow Range Site	
	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y
GRASSES								
Mid and Tall	775.	726.	267.	195.	937.	**1639.**	2022.	1917.
Short	161.	13.	323.	233.	371.	66.	109.	5.
Sedges	370.	650.	141.	**682.**	35.	239.	0.	0.
TOTALS								
Graminoids	1286.	1390.	731.	**1101.***	1342.	**1944.***	2131.	1921.
Forbs	78.	70.	**382.***	136.	270.	142.	49.	103.
Herbage	1363.	1460.	1112.	1237.	1613.	**2085.***	2179.	2023.
Mulch	1694.	**2746.***	405.	**1722.***	805.	**3392.***	1578.	**4338.***

* Significantly different from comparable treatment (P<0.05)
Brand 1980, Brand and Goetz 1986

Table 2. Mean belowground biomass in lbs/acre, 1978.

	Sandy Upland		**Badlands Upland**		**Badlands Slope**		**Sagebrush Flat**	
	Sandy Range Site		Shallow Range Site		Silty Range Site		Overflow Range Site	
	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y
0" - 12"	**28,276**	25,342	21,060	22,692	**18,545***	13,300	**25,172***	16,984

* Significantly different from comparable treatment (P<0.05)
Brand 1980, Brand and Goetz 1986

Table 3. Percent composition of aboveground biomass by growth form, 1976-1978.

	Sandy Upland		**Badlands Upland**		**Badlands Slope**		**Sagebrush Flat**	
	Sandy Range Site		Shallow Range Site		Silty Range Site		Overflow Range Site	
	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y
GRASSES								
Mid and Tall	**55.4**	49.7	**24.0**	15.8	58.1	**78.6**	92.8	94.8
Short	**11.8**	0.9	**29.0**	18.0	**23.0**	3.2	**5.0**	0.2
Sedges	27.2	**44.5**	12.7	**55.2**	2.2	**11.5**	0.0	0.0
Forbs	5.6	4.8	**34.3**	11.0	16.8	6.8	2.3	5.1

Brand 1980, Brand and Goetz 1986

Table 4. Mean percent basal cover by growth form, 1976-1978.

	Sandy Upland		**Badlands Upland**		**Badlands Slope**		**Sagebrush Flat**	
	Sandy Range Site		Shallow Range Site		Silty Range Site		Overflow Range Site	
	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y
GRASSES								
Mid and Tall	1.2	1.2	**1.0**	0.2	1.3	**1.5**	2.0	1.9
Short	**2.3**	0.0	**3.6**	0.8	**2.3**	0.4	**0.5**	0.0
Sedges	3.3	**4.6**	0.8	**2.7**	0.3	**0.5**	0.0	0.0
Forbs	0.1	0.2	0.4	0.1	0.3	0.1	0.1	0.1

Brand 1980

Table 5. Mean percent basal cover by species, 1976-1978.

	Sandy Upland		**Badlands Upland**		**Badlands Slope**		**Sagebrush Flat**	
	Sandy Range Site		Shallow Range Site		Silty Range Site		Overflow Range Site	
	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y	Grazed 8.0M	Not Grazed 40Y
GRASSES								
Western Wheatgrass	0.2	0.1	0.1	<0.1	**0.7**	0.5	**0.9**	0.3
Blue grama	**2.3**	0.1	**3.3**	0.8	**2.2**	0.4	**0.5**	0.0
Plains reedgrass	0.1	0.0	**0.3**	<0.1	0.1	0.0	0.4	**1.0**
Prairie sandreed	0.2	**0.5**	-	-	-	-	-	-
Kentucky bluegrass	<0.1	<0.1	-	-	<0.1	**0.7**	<0.1	0.0
Needleandthread	0.6	0.6	0.2	0.1	0.1	0.1	0.1	0.0
Green needle	-	-	<0.1	0.0	0.0	0.1	0.3	0.4
Other grasses	0.2	0.1	**0.7**	0.2	**0.5**	0.2	0.2	0.2
Upland sedge	3.3	**4.6**	0.8	**2.7**	0.3	**0.5**	-	-
TOTALS								
Graminoids	**6.8**	5.8	**5.4**	3.7	**3.9**	2.4	**2.4**	1.9
Forbs	0.1	0.2	0.4	0.1	0.3	0.1	0.1	0.1
Herbaceous	**6.9**	5.9	**5.8**	3.8	**4.2**	2.5	**2.5**	2.0

Brand 1980

Literature Cited

Brand, M.D. 1980. Secondary succession in the mixed grass prairie of southwestern North Dakota. PhD Dissertation. North Dakota State University. Fargo, ND. 77p.

Brand, M.D., and H. Goetz. 1986. Vegetation of exclosures in southwestern North Dakota. Journal of Range Management 39:434-437.

Hanson, H.C., and W. Whitman. 1938. Characteristics of major grassland types in western North Dakota. Ecological Monographs 8:57-114.

Manske, L.L. 1994. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program, Regina, Saskatchewan.

Manske, L.L., W.T. Barker, and M.E. Biondini. 1988. Effects of grazing management treatments on grassland plant communities and prairie grouse habitat. U.S.D.A. Forest Service. General Technical Report RM-159. p. 58-72.

Sarvis, J.T. 1941. Grazing investigations on the Northern Great Plains. North Dakota Agricultural Experiment Station Bulletin 308. 110p.

Whitman, W.C. 1953. Pyramid Park experimental area laboratory for rangeland research. North Dakota Agricultural Experiment Station Bimonthly Bulletin 16:63-66.

Whitman, W.C. 1974. Influence of grazing on the microclimate of mixed grass prairie. p. 207-218. *in* Plant Morphogenesis as the basis for scientific management of range resources. U.S.D.A. Miscellaneous Publication 1271.

Effects of Grazing Management Treatments on Rangeland Vegetation

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Grazing is not simply the removal of leaf material from grass plants. The effects of defoliation of leaf material by grazing are complex. Different grazing management treatments cause diverse changes in plant growth, and these changes affect the quantity and quality of the aboveground herbage biomass produced on grasslands. Grazing can change plant species composition, manipulate some plant and ecosystem processes, and alter levels and rates of plant growth.

The timing and severity of grazing determine whether detrimental or beneficial effects occur. Repeated heavy grazing removes a great amount of the leaf area and causes long-term reductions in the total quantity of herbage produced. Early grazing--grazing before the grass tillers have reached the third new leaf stage--and late grazing--grazing during the fall, after the end of the growing season--both reduce herbage biomass on grasslands. In contrast, grazing that is coordinated with grass growth stages is beneficial to plant growth mechanisms and ecosystem processes and stimulates greater herbage production.

The purpose of this study is to document and compare herbage biomass production, plant basal cover, and vegetative tiller development on native rangeland pastures of grazing management systems during the grazing season.

Procedure

This study was conducted at the NDSU Dickinson Research Extension Center, located in western North Dakota, U.S.A. (47°14'N.lat., 102°50'W.long.). Soils are primarily Typic Haploborolls. Mean annual temperature is 42.2°F (5.7°C). Average annual precipitation is 16.6 inches (420.9 mm). The growing-season precipitation (April to October) is 14.0 inches (356.7 mm), 85.0% of the annual precipitation (Manske 2003). The native rangeland vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie. The dominant species are western wheatgrass, needle and thread, blue grama, and threadleaf sedge.

Plant growth data were collected on permanent plots organized in a paired-plot design. Each of the replicated treatments was stratified on the basis of three range sites (sandy, shallow, and silty). Samples from the grazed treatments were collected on both grazed quadrats and ungrazed (protected with cages) quadrats and exclosures. Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986) on 7 sampling dates from May to October. Material was sorted by biotype categories (cool-season grasses, warm-season grasses, sedge, forb, standing dead, and litter) and oven dried. Plant species composition was determined during peak growth by the ten-pin point frame method (Cook and Stubbendieck 1986) between mid July and mid August. Grass plant tiller development in response to timing and severity of grazing was evaluated for 2 years following a defoliation treatment. These data were collected on individually marked tillers of western wheatgrass in microplots within exclosures in pastures of long-term grazing management treatments. The time of defoliation was mid May or mid June and the severity of defoliation was 50%, 25%, or 0%. A standard paired plot t-test was used to analyze differences between means (Mosteller and Rourke 1973).

Plant growth data were collected on native rangeland grazing treatments and a nongrazed treatment involved in pasture research projects. The stocking rates of the grazing management treatments were determined for proper full use of the forage produced on the pastures. The long-term nongrazed treatment had not been grazed, mowed, or burned for more than 30 years prior to the start of data collection. The 6.0-month seasonlong treatment native rangeland pasture was grazed by cow-calf pairs for 183 days, from mid May to mid November. The 4.5-month seasonlong treatment native rangeland pasture was grazed by cow-calf pairs for 135 days, from early June to mid October. The twice-over rotation treatment native rangeland pastures were grazed by cow-calf pairs for 135 days, from early June to mid October. Each of the three pastures was grazed for two periods, one period of 15 days between early June and mid July (third-leaf stage to flowering stage), followed by a second period of 30 days after mid July and prior to mid October.

Results

Herbage biomass was greatest on the twice-over rotation treatment (table 1, figure 1). The measurement of the amount of herbage standing after each grazing period does not include the amount of vegetation removed by livestock during the grazing period. The amount of herbage remaining on pastures following grazing was significantly greater in July, August, and September on the twice-over rotation treatment than on the seasonlong treatment. The seasonlong treatment averaged 29% less herbage standing after grazing than the twice-over rotation treatment. The quantity of herbage biomass remaining after grazing on the twice-over rotation treatment was greater than the current year's herbage growth on the long-term nongrazed treatment during the entire growing season; however, during August, the herbage remaining after grazing on the twice-over rotation treatment was not significantly different from the peak herbage on the nongrazed treatment. An average of 15% more herbage remained standing after each grazing period on the twice-over rotation treatment than the amount that grew on the nongrazed treatment. The seasonlong treatment averaged 8% less herbage standing after grazing than the amount that grew on the long-term nongrazed treatment. The amount of herbage remaining standing at the end of the grazing season on the twice-over rotation treatment was significantly greater than the herbage remaining on the nongrazed and seasonlong treatments. The greater amount of photosynthetic leaf area of the herbage remaining on the twice-over rotation treatment in mid October, at the end of the growing season, was beneficial for the continued functioning of the grassland ecosystem at a higher production level.

Grass basal cover (table 2) was greatest on the twice-over rotation treatment. Grass basal cover was 25% greater on the twice-over rotation treatment than on the seasonlong treatment. Sedge basal cover was 4% greater on the seasonlong treatment than on the twice-over rotation treatment. Forb basal cover was 36% less on the twice-over rotation treatment than on the seasonlong treatment. The greater number of forbs on the seasonlong treatment was primarily less desirable plants, both introduced and native. Most undesirable and less desirable plants are not very competitive and are not the cause of pasture problems, but they are symptoms indicating that problems exist. These plants are opportunistic and can grow in the bare spots of plant communities that are below their potential plant density.

The total plant basal cover on the twice-over rotation treatment was 9.2% greater than that on the seasonlong treatment and 30.2% greater than that on the nongrazed treatment. The relative percent composition of the plant communities (table 3) on the twice-over rotation treatment consisted of 14% more grass, 14% less sedge, and 40% less forbs and shrubs than composition of the seasonlong treatment plant communities. The average percent of ground not covered by vegetation was lowest on the twice-over rotation treatment (4.8%), followed by the seasonlong treatment (7.0%) and the nongrazed treatment (12.1%).

The greatest number of western wheatgrass tillers per square meter developed on the twice-over rotation treatment (table 4). The tiller density on the twice-over rotation treatment was 70.0% greater than that on the 6.0-month seasonlong treatment and 183.3% greater than that on the 4.5-month seasonlong treatment. The defoliation treatment that stimulated the greatest number of tillers was 25% removal of leaf material in mid June. The greatest number of stimulated tillers grew on the twice-over rotation treatment. The defoliation treatment that removed 25% of the leaf material in mid June on the twice-over rotation grazing treatment produced 123.8% more tillers than the same defoliation treatment on the 6.0-month seasonlong grazing treatment and 193.8% more tillers than that on the 4.5-month seasonlong grazing treatment. The defoliation treatment that removed 50% of the leaf material in mid June tended to suppress tiller numbers below the number of tillers produced by plants that had no defoliation treatment for two years on all three grazing treatments.

Discussion

Grazing periods that are coordinated with grass growth stages activate the defoliation resistance mechanisms that grass plants developed in response to a long history of grazing. Properly timed grazing that removes only a small portion, about 10% to 33%, of the leaf material from grasses that are between the third-leaf and flowering growth stages triggers the beneficial biological processes that increase the symbiotic activity of soil organisms in the rhizosphere and stimulate vegetative reproduction of grasses by secondary tiller development from axillary tiller buds located on the plant crown. The proliferation of grass tiller development fills in soil bare areas, reducing the less desirable plants and increasing grass density and grass growth to produce an average of 30% to 45% greater herbage biomass. The increase of herbage biomass permits an increase in stocking rates. The stocking rate on the native rangeland pastures managed by the twice-over rotation treatment was 40% greater than the stocking rate on the native rangeland of the 4.5-month

seasonlong treatment and 90% greater than the stocking rate on the native rangeland of the 6.0-month seasonlong treatment.

The defoliation resistance mechanisms do not function at full capacity following a single stimulation event. Grass tiller numbers and herbage biomass usually rise in increasing increments in grassland ecosystems for about 3 to 5 years following implementation of a biologically effective twice-over rotation system. After the ecosystem's biogeochemical cycles are functioning at elevated levels and vegetative reproduction by tillering occurs at enhanced rates, the momentum of these activities will not stop immediately upon suspension of stimulation from defoliation at appropriate times and severities but will decrease in stages. Maintaining healthy grassland ecosystem performance at sustainable high levels requires long-term biologically effective grazing management that places priorities on meeting the biological requirements of the plants and on facilitating ecological processes.

Acknowledgment

I am grateful to Sheri Schneider for assistance in production of this manuscript. I am grateful to Amy M. Kraus for assistance in preparation of this manuscript.

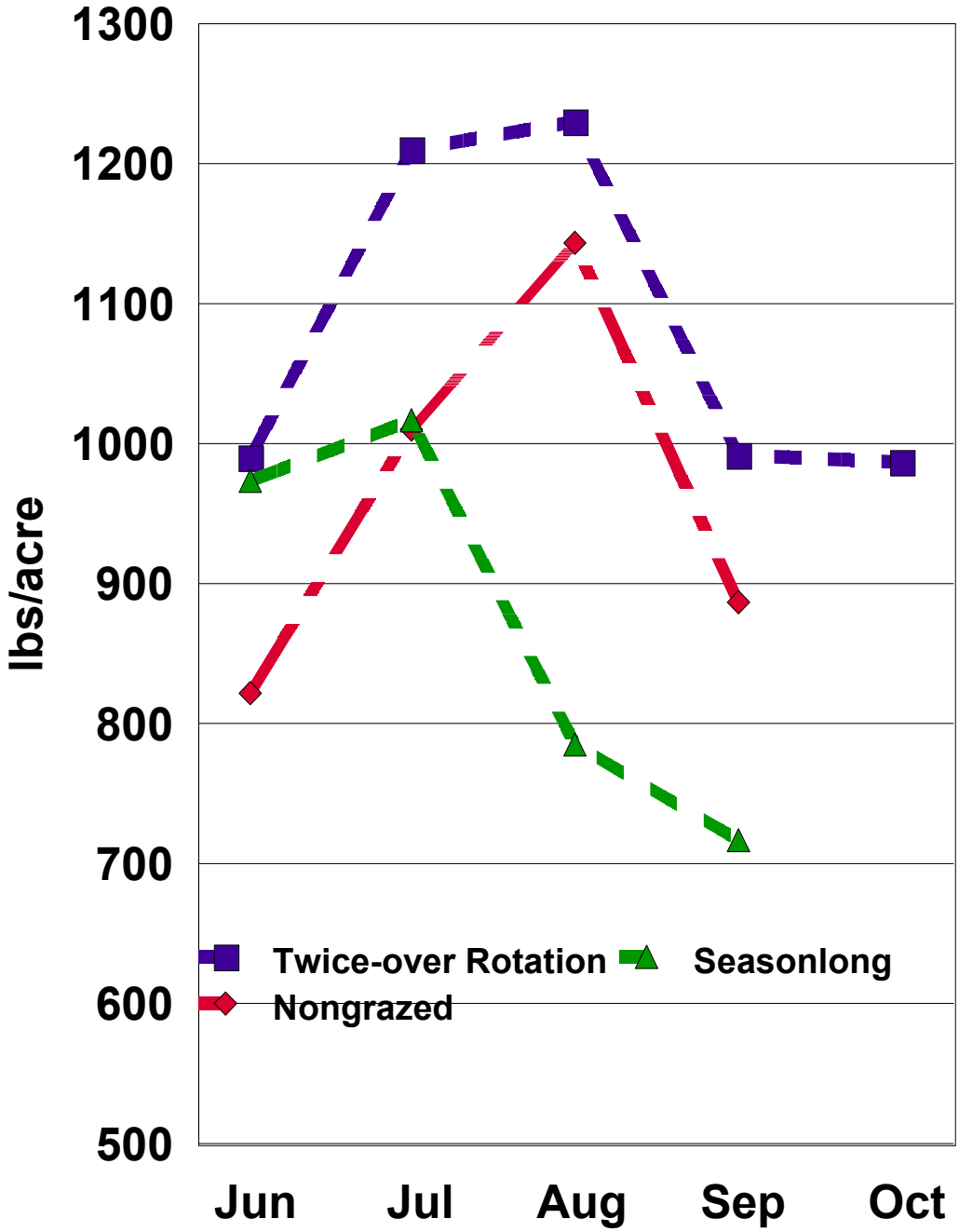


Fig 1. Herbage biomass remaining after monthly grazing periods.

Table 1. Mean herbage biomass in lbs/ac remaining after monthly grazing periods.

	Grazing Periods				
Grazing Treatments	Jun	Jul	Aug	Sep	Oct
Nongrazed	822a	1010a	1144a	888a	-
Seasonlong	974a	1017a	785b	717a	-
Twice-over rotation	990a	1211b	1231a	993b	987

Means of same column followed by the same letter are not significantly different (P<0.05).

Table 2. Mean percent basal cover.

	Grazing Treatments		
Plant Type	Seasonlong	Twice-over rotation	% Difference
Grass	14.7	18.6	+25.2
Sedge	7.7	7.6	-3.8
Forb	3.8	2.4	-35.9
Shrub	0.1	0.1	-

Table 3. Mean relative percent composition of plant communities.

	Grazing Treatments		
Plant Type	Seasonlong	Twice-over rotation	% Difference
Grass	55.1	63.2	+14.1
Sedge	30.6	28.0	-13.6
Forb and Shrub	14.5	8.7	-39.6

Table 4. Number of western wheatgrass tillers per square meter two years after defoliation treatment.

	Defoliation Treatments		
Grazing Treatments	No Defoliation for 2 years	mid June 25%	mid June 50%
6.0-m Seasonlong	626.5	657.9	563.9
4.5-m Seasonlong	375.9	501.2	344.6
Twice-over rotation	1065.1	1472.3	908.5

Literature Cited

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Manske, L.L. 2003. Ombrothermic interpretation of range plant water deficiency from temperature and precipitaiton data collected at the Ranch Headquarters of the Dickinson Research Extension Center in western North Dakota, 1982-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1019f. Dickinson, ND. 17p.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Suppression of Grasshopper Population Numbers with Biologically Effective Grazing Management

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Rangeland pestiferous grasshopper populations tend to increase when grassland habitat conditions are favorable for the development of the insect from egg to adult. Periodically, favorable habitat for rangeland grasshoppers develops in grasslands, and high numbers of grasshoppers are produced. These outbreaks cause major problems for the regions in which they occur. On traditionally managed grazinglands in the Northern Plains, grasshopper populations tend to reach high outbreak densities when plant canopy height and ground cover are reduced and herbage production is low. These conditions occur as a result of grazing-management-caused problems or during years with hot temperatures and low precipitation (Onsager 1996, 2000). The grasshopper population outbreaks can occur as the outward expansion of a "hot spot" or as an escalation of low to high numbers across an area (Lockwood, Brewer, and Schell 1996).

Problems with high numbers of grasshoppers can be reduced by improving grassland habitat to be unfavorable for these pests. Habitat condition on grasslands can be modified by biologically effective grazing management practices that increase the amount of vegetation cover, thereby reducing grasshopper numbers and suppressing population outbreaks.

Grazing management strategies that repeatedly remove most of the vegetation on grasslands reduce plant density and herbage biomass production. Areas with open vegetation canopy and spots of bare ground are favorable grasshopper habitat. With reduced vegetation canopy cover and enlarged areas of bare ground, the amount of solar radiation that reaches the soil surface increases, as does the airflow over the ground. The reduced vegetation structure results in higher air and soil temperatures and lower humidity in grasshopper habitat.

Grassland habitat with open vegetation canopy and areas of bare ground provides ideal basking sites, where grasshoppers warm themselves in the early morning sun to speed metabolic rates and increase growth rates (Belovsky et al. 2000). Patches of bare ground also are favored egg-laying sites. Higher soil and air temperatures accelerate grasshopper egg development, growth and maturation of young insects, and egg production of adult females. In addition, habitat with intense sunlight and low humidity near the soil discourages the growth of important pathogens that cause grasshopper diseases. As a result, mortality rates of immature grasshoppers decline and greater numbers of the insects survive into adulthood.

Many traditional management practices produce habitat favorable for grasshopper population outbreaks. Common practices that help grasshopper populations increase to problem levels include beginning grazing before plants have reached the third-leaf stage; grazing spring and summer pastures or haylands during the fall; and management treatments such as seasonlong, deferred, and repeat seasonal grazing that leave little residual vegetation following defoliation periods.

Onsager (2000) listed three attributes of grazing management that deters grasshopper outbreaks in the Northern Plains: (1) deliberate variation from year to year in the time and intensity of defoliation periods, (2) controllable preservation or enhancement of shading canopy during critical portions of grasshopper life cycles, and (3) reduction or elimination of bare soil.

A joint research project was conducted in western North Dakota by Dr. Lee Manske, NDSU, Dickinson Research Extension Center, Dickinson, ND, and Dr. Jerry Onsager, retired research entomologist, USDA-Agricultural Research Service, Sidney, MT, to evaluate and compare the grassland habitat conditions and grasshopper population numbers on a seasonlong grazing treatment and a twice-over rotation treatment (Manske and Onsager 1996, Stelljes 1996).

The twice-over rotation grazing treatment had denser basal cover, less bare ground, and greater herbage biomass than the seasonlong treatment. The grass basal cover on the twice-over rotation treatment was 25.2% greater than that on the seasonlong treatment (Manske 1995, 1996). The average percent of ground not covered by vegetation was lowest on

the twice-over rotation treatment, followed by the seasonlong treatment, and greatest on the nongrazed treatment. The twice-over rotation treatment had 31% less open area in the vegetation canopy than the seasonlong treatment (Manske 1995). Herbage production was greater on the twice-over rotation treatment than on the seasonlong treatment. The twice-over rotation treatment produced an average of 33% to 45% more herbage during each growing-season month than did the seasonlong treatment (Manske 1995, 1996).

Onsager (2000) followed grasshopper numbers for five growing seasons on native rangeland areas managed with a seasonlong treatment or the twice-over rotation treatment. The average number of grasshopper days per square meter was 748 on the seasonlong treatment, considerably greater than the average of 229 on the twice-over rotation treatment. During the last two years of the study, a local grasshopper outbreak (figure 1) with an average density of 22.6 adult grasshoppers per square meter occurred on the seasonlong treatment. This population outbreak did not occur on the twice-over rotation treatment, which maintained an average of only 3.9 adult grasshoppers per square meter.

The seasonlong treatment decreased the vegetation cover and promoted grasshopper population increases. The twice-over rotation treatment enhanced the vegetation cover and suppressed grasshopper population increases.

The twice-over rotation system is effective in grasshopper management because the grazing treatment properly times defoliation to lead to greater plant density and herbage production and fewer open areas in the vegetation canopy cover. These plant community characteristics develop because the biologically effective twice-over rotation system coordinates grazing with grass growth stages and removes a small amount of leaf material from grass plants between the third-leaf stage and the flowering stage. This timed defoliation stimulates plant processes and soil organism activity that enhance plant growth, and the resulting greater herbage biomass production leads to grassland habitat conditions unfavorable for grasshopper population increases.

Areas with habitat unfavorable to grasshoppers are those on which plant density is increased so that only a few small spots of bare ground occur and on which adequate herbage biomass remains after grazing periods so that the vegetation canopy is nearly closed. The improvement in the vegetation characteristics of rangeland managed with the twice-over rotation system reduces the amount of sunlight reaching the ground, increases the humidity, and lowers the temperature within the grasshopper habitat. In these grassland habitat conditions, grasshopper metabolic rates and growth rates slow and disease increases mortality rates among grasshoppers. These changes negatively affect the growth and survival of immature grasshoppers in the nymphal stages and result in reduced grasshopper numbers and in suppression of local grasshopper population outbreaks (Onsager 2000).

Producers can suppress potential grasshopper population outbreaks by implementing biologically effective grazing management that minimizes habitat favorable to the insects. Three management practices can be used to develop grassland habitat unfavorable for grasshopper outbreaks: (1) delaying the start of grazing until grasses have reached the third-leaf stage (early May for crested wheatgrass and smooth bromegrass and early June for native rangeland), (2) grazing native rangeland with a twice-over rotation management system that coordinates rotation dates with plant growth stages, and (3) grazing complementary forage types during the fall rather than grazing spring and summer pastures or haylands late in the season.

Implementing improved cultural management practices is not a quick fix to a major problem. Grazing management strategies that produce habitat unfavorable for grasshopper population outbreaks are a long-term solution to grasshopper problems and take three or more years to show substantial results. Pastures that are grazed using traditional management practices and that have had problems with increased grasshopper numbers need a change of management treatments to biologically effective grazing management practices that stimulate plant mechanisms and ecosystem processes to increase plant density and vegetation canopy.

The twice-over rotation system is a biologically effective grazing management treatment that has the three attributes needed to deter grasshopper outbreaks in the Northern Plains. The twice-over rotation grazing system: (1) deliberately varies the time and intensity of defoliation from year to year, (2) controllably enhances vegetation shading canopy during critical portions of grasshopper life cycles, and (3) reduces and almost eliminates bare soil areas. The twice-over rotation system can be used in the Northern Plains to successfully manage grasshopper population numbers.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

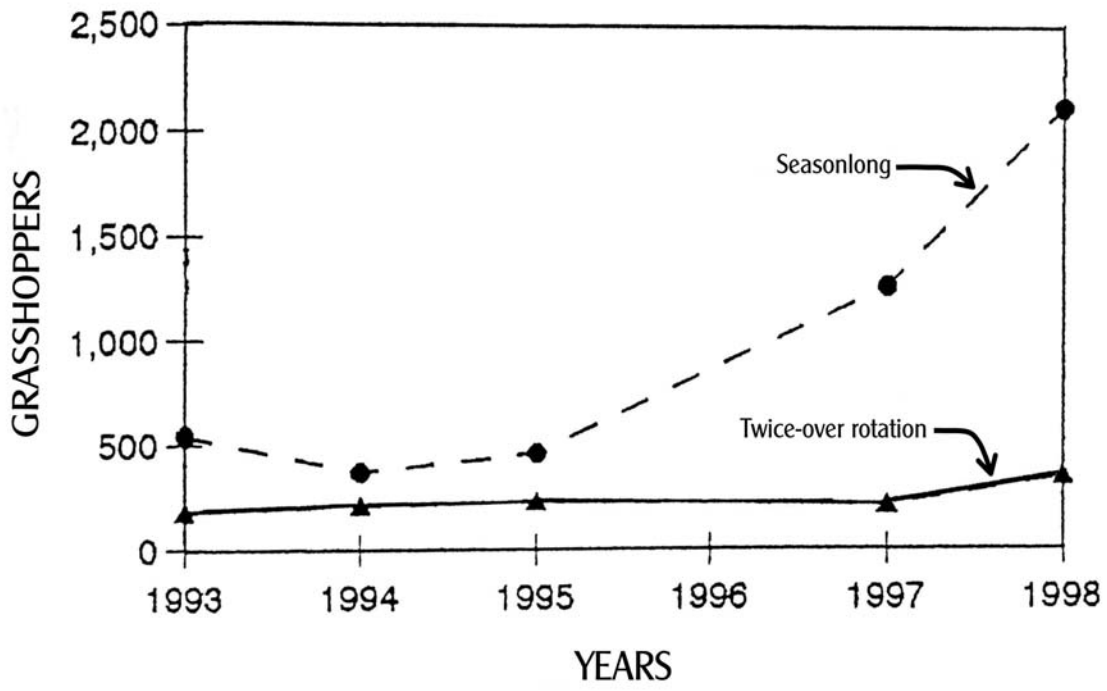


Fig. 1. Grasshopper population outbreak occurring on the seasonlong treatment during 1997 and 1998 but not occurring on the twice-over rotation treatment. Grasshopper abundance reported as grasshopper days per square meter, data from Onsager 2000.

Literature Cited

Belovsky, G.E., M.A. Brusven, D.J. Fielding, and L. Manske. 2000. Grasshopper habitat manipulation. United States Department of Agriculture, Animal and Plant Inspection Service, Grasshopper Integrated Pest Management User Handbook, Technical Bulletin No. 1809, Washington, DC. p.VII.15-1-VII.15-5.

Lockwood, J.A., M.J. Brewer, and S.P. Schell. 1996. Treating localized hot-spots of rangeland grasshoppers: A preventative strategy with promise. United States Department of Agriculture, Animal and Plant Health Inspection Service, Grasshopper Integrated Pest Management User Handbook, Technical Bulletin No. 1809, Washington, DC. p.II.10-1-II.10-8.

Manske, L.L. 1995. Modification to native range vegetation by grazing management to affect grasshopper populations, 1993-1994. NDSU Dickinson Research Extension Center. Range Research Report DREC 95-1006. Dickinson, ND. 12p.

Manske, L.L. 1996. Beneficial changes of rangeland through proper grazing. United States Department of Agriculture, Animal and Plant Inspection Service, Grasshopper Integrated Pest Management User Handbook, Technical Bulletin No. 1809, Washington, DC. p.V.7-1-V.7-7.

Manske, L.L., and J.A. Onsager. 1996. Grasshopper populations can be reduced by grazing management. Proceedings of the National Grasshopper Management Board 1996 Annual Meeting. Rapid City, SD. p. 14-15.

Onsager, J.A. 1996. The importance of grazing strategies to grasshopper management: an introduction. United States Department of Agriculture, Animal and Plant Health Inspection Service, Grasshopper Integrated Pest Management User Handbook, Technical Bulletin No. 1809, Washington, DC. p.V.1-1-V.1-3.

Onsager, J.A. 2000. Suppression of grasshoppers in the Great Plains through grazing management. Journal of Range Management 53:592-602.

Stelljes, K.B. 1996. IPM targets grasshoppers. Agricultural Research. USDA-ARS, Washington, DC. Vol.44:4-10.

Biologically Effective Grazing Management Can Enhance Biogeochemical Cycles and Improve Soil Structure of Rangeland Ecosystems

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Grass plants, grazing mammals, and grassland ecosystem processes have evolved together. During the long period of coevolution, grass plants developed defoliation resistance mechanisms--biological processes that help the plants withstand and recover from grazing. A complex system consisting of soil organisms and having numerous trophic levels is located in the rhizosphere. These symbiotic organisms developed in conjunction with the evolution of plants and interact with grass plants through the roots. The activity of rhizosphere organisms is critical for ecosystem functions and for energy and nutrient flow through the ecosystem. The details of the intricate relationships among the grass plants, the soil organisms in the rhizosphere, and the grazing mammals are not completely understood, but current knowledge has allowed development of biologically effective grazing management practices that beneficially stimulate these biological and ecological processes and improve the performance levels of the components of grassland ecosystems.

The mutually beneficial relationship between rhizosphere soil organisms and the roots of the grass plant can be enhanced by properly timed grazing. The rhizosphere--the narrow zone of soil around the roots of perennial grassland plants--contains bacteria, protozoa, nematodes, mites, springtails, and endomycorrhizal fungi. The grass plant's roots release carbon compounds, including simple sugars, to these organisms, and the rhizosphere organisms release mineral nitrogen that the plant's roots absorb. Grassland soils contain abundant quantities of nitrogen, but most of it is in the organic form and unavailable for direct use by plants. Soil microorganisms convert organic nitrogen to mineral nitrogen, the form that plants can use. Activity of the soil microorganisms increases with the availability of carbon compounds in the rhizosphere, and elevated microorganism activity results in increased mineral nitrogen available to the grass plant. The endomycorrhizal fungi also provide phosphorus, other mineral nutrients, and water that the plant needs for growth.

Grazing lead tillers between the third-leaf stage and the flowering stage can increase the amount of carbon compounds the defoliated plant releases into the rhizosphere. The increase in mineral nitrogen made available by elevated rates of microorganism activity allows the plant to accelerate growth and recover more quickly from defoliation. This beneficial activity does not seem to occur when grazing is conducted during the middle and late growth stages of the grass plant.

Activity of ectomycorrhizal fungi, a second type of beneficial soil fungi, can be stimulated by biologically effective grazing management. These fungi improve soil structure. Ectomycorrhizal fungi previously unknown in the mixed grass prairie were recently found in association with roots of grass plants managed with the twice-over rotation grazing system, which coordinates grazing periods with grass growth stages when defoliation resistance mechanisms are stimulated. The slow-growing ectomycorrhizal fungi develop a sheath around perennial grass roots and do not enter the tissue of the host plant as endomycorrhizal fungi do.

The ability of ectomycorrhizal fungi to improve soil quality results from their excretion of large amounts of insoluble polysaccharides with adhesive qualities. These substances stabilize soil particles and bind them into water-stable aggregates that range from about the size of air rifle pellets to the size of large marbles. An increase in water-stable aggregates increases soil pore size and distribution. The changes in soil quality improve soil oxygenation, water infiltration, and root distribution and decrease erodibility.

The rooting depth of rangeland soils at the location where ectomycorrhizal fungi were first discovered increased from 2-3 inches to 18-24 inches after seven years of management with the twice-over rotation system. The activity levels of ectomycorrhizal fungi are greater on pastures managed with the twice-over rotation system than on pastures under other grazing management because of the enhanced symbiotic relationship between the rhizosphere and healthy rangeland grasses.

The twice-over rotation grazing management system is biologically effective and applies defoliation treatment to grass plants at the appropriate phenological growth stages to stimulate the defoliation resistance mechanisms. A small amount of leaf material is removed by grazing animals when grasses are between the third-leaf stage and the flowering stage. This timed defoliation promotes the active passage of greater quantities of carbon compounds through the grass plant roots into the rhizosphere and stimulates soil organism activity. The increased activity of rhizosphere organisms, including endomycorrhizal fungi and ectomycorrhizal fungi, speeds the recovery of plants from grazing, improves soil structure, and accelerates the biogeochemical cycles within the grassland ecosystem.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript.

HERBAGE QUALITY AND RANGE COW REQUIREMENTS

Annual Nutritional Quality Curves for Graminoids in the Northern Plains

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Agricultural production from mixed grass prairie rangelands and domesticated grasslands of the Northern Plains can be substantially increased through the implementation of strategies that more efficiently capture the nutrients produced and convert them to a saleable product. Perennial grasses and sedges change in nutritional quality as they develop and mature through phenological stages. Annual nutritional quality curves for forage plants show these changes in nutrient content during the year. Coordination of annual nutritional quality curves of the available perennial forage plants with livestock nutritional requirement curves is necessary to the development of biologically effective management strategies.

The major perennial graminoid plants used as forage by livestock are separated into four categories based on the period during which most of the plant growth occurs: domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses. This report summarizes published information on the annual nutritional quality curves of these graminoids.

Methods

Three publications have reported the nutritional quality of perennial domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses growing on the Northern Plains region of mixed grass prairie from central North Dakota to eastern Montana. The percent crude protein, phosphorus, and moisture, and the growth stage data from these three publications were reported in Manske (1999a,b,c,d) and have been summarized in this paper.

Whitman, Bolin, Klosterman, Klostermann, Ford, Moomaw, Hoag, and Buchanan (1951) published data on the carotene, protein, and phosphorus content of grasses and sedges in western North Dakota. Graminoid species samples were collected weekly in 1946 and 1947 from the Dickinson Experiment Station at Dickinson, North Dakota. Only current year's growth was included in the sample; previous year's growth was separated and discarded. An attempt to collect ungrazed samples was made for available species except Kentucky bluegrass, which had been grazed, and smooth bromegrass, which was cut for hay in mid June. Data were reported as percent of oven-dry weight. Plant condition by stage of plant development and growth habit was reported for each species on sample dates. These data were reported as phenological growth stage in Manske (1999a,b,c,d). A summary of these data is included in this report.

Marsh, Swingle, Woodward, Payne, Frahm, Johnson, and Hide (1959) reported percent crude protein and phosphorus data from three major native range grasses from the USDA Experiment Station at Miles City, Montana. Samples were collected by clipping every 28 days from August 1948 to June 1953 except when snow covered the vegetation. Data were reported as percent of oven-dry weight. Phenological growth stages of plants on sample dates were not reported. A summary of the crude protein and phosphorus data was reported in Manske (1999c,d).

Hopper and Nesbitt (1930) reported the chemical composition of native range grasses and upland sedges and domesticated cool-season grasses collected by J.T. Sarvis from the Northern Great Plains Field Station at Mandan, North Dakota. The years of sample collection were apparently 1920, 1921, and 1925. The results of the chemical analyses, which were calculated to a uniform moisture content of 15 percent, have been recalculated to 0% moisture to facilitate comparison with other data. A brief description of physical characteristics was made for each species on the sample dates; this information is presented in Manske (1999a,b,c,d) as phenology. Percent crude protein data were summarized and reported in Manske (1999a,b,c,d).

Table 1. Common and scientific names of forage plants from (A) Whitman et al. 1951, (B) Marsh et al. 1959, and (C) Hopper and Nesbitt 1930.

Common Names	Reference Citation	Scientific Names
Domesticated grasses		
Crested wheatgrass	A, C	*Agropyron cristatum*
Smooth bromegrass	A, C	*Bromus inermis*
Timothy	C	*Phleum pratense*
Fowl bluegrass	C	*Poa palustris*
Upland Sedges		
Threadleaf sedge	A, C	*Carex filifolia*
Sun sedge	C	*Carex heliophila*
Cool-season native grasses		
Slender wheatgrass	C	*Agropyron caninum majus*
Bearded wheatgrass	C	*Agropyron caninum unilaterale*
Western wheatgrsss	A,B,C	*Agropyron smithii*
Ticklegrass	C	*Agrostis hyemalis*
Red threeawn	C	*Aristida purpurea*
Plains reedgrass	A	*Calamagrostis montanensis*
Canada wildrye	C	*Elymus canadensis*
Prairie Junegrass	A, C	*Koeleria pyramidata*
Kentucky bluegrass	A	*Poa pratensis*
Prairie wedgegrass	C	*Sphenopholis obtusata*
Needle and thread	A,B,C	*Stipa comata*
Porcupine grass	C	*Stipa spartea*
Green needlegrass	A, C	*Stipa viridula*
Warm-season native grasses		
Big bluestem	A, C	*Andropogon gerardii*
Little bluestem	A, C	*Andropogon scoparius*
Side oats grama	C	*Bouteloua curtipendula*
Blue grama	A,B,C	*Bouteloua gracilis*
Buffalo grass	C	*Buchloe dactyloides*
Prairie sandreed	A, C	*Calamovilfa longifolia*
Inland saltgrass	C	*Distichlis spicata*
Plains muhly	C	*Muhlenbergia cuspidata*
Switchgrass	C	*Panicum virgatum*

Results

The nutritional quality of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses changes with the plants' phenological development. Early season vegetative leaves of graminoids are generally high in crude protein and water. As the plants mature, their fiber content increases and percent crude protein, percent water, and digestibility decrease. The patterns of change in nutritional quality are similar from year to year because phenological development is regulated primarily by photoperiod (Manske 1998a,b), although annual variations in temperature, evaporation, and water stress may result in slight variations in nutritional quality from year to year. Nutritional quality is also related to rates of plant growth and plant senescence. These are affected by the level of photosynthetic activity, which in turn is affected by temperature. Rates of senescence increase with higher temperatures and with water stress, a result of water deficiency in the environment.

Coordination of the nutritional quality curves of ungrazed plants with livestock nutritional requirement curves is essential in the development of biologically effective management strategies. Livestock nutritional requirements (NRC 1996) change with production levels and size of the animals. A 1000-pound mature cow with average milk production requires 10.5% crude protein and 0.20% phosphorus during the first month of lactation. She requires an average of 9.6% crude protein and 0.18% phosphorus from her diet in order to maintain body weight and average lactation during the second through sixth months of lactation. She requires an average of 6.2% crude protein and 0.11% phosphorus during the dry portion of the second trimester of pregnancy and 7.8% crude protein and 0.15% phosphorus during the third trimester of pregnancy.

Domesticated Cool-Season Grass

The domesticated grass species included in the two published articles reporting nutritional quality of domesticated forage grasses of the Northern Plains are listed in table 1. Summaries of crude protein levels for ungrazed crested wheatgrass are shown in figure 1. Domesticated cool-season grasses contain the highest levels of crude protein during the early stages of development. As seed stalks begin to develop, crude protein levels begin to decrease. Crude protein levels remain above 9.6% until late June. Between the flowering stage and the seed mature stage, crude protein levels decrease rapidly. During seed development, which occurs shortly after the flowering stage, crude protein levels drop below 9.6%. They fall below 7.8% by early July and below 6.2% in early August. Phosphorus levels drop below 0.18% in late July.

One replication of smooth bromegrass in Whitman's study was not cut for hay. Summaries of crude protein levels for smooth bromegrass not cut for hay are shown in figure 2. Crude protein levels of smooth bromegrass remain above 9.6% from the early growth of the plant until late June. Crude protein levels of uncut smooth bromegrass drop below 9.6% after late June. From mid July to mid September crude protein levels decrease from around 7.8% to 5.0%. Phosphorus levels of mature uncut smooth bromegrass drop below 0.18% in early August.

Grasses that are hayed have nutrient curves different from those of grasses not cut for hay because defoliation manipulates the mechanisms that regulate vegetative reproduction. Data to illustrate this difference are limited to one example from the historical literature for the Northern Plains. Whitman's study includes one replication of data from hayed smooth bromegrass. Summaries of crude protein levels for hayed smooth bromegrass are shown in figure 3. The smooth bromegrass was cut for hay in mid June; the crude protein levels of the immature tillers that grew after the cutting event remained above 9.6% until after late September. These data from hayed smooth brome show that secondary tillers have crude protein levels above 9.6% for at least 2.5 months longer than undefoliated plants. Additional research data need to be collected on the effects haying and grazing produce on the crude protein and mineral levels of domesticated cool-season grasses.

Crude protein levels for ungrazed timothy and fowl bluegrass (Hopper and Nesbitt 1930, Manske 1999a) follow a pattern similar to that followed by other domesticated cool-season grasses. The grasses contain the highest levels of crude protein in the early stages of development. As seed stalks begin to develop, crude protein levels begin to decrease. Between the flowering stage and seed mature stage, crude protein levels rapidly decrease, usually falling below 9.6% shortly after the plant has reached flowering stage.

Native Range Upland Sedge

The native range upland sedge species included in the two published articles reporting nutritional quality of sedge plants of the Northern

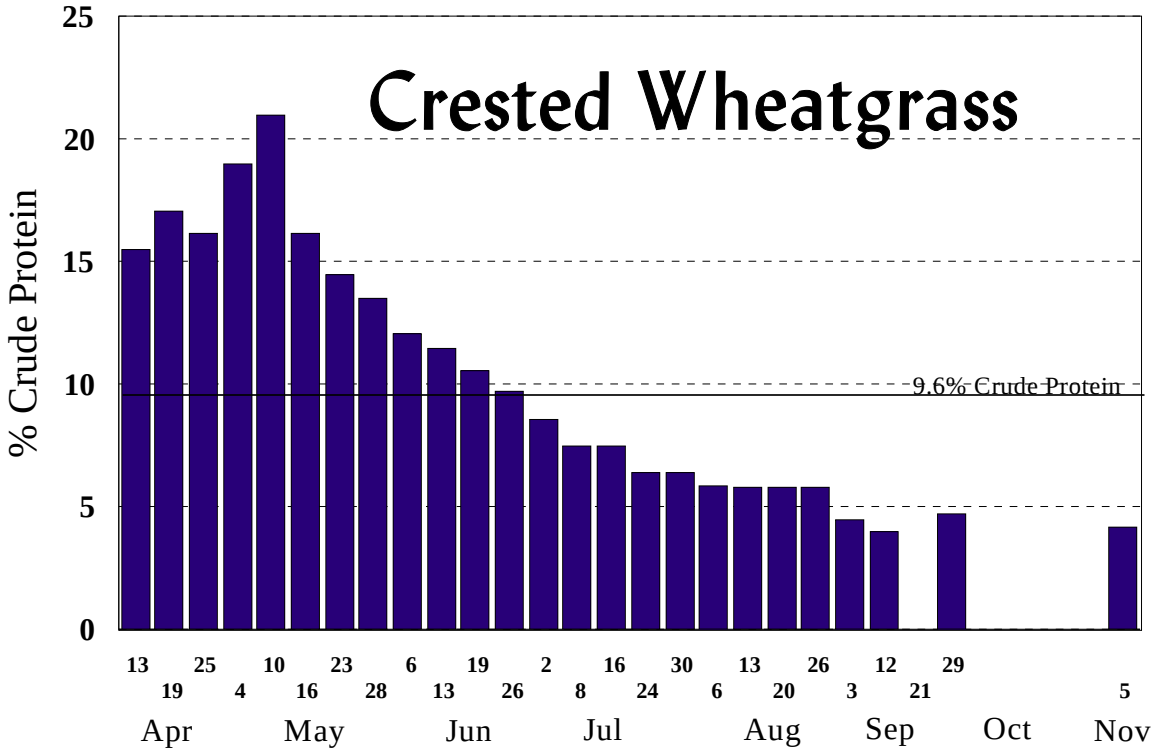


Fig 1. Mean percent crude protein of ungrazed crested wheatgrass in western North Dakota, data from Whitman et al. 1951.

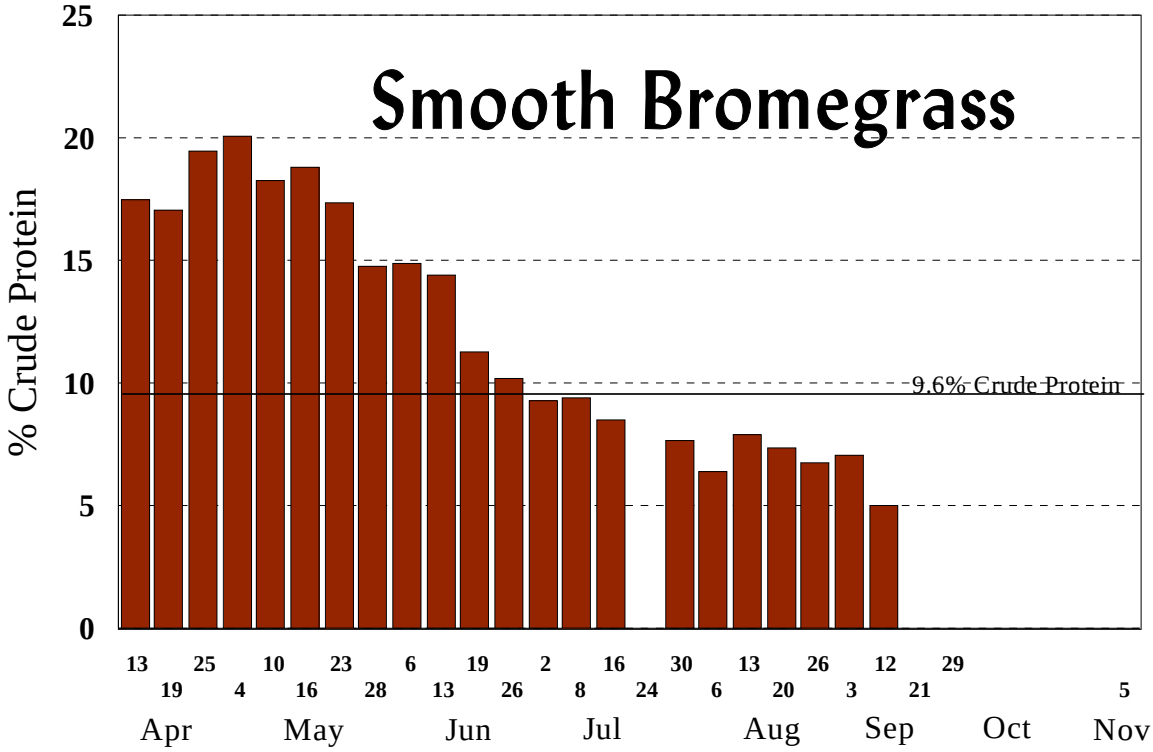


Fig 2. Mean percent crude protein of smooth bromegrass not cut for hay in western North Dakota, data from Whitman et al. 1951.

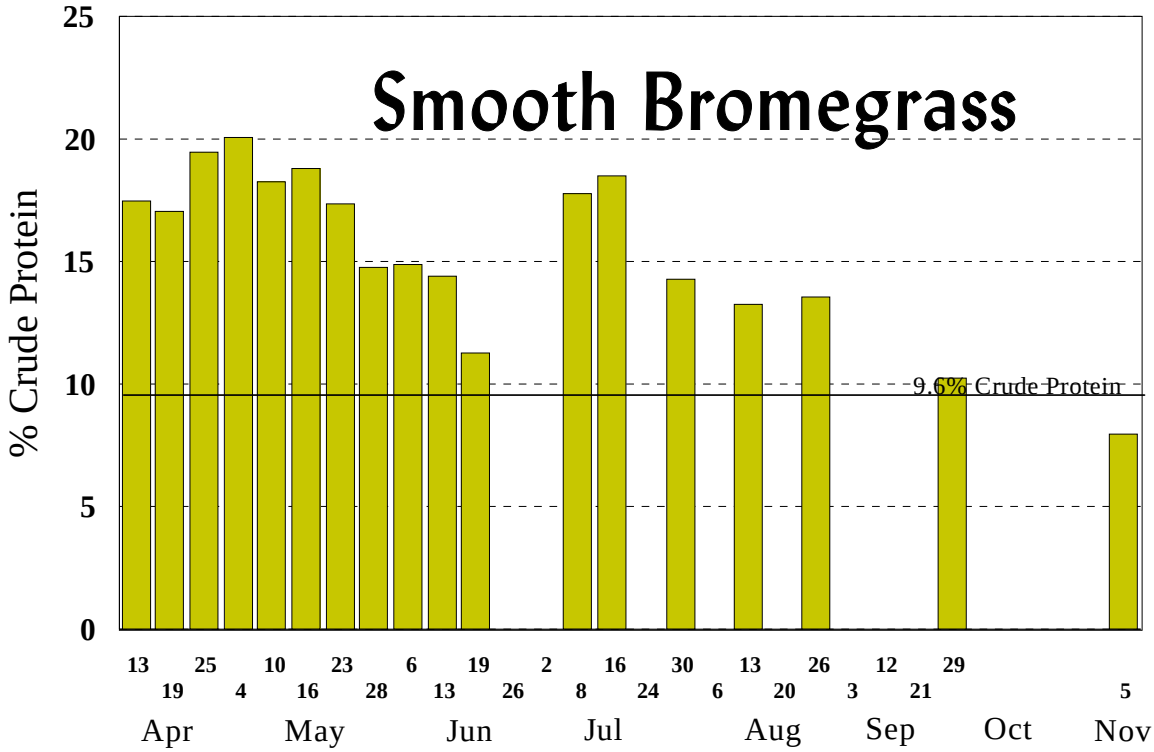


Fig 3. Mean percent crude protein of smooth bromegrass cut for hay at flowering stage in mid June in western North Dakota, data from Whitman et al. 1951.

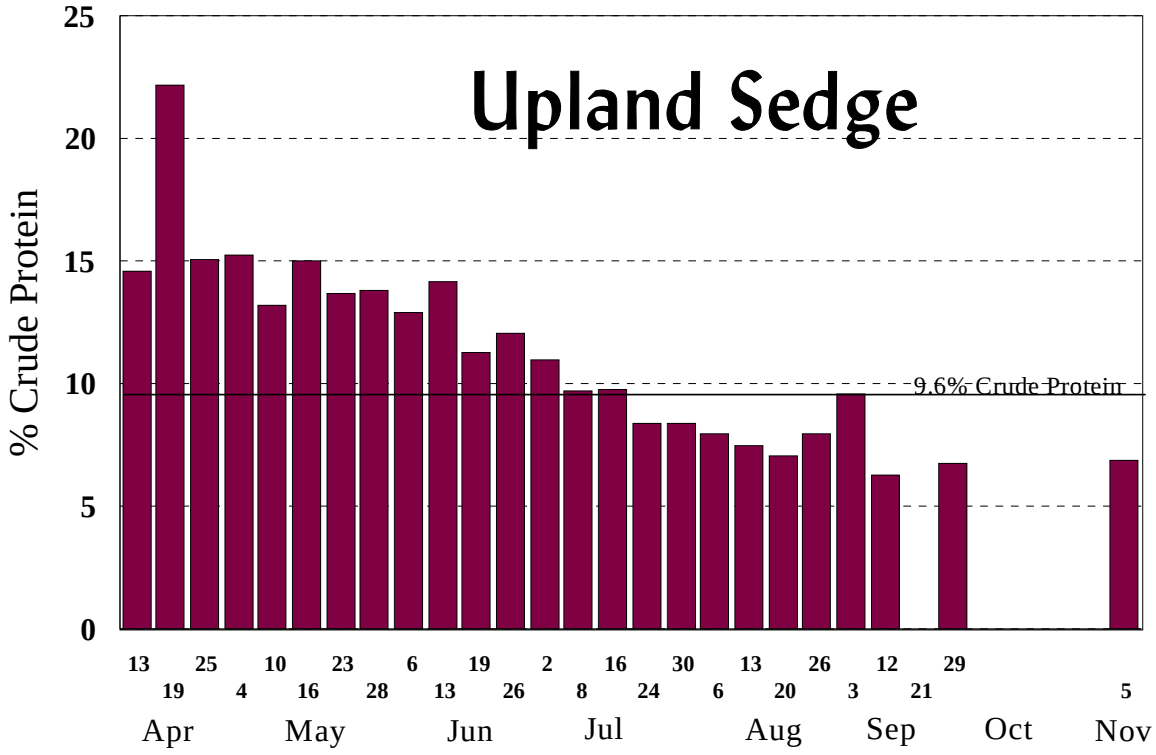


Fig 4. Mean percent crude protein of ungrazed native range upland sedges in western North Dakota, data from Whitman et al. 1951.

Plains are listed in table 1. Summaries of crude protein levels for ungrazed upland sedges are shown in figure 4. Sedges contain the highest levels of crude protein during the early stages of development. Crude protein curves of the upland sedges do not follow the same relationship with phenological growth stage as do the crude protein curves of cool-season grasses. Crude protein levels in upland sedges remain high through flowering and seed maturing stages and decrease with increases in senescence. Upland sedges grow very early and produce seed heads in late April to early May. Crude protein levels remain above 9.6% after seed mature stage, until mid July. Crude protein levels decrease below 7.8% in early August but do not fall below 6.2% for the remainder of the year. Phosphorus levels drop below 0.18% in mid May.

Graminoids defoliated by grazing and haying have nutrient curves different from those of ungrazed plants because defoliation manipulates the mechanisms that regulate vegetative reproduction. The reviewed literature contains no examples of defoliation's effects on the nutrient curves for native range upland sedges. Additional research data need to be collected on the effects grazing produces on the crude protein and mineral levels of native range upland sedges.

Native Range Cool-Season Grass

The native range cool-season grass species included in the three published articles reporting nutritional quality of forage grasses of the Northern Plains are listed in table 1. Summaries of crude protein levels for ungrazed cool-season grasses are shown in figure 5. One cool-season species in Whitman's study, Kentucky bluegrass, was not available in ungrazed condition, so grazed samples were collected. A summary of these data is shown in figure 6.

Crude protein levels of ungrazed cool-season native range grasses are very closely related to the phenological stages of growth and development, which are triggered primarily by the length of daylight. The length of daylight increases during the growing season to mid June and then decreases. The longest day length occurs at summer solstice, 21 June, when the sun's apparent path is farthest north of the equator. Ungrazed cool-season native range grasses contain the highest levels of crude protein during the early stages of development. Most cool-season plants are long-day plants which reach the flower phenological stage after exposure to a critical photoperiod and during the period of increasing daylight between mid April and mid June (21 June) (Weier et al. 1974, Leopold and Kriedemann 1975). Cool-season grasses usually reach flowering phenophase before 21 June. Crude protein levels remain above 9.6% at flower stage but decrease rapidly during seed development and seed mature stages, dropping below 7.8% by early August and below 6.2% in late August.

Crude protein levels are also related to rates of plant growth and senescence. These are affected by the level of photosynthetic activity, which in turn is affected by temperature. The optimum temperature range for photosynthesis for cool-season plants, which are C_3 photosynthesis pathway plants, is 50° to 77° F (10° to 25° C) (Coyne et al. 1995). Temperatures below 50° F (10° C) during the day or temperatures above 77° F (25° C) limit the growth rate of cool-season grasses because photosynthetic rates are reduced. Rates of senescence increase with higher temperatures and with water stress, a result of water deficiency in the environment. Water deficiencies occur about 50% of the time during August, September, and October (Manske 1998a, 1999e). Cool-season grasses do not use water as efficiently as do warm-season grasses, a factor that contributes to cool-season grasses functioning at optimum temperatures lower than those of warm-season grasses. Crude protein levels of ungrazed cool-season grasses decrease below 9.6% in mid July, dropping below 7.8% in early August and below 6.2% in late August. Phosphorus levels of ungrazed cool-season grasses drop below 0.18% in late July.

Grazed grasses have nutrient curves different from those of ungrazed grasses because defoliation manipulates the mechanisms that regulate vegetative reproduction. Data to illustrate this difference are limited to one example from the historical literature for the Northern Plains. Whitman's study includes data from grazed Kentucky bluegrass. Crude protein levels of grazed Kentucky bluegrass did not drop below 9.6% as did crude protein levels of ungrazed cool-season grasses; during most sample periods, crude protein levels of grazed Kentucky bluegrass remained at or above 9.6% until late September. Phosphorus levels of grazed Kentucky bluegrass remained above 0.18% through late September. Kentucky bluegrass is not an ideal example to illustrate the effects of grazing on the crude protein curves of all cool-season native range grasses because the lead tiller of Kentucky bluegrass has weak hormonal control of axillary bud activity and does not inhibit secondary tillering to the same extent that the lead tillers of other native range grasses do. However, these data show that secondary tillers have crude protein levels above 9.6% for at least 2.5 months longer than ungrazed plants.

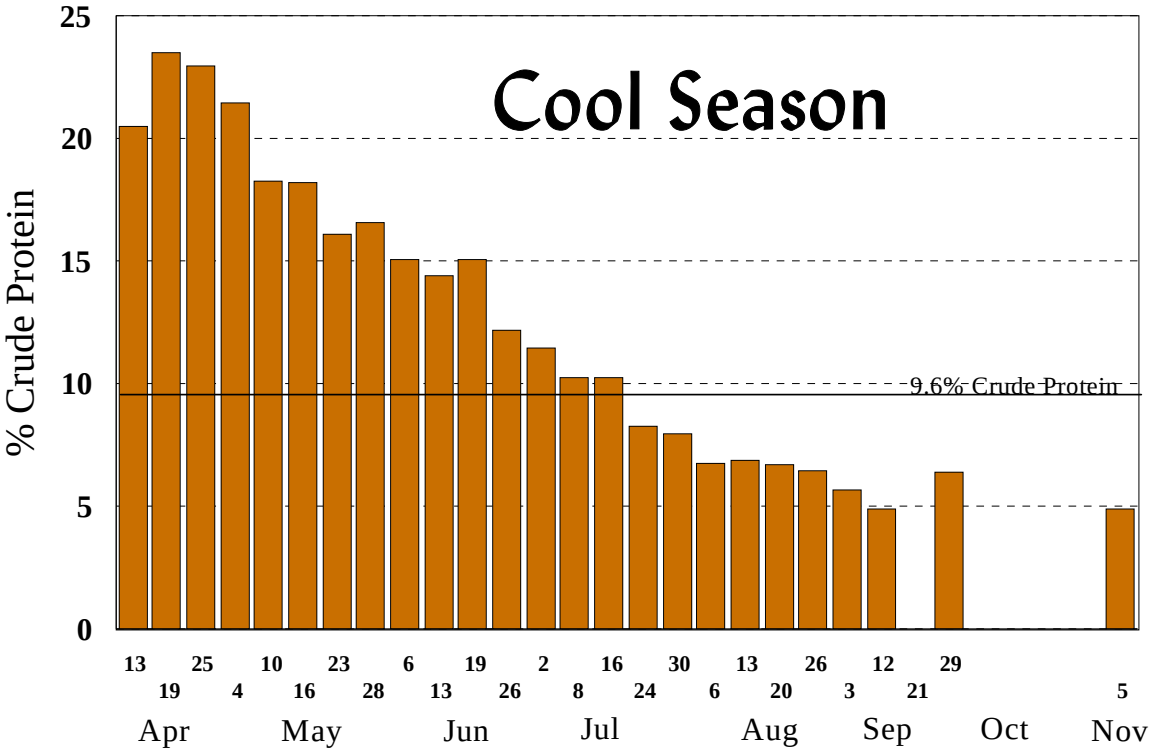


Fig 5. Mean percent crude protein of ungrazed native range cool season grasses in western North Dakota, data from Whitman et al. 1951.

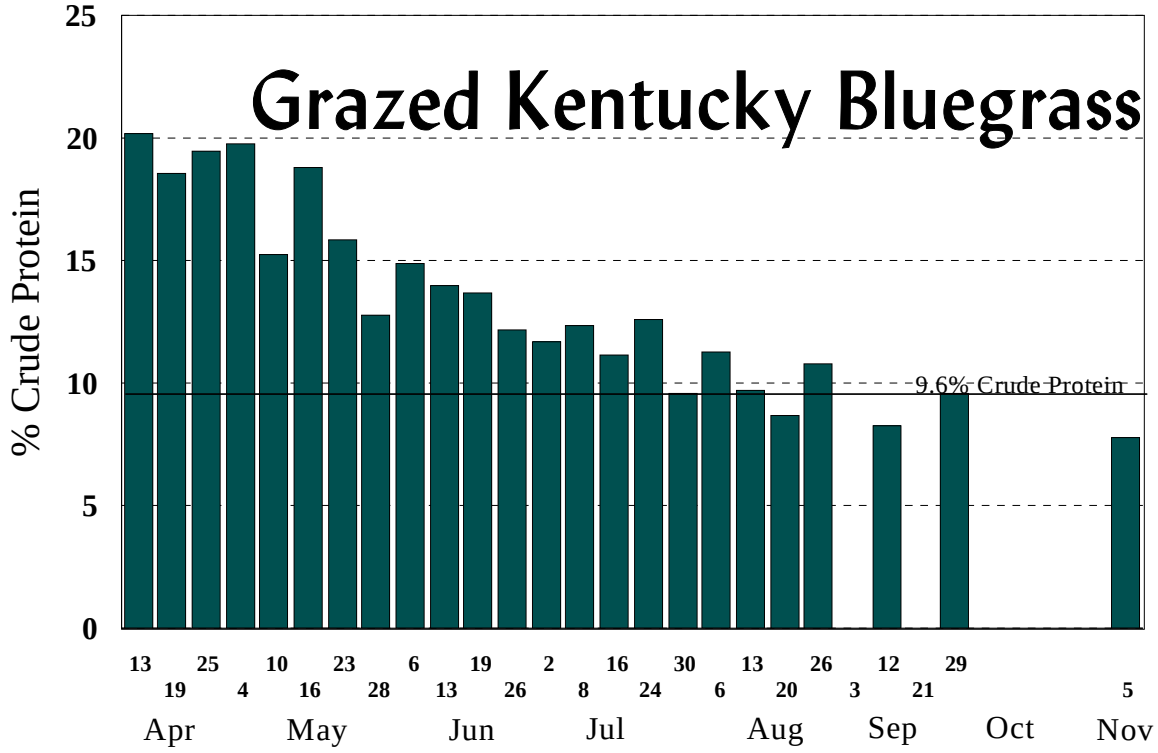


Fig 6. Mean percent crude protein of grazed Kentucky bluegrass in western North Dakota, data from Whitman et al. 1951.

Additional research data need to be collected on the effects grazing produces on the crude protein and mineral levels of native range cool-season grasses.

Native Range Warm-Season Grass

The native range warm-season grass species included in the three published articles reporting nutritional quality of forage grasses of the Northern Plains are listed in table 1. Summaries of crude protein levels for ungrazed warm-season grasses are shown in figure 7.

Crude protein levels of ungrazed warm-season native range grasses are very closely related to phenological stages of growth and development, which are triggered primarily by the length of daylight. The length of daylight increases during the growing season to mid June and then decreases. The longest day length occurs at summer solstice, 21 June, when the sun's apparent path is farthest north of the equator. Ungrazed warm-season native range grasses contain the highest levels of crude protein during the early stages of development. Most warm-season plants are short-day plants which are induced to flower by day lengths that are shorter than a critical length and that occur during the period of decreasing day length after mid June (21 June). Short-day plants are technically responding to the increase in the length of night period rather than to the decrease in the day length (Weier et al. 1974, Leopold and Kriedemann 1975). Warm-season grasses usually reach flowering phenophase after 21 June. Crude protein levels remain above 9.6% at flower stage but decrease rapidly during seed development and seed mature stages.

Crude protein levels are also related to rates of plant growth and plant senescence. These are affected by the level of photosynthetic activity, which in turn is affected by temperature. The optimum temperature range for photosynthesis for warm-season plants, which are C_4 photosynthesis pathway plants, is 86° to 105° F (30° to 40° C) (Coyne et al. 1995). Temperatures below 86° F (30° C) or above 95° F to 105° F (35° to 40° C) limit the growth rate of warm-season grasses because photosynthetic rates are reduced. Warm-season grasses use water more efficiently than do cool-season grasses, a characteristic that enables warm-season grasses to function efficiently at higher temperatures. Rates of senescence increase with higher temperatures and with water stress, a result of water deficiency in the environment. Water deficiencies occur about 50% of the time during August, September, and October (Manske 1998a, 1999e). Crude protein levels of ungrazed warm-season grasses decrease below 9.6% in late July, when plants are mature, and below 6.2% in early September. Phosphorus levels of ungrazed warm-season grasses drop below 0.18% in late August.

Grazed grasses have nutrient curves different from those of ungrazed grasses because defoliation manipulates the mechanisms that regulate vegetative reproduction. The reviewed literature contains no examples of defoliation's effects on the nutrient curves for native range warm-season grasses. Additional research data need to be collected on the effects grazing produces on the crude protein and mineral levels of native range warm-season grasses.

Discussion

Developing management strategies for operations that graze livestock on pastures and cut perennial forages for hay where the vegetation has changeable nutritional quality is challenging. Biologically effective pasture and forage management strategies must protect the health of the plants and still allow the capture of the nutrients produced on the rangelands and grasslands and the conversion of these nutrients into a saleable product at a relatively low cost. Such management strategies match the herbage nutritional quality curves, the herbage production quantity curves, the forage plant phenological development curves, and the livestock nutritional requirement curves. These management strategies include a combination of forage types that have their phenological development and nutritional quality curves at different periods of the year. Complementary forage types are used in the appropriate sequence and proportions to meet the minimum nutritional requirements of livestock during the entire grazing and feeding season.

Nutritional quality data from ungrazed plants show the natural progression and development of the vegetation without alteration from defoliation. Nutritional data from ungrazed plants can be used to evaluate the biological effectiveness of management strategies. Nutrient curves of forage plants that have been defoliated by grazing or haying are different from the nutrient curves of undefoliated plants because defoliation manipulates the mechanisms that regulate vegetative reproduction.

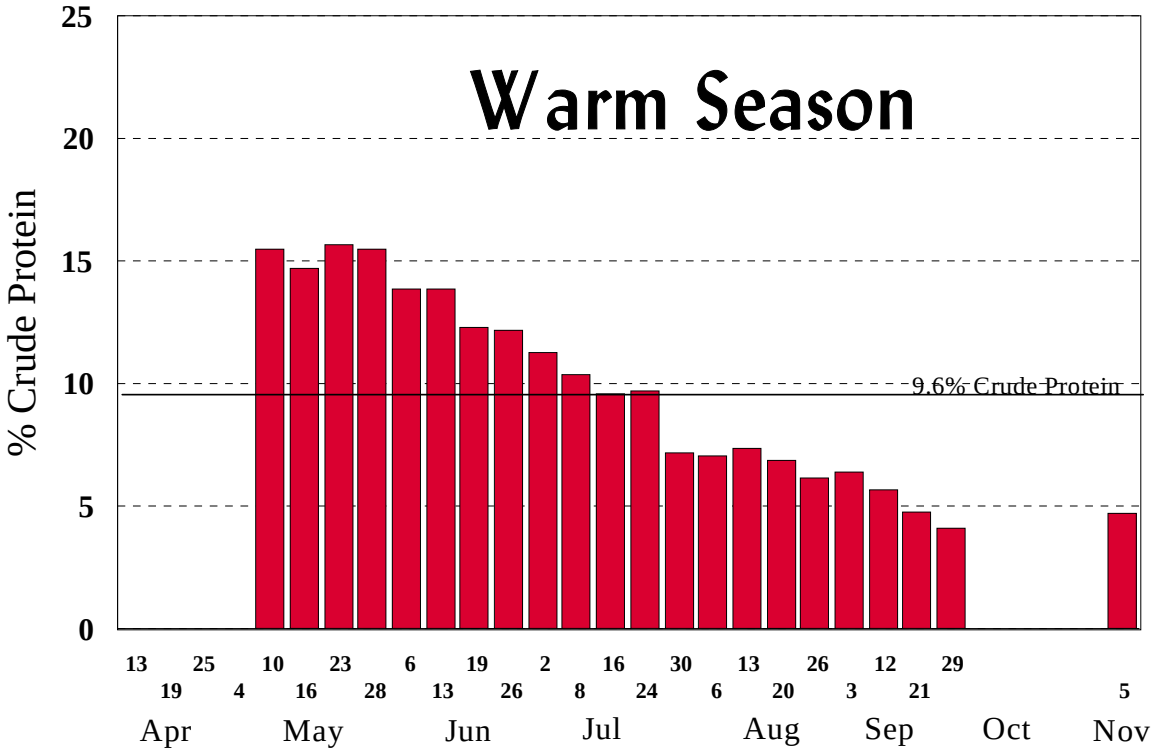


Fig 7. Mean percent crude protein of ungrazed native range warm season grasses in western North Dakota, data from Whitman et al. 1951.

Conclusion

This report summarizes the limited published data reporting sequential nutritional quality of domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses used on the Northern Plains and interprets the relationships between the changes in nutritional quality and the changes in phenological development of ungrazed plants.

The changes in nutritional quality of ungrazed domesticated cool-season grasses follow the plants' phenological stages. Plants contain the highest levels of crude protein in the earliest stages of development. As seed stalks develop, nutrient content begins to decrease, falling rapidly between the flowering stage and the seed mature stage. Crude protein levels of ungrazed domesticated cool-season grasses drop below 9.6% in late June and below 7.8% in early or mid July. Phosphorus levels of ungrazed domesticated cool-season grasses drop below 0.18% in late July or early August.

The nutritional quality of ungrazed native range upland sedges decreases as the plants mature, but the changes in nutritional quality do not follow the same relationships to phenological stages as do the changes in nutritional quality of cool-season grasses. The levels of crude protein are high in the early stages of sedge development. Crude protein levels remain high through flower stalk development, flowering, seed maturing, and seed shedding stages. Nutritional quality decreases with increased senescence in mature sedges. Crude protein levels of ungrazed native range upland sedges drop below 9.6% in mid July and below 7.8% in early August. Phosphorus levels drop below 0.18% in mid May.

The nutritional quality of ungrazed native range cool-season grasses changes with the stages of phenological development. Plants contain the highest levels of crude protein in the early stages of development. As seed stalks develop, nutrient levels begin to decrease, falling rapidly between the flowering stage and the seed mature stage. Levels of crude protein in ungrazed native range cool-season grasses drop below 9.6% in mid July, below 7.8% in early August, and below 6.2% in late August. The phosphorus content of cool-season grasses falls below 0.18% in late July.

The changes in nutritional quality of ungrazed native range warm-season grasses follow the changes in the phenological stages of growth and development. The plants contain the highest levels of crude protein during the early stages of development. As seed stalks develop, nutrient content begins to decrease, falling rapidly between the flowering stage and the seed mature stage. Crude protein levels of ungrazed native warm-season grasses drop below 9.6% in late July and below 6.2% in early September. Phosphorus levels of ungrazed native warm-season grasses drop below 0.18% in late August.

The crude protein requirements of 9.6% for cows with average lactation are not met by ungrazed domesticated cool-season grasses after late June, by ungrazed native range upland sedges after mid July, by ungrazed native range cool-season grasses after mid July, and by ungrazed native range warm-season grasses after late July.

Grazing and haying affect grass plant biological mechanisms that regulate vegetative reproduction. These effects are not the same at all phenological growth stages during the growing season. Additional research should be conducted to study the effects defoliation by grazing and haying has on phenological development, vegetative reproduction, and changes in nutritional quality of the forage plants during the growing season.

Acknowledgment

I am grateful to Amy M. Kraus and Naomi J. Thorson for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of the tables and figures and for word processing this manuscript.

Literature Cited

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and development morphology. Society for Range Management, Denver, CO.

Hopper, T.H., and L.L. Nesbitt. 1930. The chemical composition of some North Dakota pasture and hay grasses. North Dakota Agricultural Experiment Station. Bulletin 236. Fargo, ND. 38p.

Leopold, A.C., and P.E. Kriedemann. 1975. Plant growth and development. McGraw-Hill Book Co., New York, NY.

Manske, L.L. 1998a. Environmental factors' effects on range plants. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 98-3006. Dickinson, ND. 3p.

Manske, L.L. 1998b. General description of grass growth and development and defoliation resistance mechanisms. NDSU Dickinson Research Extension Center. Range Management Report DREC 98-1022. Dickinson, ND. 12p.

Manske, L.L. 1999a. Annual nutritional quality curves for domesticated cool season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1024. Dickinson, ND. 13p.

Manske, L.L. 1999b. Annual nutritional quality curves for native range upland sedges. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1025. Dickinson, ND. 7p.

Manske, L.L. 1999c. Annual nutritional quality curves for native range cool season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1026. Dickinson, ND. 16p.

Manske, L.L. 1999d. Annual nutritional quality curves for native range warm season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1027. Dickinson, ND. 13p.

Manske, L.L. 1999e. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-1998, NDSU Dickinson Research Extension Center. Range Research Report DREC 99-1018b. Dickinson, ND. 36p.

Marsh, H., K.F. Swingle, R.R. Woodward, G.F. Payne, E.E. Frahm, L.H. Johnson, and J.C. Hide. 1959. Nutrition of cattle on an eastern Montana range. Montana Agricultural Experiment Station. Bulletin 549. Bozeman, MT. 91p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Weier, T.E., C.R. Stocking, and M.G. Barbour. 1974. Botany: an introduction to plant biology. John Wiley and Sons, New York, NY.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Grass Tillers' Crude Protein

Mean percent crude protein of lead tillers and secondary tillers on twice-over grazing treatments in central North Dakota, data from Sedivec 1999.

% Crude Protein Lead Tillers

	Physiological growth stage						
	Leaf 2.5	**Leaf 3.0**	**Leaf 3.5/4.0**	**Boot to Head**	**Seed develop**	**Mature**	**Senescence**
Cool-Season	19.2	15.7	12.2	9.0	6.4	4.8	3.7
Kentucky Bluegrass	22.0	-	10.4	10.3	6.1	4.2	1.9
Warm-Season	11.9	10.5	8.8	8.7	5.2	5.3	2.9

% Crude Protein Secondary Tillers

	Secondary growth by date				
	mid Jul	**mid Aug**	**early Sep**	**late Sep**	**mid Oct**
Cool-Season	10.2	11.6	13.2	12.1	6.1
Kentucky Bluegrass	9.2	9.4	20.4	10.9	7.1
Warm-Season	-	8.9	10.0	8.2	5.7

Literature Cited

Sedivec, K. 1999. Nutritional quality of selected rangeland plants. Summary Report. NDSU Animal and Range Sciences Dept. Research Report. Fargo, ND.

Annual Mineral Quality Curves for Graminoids in the Northern Plains

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Beef cows require seventeen minerals to maintain proper body functions: seven macrominerals in large quantities and ten microminerals in trace amounts. The quantities of each mineral required vary with cow size, level of milk production, and production period (dry gestation, 3rd trimester, early lactation, lactation). Livestock mineral requirement curves show the amount of each mineral animals require during the production periods. Many essential minerals are provided to the animals by the forages they consume. The mineral content of perennial forage grasses and sedges changes as the plants develop and mature through phenological stages. Annual mineral quality curves for forage plants show these changes in mineral content during the year. Coordination of annual mineral quality curves of available perennial forage plants with livestock mineral requirement curves is necessary for the development of management strategies that efficiently provide the quantities of minerals animals require at each production stage.

The major perennial graminoid plants livestock use as forage are separated into four categories based on the period during which most of the plant growth occurs: domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses. This report summarizes published information on the annual mineral quality curves of these four graminoid categories.

Methods

Two publications have reported the changes in mineral content of perennial grasses growing on the Northern Plains mixed grass prairie of western North Dakota and eastern Montana. In the historical literature for the Northern Plains, changes in mineral content and related phenological growth stages of perennial graminoids are reported only for phosphorus. Phosphorus is the mineral most commonly deficient in diets of cattle grazing forages. Calcium and salt (sodium and chlorine) are the other minerals most likely to be deficient in forage diets.

Whitman et al. (1951) published a bulletin on the nutrient content of grasses and sedges in western North Dakota. Graminoid species samples were collected weekly in 1946 and 1947 from the Dickinson Experiment Station at Dickinson, North Dakota. Only current year's growth was included in the sample; previous year's growth was separated and discarded. An attempt to collect ungrazed samples was made for available species except Kentucky bluegrass, which had been grazed, and smooth bromegrass, which was cut for hay in mid June. Data were reported as percent of oven-dry weight. Plant condition by stage of plant development and growth habit was reported for each species on sample dates. These data were presented as phenological growth stage in Manske (1999a, b, c, d). Weekly percent phosphorus of graminoid species reported by Whitman et al. (1951) was summarized by species and included in Manske (1999a, b, c, d). These data have been summarized and presented in four graminoid categories in this report.

Marsh et al. (1959) reported nutrient content of three grasses from the USDA Experiment Station at Miles City, Montana. Samples were collected by clipping every 28 days from August 1948 to June 1953 except when snow covered the vegetation. Data were reported as percent of oven-dry weight. Phenological growth stages of plants on sample dates were not reported. A summary of the phosphorus data by species was presented in Manske (1999c, d). These data have been summarized and presented in two graminoid categories in this report.

Results

The mineral quality of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses changes with the phenological development of the plants. Early season vegetative growth of graminoids is generally high in phosphorus. As the plants mature, their phosphorus content decreases. Phenological development patterns are similar from year to year because they are regulated primarily by photoperiod (Manske 1998b, 2000), although annual differences in temperature, evaporation, and water stress may result in slight variation.

Daily Mineral Requirements

Understanding both the mineral quality curves for perennial forage plants and the mineral requirement curves for beef cows is necessary for efficient nutritional management of livestock. Beef cow daily nutritional requirements (NRC 1996), including phosphorus and calcium requirements, change with cow size, level of milk production, and production period. During the dry gestation period, beef cows with average milk production and live weights of 1000 lbs, 1200 lbs, and 1400 lbs require 0.11%, 0.12%, and 0.12% phosphorus in diet dry matter, respectively; during the 3rd trimester period, they require 0.15%, 0.16%, and 0.17% phosphorus in diet dry matter, respectively; during the early lactation period, they require 0.20%, 0.19%, and 0.19% phosphorus in diet dry matter, respectively; and during the lactation period, they require 0.18%, 0.18%, and 0.18% phosphorus in diet dry matter, respectively (table 1). During the dry gestation period, beef cows with average milk production and live weights of 1000 lbs, 1200 lbs, and 1400 lbs require 0.15%, 0.15%, and 0.16% calcium in diet dry matter, respectively; during the 3rd trimester period, they require 0.24%, 0.25%, and 0.26% calcium in diet dry matter, respectively; during the early lactation period, they require 0.30%, 0.29%, and 0.28% calcium in diet dry matter, respectively; and during the lactation period, they require 0.27%, 0.26%, and 0.26% calcium in diet dry matter, respectively (table 1). Beef cattle require greater amounts of calcium than of phosphorus. However, because perennial grasses contain considerably more calcium than phosphorus, diets of cattle grazing forages are more likely to be deficient in phosphorus.

Domesticated Cool-Season Grass

The domesticated grass species included in the study by Whitman et al. (1951) were crested wheatgrass and smooth bromegrass. Ungrazed or uncut domesticated cool-season grasses (table 2, figs. 1 and 2) contain their highest levels of phosphorus in early May, during the early stages of development. As the plants continue to develop, the percentage of phosphorus decreases. Phosphorus levels drop below 0.18% (the percentage required by lactating cows) in late July, when plants reach the mature seed stage.

One replication of smooth bromegrass in Whitman's study was cut for hay in mid June. Phosphorus levels of the immature tillers that grew after the cutting remained above 0.18% until early September (table 2, fig. 3). These data from hayed smooth bromegrass show that secondary tillers have phosphorus levels above 0.18% for at least one month longer than undefoliated plants. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of domesticated cool-season grasses.

Native Range Upland Sedge

The native range upland sedge species included in the study by Whitman et al. (1951) was threadleaf sedge. Ungrazed upland sedges (table 2, fig. 4) contain their highest levels of phosphorus during the early stages of development, in late April. As the plants continue to develop, the percentage of phosphorus decreases. Upland sedges grow very early and produce seed heads in late April to early May. Phosphorus levels drop below 0.18% (the percentage required by lactating cows) in mid May, when plants reach the mature seed stage.

Defoliation by grazing or haying affects the mineral content of graminoids. The reviewed literature contains no examples of defoliation's effects on the mineral curves of native range upland sedges. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range upland sedges.

Native Range Cool-Season Grass

The ungrazed native range cool-season grasses included in the study by Whitman et al. (1951) were western wheatgrass, plains reedgrass, prairie Junegrass, needle and thread, and green needlegrass. The grazed cool-season grass for which Whitman et al. (1951) reported data was Kentucky bluegrass. The native range cool-season grasses for which Marsh et al. (1959) reported data were western wheatgrass and needle and thread. Ungrazed native range cool-season grasses (table 2, fig. 5) contain their highest levels of phosphorus during the early stages of development, in April, May, and early June. As the plants continue to develop, the percentage of phosphorus decreases. In western North Dakota, phosphorus levels of ungrazed native range cool-season grasses drop below 0.18% (the percentage required by lactating cows) in late July, when plants reach the mature seed stage (table 2). In eastern Montana, phosphorus levels drop below 0.18% in late June (table 3). This difference between phosphorus levels of plants in two geographic areas suggests that the rate of leaf senescence may have an effect on mineral levels of grasses.

One cool-season species in Whitman's study, Kentucky bluegrass, was not available in ungrazed condition, so grazed samples were collected. During the grazing season, the grazed

plants of Kentucky bluegrass were generally higher in phosphorus content than were ungrazed plants of the other cool-season species (table 2, fig. 6). Phosphorus levels of grazed Kentucky bluegrass remained above 0.18% through late September. Kentucky bluegrass is not an ideal example to illustrate the effects of grazing on the mineral curves of cool-season native range grasses because the lead tiller of Kentucky bluegrass has weak hormonal control of axillary bud activity and does not inhibit secondary tillering to the same extent that the lead tillers of other native range grasses do (Manske 2000). However, these data show that the secondary tillers of Kentucky bluegrass have phosphorus levels above 0.18% for at least two months longer than the undefoliated cool-season plants. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range cool-season grasses.

Native Range Warm-Season Grass

The ungrazed native range warm-season grasses included in the study by Whitman et al. (1951) were big bluestem, little bluestem, blue grama, and prairie sandreed. The native range warm-season grass for which Marsh et al. (1959) reported data was blue grama. Ungrazed native range warm-season grasses (table 2, fig. 7) contain their highest levels of phosphorus in May, June, and July, during the early stages of development. As the plants continue to develop, the percentage of phosphorus decreases. In western North Dakota, phosphorus levels of ungrazed native range warm-season grasses drop below 0.18% (the percentage required by lactating cows) in late August, when plants reach the mature seed stage (table 2). In eastern Montana, the phosphorus levels drop below 0.18% in early July (table 3). This difference between phosphorus levels of plants in two geographic areas suggests that the rate of leaf senescence may have an effect on mineral levels of grasses.

Defoliation by grazing or haying affects the mineral content of graminoids. The reviewed literature contains no examples of defoliation's effects on the mineral curves of native range warm-season grasses. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range warm-season grasses.

Table 1. Daily phosphorus and calcium requirements in pounds and percent dry matter for beef cows with average milk production during four production periods (data from NRC 1996).

Production Periods		1000 lb cows		1200 lb cows		1400 lb cows	
		Phosphorus	Calcium	Phosphorus	Calcium	Phosphorus	Calcium
Dry Gestation	pounds (lb)	0.02	0.03	0.03	0.04	0.03	0.04
	percent (%)	0.11	0.15	0.11	0.15	0.12	0.16
3rd Trimester	pounds (lb)	0.03	0.05	0.04	0.06	0.05	0.07
	percent (%)	0.15	0.24	0.16	0.25	0.17	0.26
Early Lactation	pounds (lb)	0.05	0.07	0.05	0.08	0.06	0.08
	percent (%)	0.20	0.30	0.19	0.29	0.19	0.28
Lactation	pounds (lb)	0.04	0.06	0.05	0.07	0.05	0.08
	percent (%)	0.18	0.27	0.18	0.26	0.18	0.26

Table 2. Weekly percent phosphorus content of graminoids in western North Dakota, means of 1946 and 1947, data from Whitman et al. (1951).

		Domesticated		Native Range					
		cool-season		upland sedge		cool-season		warm-season	
		uncut	hayed[1]	ungrazed	grazed	ungrazed	grazed[2]	ungrazed	grazed
Apr	1								
	13	0.263	0.269	0.270		0.315	0.314		
	19	0.280	0.244	0.317		0.346	0.313		
	25	0.289	0.264	0.210		0.320	0.232		
May	4	0.306	0.302	0.210		0.301	0.299		
	10	0.285	0.285	0.185		0.303	0.258	0.267	
	16	0.246	0.236	0.170		0.276	0.280	0.226	
	23	0.253	0.260	0.176		0.239	0.268	0.231	
	28	0.247	0.247	0.162		0.237	0.264	0.264	
Jun	6	0.248	0.264	0.160		0.253	0.258	0.299	
	13	0.254	0.253	0.160		0.258	0.287	0.286	
	19	0.233	0.240	0.179		0.244	0.267	0.286	
	26	0.222	-	0.152		0.232	0.231	0.275	
Jul	2	0.211	-	0.153		0.228	0.272	0.245	
	8	0.210	0.302	0.155		0.205	0.243	0.245	
	16	0.202	0.277	0.128		0.203	0.246	0.222	
	24	0.178	-	0.122		0.186	0.238	0.226	
	30	0.189	0.220	0.115		0.176	0.229	0.208	
Aug	6	0.148	-	0.097		0.149	0.237	0.175	
	13	0.158	0.184	0.109		0.157	0.255	0.186	
	20	0.169	-	0.118		0.153	0.145	0.194	
	26	0.167	0.190	0.091		0.141	0.189	0.150	
Sep	3	0.132	-	0.135		0.124	-	0.153	
	12	0.106	-	0.085		0.119	-	0.121	
	21		-				-	0.189	
	29	0.106	0.127	0.083		0.120	0.234	0.076	
Oct									
Nov	5	0.100	0.109	0.096		0.116	0.155	0.085	

[1]Hayed cool-season grass includes only smooth bromegrass data.
[2]Grazed cool-season grass includes only Kentucky bluegrass data.

Table 3. Monthly percent phosphorus content of grasses in eastern Montana, means of 1948-1953, data from Marsh et al. (1959).

Dates	Native Range	
	cool-season	warm-season
Jan 24	0.073	-
Feb 21	0.058	0.060
Mar 24	0.070	0.073
Apr 23	0.102	0.088
May 20	0.186	0.155
Jun 15	0.176	0.200
Jul 14	0.119	0.158
Aug 9	0.111	0.154
Sep 6	0.089	0.118
Oct 5	0.095	0.106
Nov 4	0.087	0.100
Dec 1	0.077	0.073
Dec 27	0.088	0.085

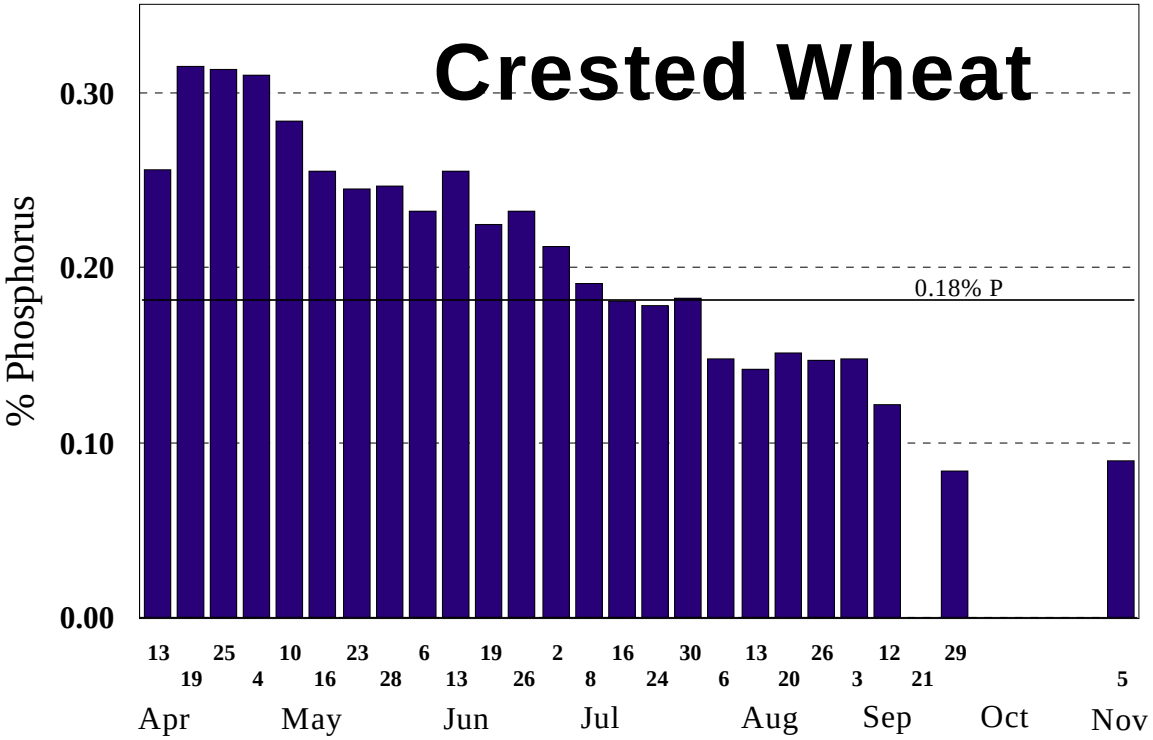


Fig 1. Mean percent phosphorus of ungrazed crested wheatgrass in western North Dakota, data from Whitman et al. 1951.

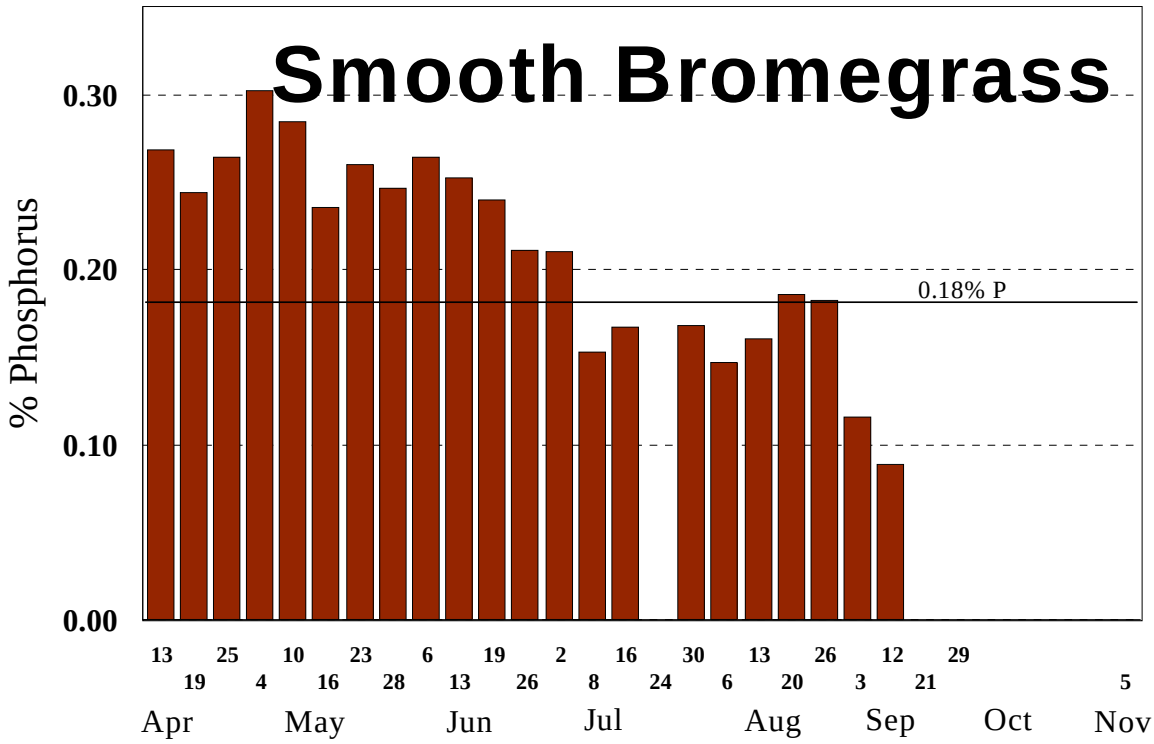


Fig 2. Mean percent phosphorus of smooth bromegrass not cut for hay in western North Dakota, data from Whitman et al. 1951.

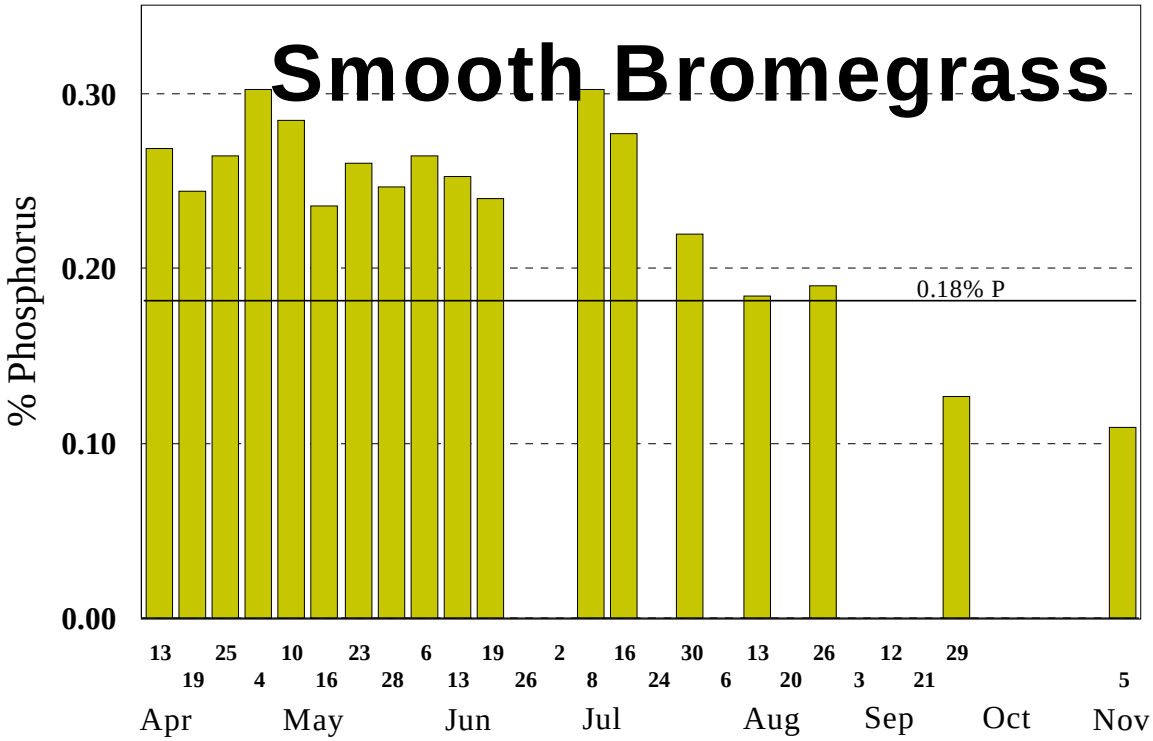


Fig 3. Mean percent phosphorus of smooth bromegrass cut for hay at flowering stage in mid June in western North Dakota, data from Whitman et al. 1951.

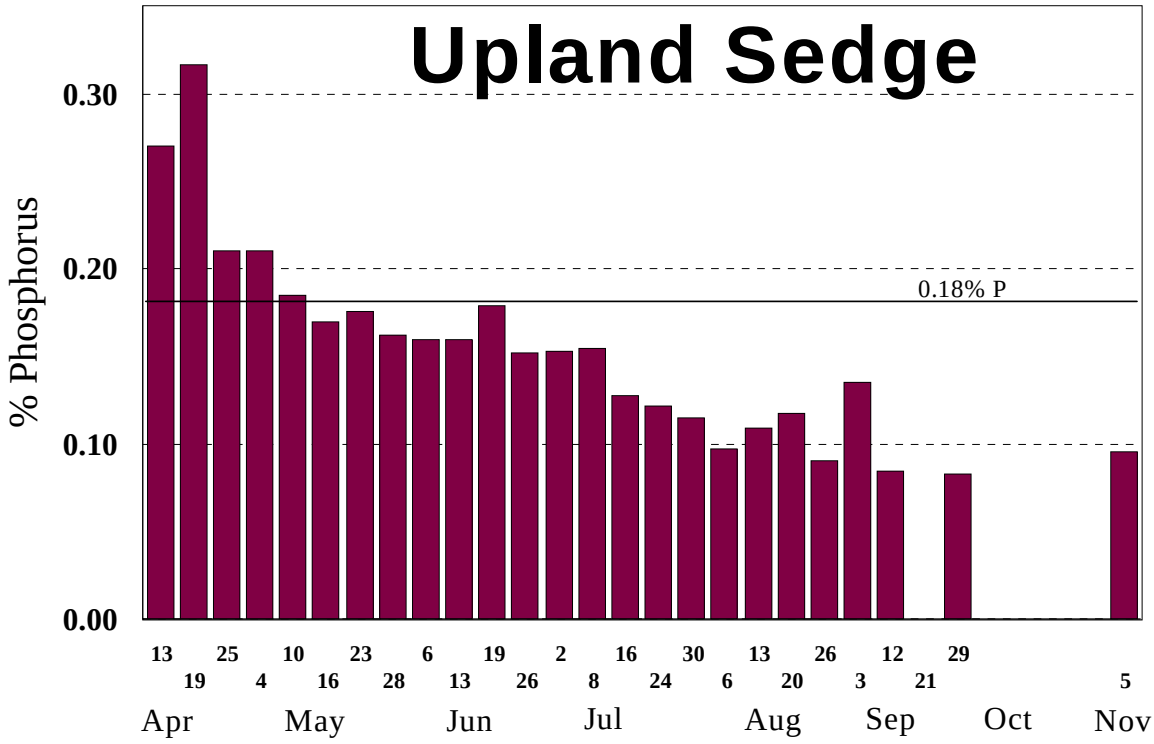


Fig 4. Mean percent phosphorus of ungrazed native range upland sedge in western North Dakota, data from Whitman et al. 1951.

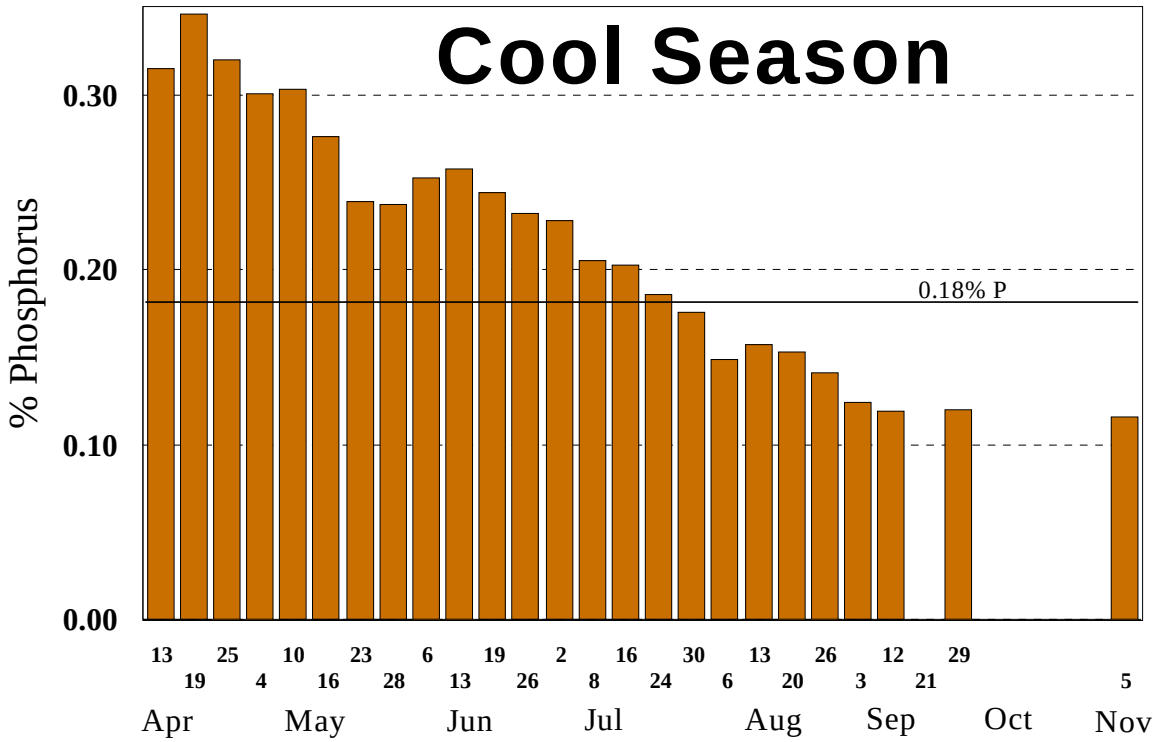


Fig 5. Mean percent phosphorus of ungrazed native range cool season grasses in western North Dakota, data from Whitman et al. 1951.

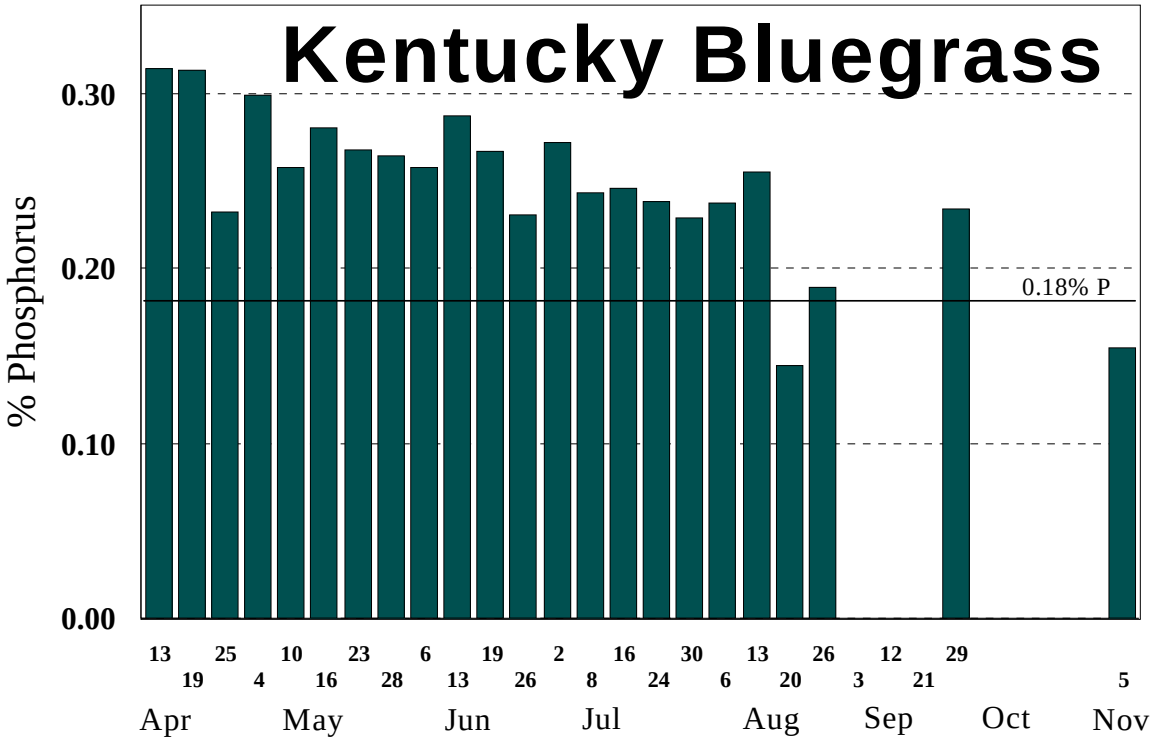


Fig 6. Mean percent phosphorus of grazed Kentucky bluegrass in western North Dakota, data from Whitman et al. 1951.

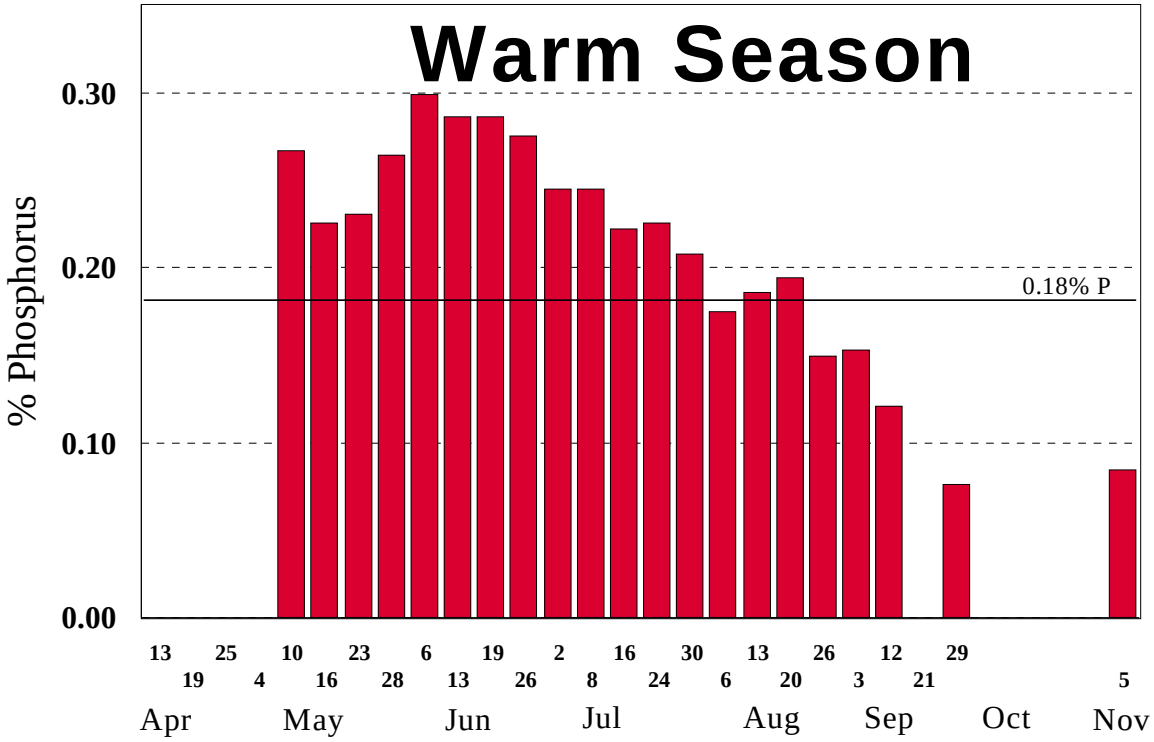


Fig 7. Mean percent phosphorus of ungrazed native range warm season grasses in western North Dakota, data from Whitman et al. 1951.

Discussion

Phosphorus content is high in domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses during early phenological stages. At this time, these forages provide adequate levels of phosphorus (above 0.18%) for lactating beef cows. As the plants mature and continue to develop, the percentage of phosphorus decreases. Phosphorus levels drop below 0.18% during the mature seed phenological stage. In western North Dakota, ungrazed domesticated cool-season grasses develop mature seeds in late July; ungrazed native range upland sedges, in mid May; ungrazed native range cool-season grasses, in late July; and ungrazed native range warm-season grasses, in late August.

Defoliation of grasses manipulates the mechanisms that regulate vegetative reproduction (Manske 2000), causing changes in plant growth and mineral quality curves. Data to illustrate these changes in mineral quality curves are limited to one example of a domesticated cool-season grass cut for hay in mid June and one example of a grazed native range cool-season grass. The data from hayed smooth bromegrass show that secondary tillers have phosphorus levels above 0.18% until early September. The data from grazed Kentucky bluegrass show that secondary tillers have phosphorus levels above 0.18% through late September. Defoliation by haying extended the period that domesticated cool-season grasses contained phosphorus levels above 0.18% from late July to early September, and grazing extended the period that native range cool-season grasses contained phosphorus levels above 0.18% from late July through late September. Mineral quality curves of forage plants defoliated by haying or grazing are different from mineral quality curves of undefoliated plants.

Lactating beef cows grazing crested wheatgrass or smooth bromegrass spring pastures can obtain adequate phosphorus from the forage during May and June. After mid May, upland sedges do not contain adequate phosphorus levels to meet the requirements of a lactating beef cow. In western North Dakota, lactating beef cows grazing native range seasonlong can obtain adequate phosphorus from cool- and warm-season grasses during June and the early portion of July. In eastern Montana, phosphorus levels of cool- and warm-season grasses are below the requirements of a lactating cow in late June and early July. During late summer, phosphorus levels of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses are below the levels required by lactating beef cows, and during fall and winter, phosphorus levels of these forages are below the levels required by dry gestating cows. Supplementation of phosphorus is needed after late June on native range pastures grazed seasonlong in eastern Montana, after mid July on native range pastures grazed seasonlong in western North Dakota, and on all pastures grazed late summer, fall, or winter.

Conclusion

This report summarizes the limited published data reporting sequential phosphorus content of domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses used on the Northern Plains and interprets the relationships between the changes in phosphorus content and the phenological development of ungrazed plants. This report also summarizes the beef cow daily requirements for phosphorus and calcium, which change with cow size, level of milk production, and production period.

The changes in mineral content of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses follow the phenological stages of the plants. Plants contain the highest levels of phosphorus in the early stages of development. As seed stalks develop, phosphorus content decreases. During the mature seed stage, phosphorus content drops below 0.18%, the level required by lactating cows with average milk production. The mature seed stage occurs in late July for domesticated cool-season grasses, in mid May for native range upland sedges, in late July for native range cool-season grasses, and in late August for native range warm-season grasses. Supplemental phosphorus should be provided to livestock during periods when forages do not contain sufficient levels.

Grazing and haying affect the biological mechanisms that regulate vegetative reproduction in grass plants. These effects are not the same at all phenological growth stages during the growing season. Additional research should be conducted to study the effects defoliation by grazing and haying has on phenological development, vegetative reproduction, and changes in mineral content of forage plants during the growing season.

The mineral requirements for beef cows change during the year with the production periods. The mineral content of perennial forage grasses and sedges changes as the plants develop and mature

through phenological stages. At some phenological stages, forage plants have insufficient mineral content to meet nutritional requirements of cattle. During these times, forage diets must be supplemented to meet livestock mineral needs. Biologically effective management strategies efficiently supply combinations of forages and supplements to provide the quantities of minerals livestock require at each production period. Such strategies can be developed through coordination of annual mineral quality curves, which illustrate the changes in forage plant mineral content during the year, and livestock mineral requirement curves, which illustrate beef cow mineral requirements at each production period.

Acknowledgment

I am grateful to Amy M. Kraus and Naomi J. Thorson for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of the tables and figures and for word processing this manuscript.

Literature Cited

Church, D.C., and W.G. Pond. 1975. Basic animal nutrition and feeding. O & B Books, Corvillis, OR.

Manske, L.L. 1998a. Range management practices addressing problems inherent in the Northern Great Plains grasslands. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 98-3002. Dickinson, ND. 3p.

Manske, L.L. 1998b. Environmental factors' effects on range plants. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 98-3006. Dickinson, ND. 3p.

Manske, L.L. 1999a. Annual nutritional quality curves for domesticated cool-season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1024. Dickinson, ND. 13p.

Manske, L.L. 1999b. Annual nutritional quality curves for native range upland sedges. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1025. Dickinson, ND. 7p.

Manske, L.L. 1999c. Annual nutritional quality curves for native range cool-season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1026. Dickinson, ND. 16p.

Manske, L.L. 1999d. Annual nutritional quality curves for native range warm-season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1027. Dickinson, ND. 13p.

Manske, L.L. 2000. Management of Northern Great Plains Prairie based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 13p.

Marsh, H., K.F. Swingle, R.R. Woodward, G.F. Payne, E.E. Frahm, L.H. Johnson, and J.C. Hide. 1959. Nutrition of cattle on an eastern Montana range. Montana Agricultural Experiment Station. Bulletin 549. Bozeman, MT. 91p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Range Cow Nutrient Requirements during Production Periods

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Improvement in profit margins from beef production requires a reduction in forage-feed costs because these costs comprise 60% to 65% of the production costs of cow-calf operations. Traditional pasture-forage management practices used to provide feed for range cows are inefficient in the capture of the forage nutrients produced on a land base and in the conversion of those nutrients into a saleable commodity like calf weight. High forage-feed costs result.

The basic concepts for traditional management practices were developed during the early stages of the beef industry in the Northern Plains when the dry matter requirements for the livestock were the major consideration and the cost of land area per animal added little to the total production costs. The traditional practices brought numerous family operations in the region through depression, drought, severe winter storms, wild fires, and other natural and man-made calamities but are not adequately serving producers facing current conditions. The old practices ineffectively address two major changes that have occurred. The first major change is that the modern fast-growing, high-performance cattle are genetically different from the old-style cattle. Modern cattle have higher rates of weight gain, produce greater quantities of milk, are larger and weigh more, and deposit less fat on their bodies. Modern animals have higher levels of nutrient requirements, which traditional practices do not efficiently meet. The second major change is that the swine, poultry, and dairy industries have switched to efficient feed management systems that evaluate feed costs by the cost per unit of weight of the nutrients. This shift has reduced production costs for these industries and increased competition for the beef industry. With traditional practices, the beef industry cannot reduce production costs enough to remain competitive.

Feed management systems for beef production in the Northern Plains need to be changed and improved. The modern animal, which has reduced body fat, performs best when provided with the required quantities of nutrients throughout the production year, and feed costs are lower when greater quantities of the produced nutrients are efficiently captured from the land base.

The nutrients beef animals require are energy, protein, minerals, vitamins, and water. The quantities of each nutrient required vary with cow size, level of milk production, and production period. Forages provide primarily energy and protein and also some portion of the required minerals and vitamins. The amounts of minerals deficient in forage can be supplied by a free-choice salt/mineral program. Vitamin A can be supplemented if carotene is low in range cow feeds. Adequate quantities of clean water must be provided for satisfactory animal performance.

Forage dry matter intake is influenced primarily by cow size. Larger cows need more feed than smaller cows for satisfactory reproductive and production performance. Daily dry matter intake is generally around 2% of body weight but ranges from 1.5% to 3.0% of body weight (Holecheck et al. 1995) and can be affected by the quality or the water content of forage and by environmental conditions. The dry matter intake requirement for beef cows is the quantity of forage dry matter that contains the required amount of energy (NRC 1996).

Modern high-performance cows produce greater quantities of milk than the old-style cows. Higher milk production requires that cows consume more energy, protein, calcium, and phosphorus for satisfactory performance (NRC 1996). Forages that do not meet these nutrient requirements cause loss of cow weight and reduced milk production.

The quantity of nutrients range cows require is not consistent throughout the year. The level of nutrients required above maintenance levels varies with the changes in nutrient demand from milk production for the nursing calf as it grows and with the changes in nutrient demand of the physiological preparation for breeding and the development of the fetus that will be the next calf (BCRC 1999). The various combinations of these changing nutritional requirements (table 1) are separated into four production periods: dry gestation, third trimester, early lactation, and lactation, which is subdivided into spring, summer, and fall portions.

The dry gestation production period has the lowest nutrient requirements because there is no nursing calf or milk production and the developing

fetus is still small during middle gestation and does not have high nutrient demands. Heavy cows can lose weight during this period without detrimental future effects on reproduction and production performance. Cows with moderate body condition should maintain body weight because the cost to replace lost pounds is greater during other production periods. Thin cows should gain weight during this period because each pound gained requires less feed and costs less than weight gained during other production periods.

The third trimester production period has increased nutrient requirements. Although the cow has no calf at her side and is not producing milk, the developing fetus is growing at an increasing rate. The weight gain from the fetus and related fluid and tissue is about one pound per day during the last 2 or 2.5 months, when the fetus is growing very rapidly (BCRC 1999). It is important that higher-quality forage that meets the nutritional requirements be provided during this period to maintain the weight of cows in moderate or good body condition and to ensure a strong, healthy calf. Feeding forages containing insufficient nutrients during this period causes a reduction in cow body condition and results in delayed estrual activity and a delay in rebreeding.

The early lactation production period has the greatest nutritional requirements of the production periods because the birth of the calf initiates production of increasing amounts of milk and the reproductive organs require repair and pre-conditioning to promote the rapid onset of the estrus cycle. Cows gaining weight during this period produce amounts of milk at or near the animals' genetic potential. Cows increasing in body condition will have adequate time to complete at least one estrus cycle prior to the start of the breeding season; this rapid recovery improves the percentage of cows that conceive in the first cycle of the breeding season (BCRC 1999). Feeding forages containing insufficient nutrients during this period causes a reduced cow body condition that results in milk production at levels below the animals' genetic potential and in a delayed onset of estrual activity so that the period between calving and the first estrus cycle is lengthened and conception rates in the cow herd are reduced.

The spring portion of the lactation production period has nutritional requirements slightly reduced from those of the previous period. The quantity of milk produced continues to increase until the peak is reached during the later part of the second month or the early part of the third month after calving (BCRC 1999). Cows gaining weight during this period produce amounts of milk at or near the animals' genetic potential. Providing harvested or pasture forages with high nutrient content prior to and during breeding season stimulates ovulation in the cows: cows with improving body condition start estrus cycles earlier and can rebreed in 80 to 85 days after calving (BCRC 1999). The rate of calf weight gain continues to increase during the spring period. Calves that are around a month old in early May have developed enough to take advantage of the greater quantities of milk produced by cows grazing high-quality forage on domesticated grass spring complementary pastures and add weight at high rates.

The summer portion of the lactation production period has nutritional requirements above maintenance. The greater part of the additional nutrients is for the production of milk for the nursing calf, and a smaller amount is for the support of an embryo at the early stages of development. The nutritional quality of the forage during the summer plays a role in maintaining the pregnancy. Cows maintaining or improving body condition have lower rates of embryo loss than cows losing body condition (BCRC 1999). The quantity of milk produced during the summer period declines from peak levels. The nutritional quality of the forage affects the rate of decrease. If the forage quality is at or above the animals' nutritional requirements, cows can maintain milk production near their genetic potential during most of the lactation period (BCRC 1999). Cows with higher milk production produce heavier calves at weaning. Cows grazing pasture treatments with forage quality insufficient to meet animal nutritional requirements have milk production below their genetic potential and produce calves that are lighter at weaning and have higher costs per pound of weight gained.

The fall portion of the lactation production period has nutritional requirements above maintenance. The greater part of the additional nutrients is for the production of milk for the nursing calf, and a smaller amount is for development of the fetus. The nutritional quality of the forage affects the quantities of milk produced. If forage quality is at or near animal nutritional requirements, milk production can be fairly high and rate of calf weight gain can be satisfactory (BCRC 1999). Forage quality of mature perennial grasses on traditionally managed pastures is below the requirements of a lactating cow. Forage-feed costs increase when the nutrient quality of the grass or forage provided does not meet the nutritional requirements of the cow. Cows lose body weight and body condition when body reserves are converted into milk production. The level of milk production and the rate of calf weight gain are low; the result is higher costs per pound of calf weight gained.

The time of year during which the cow production periods occur is set by the calving date, which is determined by the breeding date. The sequences of production periods of cows with calving dates in January to April are shown in table 2. The date of calving should be selected so that the nutritional requirements of the cow during her production periods are synchronized with the nutritional quality of the grass and forage resources. The nutritional quality of the common domesticated grassland and native rangeland pastures in the Northern Plains (Whitman et al. 1951, Manske 1999a, b) matches the nutritional requirements of the lactation production periods of cows with calving dates in January through April (figs. 1-4). The nutritional requirements of cows with calving dates in late spring, summer, or fall are not synchronized with the changes in nutritional quality of perennial forages on grazinglands (figs. 5-12). Forage from sources other than perennial grass grazinglands is required to provide low-cost nutrients for cows with calving dates later than April.

Tables 3 to 14 show cow nutrient requirements from grazingland forage or harvested forage during the production periods for 1000-pound, 1200-pound, and 1400-pound cows with calving dates in January to April. The 1200-pound cow with a calf born in mid March will be used as the example throughout this report. The 12-month nutritional requirements for a 1200-pound cow (table 10) are 9489 pounds of forage dry matter, 5217.2 pounds of energy as TDN, 835.8 pounds of crude protein, 24.1 pounds of calcium, and 16.7 pounds of phosphorus. The 12-month forage-feed costs for a cow depend on the amount paid for each pound of nutrient.

Accurate evaluations of costs among various management treatments and forage types are based on costs per pound of nutrient. Cost per pound of crude protein could be used in cost comparisons for different forage types. Small but positive profit margins can be achieved for beef production during a low market with calf weight value at $0.70 per pound at weaning time when the average calf weaning weight is 535 pounds and the pasture-forage costs are 60% of total beef production costs with average forage-feed costs of $0.62 per day, forage dry matter costs of $48.00 per ton, and crude protein costs of $0.25 per pound.

Nutritional requirements for beef cows are determined on a dry-matter basis. Almost all forages consumed by range cows have some water content. Table 15 shows the wet weight equivalent of forages with various water contents. Cows can consume a greater weight of wet forage than of dry forage (BCRC 1999).

Forage dry matter intake of grazing animals is affected by the size of the cow. Large cows consume more forage than medium- and standard-sized cows. A more accurate estimate of daily or monthly forage demand of livestock on grazinglands can be determined with the metabolic weight of the animal rather than its live weight. Metabolic weight is live weight to the 0.75 power (NRC 1996). A 1000-pound cow with a calf is the standard, which is defined as 1.00 animal unit (AU) and has a daily dry matter allocation of 26 pounds of forage (Bedell 1998). The metabolic weight of a 1200-pound cow with a calf is 1.147 animal unit equivalent (AUE), which has a daily dry matter allocation of 30 pounds of forage. The metabolic weight of a 1400-pound cow with a calf is 1.287 animal unit equivalent (AUE), which has a daily dry matter allocation of 33 pounds of forage (Manske 1998a). The amount of forage dry matter consumed in one month by one animal unit, a 1000-pound cow with a calf, is an animal unit month (AUM) (Bedell 1998). During the grazing season from May through November, the length of the average month is 30.5 days (Manske 1998b).

Range cow nutritional requirements change with cow size, milk production level, and production period. Coordination of pasture and forage quantity and quality with dietary quantity and quality requirements of the cow during production periods improves efficiency of nutrient capture and conversion, resulting in lower pasture-forage costs.

Acknowledgment

I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables and figures. I am grateful to Amy M. Kraus for assistance in preparation of this manuscript.

Table 1. Intake nutrient requirements in pounds per day for range cows with average milk production during 12 months of production periods (data from NRC 1996).

	Dry Gestation	3rd Trimester	Early Lactation	Lactation (Spring, Summer, Fall)
1000 lb cows				
Dry matter	21	21	24	24
Energy (TDN)	9.64	10.98	14.30	13.73
Crude protein	1.30	1.64	2.52	2.30
Calcium	0.03	0.05	0.07	0.06
Phosphorus	0.02	0.03	0.05	0.04
1200 lb cows				
Dry matter	24	24	27	27
Energy (TDN)	11.02	12.62	15.85	15.23
Crude protein	1.49	1.87	2.73	2.51
Calcium	0.04	0.06	0.08	0.07
Phosphorus	0.03	0.04	0.05	0.05
1400 lb cows				
Dry matter	27	27	30	30
Energy (TDN)	12.42	14.28	17.40	16.71
Crude protein	1.67	2.13	2.94	2.70
Calcium	0.04	0.07	0.08	0.08
Phosphorus	0.03	0.05	0.06	0.05

Table 2. Twelve-month range cow production period sequences for calf birth dates in January to April.

12-Months	Calf Birth Month			
	January	February	March	April
late Nov	RATION (cont')	RATION		RATION
Dec	3rd Trimester 3.0m, 90d	3rd Trimester 3.0m, 90d	Dry Gestation 1.0m, 32d	Dry Gestation 2.0m, 62d
Jan	Calf Birth		RATION 3rd Trimester 3.0m, 90d	
Feb	Early Lactation 1.0m, 32d	Calf Birth		3rd Trimester 3.0m, 90d
Mar	Lactation 2.5m, 75d	Early Lactation 1.0m, 32d	Calf Birth	
Apr		Lactation 1.5m, 45d	Early Lactation 1.5m, 45d	Calf Birth
May				Early Lactation 0.5m, 15d
Jun	PASTURE Lactation (spring) 1.0m, 31d	PASTURE Lactation (spring) 1.0m, 31d	PASTURE Lactation (spring) 1.0m, 31d	PASTURE Lactation (spring) 1.0m, 31d
Jul	Lactation (summer) 4.5m, 137d	Lactation (summer) 4.5m, 137d	Lactation (summer) 4.5m, 137d	Lactation (summer) 4.5m, 137d
Aug				
Sep				
Oct	Calf age-9m Calf Weaning			
early Nov	RATION 3rd Trimester 3.0m, 90d	Lactation (fall) 1.0m, 30d Calf age-9m Calf Weaning	Lactation (fall) 1.0m, 30d Calf age-8m Calf Weaning	Lactation (fall) 1.0m, 30d Calf age-7m Calf Weaning

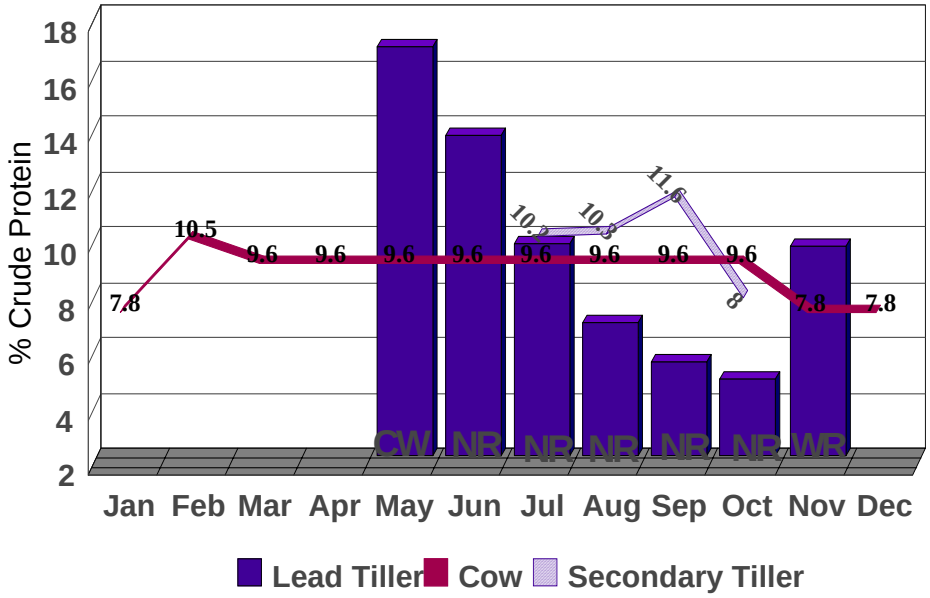


Fig. 1. Cow nutritional requirements for calf birth in January and pasture nutritional quality.

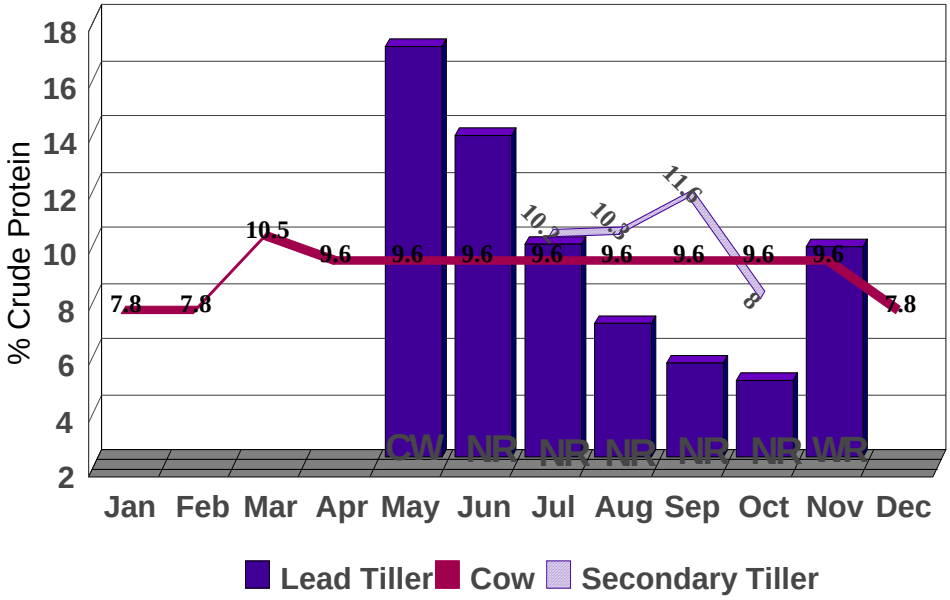


Fig. 2. Cow nutritional requirements for calf birth in February and pasture nutritional quality.

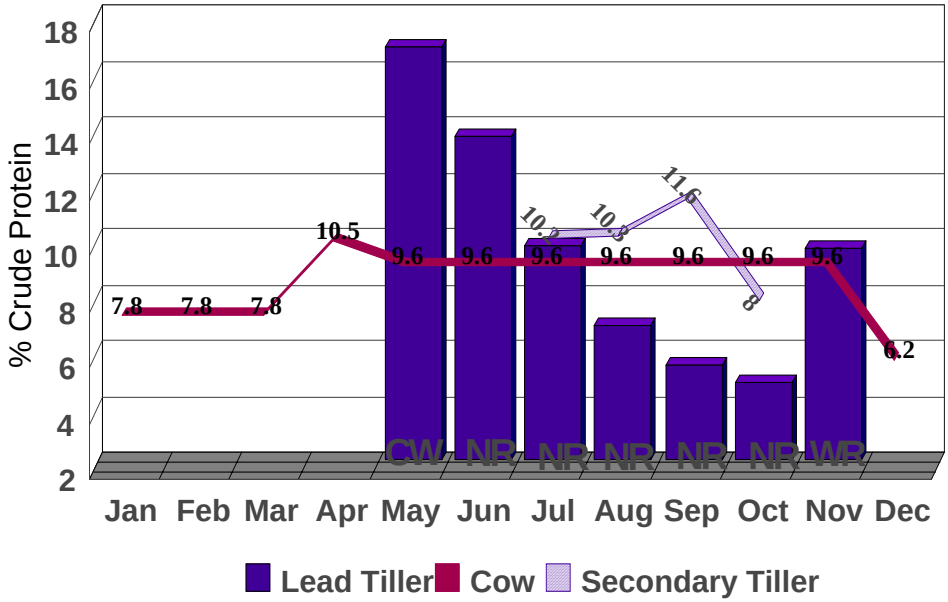


Fig. 3. Cow nutritional requirements for calf birth in March and pasture nutritional quality.

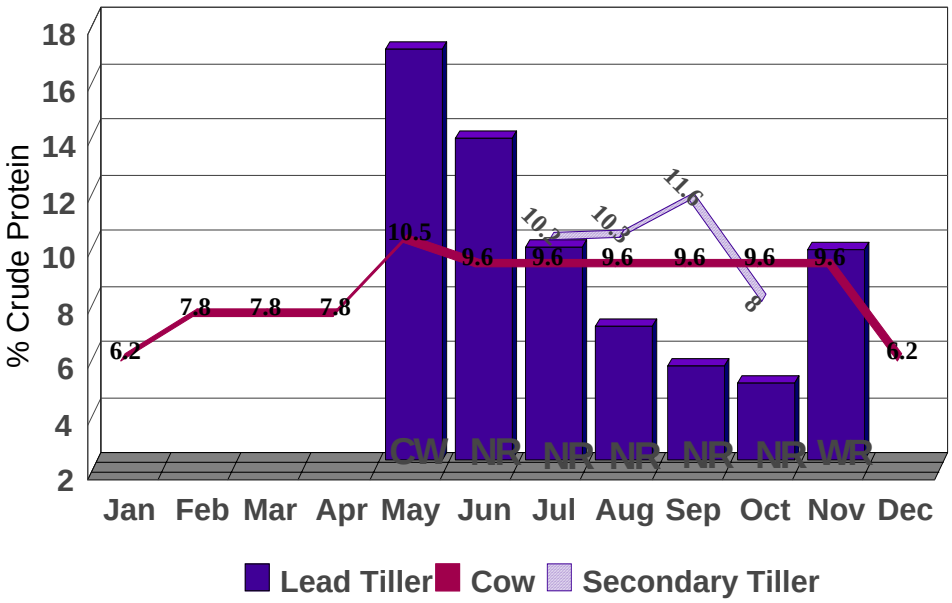


Fig. 4. Cow nutritional requirements for calf birth in April and pasture nutritional quality.

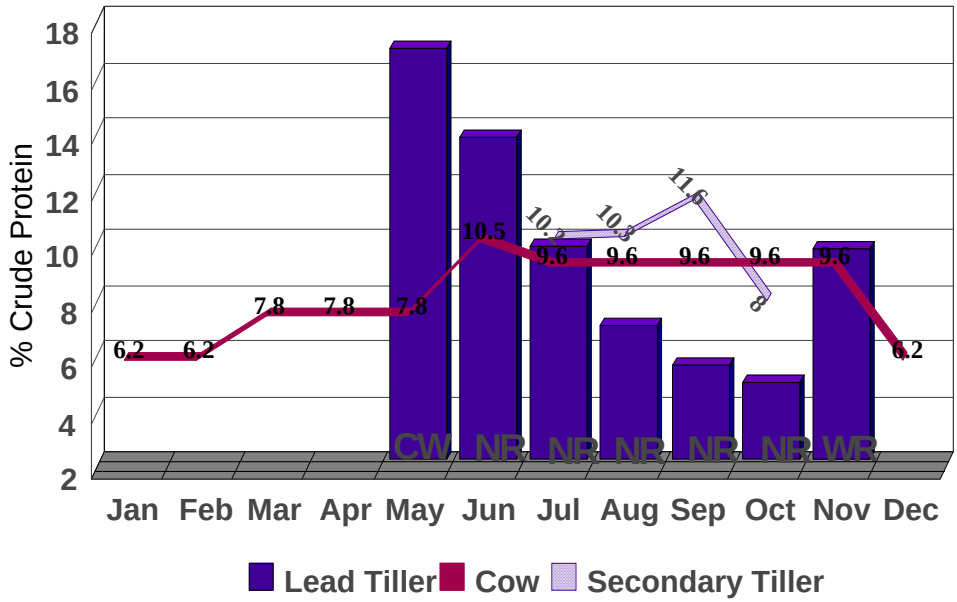


Fig. 5. Cow nutritional requirements for calf birth in May and pasture nutritional quality.

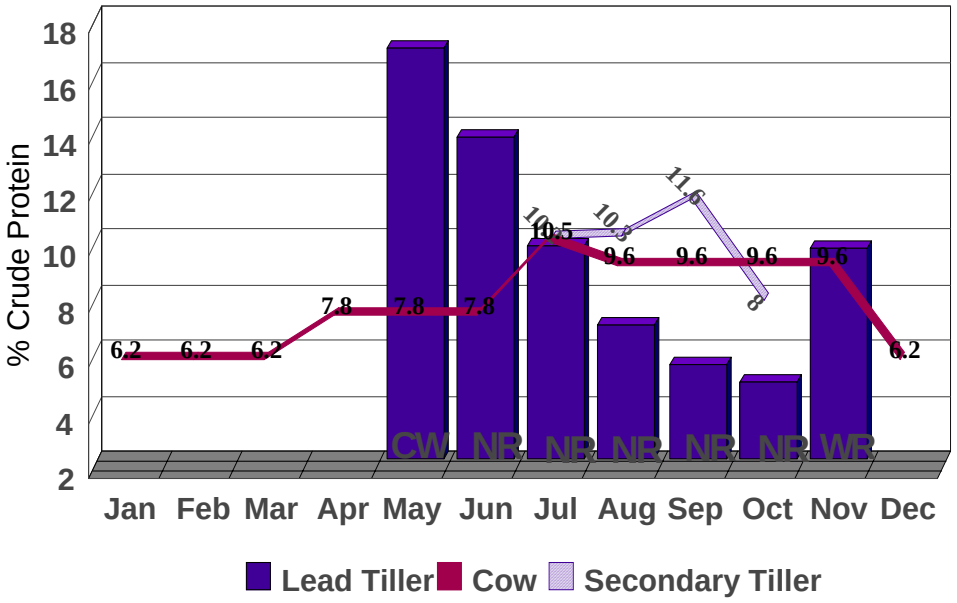


Fig. 6. Cow nutritional requirements for calf birth in June and pasture nutritional quality.

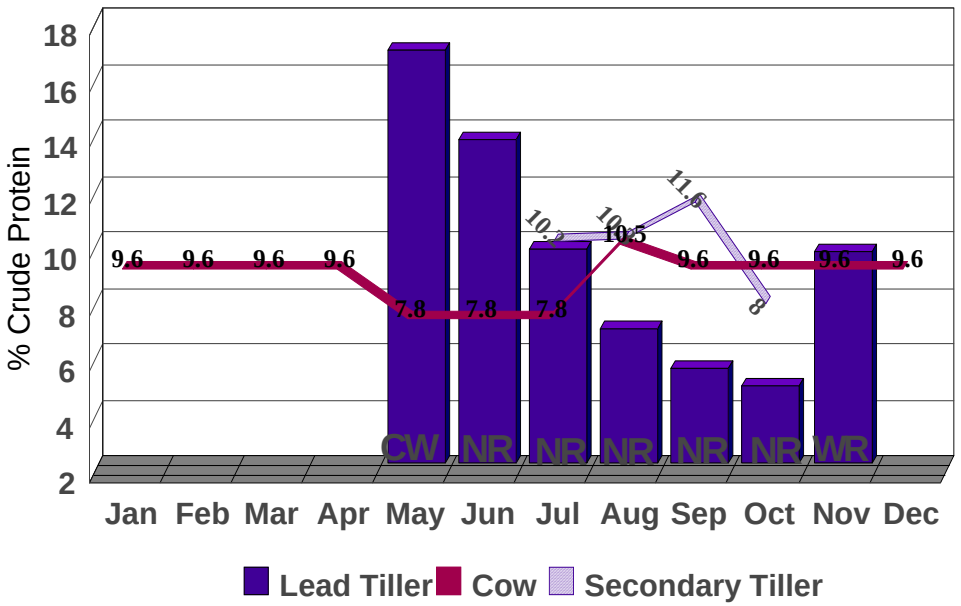


Fig. 7. Cow nutritional requirements for calf birth in July and pasture nutritional quality.

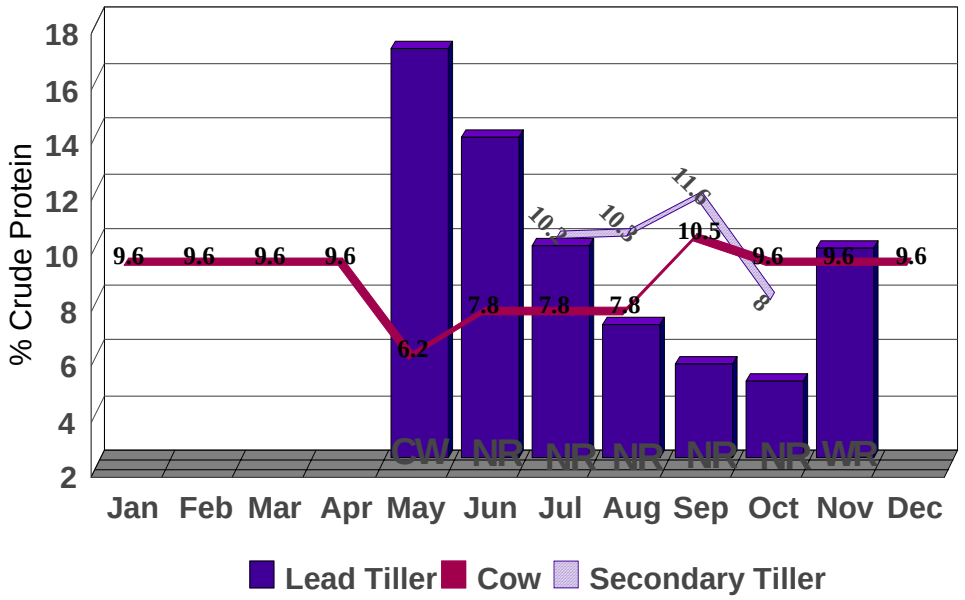


Fig. 8. Cow nutritional requirements for calf birth in August and pasture nutritional quality.

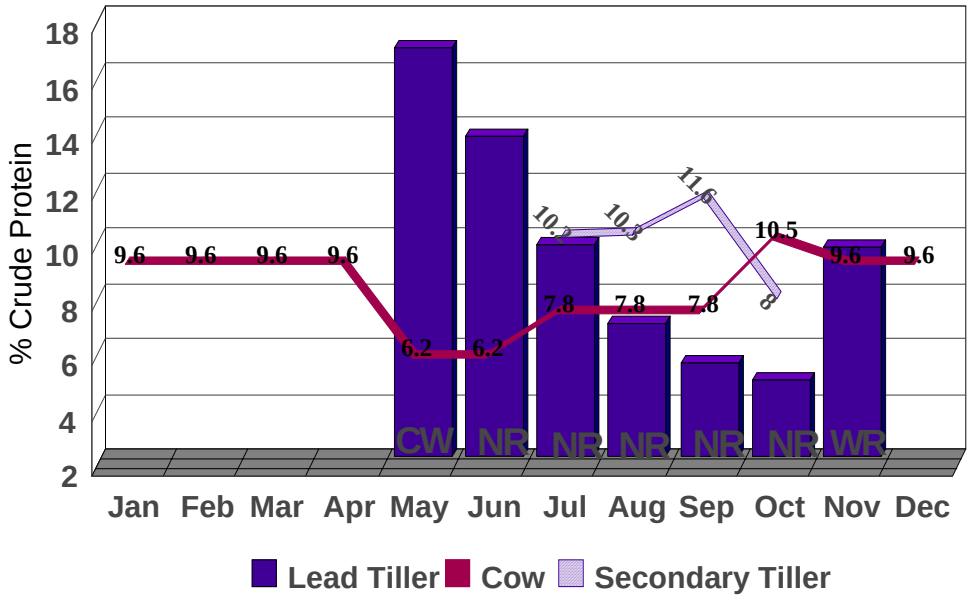


Fig. 9. Cow nutritional requirements for calf birth in September and pasture nutritional quality.

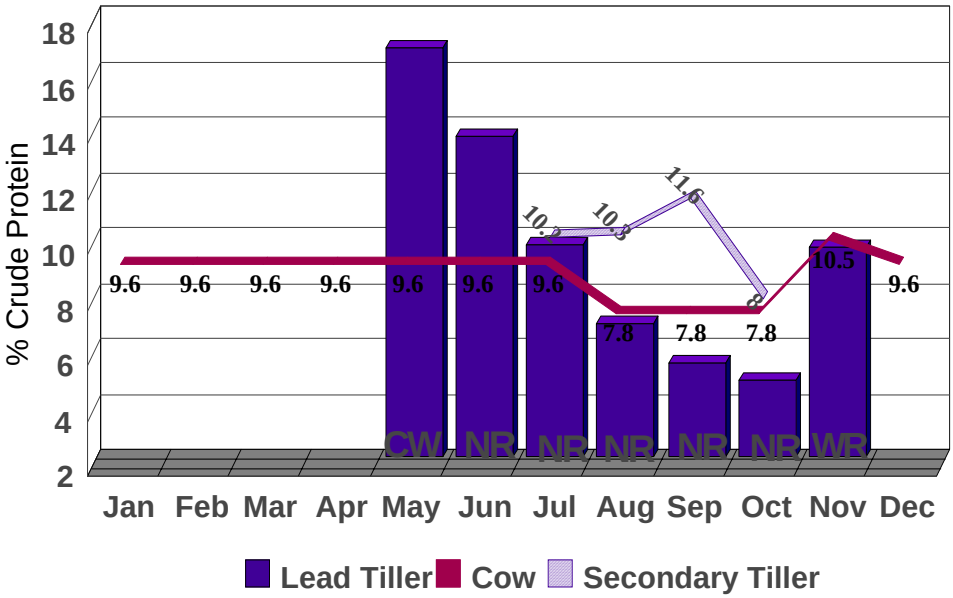


Fig. 10. Cow nutritional requirements for calf birth in October and pasture nutritional quality.

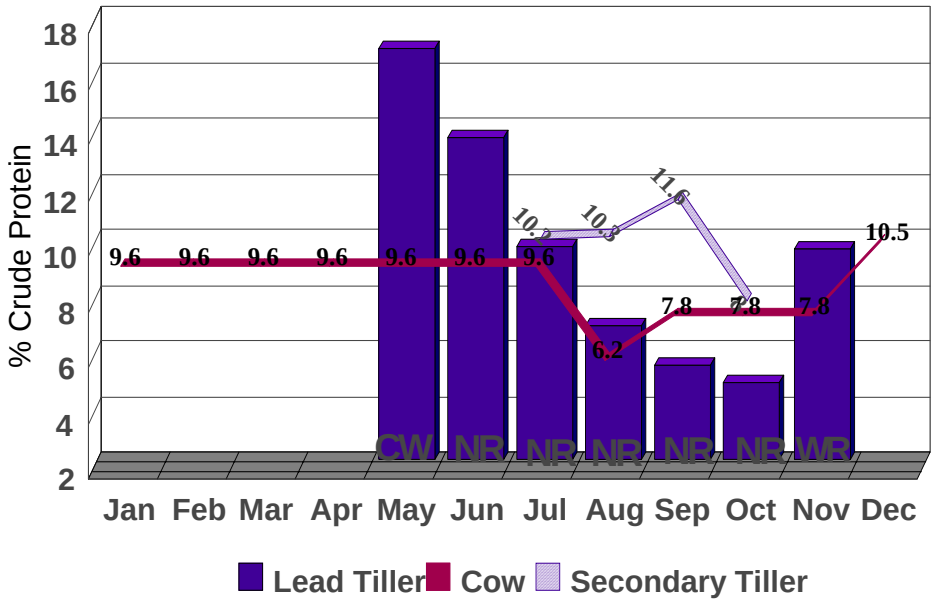


Fig. 11. Cow nutritional requirements for calf birth in November and pasture nutritional quality.

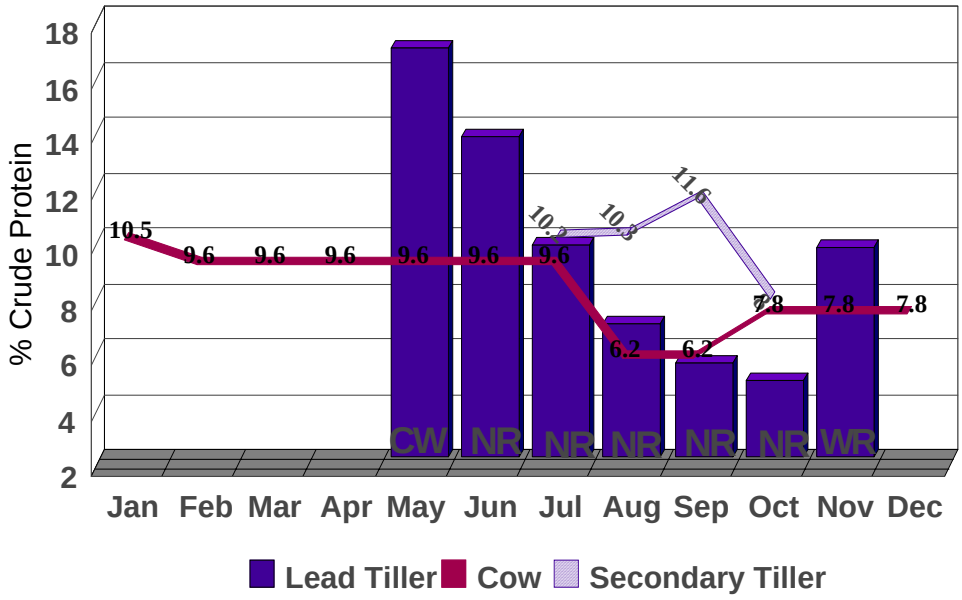


Fig. 12. Cow nutritional requirements for calf birth in December and pasture nutritional quality.

Table 3. Twelve-month nutrient requirements for 1000-pound range cows with calf birth dates in January.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		75	31	137	
Daily Requirements in Pounds										
Dry Matter			21		24				24	
Energy (TDN)			10.98		14.30				13.73	
Crude Protein			1.64		2.52				2.30	
Calcium			0.05		0.07				0.06	
Phosphorus			0.03		0.05				0.04	
Production Period Requirements in Pounds										
Dry Matter			1890		768		1800	744	3288	
Energy (TDN)			988.20		457.60		1029.75	425.63	1881.01	
Crude Protein			147.60		80.64		172.50	71.30	315.10	
Calcium			4.50		2.24		4.50	1.86	8.22	
Phosphorus			2.70		1.60		3.00	1.24	5.48	

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	4458	4032	8490
Energy (TDN)	2475.55	2306.64	4782.19
Crude Protein	400.74	386.40	787.14
Calcium	11.24	10.08	21.32
Phosphorus	7.30	6.72	14.02

Table 4. Twelve-month nutrient requirements for 1200-pound range cows with calf birth dates in January.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		75	31	137	
Daily Requirements in Pounds										
Dry Matter			24		27				27	
Energy (TDN)			12.62		15.85				15.23	
Crude Protein			1.87		2.73				2.51	
Calcium			0.06		0.08				0.07	
Phosphorus			0.04		0.05				0.05	
Production Period Requirements in Pounds										
Dry Matter			2160		864		2025	837	3699	
Energy (TDN)			1135.80		507.20		1142.25	472.13	2086.51	
Crude Protein			168.30		87.36		188.25	77.81	343.87	
Calcium			5.40		2.56		5.25	2.17	9.59	
Phosphorus			3.60		1.60		3.75	1.55	6.85	

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	5049	4536	9585
Energy (TDN)	2785.25	2558.64	5343.89
Crude Protein	443.91	421.68	865.59
Calcium	13.21	11.76	24.97
Phosphorus	8.95	8.40	17.35

Table 5. Twelve-month nutrient requirements for 1400-pound range cows with calf birth dates in January.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		75	31	137	
Daily Requirements in Pounds										
Dry Matter			27		30				30	
Energy (TDN)			14.28		17.40				16.71	
Crude Protein			2.13		2.94				2.70	
Calcium			0.07		0.08				0.08	
Phosphorus			0.05		0.06				0.05	
Production Period Requirements in Pounds										
Dry Matter			2430		960		2250	930	4110	
Energy (TDN)			1285.20		556.80		1253.25	518.01	2289.27	
Crude Protein			191.70		94.08		202.50	83.70	369.90	
Calcium			6.30		2.56		6.00	2.48	10.96	
Phosphorus			4.50		1.92		3.75	1.55	6.85	
12-Month Requirements in Pounds										
			Totals for Rations		Totals for Pastures		Totals for 12 Months			
Dry Matter			5640		5040		10680			
Energy (TDN)			3095.25		2807.28		5902.53			
Crude Protein			488.28		453.60		941.88			
Calcium			14.86		13.44		28.30			
Phosphorus			10.17		8.40		18.57			

Table 6. Twelve-month nutrient requirements for 1000-pound range cows with calf birth dates in February.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		45	31	137	30
Daily Requirements in Pounds										
Dry Matter			21		24				24	
Energy (TDN)			10.98		14.30				13.73	
Crude Protein			1.64		2.52				2.30	
Calcium			0.05		0.07				0.06	
Phosphorus			0.03		0.05				0.04	
Production Period Requirements in Pounds										
Dry Matter			1890		768		1080	744	3288	720
Energy (TDN)			988.20		457.60		617.85	425.63	1881.01	411.90
Crude Protein			147.60		80.64		103.50	71.30	315.10	69.00
Calcium			4.50		2.24		2.70	1.86	8.22	1.80
Phosphorus			2.70		1.60		1.80	1.24	5.48	1.20

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	3738	4752	8490
Energy (TDN)	2063.65	2718.54	4782.19
Crude Protein	331.74	455.40	787.14
Calcium	9.44	11.88	21.32
Phosphorus	6.10	7.92	14.02

Table 7. Twelve-month nutrient requirements for 1200-pound range cows with calf birth dates in February.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		45	31	137	30
Daily Requirements in Pounds										
Dry Matter			24		27				27	
Energy (TDN)			12.62		15.85				15.23	
Crude Protein			1.87		2.73				2.51	
Calcium			0.06		0.08				0.07	
Phosphorus			0.04		0.05				0.05	
Production Period Requirements in Pounds										
Dry Matter			2160		864		1215	837	3699	810
Energy (TDN)			1135.80		507.20		685.35	472.13	2086.51	456.90
Crude Protein			168.30		87.36		112.95	77.81	343.87	75.30
Calcium			5.40		2.56		3.15	2.17	9.59	2.10
Phosphorus			3.60		1.60		2.25	1.55	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	4239	5346	9585
Energy (TDN)	2328.35	3015.54	5343.89
Crude Protein	368.61	496.98	865.59
Calcium	11.11	13.86	24.97
Phosphorus	7.45	9.90	17.35

Table 8. Twelve-month nutrient requirements for 1400-pound range cows with calf birth dates in February.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days			90		32		45	31	137	30
Daily Requirements in Pounds										
Dry Matter			27		30				30	
Energy (TDN)			14.28		17.40				16.71	
Crude Protein			2.13		2.94				2.70	
Calcium			0.07		0.08				0.08	
Phosphorus			0.05		0.06				0.05	
Production Period Requirements in Pounds										
Dry Matter			2430		960		1350	930	4110	900
Energy (TDN)			1285.20		556.80		751.95	518.01	2289.27	501.30
Crude Protein			191.70		94.08		121.50	83.70	369.90	81.00
Calcium			6.30		2.56		3.60	2.48	10.96	2.40
Phosphorus			4.50		1.92		2.25	1.55	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	4740	5940	10680
Energy (TDN)	2593.95	3308.58	5902.53
Crude Protein	407.28	534.60	941.88
Calcium	12.46	15.84	28.30
Phosphorus	8.67	9.90	18.57

Table 9. Twelve-month nutrient requirements for 1000-pound range cows with calf birth dates in March.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days		32	90		45			31	137	30
Daily Requirements in Pounds										
Dry Matter		21	21		24				24	
Energy (TDN)		9.64	10.98		14.30				13.73	
Crude Protein		1.30	1.64		2.52				2.30	
Calcium		0.03	0.05		0.07				0.06	
Phosphorus		0.02	0.03		0.05				0.04	
Production Period Requirements in Pounds										
Dry Matter		672	1890		1080			744	3288	720
Energy (TDN)		308.48	988.20		643.50			425.63	1881.01	411.90
Crude Protein		41.60	147.60		113.40			71.30	315.10	69.00
Calcium		0.96	4.50		3.15			1.86	8.22	1.80
Phosphorus		0.64	2.70		2.25			1.24	5.48	1.20

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	2970	5424	8394
Energy (TDN)	1631.70	3027.02	4658.72
Crude Protein	261.00	497.00	758.00
Calcium	7.65	12.84	20.49
Phosphorus	4.95	8.56	13.51

Table 10. Twelve-month nutrient requirements for 1200-pound range cows with calf birth dates in March.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days		32	90		45			31	137	30
Daily Requirements in Pounds										
Dry Matter		24	24		27				27	
Energy (TDN)		11.02	12.62		15.85				15.23	
Crude Protein		1.49	1.87		2.73				2.51	
Calcium		0.04	0.06		0.08				0.07	
Phosphorus		0.03	0.04		0.05				0.05	
Production Period Requirements in Pounds										
Dry Matter		768	2160		1215			837	3699	810
Energy (TDN)		352.64	1135.80		713.25			472.13	2086.51	456.90
Crude Protein		47.68	168.30		122.85			77.81	343.87	75.30
Calcium		1.28	5.40		3.60			2.17	9.59	2.10
Phosphorus		0.96	3.60		2.25			1.55	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	3375	6114	9489
Energy (TDN)	1849.05	3368.18	5217.23
Crude Protein	291.15	544.66	835.80
Calcium	9.00	15.14	24.14
Phosphorus	5.85	10.86	16.71

Table 11. Twelve-month nutrient requirements for 1400-pound range cows with calf birth dates in March.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days		32	90		45			31	137	30
Daily Requirements in Pounds										
Dry Matter		27	27		30				30	
Energy (TDN)		12.42	14.28		17.40				16.71	
Crude Protein		1.67	2.13		2.94				2.70	
Calcium		0.04	0.07		0.08				0.08	
Phosphorus		0.03	0.05		0.06				0.05	
Production Period Requirements in Pounds										
Dry Matter		864	2430		1350			930	4110	900
Energy (TDN)		397.44	1285.20		783.00			518.01	2289.27	501.30
Crude Protein		53.44	191.70		132.30			83.70	369.90	81.00
Calcium		1.28	6.30		3.60			2.48	10.96	2.40
Phosphorus		0.96	4.50		2.70			1.55	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	3780	6804	10584
Energy (TDN)	2068.20	3706.02	5774.22
Crude Protein	324.00	588.04	912.04
Calcium	9.90	17.12	27.02
Phosphorus	7.20	10.86	18.06

Table 12. Twelve-month nutrient requirements for 1000-pound range cows with calf birth dates in April.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days	62		90		15	15		16	137	30
Daily Requirements in Pounds										
Dry Matter	21		21		24				24	
Energy (TDN)	9.64		10.98		14.30				13.73	
Crude Protein	1.30		1.64		2.52				2.30	
Calcium	0.03		0.05		0.07				0.06	
Phosphorus	0.02		0.03		0.05				0.04	
Production Period Requirements in Pounds										
Dry Matter	1302		1890		360	360		384	3288	720
Energy (TDN)	597.68		988.20		214.50	214.50		219.68	1881.01	411.90
Crude Protein	80.60		147.60		37.50	37.50		36.80	315.10	69.00
Calcium	1.86		4.50		1.05	1.05		0.96	8.22	1.80
Phosphorus	1.24		2.70		0.75	0.75		0.64	5.48	1.20

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	3552	4752	8304
Energy (TDN)	1800.38	2727.09	4527.47
Crude Protein	265.70	458.40	724.10
Calcium	7.41	12.03	19.44
Phosphorus	4.69	8.07	12.76

Table 13. Twelve-month nutrient requirements for 1200-pound range cows with calf birth dates in April.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days	62		90		15	15		16	137	30
Daily Requirements in Pounds										
Dry Matter	24		24		27				27	
Energy (TDN)	11.02		12.62		15.85				15.23	
Crude Protein	1.49		1.87		2.73				2.51	
Calcium	0.04		0.06		0.08				0.07	
Phosphorus	0.03		0.04		0.05				0.05	
Production Period Requirements in Pounds										
Dry Matter	1488		2160		405	405		432	3699	810
Energy (TDN)	683.24		1135.80		237.75	237.75		243.68	2086.51	456.90
Crude Protein	92.38		168.30		40.95	40.95		40.16	343.87	75.30
Calcium	2.48		5.40		1.20	1.20		1.12	9.59	2.10
Phosphorus	1.86		3.60		0.75	0.75		0.80	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	4053	5346	9399
Energy (TDN)	2056.79	3024.84	5081.63
Crude Protein	301.63	500.28	801.91
Calcium	9.08	14.01	23.09
Phosphorus	6.21	9.90	16.11

Table 14. Twelve-month nutrient requirements for 1400-pound range cows with calf birth dates in April.

	Dry Gestation		3rd Trimester		Early Lactation		Lactation			
	Ration	Pasture	Ration	Pasture	Ration	Pasture	Ration	Spring Pasture	Summer Pasture	Fall Pasture
Days	62		90		15	15		16	137	30
Daily Requirements in Pounds										
Dry Matter	27		27		30				30	
Energy (TDN)	12.42		14.28		17.40				16.71	
Crude Protein	1.67		2.13		2.94				2.70	
Calcium	0.04		0.07		0.08				0.08	
Phosphorus	0.03		0.05		0.06				0.05	
Production Period Requirements in Pounds										
Dry Matter	1674		2430		450	450		480	4110	900
Energy (TDN)	770.04		1285.20		261.00	261.00		267.36	2289.27	501.30
Crude Protein	103.54		191.70		44.10	44.10		43.20	369.90	81.00
Calcium	2.48		6.30		1.20	1.20		1.28	10.96	2.40
Phosphorus	1.86		4.50		0.90	0.90		0.80	6.85	1.50

12-Month Requirements in Pounds

	Totals for Rations	Totals for Pastures	Totals for 12 Months
Dry Matter	4554	5940	10494
Energy (TDN)	2316.24	3318.93	5635.17
Crude Protein	339.34	538.20	877.54
Calcium	9.98	15.84	25.84
Phosphorus	7.26	10.05	17.31

Table 15. Dry weight of forage and as fed weight of forage in pounds at various percent water content levels.

% water	dry weight	dry weight	dry weight	dry weight	dry weight	dry weight
0	21	24	26	27	30	33
	wet weight	wet weight	wet weight	wet weight	wet weight	wet weight
5	22.1	25.3	27.4	28.4	31.6	34.7
10	23.3	26.7	28.9	30.0	33.3	36.7
15	24.7	28.2	30.6	31.8	35.3	38.8
20	26.3	30.0	32.5	33.8	37.5	41.3
25	28.0	32.0	34.7	36.0	40.0	44.0
30	30.0	34.3	37.1	38.6	42.9	47.1
35	32.3	36.9	40.0	41.5	46.2	50.8
40	35.0	40.0	43.3	45.0	50.0	55.0
45	38.2	43.6	47.3	49.1	54.5	60.0
50	42.0	48.0	52.0	54.0	60.0	66.0
55	46.7	53.3	57.8	60.0	66.7	73.3
60	52.5	60.0	65.0	67.5	75.0	82.5
65	60.0	68.6	74.3	77.1	85.7	94.3
70	70.0	80.0	86.7	90.0	100.0	110.0
75	84.0	96.0	104.0	108.0	120.0	132.0
80	105.0	120.0	130.0	135.0	150.0	165.0
85	140.0	160.0	173.3	180.0	200.0	220.0
90	210.0	240.0	260.0	270.0	300.0	330.0
95	420.0	480.0	520.0	540.0	600.0	660.0

Literature Cited

Bedell, T.E. (Chair.). 1998. Glossary of terms used in range management. Society for Range Management, Denver, CO.

Beef Cattle Resource Committee. 1999. Beef Cattle Handbook. University of Wisconsin-Cooperative Extension Publishing Unit. Midwest Plan Service, Ames, IA.

Holecheck, J.L., R.D. Pieper, and C.H. Herbel. 1995. Range management principles and practices. Prentice Hall, NJ.

Manske, L.L. 1998a. Animal unit equivalent for beef cattle based on metabolic weight. NDSU Dickinson Research Extension Center. Range Management Report DREC 98-1020. Dickinson, ND. 3p.

Manske, L.L. 1998b. How long is the average grazing season month? NDSU Dickinson Research Extension Center. Range Management Report DREC 98-1021. Dickinson, ND. 2p.

Manske, L.L. 1999a. Annual nutritional quality curves for native range cool-season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1026. Dickinson, ND. 16p.

Manske, L.L. 1999b. Annual nutritional quality curves for native range warm-season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1027. Dickinson, ND. 13p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Mineral Requirements for Beef Cows Grazing Native Rangeland

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Beef cows grazing native rangeland require seven macrominerals and ten microminerals for normal body functions. Understanding livestock mineral requirements, functions of each mineral, and mineral concentrations that result in deficiencies or toxicities is necessary to maintain beef cows at high levels of production. The quantities of each mineral required vary with cow size, level of milk production, and production period (dry gestation, 3rd trimester, early lactation, and lactation). Animals acquire most of these essential minerals from forages. Forage plant growth can be altered by differential defoliation treatment effects on plant growth processes (Manske 2000). Mineral concentrations in native range herbage are not constant, and the patterns of change during the grazing season differ with management treatment. Supplementation of minerals during periods when concentrations in herbage are below those required by beef cattle is necessary to maintain optimum livestock performance. This report summarizes information on the mineral requirements for beef cows grazing native rangeland of the mixed grass prairie in the Northern Plains.

Beef Cow Macromineral Requirements

The macrominerals required by beef cattle are calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), chlorine (Cl), and sulfur (S). Phosphorus and calcium make up about 70% to 75% of the mineral matter in beef cattle, including over 90% of the mineral matter in the skeleton. Calcium is the most abundant mineral in the cow's body, with 98% of the calcium in the bones and teeth and the remainder in the extracellular fluids and soft tissue (NRC 1996). About 80% of the phosphorus in the cow's body is in the bones and teeth; the remainder occurs in soft tissue, mostly in organic forms. Phosphorus and calcium function together with magnesium in bone formation, and these minerals are required for normal skeletal development and maintenance (NRC 1996). Phosphorus exists in blood serum both in organic forms, as a constituent of lipids, and in inorganic forms. Phosphorus is a component of phospholipids, which are important in lipid transport and metabolism and in cell-membrane structure and cell growth. As a component of AMP, ADP, ATP, and creatine phosphate, phosphorus functions in energy metabolism, utilization, and transfer. Phosphorus is required for protein synthesis as phosphate, a component of RNA and DNA. Calcium exists in blood serum in both organic and inorganic forms. Slight changes in calcium, potassium, magnesium, and sodium concentrations control muscle contractions and the transmission of nerve impulses. Calcium and sulfur are required for normal blood coagulation (Church and Pond 1975, NRC 1996). Phosphorus, calcium, potassium, and magnesium are constituents of several enzyme systems. Phosphorus, calcium, potassium, magnesium, sodium, chlorine, and sulfur function in regulating fluid balance by maintaining osmotic pressure and the acid-base balance of the entire system. The blood contains more sodium and chlorine than other minerals. Sodium and chlorine are electrolytes and function in maintaining osmotic pressure in the body cells. Chlorine is required to form hydrochloric acid in gastric juice (Church and Pond 1975, NRC 1996). Phosphorus and sulfur are required by ruminal microorganisms for their growth and cellular metabolism (NRC 1996).

Relative levels of calcium and phosphorus are important. Dietary calcium to phosphorus ratios between 1:1 and 7:1 result in similar normal animal performance. Dietary phosphorus absorption (NRC 1996) occurs rapidly in the small intestine by passive diffusion across the intestine cell membrane against a concentration gradient in the presence of calcium. Cattle are not known to have an active transport system for phosphorus. About 68% of dietary phosphorus is absorbed. Dietary calcium absorption (NRC 1996) occurs in the first two sections of the small intestine both by passive diffusion and by active transport with a vitamin D-dependent protein carrier. About 50% of dietary calcium is absorbed. Calcium is maintained at a relatively constant concentration in the blood plasma by an elaborate control system that involves calcium deposition in and resorption from the bones, variations in reabsorption rate in the kidneys, and variations in the levels of absorption in the intestines. During periods when blood phosphorus or calcium concentrations are low, the kidney tubules can reabsorb an increased amount of the deficient minerals and the body can thereby conserve them. The skeleton of mature animals provides a large reserve of phosphorus and

calcium that can be drawn on during periods of inadequate phosphorus or calcium intake. Skeletal reserves can subsequently be replenished during periods when phosphorus and calcium intake are high relative to requirements (Church and Pond 1975, NRC 1996).

The concentrations of calcium and phosphorus required by beef cows during lactation are 0.26%-0.27% and 0.18% diet dry matter, respectively (NRC 1996). A deficiency of either calcium or phosphorus can adversely affect the skeletal system. In young growing animals inadequate calcium or phosphorus can cause rickets, which develops when the blood becomes low or deficient in calcium, phosphorus, or both, and normal deposition of calcium and phosphorus in growing bones cannot occur. The bones become soft and weak. In severe cases, bones can become deformed, and with increased severity of the condition, bones can break or fracture readily. A deficiency of calcium or phosphorus in older mature animals can cause osteoporosis, which develops when large amounts of calcium and phosphorus are withdrawn from the bones to meet other systems' needs for these minerals. During prolonged periods of calcium and phosphorus deficiency, the bones become porous and weak, and in severe cases, they can break easily (Church and Pond 1975, NRC 1996).

Pregnancy and lactation produce high demands for calcium and phosphorus. Production of one pound of milk requires 0.020 ounces of calcium and 0.015 ounces of phosphorus (NRC 1996). Most cases of calcium deficiency occur early in lactation, during the period when milk production causes large drains on body calcium reserves. Calcium deficiency during lactation causes milk fever. Severe calcium deficiency produces hypocalcemia (low blood calcium) and interferes with the role calcium plays in normal muscle contractions, including those of the heart, and in normal transmission of nerve impulses; this condition results in tetany, convulsions, and, if not treated early, possibly death (Church and Pond 1975, NRC 1996).

Even when cattle diets are only slightly deficient in calcium or phosphorus, animal performance may suffer. Calcium deficiency causes reduced feed intake, loss of body weight, and failure of cows to come into heat regularly. Calcium deficiency also causes a reduction in the quantity of milk produced: the quality of the milk is not changed, and the mineral content of the milk remains relatively constant; however, reduction in the quantity of milk produced by a cow results in lower calf daily gain (Manske 1998). Phosphorus deficiency in beef cattle results in reduced growth and feed efficiency, decreased feed intake, impaired reproduction, reduced milk production, and weak, fragile bones. Cattle grazing forages low in phosphorus experience lower fertility and lighter calf weaning weights (NRC 1996).

Deficiencies of other macrominerals are also detrimental to beef cattle. Adequate quantities of supplemental minerals should be provided to livestock during periods when forages do not contain sufficient levels.

The concentration of magnesium required by beef cows during lactation is 0.17%-0.20% diet dry matter (NRC 1996). Magnesium deficiency causes grass tetany (hypomagnesemia or low blood magnesium), occurring most commonly in lactating cows grazing lush spring pastures high in protein and potassium. Magnesium deficiency in beef cattle results in nervousness, reduced feed intake, muscular twitching, and staggering gait. In advanced stages of magnesium deficiency, convulsions occur, the animal cannot stand, and death soon follows (Church and Pond 1975, NRC 1996). The maximum tolerable concentration of magnesium has been estimated at 0.40% diet dry matter (NRC 1996).

Intake of proper amounts of potassium, the third most abundant mineral in beef cattle, is important. The concentration of potassium required by beef cows during lactation is 0.70% diet dry matter (NRC 1996). Deficiency of potassium causes decreased feed intake and reduced weight gain. Cattle consuming diets with more than 3% potassium while grazing lush spring pastures experience reduced magnesium absorption and the related magnesium deficiency symptoms (Church and Pond 1975, NRC 1996). The maximum tolerable concentration of potassium has been set at 3.0% diet dry matter because of potassium's antagonistic action to magnesium absorption. High levels of potassium are not known to cause any other adverse effects (NRC 1996).

The concentration of sulfur required by beef cows is 0.15% diet dry matter (NRC 1996). Deficiency of sulfur, a component of some amino acids and some vitamins, causes reduced feed intake and decreased microbial digestion and protein synthesis. Severe sulfur deficiency results in diminished feed intake, major loss of body weight, weak and emaciated condition, excessive salivation, and death (Church and Pond 1975, NRC 1996). The maximum tolerable concentration of dietary sulfur has been estimated at 0.40% diet dry matter, but sulfur toxicity is not a practical problem because

absorption of inorganic sulfur is low (Church and Pond 1975, NRC 1996).

Grazing cattle require supplemental salt (sodium and chlorine) because forages do not contain adequate amounts. The concentration of sodium required by beef cows during lactation is 0.10% diet dry matter (NRC 1996). The concentration of chlorine required by beef cows is not well defined, but the amounts supplied by dietary salt appear to be adequate (Church and Pond 1975, NRC 1996). Severe salt deficiency causes reduced feed intake, rapid loss of body weight, and reduced milk production. In some arid and semi-arid regions of the country, a portion of the required amount of salt is provided by the alkaline water. Supplemental salt can be provided free-choice in loose or block forms. Cattle grazing pastures consume more salt during spring and early summer when the forage is more succulent than later in the season when the forage is drier. High levels of dietary salt reduce feed intake. Cattle occasionally consume greater amounts of salt than required but will generally not consume excessive amounts except after experiencing periods without sufficient quantities (Church and Pond 1975, NRC 1996). The maximum tolerable concentration of dietary salt is estimated at 9.0% diet dry matter. Salt in drinking water is much more toxic; the maximum tolerable concentration of sodium in water is 0.70% (NRC 1996).

Toxicity of magnesium, potassium, sodium, or chlorine is unlikely because amounts in excess of those required are readily excreted by the kidneys. Toxicity problems can develop, however, when drinking water intake is restricted, drinking water contains more than 7,000 mg Na/kg (ppm), or the kidneys malfunction (Church and Pond 1975, NRC 1996).

Beef Cow Micromineral Requirements

The microminerals required by beef cattle are chromium (Cr), cobalt (Co), copper (Cu), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn). Microminerals are primarily components of enzymes and organic compounds or are elements for activation of enzyme systems. The functions of microminerals are determined by the function of the compounds of which the microminerals are a part.

Chromium (Cr) is a cofactor in the action of insulin and is important in glucose utilization and the synthesis of cholesterol and fatty acids. Beef cattle may need supplemental chromium in some situations, but the current data are not sufficient to allow accurate determination of requirements. The maximum tolerable concentration in diet dry matter is estimated to be 1,000 mg Cr/kg (ppm) (Church and Pond 1975, NRC 1996).

Cobalt (Co) functions as a component of vitamin B_{12}. Two vitamin B_{12}-dependent enzymes are known to occur in cattle. Cattle are not dependent on a dietary source of vitamin B_{12} because ruminal microorganisms can synthesize B_{12} from dietary cobalt. The recommended concentration of cobalt in beef cattle diets is approximately 0.10 mg Co/kg (ppm) diet dry matter. Early signs of cobalt deficiency are decreased appetite, reduced milk production, and either failure to grow or moderate weight loss. With severe deficiency, animals exhibit unthriftiness, rapid weight loss, fatty degeneration of the liver, and pale skin and mucous membrane as a result of anemia. Cobalt concentrations in forages are dependent on levels of cobalt in the soil. Availability of cobalt in soil is highly dependent on soil pH, and some soils are deficient in cobalt. Legumes are generally higher in cobalt than grasses. Cobalt can be supplemented in mineral mixtures as cobalt sulfate and cobalt carbonate. Cobalt toxicity is not likely to occur because cattle can tolerate approximately 100 times the dietary requirements. Signs of cobalt toxicity are decreased feed intake, reduced body weight gain, anemia, emaciation, hyperchromia, debility, and increased liver cobalt (Church and Pond 1975, NRC 1996).

Copper (Cu) functions as an essential component of a number of enzymes and is required for normal red blood cell formation, normal bone formation, normal elastin formation in the aorta and cardiovascular system, normal myelination of the brain cells and spinal cord, and normal pigmentation of hair. Copper is important to the functions of the immune system. The recommended concentration of copper in beef cattle diets is 10 mg Cu/kg (ppm) diet dry matter. Copper requirements are affected by dietary molybdenum (Mo) and sulfur (S). Antagonistic action of molybdenum occurs at levels above 2 mg Mo/kg diet, and antagonistic action of sulfur occurs at levels above 0.25% sulfur. Molybdenum and sulfur interact in the rumen to form thiomolybdates, compounds that react with copper to form insoluble complexes that are poorly absorbed. Thiomolybdates also reduce metabolism of copper post absorption. Sulfur can react with copper to form copper sulfide, which also reduces absorption of copper. High concentrations of iron and zinc also reduce copper status. Copper deficiency is a widespread problem in many areas of North America. Signs of copper deficiency are anemia; reduced growth rate; changes in the growth, physical

appearance, and pigmentation of hair; cardiac failure; fragile bones that easily fracture; diarrhea; and low reproduction levels resulting from delayed or depressed estrus. Copper concentrations in forages are highly variable, depending on plant species and availability of copper in the soil. Legumes are usually higher in copper than grasses. Copper can be supplemented in mineral mixtures in the sulfate or carbonate forms. Feed-grade copper oxide is largely biologically unavailable but has been used as a source of slow-release copper because it remains in the digestive tract for months. The maximum tolerable concentration of copper for cattle has been estimated at 100 mg Cu/kg (ppm) diet dry matter, but this amount is dependent on the concentrations of molybdenum, sulfur, and iron in the diet. The liver can accumulate large amounts of copper before signs of toxicity are observed (Church and Pond 1975, NRC 1996).

Iodine (I) is an essential component of thyroid hormones, which regulate the rate of energy metabolism. Iodine requirements of beef cattle have not been determined with certainty, but 0.5 mg I/kg (ppm) diet dry matter should be adequate. Signs of iodine deficiency are enlargement of the thyroid, calves born weak or dead, and reduced reproduction that results from irregular cycling, low conception rate, and retained placenta in cows and from decreased libido and semen quality in bulls. Iodine concentrations in forage depend on the availability of iodine in the soil, and many of the soils in central North America are deficient in iodine. Iodine can be supplemented in iodized salt or in mineral mixtures as calcium iodate or an organic form of iodine. Cattle tolerate maximum iodine levels of 50 mg I/kg (ppm) diet dry matter. Signs of iodine toxicity are coughing, excessive nasal discharge, reduced feed intake, and reduced weight gain (Church and Pond 1975, NRC 1996).

Iron (Fe) is a component of hemoglobin in red blood cells, myoglobin in muscles, and other proteins involved in transport of oxygen to tissues or utilization of oxygen. Iron is also a constituent of several enzymes associated with the mechanisms of electron transport, and iron is a component of several metalloenzymes. Iron is important to the functions of the immune system. The iron requirement of beef cattle is approximately 50 mg Fe/kg (ppm) diet dry matter. Iron requirements of older cattle are not well defined but are probably lower than those of young calves, in which blood volume is increasing. Iron deficiency is unlikely in cattle because adequate levels of iron are available from numerous sources. Iron concentration in forages is highly variable, but most forages are high in iron, containing from 70 to 500 mg Fe/kg. Water and ingested soil can be significant sources of iron for beef cattle. When iron needs to be supplemented, it can be added to mineral mixtures as ferrous sulfate or ferrous carbonate. Ferric oxide is basically biologically unavailable. Dietary iron concentrations as low as 250 to 500 mg/kg have caused copper depletion in cattle. In areas where drinking water or forages are high in iron, dietary copper may need to be increased to prevent copper deficiency. The maximum tolerable concentration of iron for cattle has been estimated at 1,000 mg Fe/kg (ppm) diet dry matter. Signs of iron toxicity are diarrhea, metabolic acidosis, hypothermia, reduced feed intake, and reduced weight gain (Church and Pond 1975, NRC 1996).

Manganese (Mn) is a component of a few metalloenzymes that function in carbohydrate metabolism and lipid metabolism. Manganese also stimulates and activates a number of other enzymes. Manganese is important in cattle reproduction because it is required for normal estrus and ovulation in cows and for normal libido and spermatogenesis in bulls. Manganese is essential for normal bone formation and growth. Manganese is important to the functions of the immune system. The recommended concentration of manganese for breeding cattle is 40 mg Mn/kg (ppm) diet dry matter. Signs of manganese deficiency are skeletal abnormalities in young animals and, in older animals, low reproductive performance resulting from depressed or irregular estrus, low conception rate, abortion, stillbirths, and low birth weights. Manganese concentrations in forage are generally adequate but are variable, depending on the availability of manganese because of soil pH and soil drainage. Manganese can be supplemented in mineral mixtures as manganese sulfate, manganese oxide, or various organic forms. Manganese oxide is less readily available biologically than manganese sulfate. Maximum tolerable concentration of manganese is set at 1,000 mg Mn/kg (ppm) diet dry matter (Church and Pond 1975, NRC 1996).

Molybdenum (Mo) is a component of a metalloenzyme and other enzymes. The requirements for molybdenum have not been established. No evidence that molybdenum deficiency occurs in cattle under practical conditions has been found. Metabolism of molybdenum is affected by copper and sulfur, which are antagonistic. Sulfide and molybdate interact in the rumen to form thiomolybdates, compounds that cause decreased absorption and reduced post absorption metabolism of molybdenum and increased urinary excretion of molybdate. Molybdenum concentrations in forages are generally adequate but vary greatly, depending on soil type and

soil pH. Neutral or alkaline soils coupled with high moisture and organic matter favor molybdenum uptake by forages. High concentrations of molybdenum can cause toxicity. The maximum tolerable concentration of molybdenum for cattle has been estimated to be 10 mg Mo/kg (ppm) diet dry matter. Signs of molybdenum toxicity are diarrhea, anorexia, loss of weight, stiffness, and changes in hair color. Supplementation of large quantities of copper will overcome molybdenosis (Church and Pond 1975, NRC 1996).

Nickel (Ni) is an essential component of urease in rumen bacteria. Nickel deficiency in animals can be produced experimentally, but the function of nickel in mammalian metabolism is unknown. Research data are not sufficient to determine nickel requirements of beef cattle. Nickel can be supplemented in mineral mixtures as nickel chloride. The maximum tolerable concentration of nickel is estimated to be 50 mg Ni/kg (ppm) diet dry matter (Church and Pond 1975, NRC 1996).

Selenium (Se) is part of at least two metalloenzymes, and its functions are interrelated with vitamin E. Failure of functions involving selenium can result in nutritional muscular dystrophy. Selenium is also a component of an enzyme that has a role in maintaining integrity of cellular membranes. Selenium is required for normal pancreatic morphology and is involved in normal absorption of lipids and tocophenols. Selenium is important to the functions of the immune system. The factors that affect selenium requirements are not well defined, but beef cattle requirements can be met by 0.1-0.2 mg Se/kg (ppm) diet dry matter. Selenium deficiency results in degeneration of muscle tissue (white muscle disease) in young animals. Signs of deficiency are stiffness, lameness, and possible cardiac failure. Signs of selenium deficiency in older animals are unthriftiness, weight loss, diarrhea, anemia, and reduced immune responses. Selenium concentrations in forages vary greatly and depend primarily on the selenium content of the soil. Soils developed from Cretaceous or Eocene shales contain high levels of selenium. Some species of milkvetch (*Astragalus spp.*) absorb selenium more readily than other native plants. Cattle grazing plants high in selenium can consume toxic amounts. The maximum tolerable concentration of selenium has been estimated to be 2 mg Se/kg (ppm) diet dry matter. Signs of selenium toxicity are lameness, anorexia, emaciation, loss of vitality, liver cirrhosis, inflamed kidneys, loss of hair from the tail, and cracked, deformed, and elongated hoofs. Signs of acute selenium toxicity are labored breathing, diarrhea, loss of coordination, abnormal posture, and death from respiratory failure (Church and Pond 1975, NRC 1996).

Zinc (Zn) is a constituent of many enzymes and many metalloenzyme systems, and zinc is effective in activation of a large number of other enzymes. Zinc is required for normal protein synthesis and metabolism. A component of insulin, zinc functions in carbohydrate metabolism. Zinc is important for normal development and functioning of the immune system. The recommended requirement of zinc in beef cattle diets is 30 mg Zn/kg (ppm) diet dry matter, although zinc requirements of beef cattle fed forage-based diets and requirements for reproduction and milk production are not well defined. Dietary factors that affect zinc requirements in ruminants are not understood. Subclinical deficiencies of zinc cause decreased weight gain, reduced milk production, and reduced reproductive performance. Signs of severe zinc deficiency are listlessness, excessive salivation, reduced testicular growth, swollen feet, loss of hair, failure of wounds to heal, reduced growth, reduced feed intake, reduced feed efficiency, and lesions with horny growths on legs, neck, and head and around the nostrils. The zinc content of forages is affected by a number of factors, including plant species, plant maturity, and soil zinc. Legumes are generally higher in zinc than grasses. A relatively large portion of the zinc in forages is associated with the plant cell wall, but it is not known whether zinc's association with fiber reduces absorption. Zinc can be supplemented in mineral mixtures with feed-grade sources of bioavailable zinc in the form of zinc oxide, zinc sulfate, zinc methionine, and zinc proteinate. The maximum tolerable concentration of zinc is 500 mg Zn/kg (ppm) diet dry matter, a much greater amount than required. Signs of zinc toxicity are reduced feed intake, reduced feed efficiency, and decreased weight gain (Church and Pond 1975, NRC 1996).

Daily Mineral Requirements

Understanding mineral requirements for beef cows is necessary for effective nutritional management of livestock grazing native rangeland. Beef cow daily nutritional requirements (NRC 1996) change with cow size, level of milk production, and production period. Requirements for some macrominerals change with cow production period. Fetal development requires increased amounts of dietary calcium, phosphorus, and magnesium. Lactation requires increased amounts of dietary calcium, phosphorus, magnesium, potassium, and sodium. Milk production increases the demand for iodine and zinc, but dietary requirements do not increase because the demands are likely met by increases in absorption (NRC 1996). Daily macromineral and micromineral requirements for 1000-, 1200-, and 1400-pound cows with average milk production are shown in tables 1-6. Lactating

cows grazing native rangeland require diet dry matter containing 0.26-0.27% calcium, 0.18% phosphorus, 0.17-0.20% magnesium, 0.70% potassium, 0.10% sodium, and 0.15% sulfur. Lactating cows require diet dry matter containing the following micromineral concentrations: 0.10 ppm cobalt, 10.0 ppm copper, 0.50 ppm iodine, 50.0 ppm iron, 40.0 ppm manganese, 0.10 ppm selenium, and 30.0 ppm zinc. The amounts of chlorine, chromium, molybdenum, and nickel lactating cows require from diet dry matter are not known.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables.

Table 1. Daily macromineral requirements in pounds per day and percent diet dry matter for 1000-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Macrominerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	21	21	24	24
Calcium	%	0.15	0.24	0.30	0.27
	lbs/day	0.03	0.05	0.07	0.06
Phosphorus	%	0.11	0.15	0.20	0.18
	lbs/day	0.02	0.03	0.05	0.04
Magnesium	%	0.12		0.17-0.20	
	lbs/day	0.03		0.04-0.05	
Potassium	%	0.60		0.70	
	lbs/day	0.13		0.17	
Sodium	%	0.06-0.08		0.10	
	lbs/day	0.01-0.02		0.02	
Chlorine	%	requirements are not well defined but a deficiency does not seem likely in practical conditions			
	lbs/day				
Sulfur	%	0.15		0.15	
	lbs/day	0.03		0.04	

Table 2. Daily macromineral requirements in pounds per day and percent diet dry matter for 1200-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Macrominerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	24	24	27	27
Calcium	%	0.15	0.25	0.29	0.26
	lbs/day	0.04	0.06	0.08	0.07
Phosphorus	%	0.12	0.16	0.19	0.18
	lbs/day	0.03	0.04	0.05	0.05
Magnesium	%	0.12		0.17-0.20	
	lbs/day	0.03		0.045-0.05	
Potassium	%	0.60		0.70	
	lbs/day	0.14		0.19	
Sodium	%	0.06-0.08		0.10	
	lbs/day	0.01-0.02		0.03	
Chlorine	%	requirements are not well defined but a deficiency does not seem likely in practical conditions			
	lbs/day				
Sulfur	%	0.15		0.15	
	lbs/day	0.04		0.04	

Table 3. Daily macromineral requirements in pounds per day and percent diet dry matter for 1400-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Macrominerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	27	27	30	30
Calcium	%	0.16	0.26	0.28	0.26
	lbs/day	0.04	0.07	0.08	0.08
Phosphorus	%	0.12	0.17	0.19	0.18
	lbs/day	0.03	0.05	0.06	0.05
Magnesium	%	0.12		0.17-0.20	
	lbs/day	0.03		0.05-0.06	
Potassium	%	0.60		0.70	
	lbs/day	0.16		0.21	
Sodium	%	0.06-0.08		0.10	
	lbs/day	0.016-0.022		0.03	
Chlorine	%	requirements are not well defined but a deficiency does not seem likely in practical conditions			
	lbs/day				
Sulfur	%	0.15		0.15	
	lbs/day	0.04		0.05	

Table 4. Daily micromineral requirements in grams per day and mg/kg (ppm) of diet dry matter for 1000-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Microminerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	21	21	24	24
Chromium	mg/kg (ppm)	current information is not sufficient to determine requirements			
	g/day				
Cobalt	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0010	0.0010	0.0011	0.0011
Copper	mg/kg (ppm)	10.0	10.0	10.0	10.0
	g/day	0.0953	0.0953	0.1089	0.1089
Iodine	mg/kg (ppm)	0.50	0.50	0.50	0.50
	g/day	0.0048	0.0048	0.0054	0.0054
Iron	mg/kg (ppm)	50.0	50.0	50.0	50.0
	g/day	0.4763	0.4763	0.5443	0.5443
Manganese	mg/kg (ppm)	40.0	40.0	40.0	40.0
	g/day	0.3810	0.3810	0.4355	0.4355
Molybdenum	mg/kg (ppm)	requirements are not established but there is no evidence that deficiency occurs			
	g/day				
Nickel	mg/kg (ppm)	research data are not sufficient to determine requirements			
	g/day				
Selenium	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0010	0.0010	0.0011	0.0011
Zinc	mg/kg (ppm)	30.0	30.0	30.0	30.0
	g/day	0.2858	0.2858	0.3266	0.3266

Table 5. Daily micromineral requirements in grams per day and mg/kg (ppm) of diet dry matter for 1200-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Microminerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	24	24	27	27
Chromium	mg/kg (ppm)	current information is not sufficient to determine requirements			
	g/day				
Cobalt	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0011	0.0011	0.0012	0.0012
Copper	mg/kg (ppm)	10.0	10.0	10.0	10.0
	g/day	0.1089	0.1089	0.1225	0.1225
Iodine	mg/kg (ppm)	0.50	0.50	0.50	0.50
	g/day	0.0054	0.0054	0.0061	0.0061
Iron	mg/kg (ppm)	50.0	50.0	50.0	50.0
	g/day	0.5443	0.5443	0.6124	0.6124
Manganese	mg/kg (ppm)	40.0	40.0	40.0	40.0
	g/day	0.4355	0.4355	0.4899	0.4899
Molybdenum	mg/kg (ppm)	requirements are not established but there is no evidence that deficiency occurs			
	g/day				
Nickel	mg/kg (ppm)	research data are not sufficient to determine requirements			
	g/day				
Selenium	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0011	0.0011	0.0012	0.0012
Zinc	mg/kg (ppm)	30.0	30.0	30.0	30.0
	g/day	0.3266	0.3266	0.3674	0.3674

Table 6. Daily micromineral requirements in grams per day and mg/kg (ppm) of diet dry matter for 1400-pound beef cows with average milk production during four production periods (data from NRC 1996).

		Production Periods			
Microminerals		Dry Gestation	3rd Trimester	Early Lactation	Lactation
Dry matter	lbs	27	27	30	30
Chromium	mg/kg (ppm)	current information is not sufficient to determine requirements			
	g/day				
Cobalt	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0012	0.0012	0.0014	0.0014
Copper	mg/kg (ppm)	10.0	10.0	10.0	10.0
	g/day	0.1225	0.1225	0.1361	0.1361
Iodine	mg/kg (ppm)	0.50	0.50	0.50	0.50
	g/day	0.0061	0.0061	0.0068	0.0068
Iron	mg/kg (ppm)	50.0	50.0	50.0	50.0
	g/day	0.6124	0.6124	0.6804	0.6804
Manganese	mg/kg (ppm)	40.0	40.0	40.0	40.0
	g/day	0.4899	0.4899	0.5443	0.5443
Molybdenum	mg/kg (ppm)	requirements are not established but there is no evidence that deficiency occurs			
	g/day				
Nickel	mg/kg (ppm)	research data are not sufficient to determine requirements			
	g/day				
Selenium	mg/kg (ppm)	0.10	0.10	0.10	0.10
	g/day	0.0012	0.0012	0.0014	0.0014
Zinc	mg/kg (ppm)	30.0	30.0	30.0	30.0
	g/day	0.3674	0.3674	0.4082	0.4082

Literature Cited

Church, D.C., and W.G. Pond. 1975. Basic animal nutrition and feeding. O & B Books, Corvallis, OR.

Manske, L.L. 1998. Range management practices addressing problems inherent in the Northern Great Plains grasslands. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 98-3002. Dickinson, ND. 3p.

Manske, L.L. 2000. Management of Northern Great Plains Prairie based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 13p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

TWELVE-MONTH GRAZINGLAND AND HARVESTED FORAGE MANAGEMENT STRATEGIES

Cow and Calf Performance as Affected by Grazing Management

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Weight gain performance of cow and calf pairs on grazinglands does not occur at the same rate during the entire grazing season and is affected, within the parameters of the animals' genetic growth potentials, by the quantity and quality of the herbage. These herbage characteristics change on a seasonal pattern of grass growth, maturity, and senescence during the grazing season, but this pattern can be modified by grazing management treatments. The timing and severity of defoliation by grazing determine whether beneficial or harmful effects occur. Grazing can change plant species composition, manipulate some plant and ecosystem processes, and alter levels and rates of plant growth. Changes different grazing treatments cause in the quantity of plant growth and the quality of herbage are important manageable factors affecting cow and calf weight performance.

The purpose of this study is to document and compare cow and calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day on pasture-forage types of grazing management systems during the grazing season.

Procedure

This study was conducted at the NDSU Dickinson Research Extension Center, located in western North Dakota. Soils are primarily Typic Haploborolls. Average annual precipitation is 16.1 inches, with 13.6 inches (84.7%) falling as rain between April and October. Mean annual temperature is 40.8°F. January is the coldest month, with a mean temperature of 11.1°F. July and August are the warmest months, with mean temperatures of 68.6°F and 67.0°F, respectively (Manske 2003).

Grazing management systems were evaluated during the grazing season, the period from early May to mid November, when perennial forage plants are growing and biologically active. The 6.5-month (198-day) grazing season was separated into three portions. The spring portion was 31 days from early to late May, the summer portion was 137 days from early June to mid October, and the fall portion was 30 days from mid October to mid November. These three portions of the grazing season coincide with three subdivisions of the lactation production period for cows with calves born during March and early April.

Pasture-forage types were evaluated during the three portions of the grazing season. The native rangeland (NR) pasture-forage type is the Wheatgrass-Needlegrass Vegetation Type (Barker and Whitman 1988) of the mixed grass prairie. The dominant native range species are western wheatgrass, needle and thread, blue grama, and threadleaved sedge. The crested wheatgrass (CW) and Altai wildrye (AW) domesticated grass pasture-forage types were seeded as monocultures, but a small assortment of forbs and other grass species developed as minor components. The cropland aftermath (CA) pasture-forage type consisted primarily of annual cereal residue of oat, barley, and/or chopped corn stubble.

Cow and calf weight performance data were collected on grazing management systems involved in pasture research projects conducted between 1983 and 1998. Commercial crossbred cattle were used on all treatments. Individual animals were weighed on and off each treatment, at 15-day intervals during the early portion of the grazing season, and at 30-day intervals during the latter portion of the grazing season. Weight performance of cows and of calves was calculated for each treatment, and differences between means were analyzed by a standard paired plot t-test (Mosteller and Rourke 1973). Portions of this data set were reported by Manske (1994a, b).

Response surface analysis (Kerlinger and Pedhazur 1973) with a repeated observation design was used to compare animal response curves among native rangeland grazing management treatments. The deferred treatment grazed one pasture from mid July to mid November. The seasonlong treatment grazed one pasture from mid June to late October. The twice-over rotation treatment grazed three pastures in rotation, with each grazed two periods between early June and mid October. Cow and calf mean weights from five years of pasture management research were adjusted to the 8th and 23rd day of each month of the grazing period. Biweekly live weight performance periods of weight gain per day and

accumulated weight gain for cows and calves were used to evaluate each grazing management treatment. The response surface analysis curves were reported by Manske et al. (1988).

Grazing Management Systems

6.0-month seasonlong system

The 6.0-month seasonlong (6.0-m SL) management system started grazing in mid May. Livestock were moved to a single native rangeland pasture stocked at 4.04 acres per cow-calf pair per month. Livestock grazed on the pasture for 183 days during the three portions of the grazing season, with 16 days in spring, 137 days in summer, and 30 days in fall, and were removed from the pasture in mid November, when the calves were weaned.

4.5-month seasonlong system

The 4.5-month seasonlong (4.5-m SL) management system started grazing in early May. For the first 31 days, during the spring portion of the grazing season, livestock grazed an unfertilized crested wheatgrass pasture stocked at 1.82 acres per cow-calf pair per month. In early June, livestock were moved to one native rangeland pasture stocked at 2.86 acres per cow-calf pair per month. Livestock grazed this pasture for 137 days, during the summer portion of the grazing season. In mid October they were moved to cropland aftermath stocked at 6.63 acres per cow-calf pair per month. Livestock grazed this pasture-forage type during the fall portion of the grazing season and were removed from the pasture in mid November, when the calves were weaned.

4.0-month deferred system

The 4.0-month deferred (4.0-m Def) management system started grazing in early May. For the first 76 days, during the spring and early summer portions of the grazing season, livestock grazed an unfertilized crested wheatgrass pasture stocked at 1.67 acres per cow-calf pair per month. In mid July the livestock were moved to one native rangeland pasture stocked at 2.22 acres per cow-calf pair per month. Livestock grazed this pasture for 122 days, during late summer and fall portions of the grazing season, and were removed from the pasture in mid November, when the calves were weaned.

4.5-month twice-over rotation system

The 4.5-month twice-over rotation (4.5-m TOR) management system started grazing in early May. For the first 31 days, during the spring portion of the grazing season, livestock grazed a fertilized (50 lbs N/acre applied during the first week of April) crested wheatgrass pasture stocked at 0.75 acres per cow-calf pair per month. The livestock were then moved to one of three native rangeland pastures stocked at 2.04 acres per cow-calf pair per month. Livestock remained on native rangeland for 137 days, during the summer portion of the grazing season, grazing each pasture for two periods, one 15-day period between 1 June and 15 July (when lead tillers of grasses were between the third-leaf stage and flowering stage) and one 30-day period after 15 July (after secondary tillers of grasses reached the third-leaf stage) and prior to mid October. The first pasture grazed in the sequence was the last pasture grazed the previous year. In mid October, the livestock were moved to an Altai wildrye pasture stocked at 1.39 acres per cow-calf pair per month. Livestock grazed this pasture for 30 days, during the fall portion of the grazing season, and were removed from the pasture in mid November, when the calves were weaned.

Results

Length of grazing period for pasture-forage types (table 1) and acres per cow-calf pair (table 1, figure 1) are shown for each grazing management system. Cow performance during the three portions of the grazing season for the grazing management systems is shown in table 2 and figures 2, 3, 4, 5, 6, 7, 11, and 12. Calf performance during the three portions of the grazing season for the grazing management systems is shown in table 3 and figures 2, 3, 4, 8, 9, 10, 13, and 14.

The stocking rate during the 6.5-month grazing season on the twice-over rotation system was 17% greater than the stocking rate on the deferred system, 90% greater than the stocking rate on the 4.5-month seasonlong system, and 135% greater than the stocking rate on the 6.0-month seasonlong system.

Grazing Management Systems

6.0-month seasonlong system

The 6.0-month seasonlong management system comprised a native rangeland pasture grazed from mid May to mid November, with 16 days during spring, 137 days during summer, and 30 days during fall portions of the grazing season. Over the entire grazing season, cows gained an accumulated weight of 21.96 lbs, at a rate of 0.91 lbs per acre and 0.12 lbs per day, and calves gained an accumulated weight of 329.40 lbs, at a rate of 13.59 lbs per acre and 1.80 lbs per day. On the native rangeland pasture, calf weight performance was a gain of 28.80 lbs, at a rate of

13.64 lbs per acre and 1.80 lbs per day, during the spring portion of the grazing season; a gain of 282.87 lbs, at a rate of 15.63 lbs per acre and 1.80 lbs per day, during the summer portion of the grazing season; and a gain of 17.73 lbs, at a rate of 4.38 lbs per acre and 0.59 lbs per day, during the fall portion of the grazing season.

4.5-month seasonlong system

The 4.5-month seasonlong management system comprised an unfertilized crested wheatgrass pasture grazed from early to late May, a native rangeland pasture grazed from early June to mid October, and a cropland aftermath pasture grazed from mid October to mid November. Over the entire grazing season, cows gained an accumulated weight of 58.86 lbs, at a rate of 2.78 lbs per acre and 0.30 lbs per day. Cow weight performance on individual pasture-forage types was a gain of 60.45 lbs, at a rate of 32.15 lbs per acre and 1.95 lbs per day, on the unfertilized crested wheatgrass pasture; a gain of 46.58 lbs, at a rate of 3.67 lbs per acre and 0.34 lbs per day, on the native rangeland pasture; and a loss of 48.17 lbs, at a rate of 7.27 lbs per acre and 1.61 lbs per day, on the cropland aftermath pasture. Over the entire grazing season, calves gained an accumulated weight of 358.11 lbs, at a rate of 16.88 lbs per acre and 1.81 lbs per day. Calf weight performance on individual pasture-forage types was a gain of 59.21 lbs, at a rate of 31.49 lbs per acre and 1.91 lbs per day, on the unfertilized crested wheatgrass pasture; a gain of 286.33 lbs, at a rate of 22.55 lbs per acre and 2.09 lbs per day, on the native rangeland pasture; and a gain of 12.57 lbs, at a rate of 1.90 lbs per acre and 0.42 lbs per day, on the cropland aftermath pasture.

4.0-month deferred system

The 4.0-month deferred management system comprised an unfertilized crested wheatgrass pasture grazed from early May to mid July and a native rangeland pasture grazed from mid July to mid November. Over the entire grazing season, cows gained an accumulated weight of 108.20 lbs, at a rate of 8.30 lbs per acre and 0.55 lbs per day. Cow weight performance on individual pasture-forage types was a gain of 69.16 lbs, at a rate of 16.63 lbs per acre and 0.91 lbs per day, on the unfertilized crested wheatgrass pasture, and a gain of 39.04 lbs, at a rate of 4.40 lbs per acre and 0.32 lbs per day, on the native rangeland pasture. Over the entire grazing season, calves gained an accumulated weight of 355.64 lbs, at a rate of 27.27 lbs per acre and 1.80 lbs per day. Calf weight performance on individual pasture-forage types was a gain of 136.04 lbs, at a rate of 32.70 lbs per acre and 1.79 lbs per day, on the unfertilized crested wheatgrass pasture; and a gain of 196.50 lbs, at a rate of 29.32 lbs per acre and 2.13 lbs per day, during the summer portion of the grazing season, and a gain of 23.10 lbs, at a rate of 10.36 lbs per acre and 0.77 lbs per day, during the fall portion of the grazing season, on the native rangeland pasture.

4.5-month twice-over rotation system

The twice-over rotation management system comprised a fertilized crested wheatgrass complementary pasture grazed from early to late May, three native rangeland pastures grazed in rotation from early June to mid October, and an Altai wildrye pasture grazed from mid October to mid November. Over the entire grazing season, cows gained an accumulated weight of 184.52 lbs, at a rate of 16.56 lbs per acre and 0.93 lbs per day. Cow weight performance on individual pasture-forage types was a gain of 83.08 lbs, at a rate of 110.77 lbs per acre and 2.68 lbs per day, on the fertilized crested wheatgrass pasture; a gain of 84.94 lbs, at a rate of 9.44 lbs per acre and 0.62 lbs per day, on the native rangeland pastures; and a gain of 16.50 lbs, at a rate of 11.87 lbs per acre and 0.55 lbs per day, on the Altai wildrye pasture. Over the entire grazing season, calves gained an accumulated weight of 432.12 lbs, at a rate of 37.98 lbs per acre and 2.14 lbs per day. Calf weight performance on individual pasture-forage types was a gain of 67.58 lbs, at a rate of 90.11 lbs per acre and 2.18 lbs per day, on the fertilized crested wheatgrass pasture; a gain of 302.77 lbs, at a rate of 33.64 lbs per acre and 2.21 lbs per day, on the native rangeland pastures; and a gain of 52.77 lbs, at a rate of 37.96 lbs per acre and 1.73 lbs per day, on the Altai wildrye pasture.

Cow and calf weight performance was greater on the twice-over rotation management system than on the traditional management systems. Cow accumulated weight on the twice-over system was 70.5% greater than that on the deferred system, with the rate of gain 99.5% greater per acre and 69.1% greater per day. Cow accumulated weight on the twice-over system was 213.5% greater than that on the 4.5-month seasonlong system, with the rate of gain 495.7% greater per acre and 210.0% greater per day. Cow accumulated weight on the twice-over system was 740.3% greater than that on the 6.0-month seasonlong system, with the rate of gain 1719.8% greater per acre and 675.0% greater per day. Calf accumulated weight on the twice-over system was 19.0% greater than that on the deferred system, with the rate of gain 39.3% greater per acre and 18.9% greater per day. Calf accumulated weight on the twice-over system was 18.2% greater than that

on the 4.5-month seasonlong system, with the rate of gain 125.0% greater per acre and 18.2% greater per day. Calf accumulated weight on the twice-over system was 28.5% greater than that on the 6.0-month seasonlong system, with the rate of gain 179.5% greater per acre and 18.9% greater per day.

Pasture-Forage Types

Crested wheatgrass pasture forage

The stocking rate on the crested wheatgrass pasture-forage type of the twice-over rotation system was 122.7% greater than the stocking rate on the crested wheatgrass pasture of the deferred system, 142.6% greater than the stocking rate on the crested wheatgrass pasture of the 4.5-month seasonlong system, and 438.7% greater than the stocking rate on the spring native rangeland pasture-forage type of the 6.0-month seasonlong system.

Cow and calf weight performance was greater on the fertilized crested wheatgrass pasture of the twice-over rotation management system than on the pastures of the traditional management systems grazed during the same time period. Cow accumulated weight was 20.1% greater on the crested wheatgrass pasture of the twice-over system than on the crested wheatgrass pasture of the deferred system; the rate of gain was 566.1% greater per acre and 194.5% greater per day. Cow accumulated weight was 37.4% greater on the crested wheatgrass pasture of the twice-over system than on the crested wheatgrass pasture of the seasonlong system; the rate of gain was 244.5% greater per acre and 37.4% greater per day. Calf accumulated weight was 50.2% lower on the crested wheatgrass pasture of the twice-over system than on the crested wheatgrass pasture of the deferred system because of the difference in the length of the grazing period; however, the rate of gain on the crested wheatgrass pasture of the twice-over system was 175.6% greater per acre and 21.8% greater per day. Calf accumulated weight was 14.1% greater on the crested wheatgrass pasture of the twice-over system than on the crested wheatgrass pasture of the seasonlong system; the rate of gain was 186.2% greater per acre and 14.1% greater per day. Calf accumulated weight was 134.7% greater on the crested wheatgrass pasture of the twice-over system than on the 6.0-month seasonlong native rangeland grazed during May; the rate of gain was 560.6% greater per acre and 21.1% greater per day.

Cow and calf weight performance was strong on unfertilized crested wheatgrass during May but decreased considerably when grazing continued until mid July. During most years, cow-calf pairs could be expected to perform well on unfertilized domesticated cool-season grass pastures, like crested wheatgrass and smooth bromegrass, through mid June. Fertilization of crested wheatgrass pastures during the first week in April increased the amount of aboveground herbage available during May. Fertilization of crested wheatgrass pastures shortened by several weeks the period that livestock performed well but increased the stocking rate and cow and calf performance during May.

Native rangeland pasture forage

The stocking rate on the native rangeland pasture-forage type managed by the twice-over rotation treatment was 8.9% greater than the stocking rate on the native rangeland of the deferred treatment, 40% greater than the stocking rate on the native rangeland of the 4.5-month seasonlong treatment, and 99% greater than the stocking rate on the native rangeland of the 6.0-month seasonlong treatment.

Cow and calf weight performance was greater on the native rangeland pastures of the twice-over rotation management treatment than on the native rangeland pastures of the traditional management treatments. Cow accumulated weight was 117.6% greater on the twice-over rotation treatment than on the deferred treatment; the rate of gain was 114.6% greater per acre and 93.8% greater per day. Cow accumulated weight was 82.4% greater on the twice-over rotation treatment than on the 4.5-month seasonlong treatment; the rate of gain was 157.2% greater per acre and 82.4% greater per day. Cow accumulated weight was 286.8% greater on the twice-over rotation treatment than on the 6.0-month seasonlong treatment; the rate of gain was 937.4% greater per acre and 416.7% greater per day. Calf accumulated weight was 54.1% greater on the twice-over rotation treatment than on the deferred treatment; the rate of gain was 14.7% greater per acre and 3.8% greater per day. Calf accumulated weight was 5.7% greater on the twice-over rotation treatment than on the 4.5-month seasonlong treatment; the rate of gain was 49.2% greater per acre and 5.7% greater per day. Calf accumulated weight was 7.0% greater on the twice-over rotation treatment than on the 6.0-month seasonlong treatment; the rate of gain was 115.2% greater per acre and 22.8% greater per day.

Cow and calf weight gain per day and accumulated weight gain on native rangeland pasture-forage types managed with seasonlong, deferred, and twice-over rotation management treatments were evaluated with response surface analysis, and the results were reported by Manske et al. (1988). The response surface analysis curves are shown in figures 11-14.

Weight gain per day of cows grazing seasonlong and deferred treatments steadily decreased from the start of the grazing period (fig. 11) (Manske et al. 1988). There was no significant difference ($P>0.05$) in the cow weight gain per day between seasonlong and deferred treatments (fig. 11) (Manske et al. 1988, Manske 1994a, b). The weight gain per day was negative for cows during the latter portion of the grazing period on both the seasonlong and deferred treatments. The cow weight gain per day response curve for the twice-over rotation treatment was significantly different ($P<0.05$) from the response curves for the seasonlong and deferred treatments (fig. 11) (Manske et al. 1988, Manske 1994a, b). Cows on the twice-over rotation treatment initially had a reduction in gain per day, but a period with no reduction occurred during the middle portion of the grazing period before cows lost a small amount of weight during the last two weeks of the grazing period (fig. 11).

Cow accumulated weight gain was not different on seasonlong and deferred treatments, but the accumulated weight gain response curves for the seasonlong and deferred treatments were significantly different ($P<0.05$) from the start of the grazing period (fig. 12) (Manske et al. 1988, Manske 1994a, b). The upward slopes of the accumulated weight gain response curves were similar, but the downward slope of the curve for the deferred treatment was greater than the downward slope of the curve for the seasonlong treatment (fig. 12). The rate of weight loss during the latter portion of the grazing season was greater on the deferred treatment.

Cow weight gain per acre was significantly greater ($P<0.05$) on the twice-over rotation treatment than on deferred and seasonlong treatments, and the cow accumulated weight gain response curve for the twice-over rotation treatment was significantly different ($P<0.05$) from the response curves for the seasonlong and deferred treatments (fig. 12) (Manske et al. 1988, Manske 1994a, b). The upward slopes of these three curves were not different, but the downward slope of the curve for the twice-over rotation treatment was significantly less steep than the downward slope of the curves for the seasonlong and deferred treatments (fig. 12) (Manske et al. 1988). The accumulated weight loss during the latter portion of the grazing season was greater on the seasonlong and deferred treatments. Cow performance during the grazing period was greatest on the twice-over rotation treatment.

Calf weight gain per day decreased with the progression of the grazing period. The rate of decrease was different for the three grazing treatments (fig. 13) (Manske et al. 1988). The shape of the calf weight gain per day response curves for the treatments was not different, but the downward slope of the curves for the deferred treatment was significantly greater ($P<0.002$) than the downward slope of the curve for the seasonlong treatment (Manske et al. 1988). The downward slope of the curve for the twice-over rotation treatment was significantly less ($P<0.01$) than the downward slope of the curves for the seasonlong and deferred treatments (fig. 13) (Manske et al. 1988). Calf performance during the grazing period was greatest on the twice-over rotation treatment.

Calf accumulated weight gain was significantly greater ($P<0.004$) on the seasonlong treatment than on the deferred treatment (fig. 14) (Manske et al. 1988). Calf accumulated weight gain was significantly greater ($P<0.0001$) on the twice-over rotation treatment than on the seasonlong and deferred grazing treatments. The greatest differences among these three performance response curves occurred during the latter portion of the grazing period (fig. 14) (Manske et al. 1988).

The decrease in the downward slope of the calf accumulated weight gain curves (fig. 14) during the latter portion of the grazing period tended to follow the same trend as the downward slopes of the cow accumulated weight gain curves (fig. 12) for each treatment. The greatest downward slope occurred for the cows and calves on the deferred treatment. The least downward slope occurred for the cows and calves on the twice-over rotation treatment. The slopes of the curves for the seasonlong treatment were between the slopes of the curves for the other two treatments (Manske et al. 1988).

The cow and calf weight performances on the three native rangeland grazing management treatments were not very different during the early portion of the grazing period. Cow weight gain on the seasonlong and deferred treatments steadily decreased and cows lost weight during the latter portion of the grazing season. Cows on the twice-over rotation treatment gained weight during the early and middle portions of the grazing period and lost a small amount of weight at the end of the grazing period. Calf weight gain was greater on the seasonlong treatment than on the deferred treatment and was greater on the twice-over rotation treatment than on the seasonlong and deferred treatments. During the latter portion of the grazing period, cow and calf weight performance was greatest on the twice-over rotation treatment, poor on the seasonlong treatment, and poorest on the deferred treatment.

Fall pasture forage

The stocking rate on the Altai wildrye fall pasture-forage type of the twice-over rotation system was 377.1% greater than the stocking rate on the cropland aftermath pasture of the 4.5-month seasonlong system, 30.9% greater than the stocking rate on the spring unfertilized crested wheatgrass pasture of the 4.5-month seasonlong system, and 46.0% lower than the stocking rate on the spring fertilized crested wheatgrass pasture of the twice-over rotation system.

Cow and calf weight performance was greater on the Altai wildrye complementary domesticated grass pasture of the twice-over rotation system than on the cropland aftermath pasture of the 4.5-month seasonlong system. Cows gained weight on the Altai wildrye pasture and lost considerable weight on the cropland aftermath pasture. Calf accumulated weight was 319.8% greater on the Altai wildrye pasture than on the cropland aftermath pasture; the rate of gain was 1897.9% greater per acre and 311.9% greater per day.

Cow and calf weight performance during the fall portion of the grazing season was poor on native rangeland managed by the 6.0-month seasonlong and deferred treatments and on the cropland aftermath pasture of the 4.5-month seasonlong system. Cows on these pasture-forage types lost weight during the period between mid October and mid November, and calves with those cows gained little weight. Cow and calf weight performance on Altai wildrye pastures of the twice-over system was favorable between mid October and mid November, but not as impressive as cow and calf weight performance on the spring fertilized crested wheatgrass pastures of the twice-over system. Weight gains of cows and calves grazing Altai wildrye were considerably greater than those of livestock grazing other pasture-forage types during the same period.

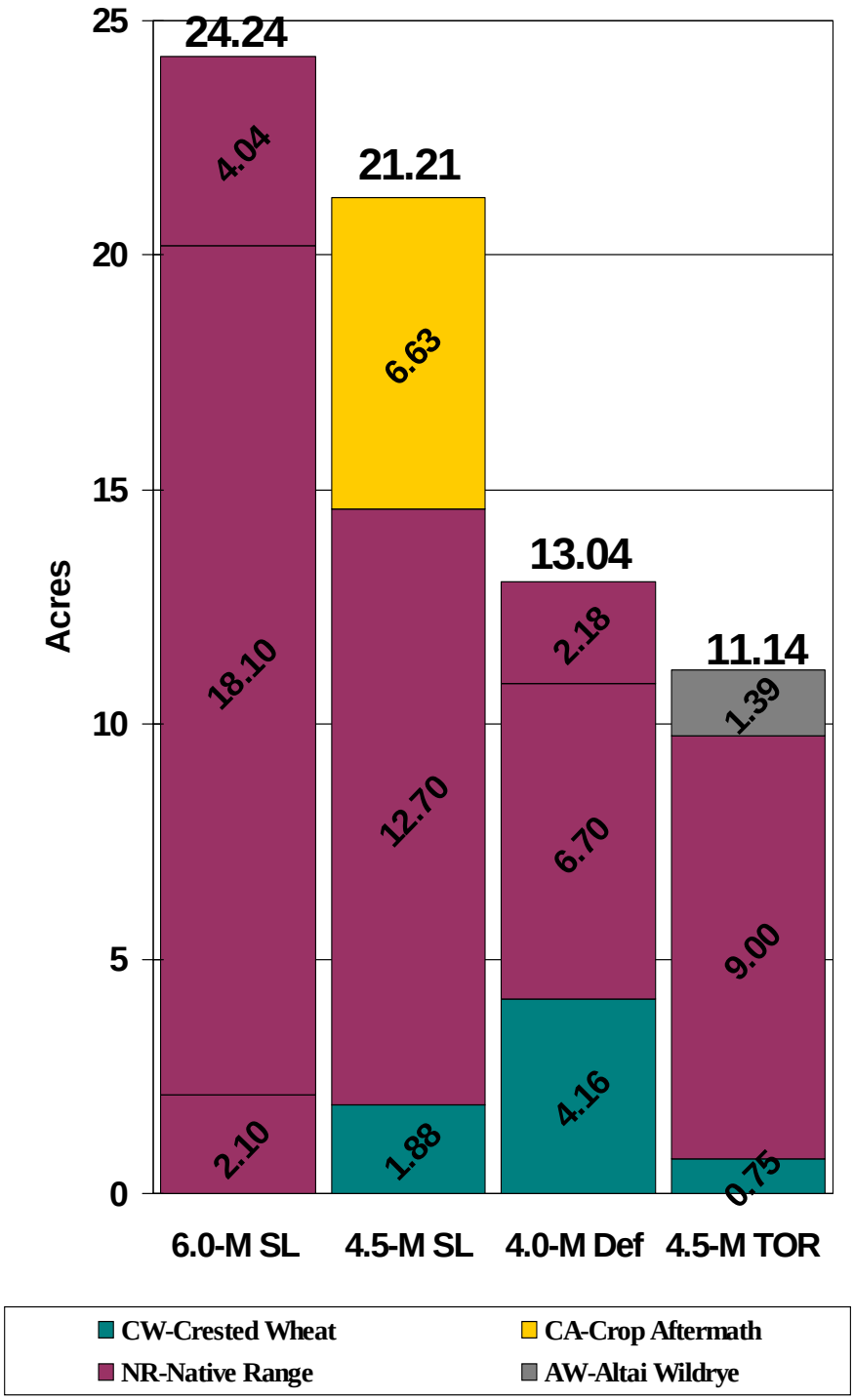


Fig. 1. Acres per cow-calf pair during spring, summer, and fall portions of the grazing season.

Table 1. Pasture-forage types, number of days per grazing period, and acres per cow-calf pair for grazing management systems.

	6.0-M Seasonlong	**4.5-M Seasonlong**	**4.0-M Deferred**	**4.5-M Twice-over Rotation**
Spring	Native Rangeland	Crested Wheatgrass Unfertilized	Crested Wheatgrass Unfertilized	Crested Wheatgrass Fertilized
Days	16	31	76	31
Acres	2.10	1.88	4.16	0.75
Summer	Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland
Days	137	137	92	137
Acres	18.10	12.70	6.70	9.00
Fall	Native Rangeland	Cropland Aftermath	Native Rangeland	Altai Wildrye
Days	30	30	30	30
Acres	4.04	6.63	2.18	1.39
Grazing Season				
Days	183	198	198	198
Acres	24.24	21.21	13.04	11.14

Table 2. Cow performance during the three portions of the grazing season on grazing management systems.

	6.0-M Seasonlong	**4.5-M Seasonlong**	**4.0-M Deferred**	**4.5-M Twice-over Rotation**
Spring	Native Rangeland	Crested Wheatgrass Unfertilized	Crested Wheatgrass Unfertilized	Crested Wheatgrass Fertilized
Accumulated Wt		60.45	69.16	83.08
Gain/Acre		32.15	16.63	110.77
Gain/Day		1.95	0.91	2.68
Summer	Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland
Accumulated Wt	21.96	46.58	39.04	84.94
Gain/Acre	0.91	3.67	4.40	9.44
Gain/Day	0.12	0.34	0.32	0.62
Fall	Native Rangeland	Cropland Aftermath	Native Rangeland	Altai Wildrye
Accumulated Wt		-48.17		16.50
Gain/Acre		-7.27		11.87
Gain/Day		-1.61		0.55
Grazing Season				
Accumulated Wt	21.96	58.86	108.20	184.52
Gain/Acre	0.91	2.78	8.30	16.56
Gain/Day	0.12	0.30	0.55	0.93

Table 3. Calf performance during the three portions of the grazing season on grazing management systems.

	6.0-M Seasonlong	**4.5-M Seasonlong**	**4.0-M Deferred**	**4.5-M Twice-over Rotation**
Spring	Native Rangeland	Crested Wheatgrass Unfertilized	Crested Wheatgrass Unfertilized	Crested Wheatgrass Fertilized
Accumulated Wt	28.80	59.21	136.04	67.58
Gain/Acre	13.64	31.49	32.70	90.11
Gain/Day	1.80	1.91	1.79	2.18
Summer	Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland
Accumulated Wt	282.87	286.33	196.50	302.77
Gain/Acre	15.63	22.55	29.32	33.64
Gain/Day	1.80	2.09	2.13	2.21
Fall	Native Rangeland	Cropland Aftermath	Native Rangeland	Altai Wildrye
Accumulated Wt	17.73	12.57	23.10	52.77
Gain/Acre	4.38	1.90	10.36	37.96
Gain/Day	0.59	0.42	0.77	1.73
Grazing Season				
Accumulated Wt	329.40	358.11	355.64	423.12
Gain/Acre	13.59	16.88	27.27	37.98
Gain/Day	1.80	1.81	1.80	2.14

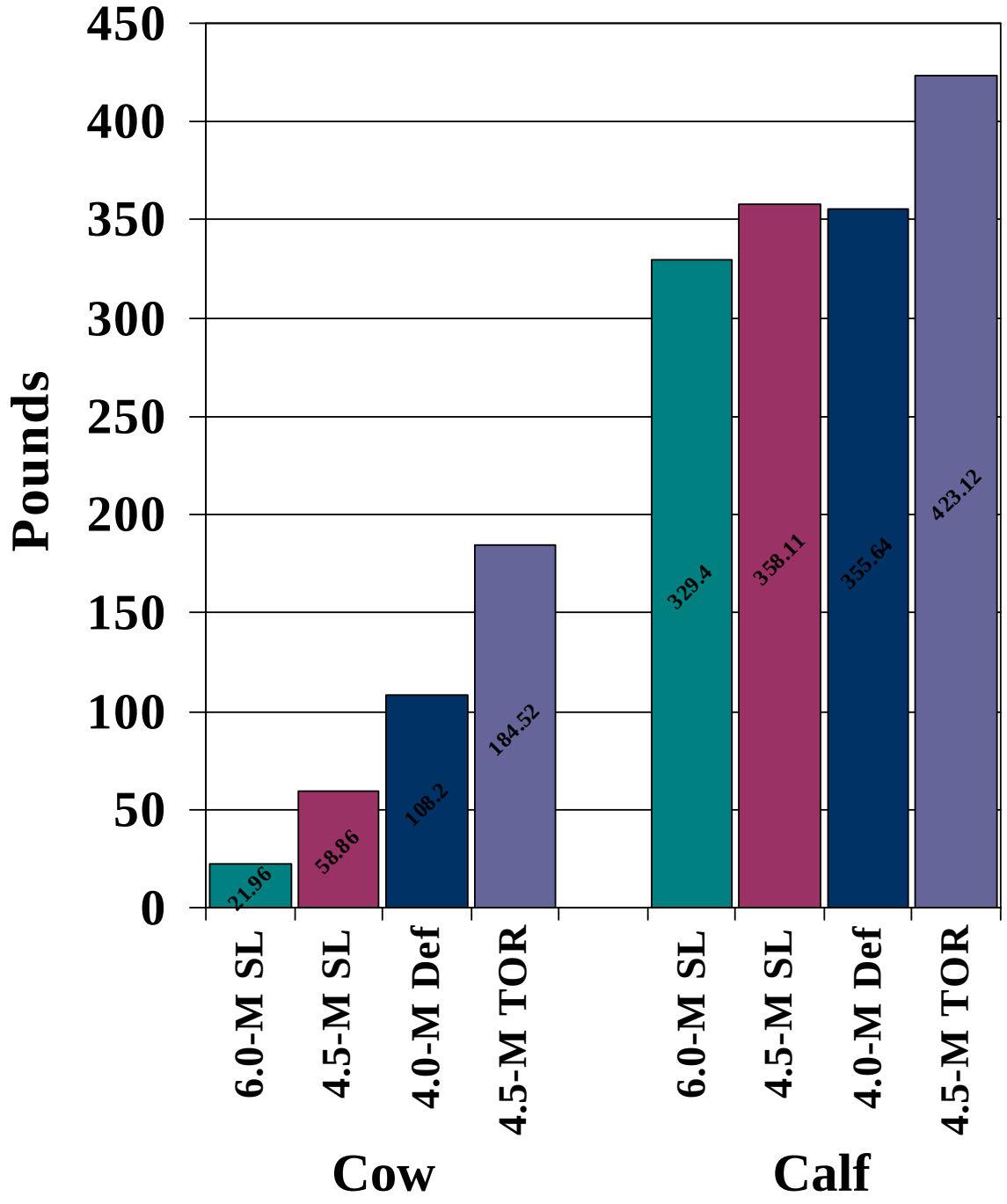


Fig. 2. Cow and calf accumulated weight gain on grazing management systems during the grazing season.

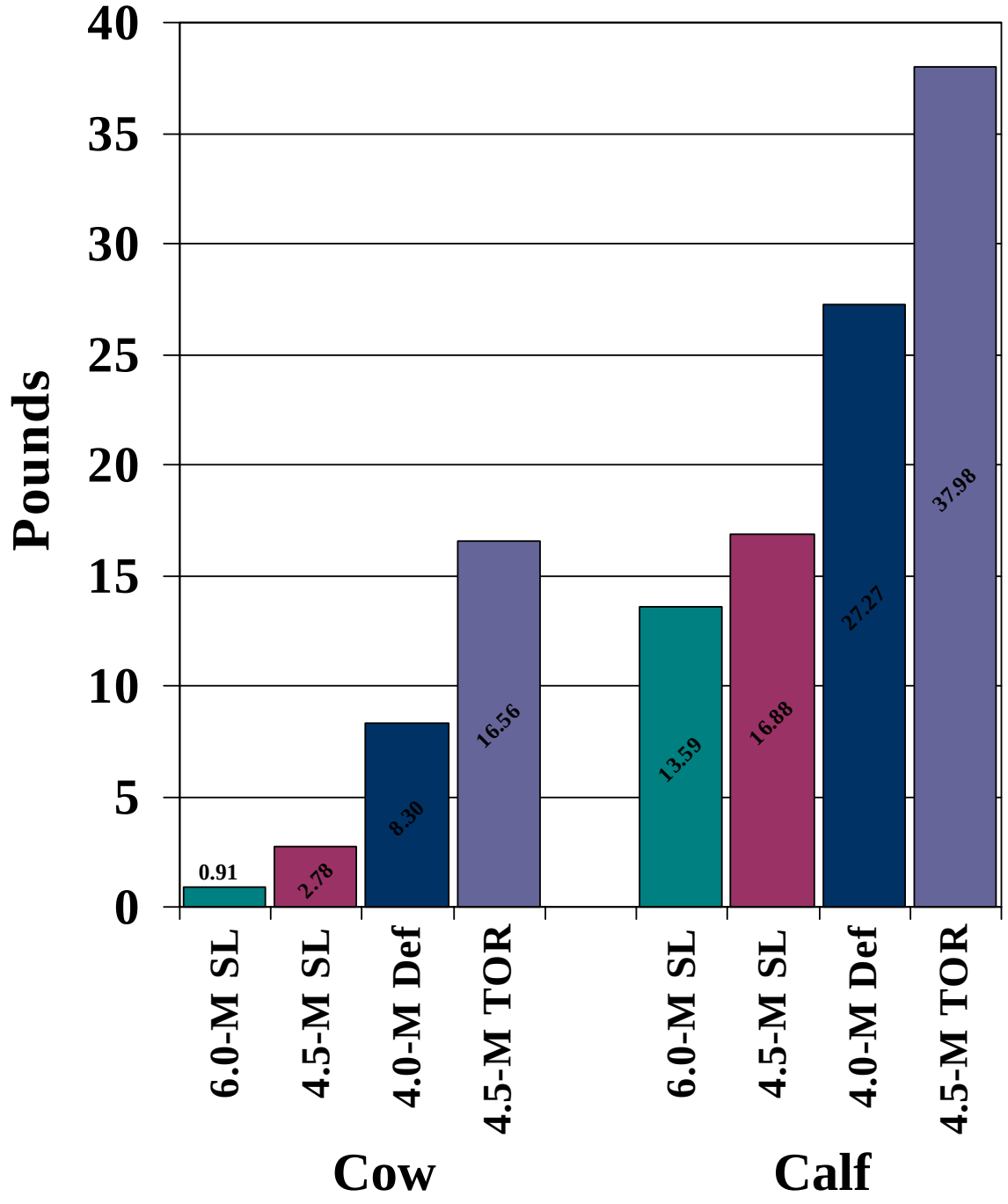


Fig. 3. Cow and calf weight gain per acre on grazing management systems during the grazing season.

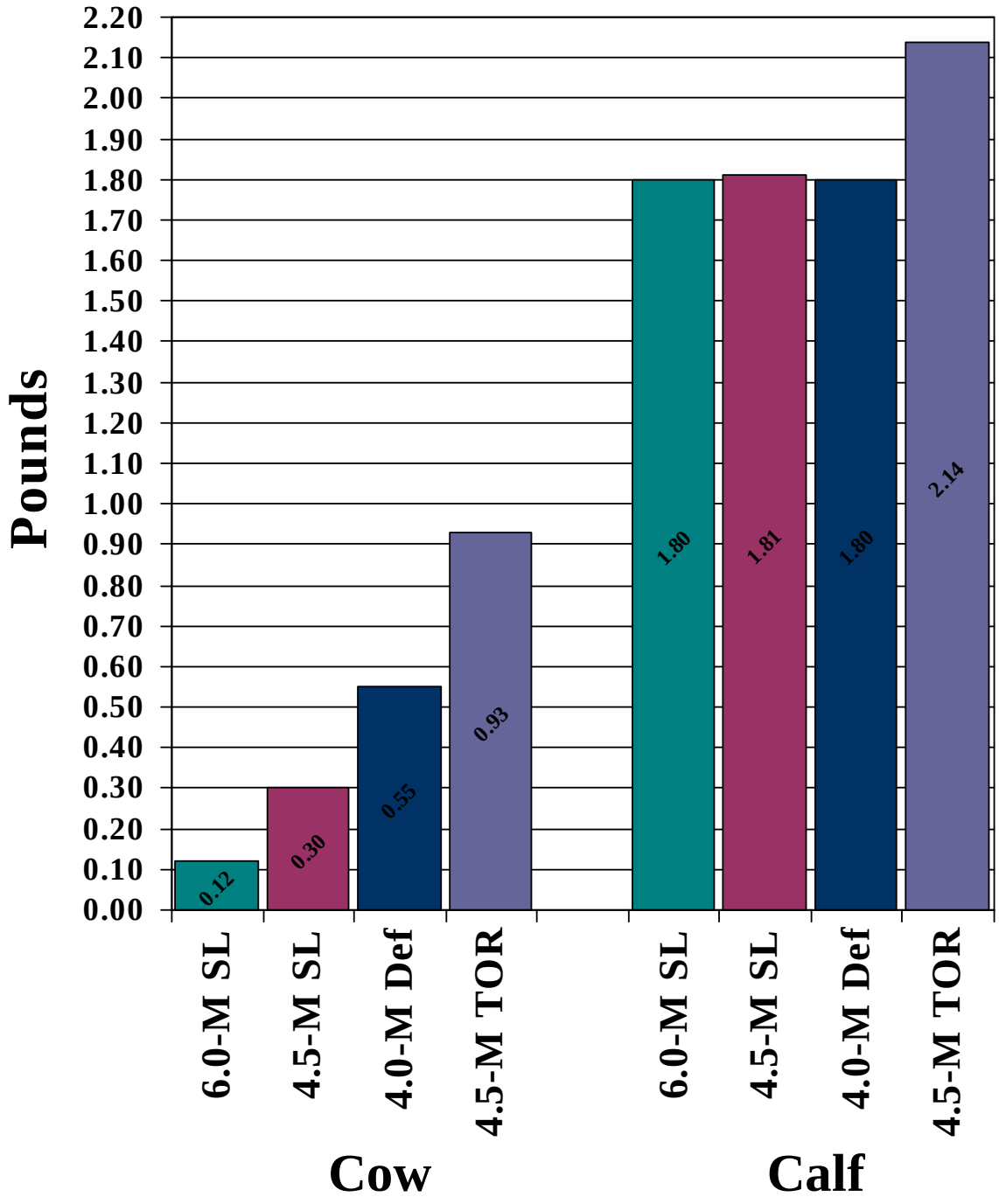


Fig. 4. Cow and calf average weight gain per day on grazing management systems during the grazing season.

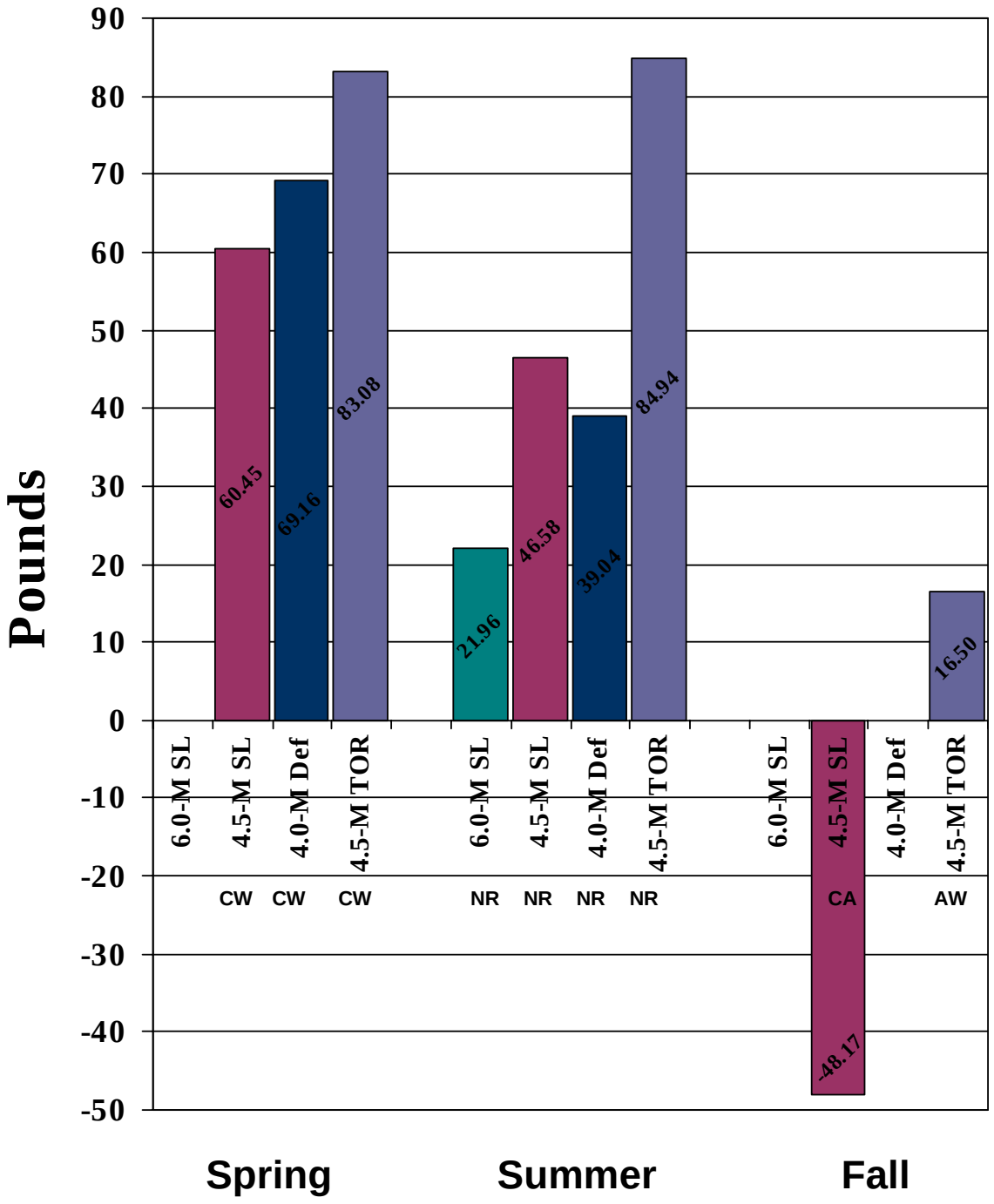


Fig. 5. Cow accumulated weight on pasture-forage types during the grazing season.

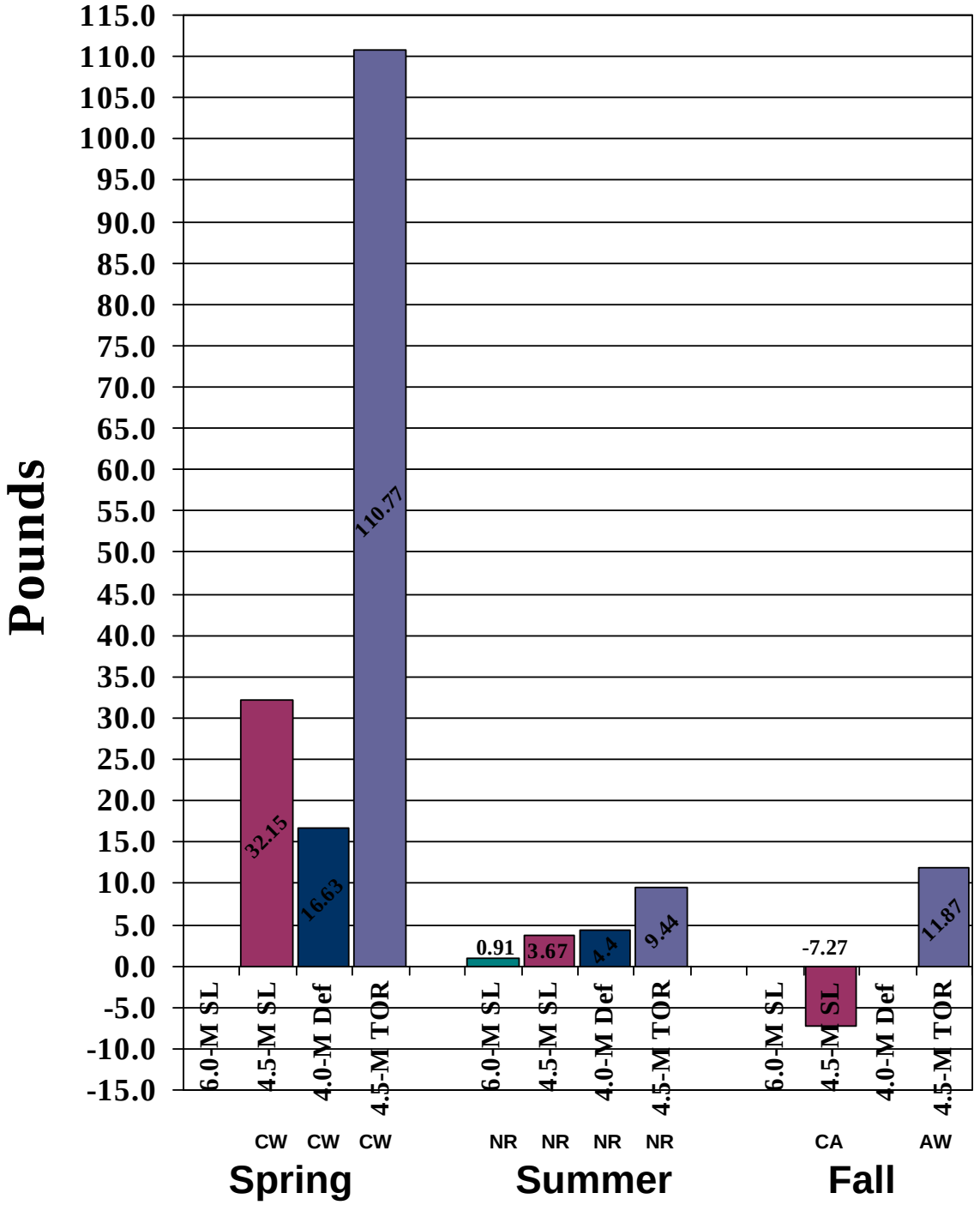


Fig. 6. Cow weight gain per acre on pasture-forage types during the grazing season.

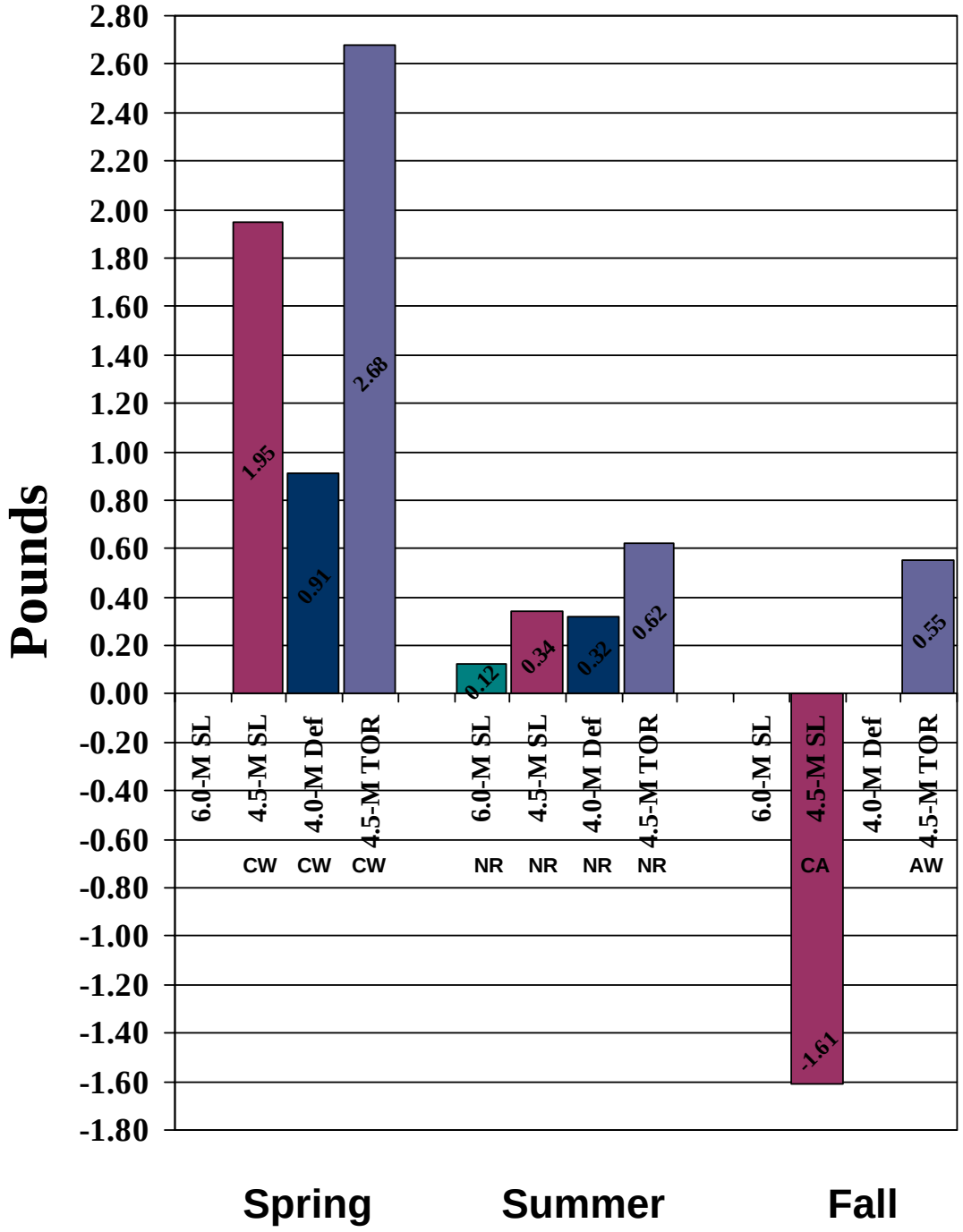


Fig. 7. Cow weight gain per day on pasture-forage types during the grazing season.

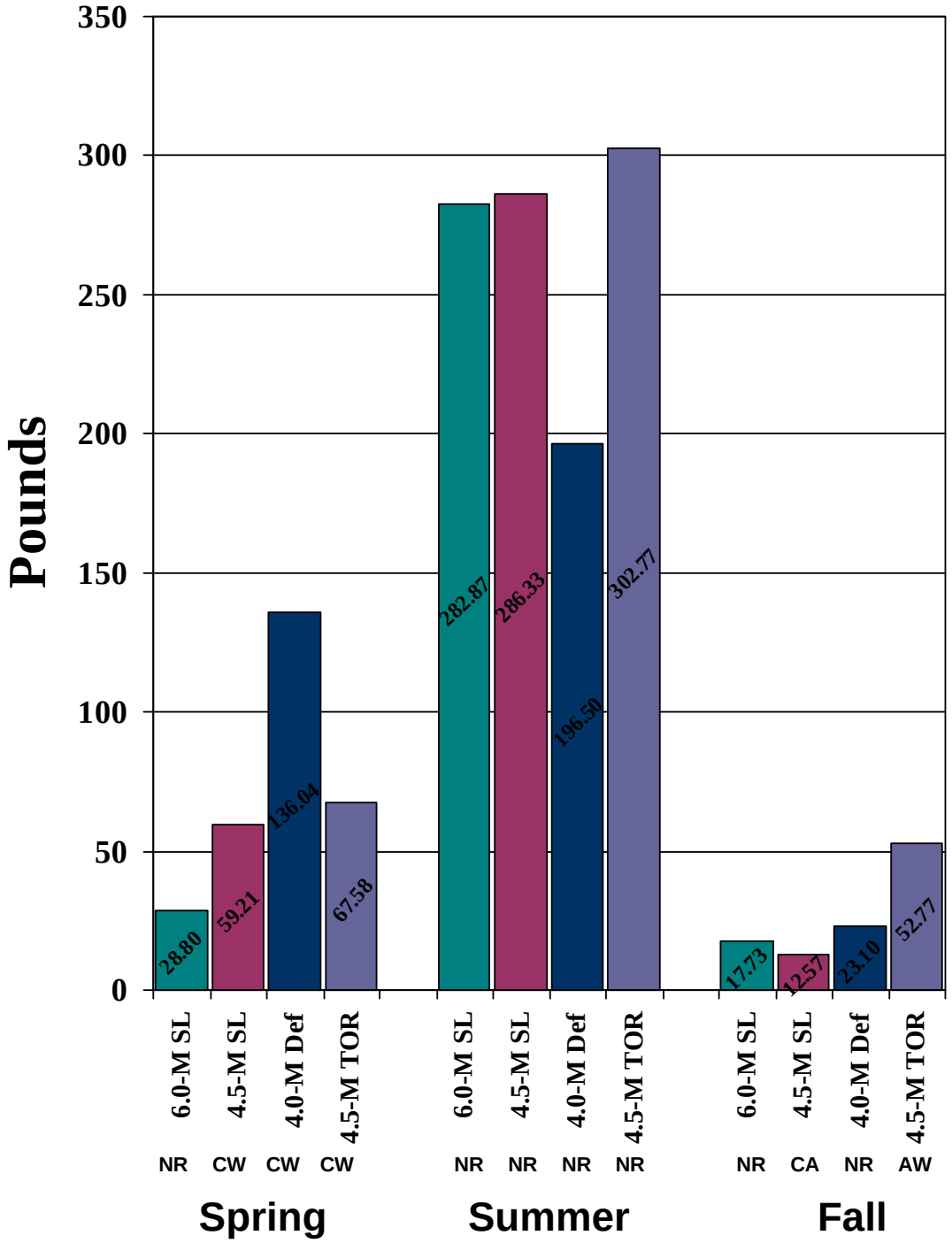


Fig. 8. Calf accumulated weight on pasture-forage types during the grazing season.

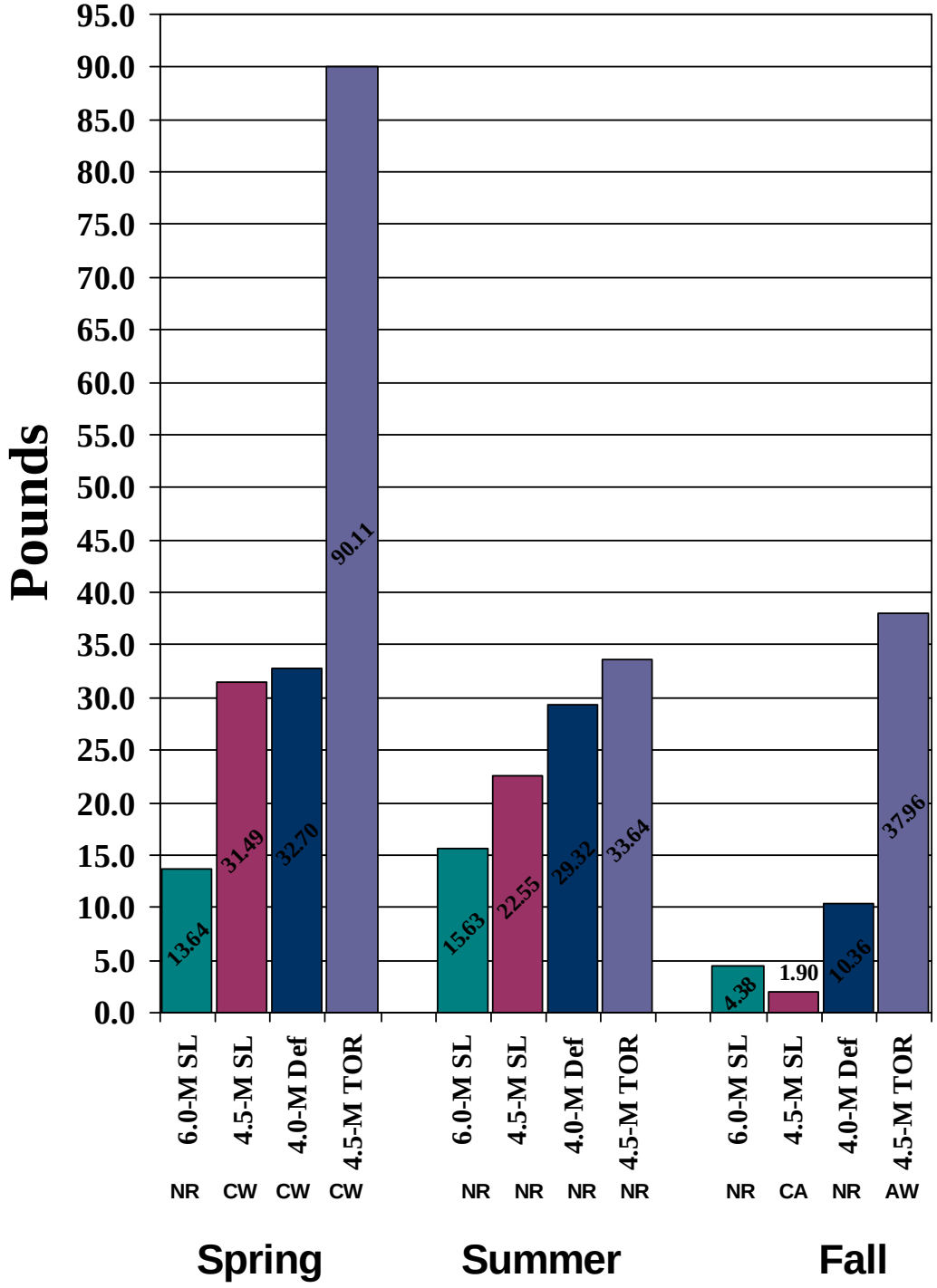


Fig. 9. Calf weight gain per acre on pasture-forage types during the grazing season.

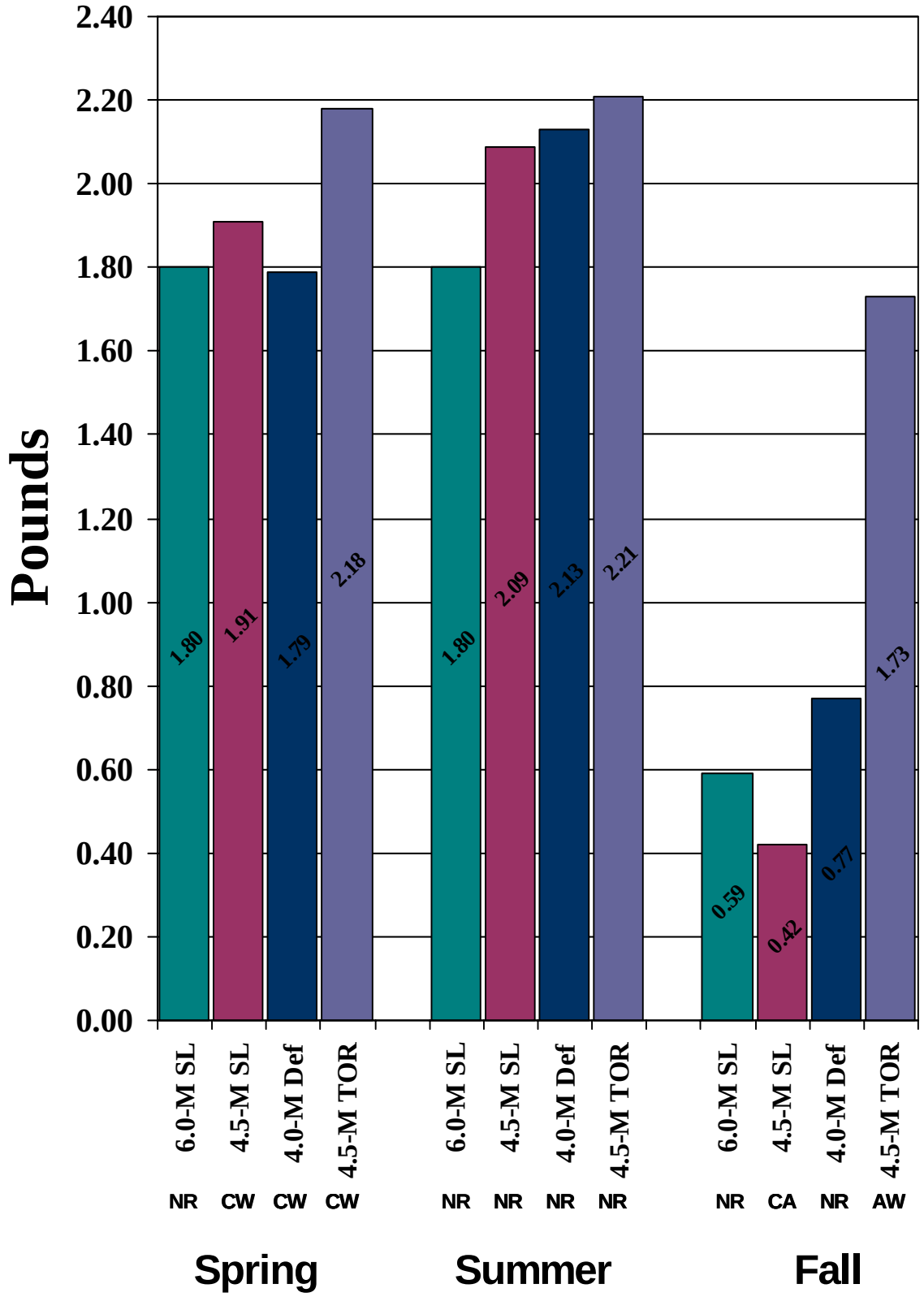


Fig. 10. Calf weight gain per day on pasture-forage types during the grazing season.

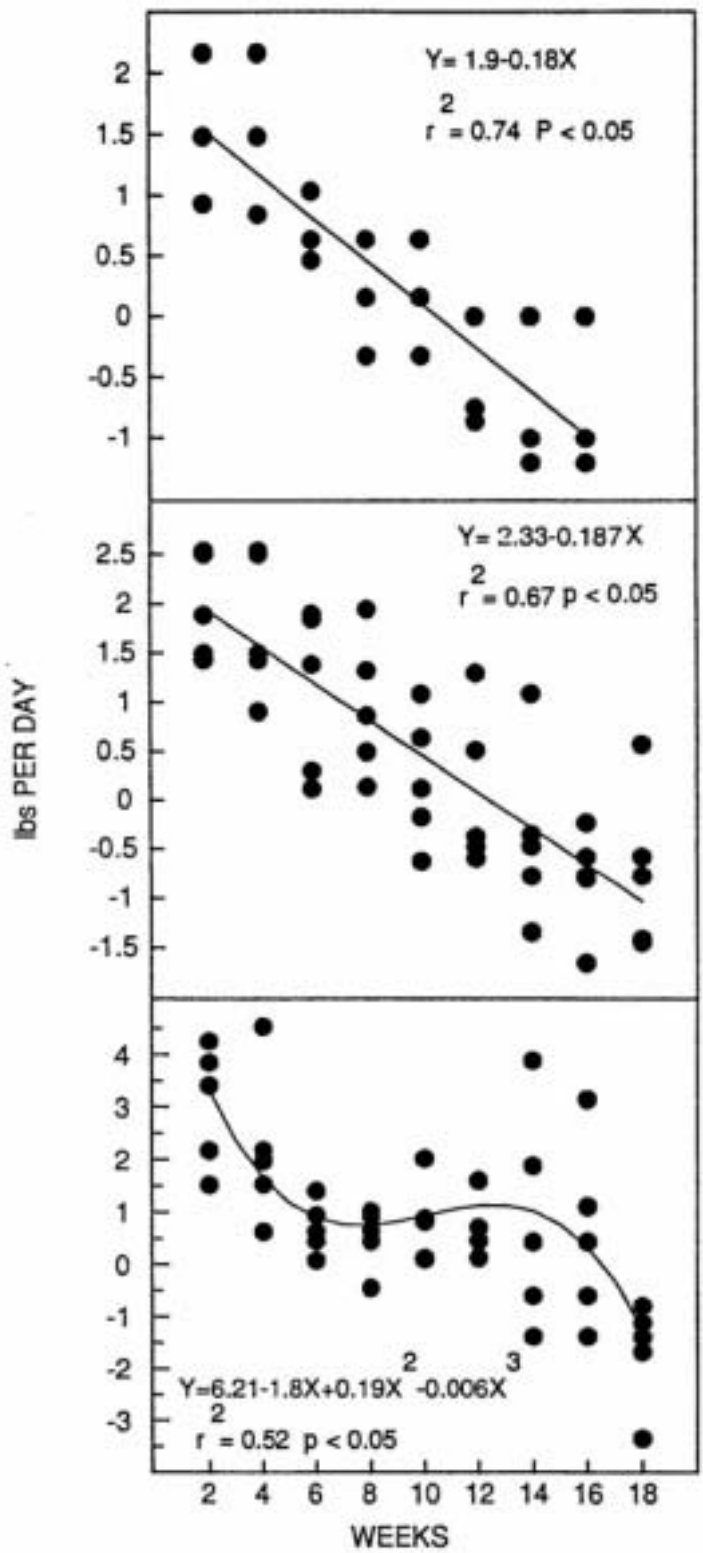


Fig. 11. Cow weight gain per day response curves for deferred (top), seasonlong (middle), and twice-over rotation (bottom) treatments (from Manske et al. 1988).

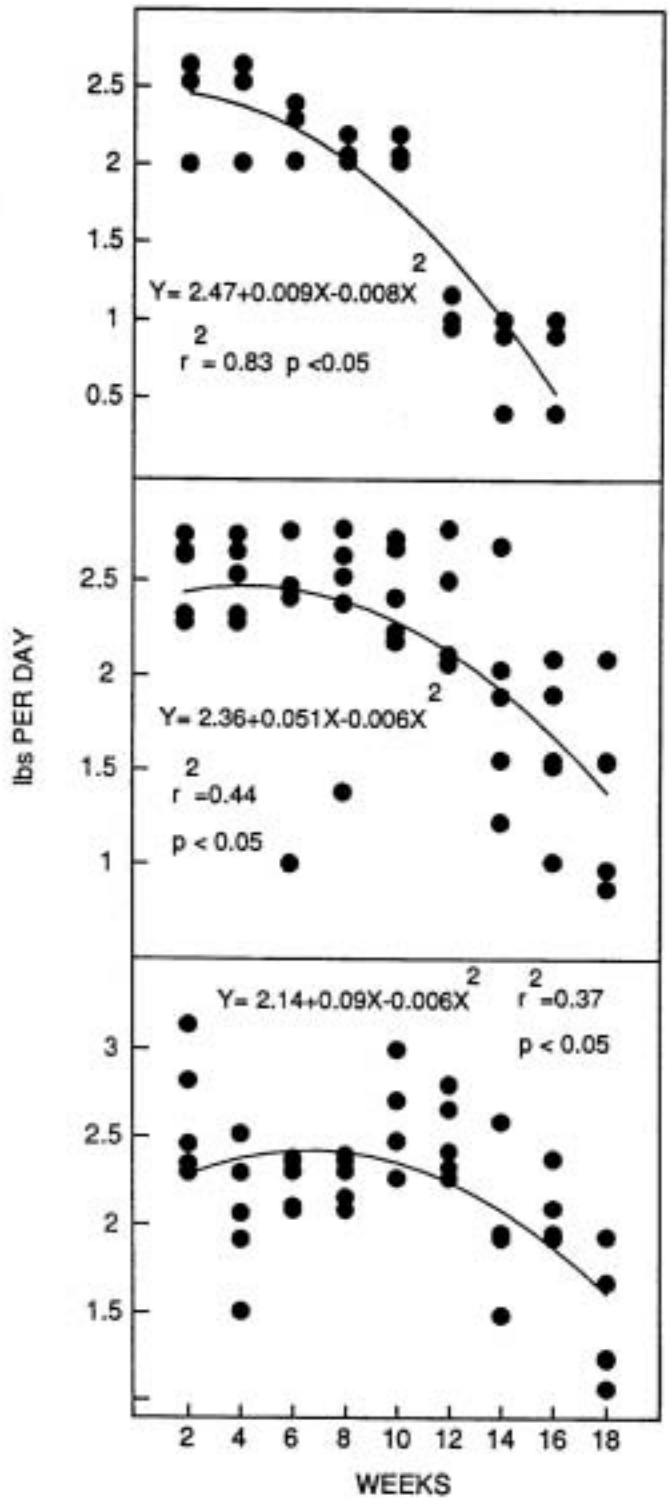


Fig. 12. Cow accumulated weight gain response curves for deferred (top), seasonlong (middle), and twice-over rotation (bottom) treatments (from Manske et al. 1988).

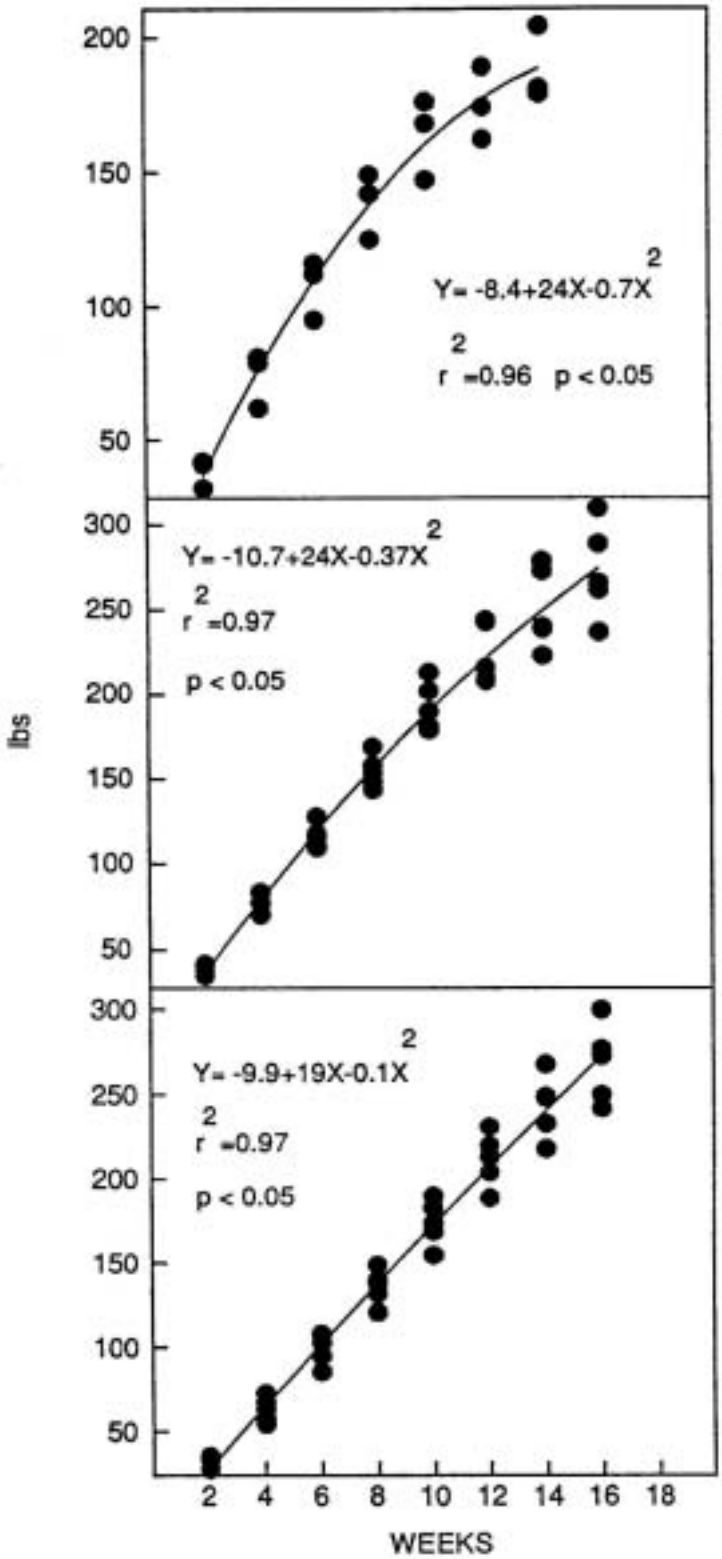


Fig. 13. Calf weight gain per day response curves for deferred (top), seasonlong (middle), and twice-over rotation (bottom) treatments (from Manske et al. 1988).

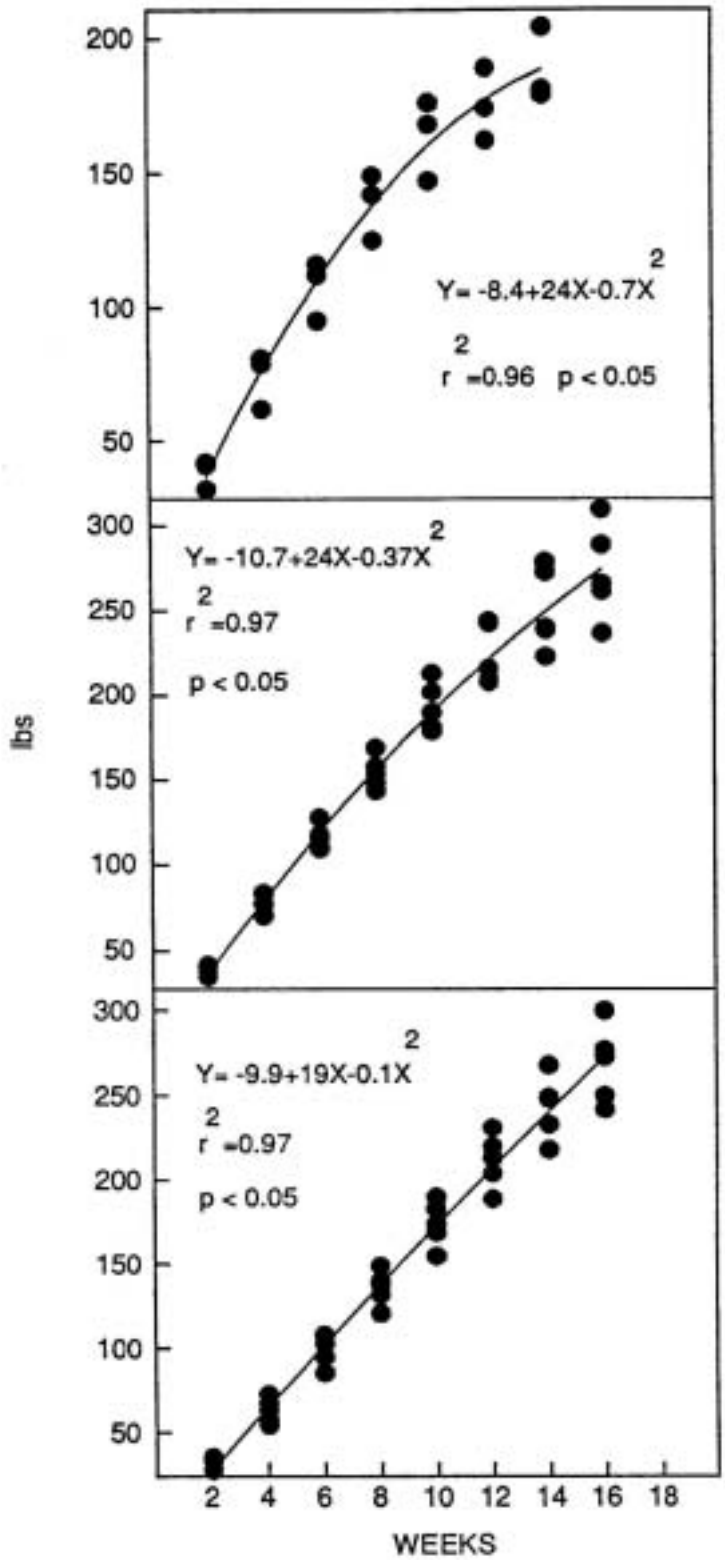


Fig. 14. Calf accumulated weight gain response curves for deferred (top), seasonlong (middle), and twice-over rotation (bottom) treatments (from Manske et al. 1988).

Discussion

Cows and calves do not gain weight at the same rate during the entire grazing season. The differences in cow and calf weight performance are caused by differences in pasture-forage types, changes in the growth stage of plants, and differing effects grazing management practices have on plant growth.

Twice-over and traditional grazing management systems

Individual cow and calf weight performance and cow and calf weight production per acre were greater on the twice-over rotation system than on traditional management systems. Individual cow weight performance was about three times greater on the twice-over rotation system than average individual cow weight gain on traditional management systems, and cow weight gain per acre was more than four times greater on the twice-over rotation system than on traditional management systems. Individual calf weight performance was about 20% greater on the twice-over rotation system than average individual calf weight gain on traditional management systems, and calf weight gain per acre was about two times greater on the twice-over rotation system than on traditional management systems.

Crested wheatgrass pasture forage

Crested wheatgrass develops three new leaves on lead tillers four to five weeks earlier in the spring than cool-season native grass species, and both unfertilized and fertilized crested wheatgrass provide excellent complementary spring pastures during May. Crude protein content of unfertilized pastures decreases as the season progresses, dropping below the requirements for lactating cows in late June. Fertilization of crested wheatgrass pastures with 40 to 60 pounds of nitrogen per acre during the first week of April nearly doubled the amount of herbage biomass on the pastures during May. The readily available mineral nitrogen improved the water use efficiency of plants and was responsible for some true increase in herbage production. However, much of the observed increase of aboveground herbage in May came from the increased rate of growth of less developed tillers that were already in the plant population and would have grown later in the season. This rapid earlier growth of the less developed tillers reduced the amount of aboveground herbage biomass later in the spring on fertilized pastures and shortened by several weeks the period in which the herbage quantity and quality met lactating cow requirements.

Cow and calf weight gain per acre on crested wheatgrass pastures has phenomenal potential during May. High rates of weight gain can be achieved if the cows are approaching their peak lactation levels at the start of the grazing period and the calves are old enough to consume the milk produced and gain great amounts of weight per day. Cows that are at early lactation and have newborn or young calves gain weight on crested wheatgrass pastures in May, but these cow-calf pairs cannot gain weight at rates near potential because they cannot capture a high proportion of the available nutrients efficiently and convert the nutrients into milk production and calf weight.

Crested wheatgrass can tolerate short-term heavy defoliation only if the plants are permitted adequate time to recover following the grazing period. Crested wheatgrass pastures grazed so heavily in May that only 2.5 to 3 inches of live plant residue remain at the end of the month require the rest of the growing season to recover. The photosynthetic activity of the leaf area produced by the secondary tillers that develop later in June restores plant health and replenishes the carbohydrate reserves preparing plants for next season's grazing period. Consumption of the dry herbage from the previous growing season's secondary tillers reduces the rate of passage of the current season's lush green vegetation and helps to prevent grass tetany and milk fever in grazing cows. Crested wheatgrass fields that are grazed as complementary spring pastures in a management system should be neither cut for hay during the summer nor grazed during the fall or winter.

Native rangeland pasture forage

Cow and calf weight performance generally did not differ among native rangeland treatments during the early grazing period of June and July, but during the latter portion of the grazing period, after early August, animal weight performance was greater on the twice-over rotation treatment than on the seasonlong and deferred treatments.

Cow weight gain per day on the seasonlong and deferred treatments steadily decreased as the grazing period progressed. Cows on the seasonlong and deferred treatments gained weight during the early portion of the grazing period but lost weight during the latter portion. Weight loss occurred at a greater rate on the deferred treatment. Cows on the twice-over rotation treatment gained weight at a greater rate than did cows on the seasonlong and deferred treatments. Cows on the twice-over rotation treatment gained weight during the early and middle portions of the grazing period and lost a small amount

of weight at the end of the grazing period. Cow accumulated weight gain, gain per acre, and gain per day were greater on the twice-over rotation treatment than on the seasonlong and deferred treatments.

Calf weight performance during the early portion of the grazing period was about the same on all native rangeland treatments. The greatest differences occurred during the latter portions of the grazing period. Calf weight gain per day on the seasonlong and deferred treatments decreased as the grazing season progressed. The decrease in calf gain per day was greater on the deferred treatment. The decrease in calf gain per day during the latter portion of the grazing period was smaller on the twice-over rotation treatment than on the seasonlong and deferred treatments. Calf accumulated weight gain was greater on the seasonlong treatment than on the deferred treatment. Calf accumulated weight gain was greater on the twice-over rotation treatment than on the seasonlong and deferred treatments.

The 6.0-month seasonlong grazing treatment started grazing native rangeland early, before the plants developed three new leaves. Starting grazing before the third-leaf stage deprives grass plants of needed leaf area and results in reductions in grass growth and herbage production (Campbell 1952, Rogler et al. 1962, Manske 2000). The nutritional quality of the herbage on native rangeland was at or above the cows' requirements 42.1% and below the cows' requirements 57.9% of the 183-day grazing period. Early in the grazing period, cows were able to select forage that provided adequate nutrition and they could gain weight, but after early August, cows were unable to select adequate forage to maintain body weight and milk production. The loss of herbage production caused by grazing early resulted in reduced stocking rates and reduced animal performance. During the latter portion of the grazing period, cows lost all but a small amount of their accumulated weight. Calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day were greatly reduced soon after the cows started to lose weight.

The 4.5-month seasonlong grazing treatment delayed grazing on native rangeland until the cool-season native grasses had reached the third-leaf stage. At this time of year, herbage was still actively growing and early leaves on several grass species were fully expanded and at or near full weight. The nutritional quality of the herbage on native rangeland was at or above the cows' requirements 44.5% and below the cows' requirements 55.5% of the 137-day grazing period. Early in the grazing period, cows were able to select forage that provided adequate nutrition and they could gain weight, but they had a steady decline in weight gain per day from the start of the grazing period. After early August, most of the growth of grasses had been completed and the nutrient content of the available vegetation had dropped below cow requirements. Cows were unable to select adequate forage to maintain body weight and milk production during the latter portion of the grazing period. Calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day were greatly reduced soon after the cows started to lose weight.

The deferred grazing treatment deferred grazing on native rangeland until most grass species had reached the seed development stage and nearly all of the plant growth in weight had been completed. Grasses decrease in nutritional quality following the flowering stage, and their nutrient content soon drops below the minimum requirements of livestock. Most of the grass leaves of the available forage were fully expanded and at later stages of senescence. The nutritional quality of the herbage on native rangeland was at or above the cows' requirements 13.1% and below the cows' requirements 86.9% of the 122-day grazing period. Early in the grazing period, cows were able to select forage that provided adequate nutrition and they could gain weight, but after early August, cows were unable to select adequate forage to maintain body weight and milk production. Calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day were greatly reduced soon after the cows started to lose weight.

Loss of weight by cows during the latter portion of the grazing period on the traditional management treatments--6.0-month seasonlong, 4.5-month seasonlong, and deferred management treatments--is not apparent because cow weight gain during the early portion of the grazing season was greater than weight loss during the latter portion of the grazing season. The loss of weight is not harmful to the health of the animals but does indicate that cows were unable to maintain body weight and lactation on the forage available. Calf weight performance decreased greatly during the period that the cows lost weight. Cow and calf weight performance on native rangeland managed by traditional treatments is below the genetic potentials of modern livestock.

The twice-over rotation grazing treatment delayed grazing on native rangeland until the cool-season native grasses had developed three new leaves. After the three-and-a-half-leaf stage, grass plants can physiologically tolerate moderate defoliation, and grazing at appropriate stocking rates

will not cause a reduction in herbage production. From early June to mid July, when lead tillers are actively growing, grazing that removes about 10% to 33% of the young leaf material on 60% to 80% of the plants manipulates grass plant biological processes that activate and enhance vegetative reproduction processes resulting in stimulation of secondary tiller growth. During the early portion of the grazing period, prior to mid July, livestock were moved through each of the three pastures one time. Cow gain per day decreased during the first pasture rotation because the fully expanded leaves of lead tillers were decreasing in nutritional quality; however, the nutritional quality of the herbage remained above the cows' minimum dietary requirements so that the animals continued to gain weight. Cow weight gain per day remained fairly steady during the middle portion of the grazing period, when cows were rotated a second time through each pasture. The nutritional quality of the herbage on native rangeland was at or above the cows' requirements 89.8% and below the cows' requirements 10.2% of the 137-day grazing period. Cows prolonged their weight gain late into the grazing period, and the twice-over rotation strategy delayed by two to two and a half months the weight loss typical on traditional grazing treatments.

The improved cow weight performance on the twice-over rotation treatment is a result of two management-related changes in plant growth. First, a high proportion of the grass leaves consumed by the cows during the early portion of the grazing period were near full weight and of high quality so that animals could fulfill their daily dietary needs by grazing fewer plants. This allowed a high number of immature leaves to escape grazing during the first pasture rotation and to be available fully expanded, near maximum weight, and at high nutrient quality during the second pasture rotation. Second, light grazing during the early portion of the grazing period stimulated grass plant vegetative tillering and increased plant density and the number of leaves available for grazing during the second pasture rotation. During the middle and late portions of the grazing period, the leaves on the secondary tillers were phenologically younger, less developed, and of higher nutritional quality than leaves on the lead tillers of the same species (Sedivec 1999). Together, grazing primarily fully expanded leaves, which reduces the number of plants per animal per day, and the increase in grass density from secondary tillers result in the increase in herbage biomass and permit an increase in stocking rate. Calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day were lower during the latter portion of the grazing season than during the early portion. The rate of decline in calf performance during the latter portion of the grazing period on the twice-over rotation treatment was considerably less than the decline on traditional grazing treatments.

Fall pasture forage

Manipulating vegetative reproduction of native grasses and increasing secondary tillers improve herbage quality and extend the period of improved livestock performance two to two and a half months during the latter portion of the grazing period, until late September or mid October. The biology of native grass plants does not permit extending these conditions beyond mid October, when native rangeland herbage quality is insufficient to meet the requirements of lactating cows.

Wildryes such as Altai and Russian are the only perennial grasses that retain nutrient quality in the aboveground portions of the plant until about mid November. Weight gains of cows and calves grazing Altai wildrye complementary pastures during mid October to mid November were considerably greater than those of livestock grazing native rangeland managed by 6.0-month seasonlong and deferred treatments and those of livestock grazing cropland aftermath pastures during the same period; cows on the native rangeland and cropland aftermath lost weight and the calves with these cows gained little weight. No perennial grass in the Northern Plains retains sufficient nutritional quality to dependably meet the nutritional requirements of grazing lactating cows later than mid November.

Conclusion

The twice-over rotation system has greater individual cow and calf weight performance and greater cow and calf weight production per acre than traditional management systems. The improved animal performance on the twice-over rotation system results from increased efficiency of capturing value from the land resources. Sustaining increased value capture requires improvement of the biological effectiveness, nutrient capture efficiency, and nutrient conversion efficiency of grazing management.

The biological performance level of the plant component of grassland ecosystems determines the weight performance of the livestock component. Improved biological effectiveness of grazing management increases herbage and nutrient production by meeting the biological requirements of plants and ecosystem processes. Livestock grazing coordinated with specific plant growth stages and seasons of the year beneficially manipulates plant

biological processes, stimulates soil organism activity, and enhances the biogeochemical cycles responsible for the flow of nitrogen, carbon, and water through ecosystems.

Nutrients are necessary to support the life and production of a beef cow and calf. The nutrients, not the dry matter, are the valuable products from forage plants. When the focus is shifted to harvesting greater nutrient weight per acre rather than greater forage dry matter weight per acre and to improving nutrient capture efficiency, the weight of nutrients grazing captures from the land resource increases. Produced nutrients are efficiently captured by livestock grazing pasture-forage types during their optimum plant growth stages, when the percent nutrient content and the weight of forage dry matter yield the greatest nutrient weight per acre.

Cows and calves grazing herbage that is at or above their nutritional requirements have greater weight production levels than cows and calves grazing herbage that is below their nutritional requirements. Improved nutrient conversion efficiency increases cow and calf weight production levels by providing nutrients at the times and in the amounts required during each production period. Livestock produce at greater efficiencies when not limited by periods with nutrient deficiency. Increased livestock weight performance from improved efficiency of nutrient conversion can be maintained when appropriate pasture-forage types are combined in sequence so that the herbage production curves and nutritional quality curves meet the cow and calf dietary quantity and quality requirements during the entire grazing season.

Acknowledgment

I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables and figures. I am grateful to Amy Kraus for assistance in the preparation of this manuscript.

Literature Cited

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Kerlinger, F.N., and E.J. Pedhazur. 1973. Multiple regression in behavioral research. Holt, Rinehart, and Winston, Inc. New York, NY.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988. Cow and calf performance on seasonlong and twice-over rotation grazing treatments in western North Dakota. North Dakota Cow-Calf Conference. Bismarck, ND. p. 5-17.

Manske, L.L. 1994a. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program. Regina, Saskatchewan, Canada.

Manske, L.L. 1994b. Grazing management for Northern Great Plains rangelands. NDSU Dickinson Research Extension Center. Range Research Report DREC 94-1004. Dickinson, ND. 11p.

Manske, L.L. 2000. Grazing before grass is ready. NDSU Dickinson Research Extension Center. Range Management Report DREC 00-1032. Dickinson, ND. 6p.

Manske, L.L. 2003. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1018f. Dickinson, ND. 37p.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. North Dakota Agricultural Experiment Station. Bulletin 439. Fargo, ND. 15p.

Sedivec, K.K. 1999. Nutritional quality of selected rangeland plants. Summary Report. NDSU Animal and Range Sciences Dept. Research Report. Fargo, ND.

Cow and Calf Performance on Pasture-Forage Types during the Fall, mid October to mid November

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Cow and calf weight performance is affected by changes in the quantity and quality of the herbage on grazinglands. As perennial plants in the Northern Plains mature during the growing season, they translocate leaf cell contents to other plant parts, and a decrease in herbage weight and nutrient quality results. By the late portion of the grazing season, most perennial plants are in the late stages of aging, or senescence. Weight performance of livestock grazing on the maturing vegetation decreases. The scope of this reduction in cow and calf weight gain during the late portion of the grazing season may not be obvious to beef producers when the spring, summer, and fall livestock weight gains are averaged across the entire grazing season. Evaluation of the fall cow and calf weight gains separately from animal performance during the other portions of the grazing season reveals the extent to which the late-season decline in herbage quality and quantity affects animal performance.

The purpose of this study is to document and compare cow and calf accumulated weight gain, rate of weight gain per acre, and rate of weight gain per day on pasture-forage types during the fall portion of the grazing season, mid October to mid November, on grazing management systems.

Procedure

This study was conducted at the NDSU Dickinson Research Extension Center, located in western North Dakota. Soils are primarily Typic Haploborolls. Average annual precipitation is 16.1 inches, with 13.6 inches (84.7%) falling as rain between April and October. Mean annual temperature is 40.8°F. January is the coldest month, with a mean temperature of 11.1°F. July and August are the warmest months, with mean temperatures of 68.6°F and 67.0°F, respectively. Mid October is generally considered to be the end of the growing season for perennial plants. Mean temperatures of October and November are 43.8°F and 28.3°F, respectively. October had water stress conditions 48.6% of the time during the past 111 years (1892-2002). Average precipitation in October and November is 0.94 inches and 0.54 inches, respectively (Manske 2003a).

Pasture-forage types of grazing management treatments were evaluated from mid October to mid November, during the fall portion of the grazing season, the 30-day period following the end of the growing season for perennial plants. The native rangeland (NR) pasture-forage type is the Wheatgrass-Needlegrass Vegetation Type (Barker and Whitman 1988) of the mixed grass prairie. The dominant native range species are western wheatgrass, needle and thread, blue grama, and threadleaved sedge. The Altai wildrye (AW) domesticated grass pasture-forage type was seeded as a monoculture, but a small assortment of forb and other grass species developed as minor components. The cropland aftermath (CA) pasture-forage type consisted primarily of annual cereal residue of oat, barley, and/or chopped corn stubble.

Cow and calf weight performance data were collected on grazing management treatments involved in pasture research projects conducted between 1983 and 1998. Commercial crossbred cattle were used on all treatments. Individual animals were weighed on and off each treatment, at 15-day intervals, or at 30-day intervals during the latter portion of the grazing season. Weight performance of cows and of calves was calculated for each treatment, and differences between means were analyzed by a standard paired plot t-test (Mosteller and Rourke 1973). Portions of this data set were reported by Manske (1994a, b).

Grazing Management Treatments during the Fall

6.0-month seasonlong system

The 6.0-month seasonlong (6.0-m SL) management system continued livestock grazing during the fall portion of the grazing season, for 30 days from mid October to mid November, on a native rangeland pasture stocked at 4.04 acres per cow-calf pair per month. Livestock on this system grazed a single native rangeland pasture from mid May until mid November.

5.0-6.0-month seasonlong II system

The 5.0-6.0-month seasonlong II (SL 5.0-6.0-m II) management system continued livestock grazing during the fall portion of the grazing season, for 30 days from mid October to mid November, on a native rangeland pasture stocked at 2.53 acres per cow-calf pair per month. Livestock on this system grazed a single native rangeland pasture; livestock were turned onto the pasture between mid May and mid June and were removed in mid November.

4.5-month seasonlong system

The 4.5-month seasonlong (4.5-m SL) management system continued livestock grazing during the fall portion of the grazing season, for 30 days from mid October to mid November, on a cropland aftermath pasture stocked at 6.63 acres per cow-calf pair per month. Livestock on this system grazed an unfertilized crested wheatgrass pasture from early to late May and a native rangeland pasture from early June to mid October.

4.5-month seasonlong II system

The 4.5-month seasonlong II (SL 4.5-m II) management system continued livestock grazing during the fall portion of the grazing season, for 15 days from mid to late October, on a native rangeland pasture stocked at 3.26 acres per cow-calf pair per month. Livestock on this system grazed an unfertilized crested wheatgrass pasture from early May to mid June and a native rangeland pasture from mid June to late October.

4.0-month deferred system

The 4.0-month deferred (4.0-m Def) management system continued livestock grazing during the fall portion of the grazing season, for 30 days from mid October to mid November, on a native rangeland pasture stocked at 2.18 acres per cow-calf pair per month. Livestock on this system grazed an unfertilized crested wheatgrass pasture from early May to mid July and a native rangeland pasture from mid July to mid November.

4.5-month twice-over rotation system

The 4.5-month twice-over rotation (4.5-m TOR) management system continued livestock grazing for 30 days from mid October to mid November on an Altai wildrye pasture stocked at 1.39 acres per cow-calf pair per month. Livestock on this system grazed a fertilized crested wheatgrass pasture from early to late May and three native rangeland pastures in rotation from early June to mid October.

Results

Length of grazing period and acres per cow-calf pair for pasture-forage types during the fall portion of the grazing season are shown in table 1 for each grazing management system. Cow performance during the fall portion of the grazing season is shown in table 1 and figures 1, 2, and 3. Calf performance during the fall portion of the grazing season is shown in table 1 and figures 4, 5, and 6.

The stocking rate on the Altai wildrye pasture of the twice-over rotation system during the 30-day fall portion of the grazing season was 56.83% greater than the stocking rate on the fall native rangeland pasture of the deferred system, 134.56% greater than the stocking rate on the fall native rangeland pasture of the 4.5-month seasonlong II system, 377.06% greater than the stocking rate on the fall cropland aftermath pasture of the 4.5-month seasonlong system, 82.03% greater than the stocking rate on the fall native rangeland pasture of the 5.0-6.0-month seasonlong II system, and 190.68% greater than the stocking rate on the fall native rangeland pasture of the 6.0-month seasonlong system.

Grazing Management Systems

6.0-month seasonlong system

The 6.0-month seasonlong management system during the 30-day fall portion of the grazing season comprised a native rangeland pasture that livestock grazed from mid October to mid November. Cow weight performance on the native rangeland pasture was a loss of 52.20 lbs, at a rate of 12.90 lbs per acre and 1.74 lbs per day. Calf weight performance on the native rangeland pasture was a gain of 17.73 lbs, at a rate of 4.38 lbs per acre and 0.59 lbs per day.

5.0-6.0-month seasonlong II system

The 5.0-6.0-month seasonlong II management system during the 30-day fall portion of the grazing season comprised a native rangeland pasture that livestock grazed from mid October to mid November. Cow weight performance on the native rangeland pasture was a loss of 24.60 lbs, at a rate of 9.77 lbs per acre and 0.82 lbs per day. Calf weight performance on the native rangeland pasture was a gain of 27.60 lbs, at a rate of 10.90 lbs per acre and 0.92 lbs per day.

4.5-month seasonlong system

The 4.5-month seasonlong management system during the 30-day fall portion of the grazing season comprised a cropland aftermath pasture that livestock grazed from mid October to mid November. Cow weight performance on the cropland aftermath pasture was a loss of 48.17 lbs, at a rate of 7.27 lbs per acre and 1.61 lbs per day. Calf weight performance on the cropland aftermath pasture was a gain of 12.57 lbs, at a rate of 1.90 lbs per acre and 0.42 lbs per day.

4.5-month seasonlong II system

The 4.5-month seasonlong II management system during 15 days of the fall portion of the grazing season comprised a native rangeland pasture that livestock grazed from mid to late October. Cow weight performance on the native rangeland pasture was a loss of 7.74 lbs, at a rate of 4.75 lbs per acre and 0.52 lbs per day. Calf weight performance on the native rangeland pasture was a gain of 20.33 lbs, at a rate of 12.47 lbs per acre and 1.35 lbs per day.

4.0-month deferred system

The 4.0-month deferred management system during the 30-day fall portion of the grazing season comprised a native rangeland pasture that livestock grazed from mid October to mid November. Cow weight performance on the native rangeland pasture was a loss of 22.20 lbs, at a rate of 9.96 lbs per acre and 0.74 lbs per day. Calf weight performance on the native rangeland pasture was a gain of 23.10 lbs, at a rate of 10.36 lbs per acre and 0.77 lbs per day.

4.5-month twice-over rotation system

The 4.5-month twice-over rotation management system during the 30-day fall portion of the grazing season comprised an Altai wildrye pasture that livestock grazed from mid October to mid November. Cow weight performance on the Altai wildrye pasture was a gain of 16.50 lbs, at a rate of 11.87 lbs per acre and 0.55 lbs per day. Calf weight performance on the Altai wildrye pasture was a gain of 52.77 lbs, at a rate of 37.96 lbs per acre and 1.73 lbs per day.

Cow weight performance was greater on the Altai wildrye pasture of the twice-over rotation management system than on any of the five traditional management systems. Cows grazing the Altai wildrye pasture gained weight and cows grazing the native rangeland and cropland aftermath pastures of the five traditional management systems lost considerable weight during the fall portion of the grazing season. Cow accumulated weight on the deferred system was 234.6% lower than that on the twice-over system; the rate of gain was 183.9% lower per acre and 243.6% lower per day. Cow accumulated weight on the 4.5-month seasonlong II system was 146.9% lower than that on the twice-over system; the rate of gain was 140.0% lower per acre and 194.6% lower per day. Cow accumulated weight on the 4.5-month seasonlong system was 391.9% lower than that on the twice-over system; the rate of gain was 161.3% lower per acre and 392.7% lower per day. Cow accumulated weight on the 5.0-6.0-month seasonlong II system was 249.1% lower than that on the twice-over system; the rate of gain was 182.3% lower per acre and 249.1% lower per day. Cow accumulated weight on the 6.0-month seasonlong system was 416.4% lower than that on the twice-over system; the rate of gain was 208.7% lower per acre and 416.4% lower per day.

Calf weight performance was greater on the Altai wildrye pasture of the twice-over rotation management system than on any of the five traditional management systems. Calf accumulated weight on the twice-over system was 128.4% greater than that on the deferred system, with the rate of gain 266.4% greater per acre and 124.7% greater per day. Calf accumulated weight on the twice-over system was 159.6% greater than that on the 4.5-month seasonlong II system, with the rate of gain 204.4% greater per acre and 28.2% greater per day. Calf accumulated weight on the twice-over system was 319.8% greater than that on the 4.5-month seasonlong system, with the rate of gain 1897.9% greater per acre and 311.9% greater per day. Calf accumulated weight on the twice-over system was 91.2% greater than that on the 5.0-6.0-month seasonlong II system, with the rate of gain 248.3% greater per acre and 88.0% greater per day. Calf accumulated weight on the twice-over system was 197.6% greater than that on the 6.0-month seasonlong system, with the rate of gain 766.7% greater per acre and 193.2% greater per day.

Fall Pasture-Forage Types

Cows grazing native rangeland for 15 days (mid to late October) lost about 8 lbs, at a rate of 5 lbs per acre and 0.5 lbs per day. Cows grazing native rangeland for 30 days (mid October to mid November) lost about 22 lbs to 52 lbs, at a rate of 10 lbs to 13 lbs per acre and 0.7 lbs to 1.7 lbs per day. Cows grazing cropland aftermath for 30 days lost about 48 lbs, at a rate of 7 lbs per acre and 1.6 lbs per day. Cows grazing Altai wildrye for 30 days gained

16.5 lbs, at a rate of 12 lbs per acre and 0.55 lbs per day.

The Altai wildrye pasture of the twice-over rotation system was the only pasture-forage type on which cows gained weight during the fall portion of the grazing season. Cows lost weight during the fall portion of the grazing season on native rangeland and cropland aftermath pasture-forage types.

Calves on native rangeland for 15 days (mid to late October) gained about 20 lbs, at a rate of 12 lbs per acre and 1.35 lbs per day. Calves on native rangeland for 30 days (mid October to mid November) gained 18 lbs to 28 lbs, at a rate of 4 lbs to 11 lbs per acre and 0.6 lbs to 0.9 lbs per day. Calves on cropland aftermath for 30 days gained about 13 lbs, at a rate of 2 lbs per acre and 0.4 lbs per day. Calves on Altai wildrye for 30 days gained about 53 lbs, at a rate of 38 lbs per acre and 1.7 lbs per day.

Calves gained a small amount of weight during the fall portion of the grazing season on native rangeland and cropland aftermath pasture-forage types. The market value of the calf accumulated weight at $0.70 per pound is less than the rent costs of the native rangeland and cropland aftermath pastures. Calf weight gain on the Altai wildrye pasture-forage type of the twice-over rotation system was greater than calf weight gain on the native rangeland and crop aftermath pasture-forage types. The market value of the calf accumulated weight at $0.70 per pound is greater than the rent costs of the Altai wildrye pasture.

Table 1. Cow and calf performance during the fall portions of the grazing season on grazing management systems.

	6.0-M Seasonlong	**5-6-M Seasonlong II**	**4.5-M Seasonlong**	**4.5-M Seasonlong II**	**4.0-M Deferred**	**4.5-M Twice-over Rotation**
Fall	Native Rangeland	Native Rangeland	Cropland Aftermath	Native Rangeland	Native Rangeland	Altai Wildrye
Days	30	30	30	15	30	30
Acres	4.04	2.53	6.63	1.63	2.18	1.39
Cow						
Accumulated Wt	-52.20	-24.60	-48.17	-7.74	-22.20	16.50
Gain/Acre	-12.90	-9.77	-7.27	-4.75	-9.96	11.87
Gain/Day	-1.74	-0.82	-1.61	-0.52	-0.74	0.55
Calf						
Accumulated Wt	17.73	27.60	12.57	20.33	23.10	52.77
Gain/Acre	4.38	10.90	1.90	12.47	10.36	37.96
Gain/Day	0.59	0.92	0.42	1.35	0.77	1.73

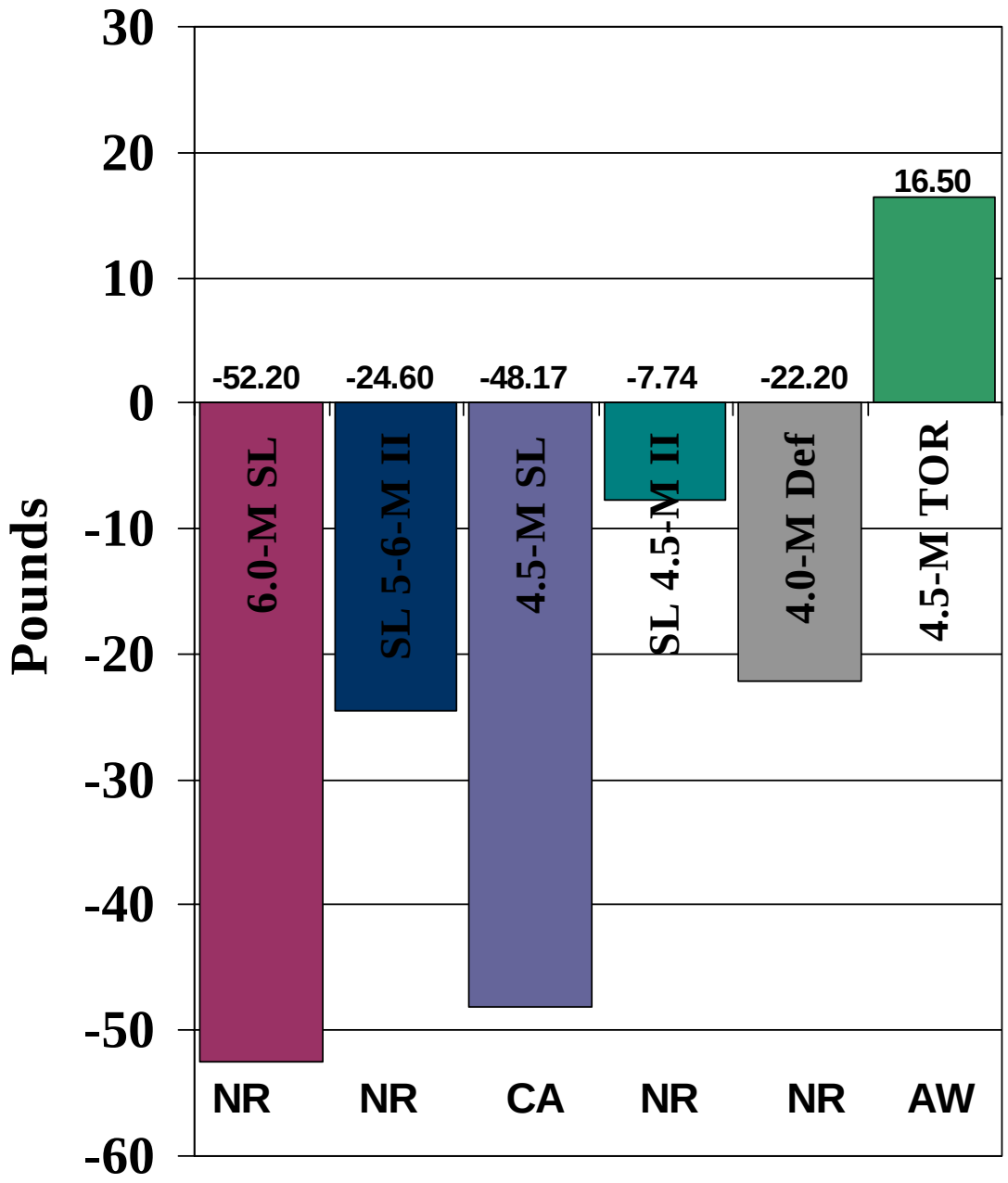


Fig. 1. Cow accumulated weight on grazing management systems during the fall portion of the grazing season.

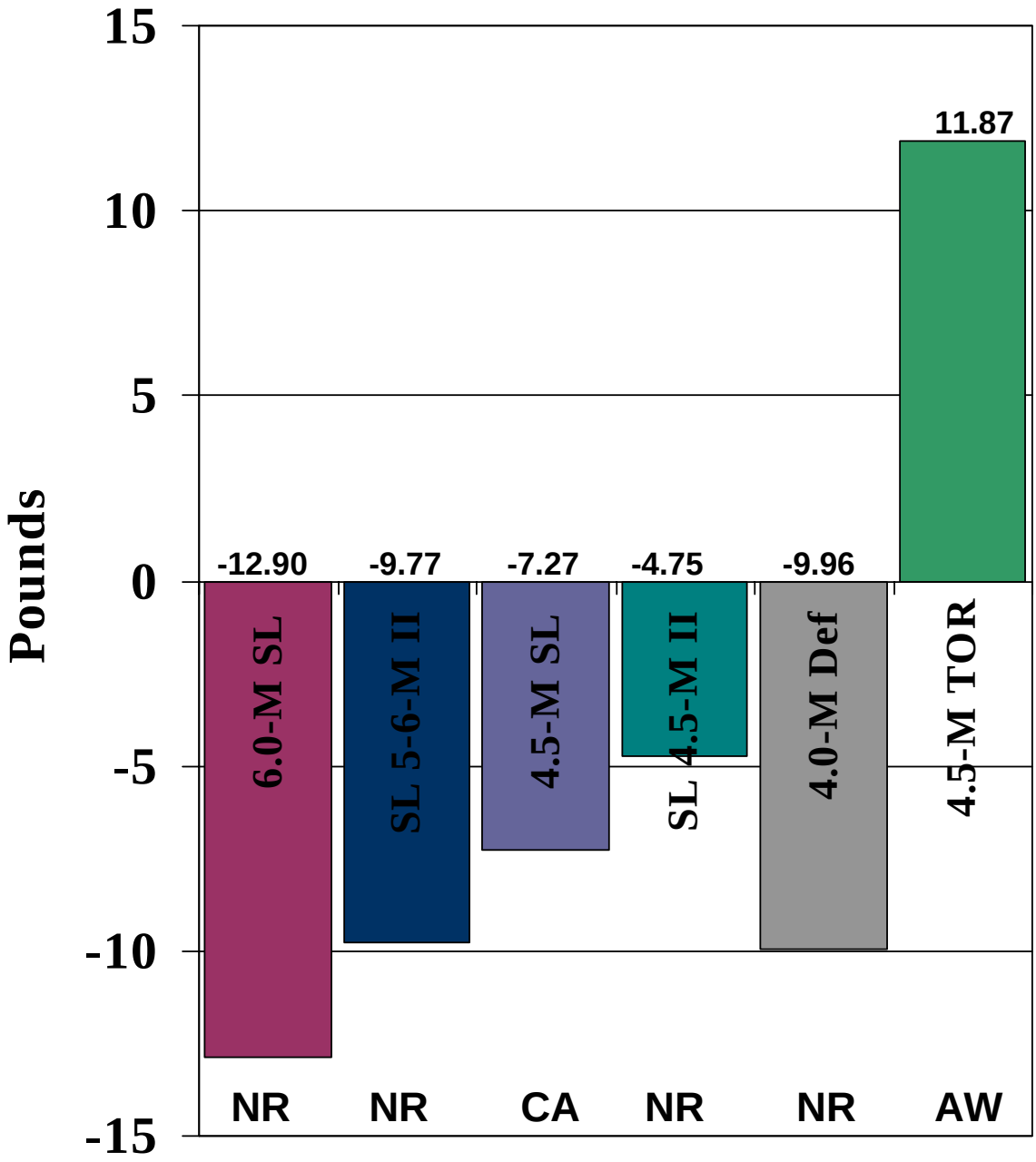


Fig. 2. Cow weight gain per acre on grazing management systems during the fall portion of the grazing season.

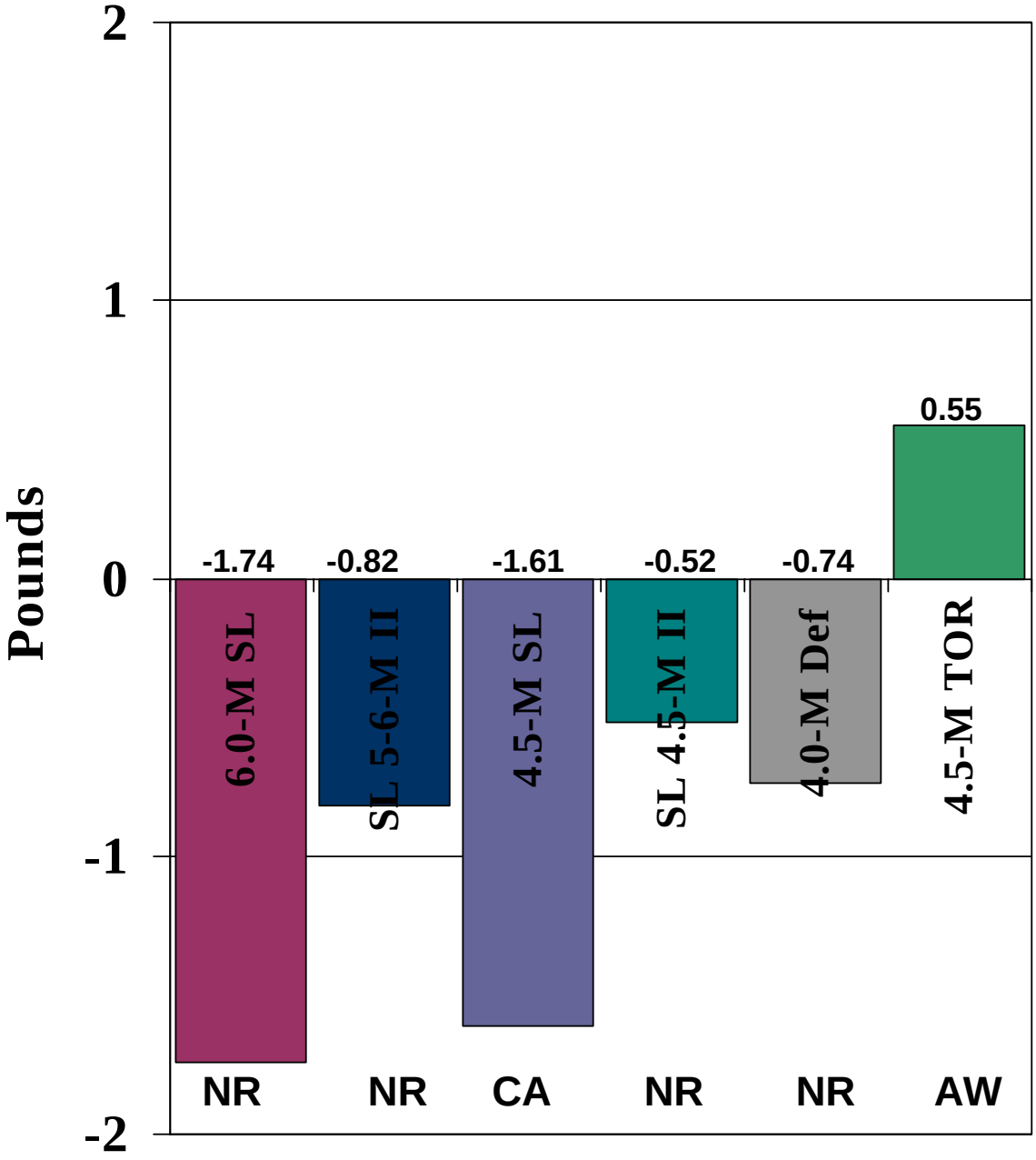


Fig. 3. Cow weight gain per day on grazing management systems during the fall portion of the grazing season.

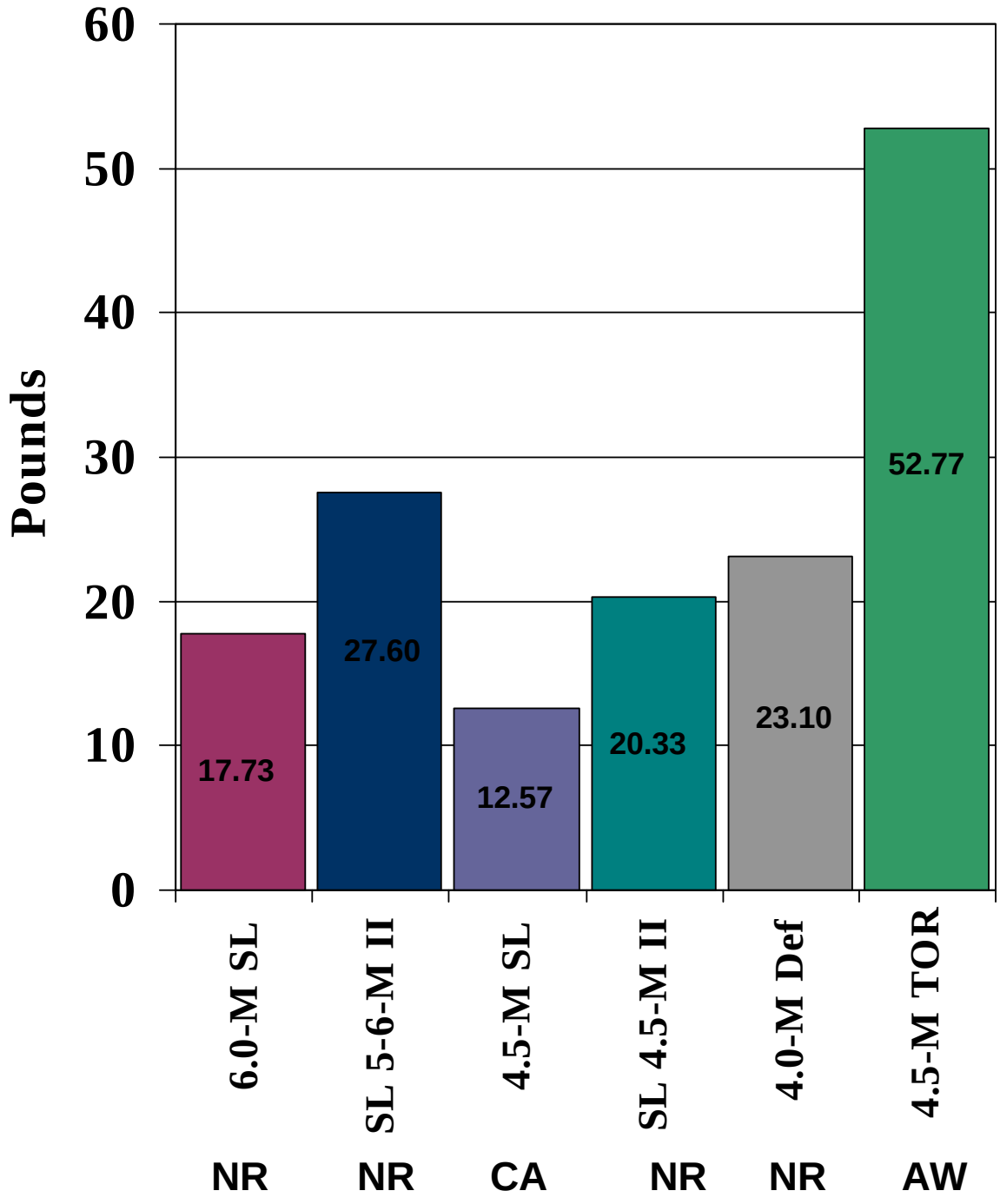


Fig. 4. Calf accumulated weight on grazing management systems during the fall portion of the grazing season.

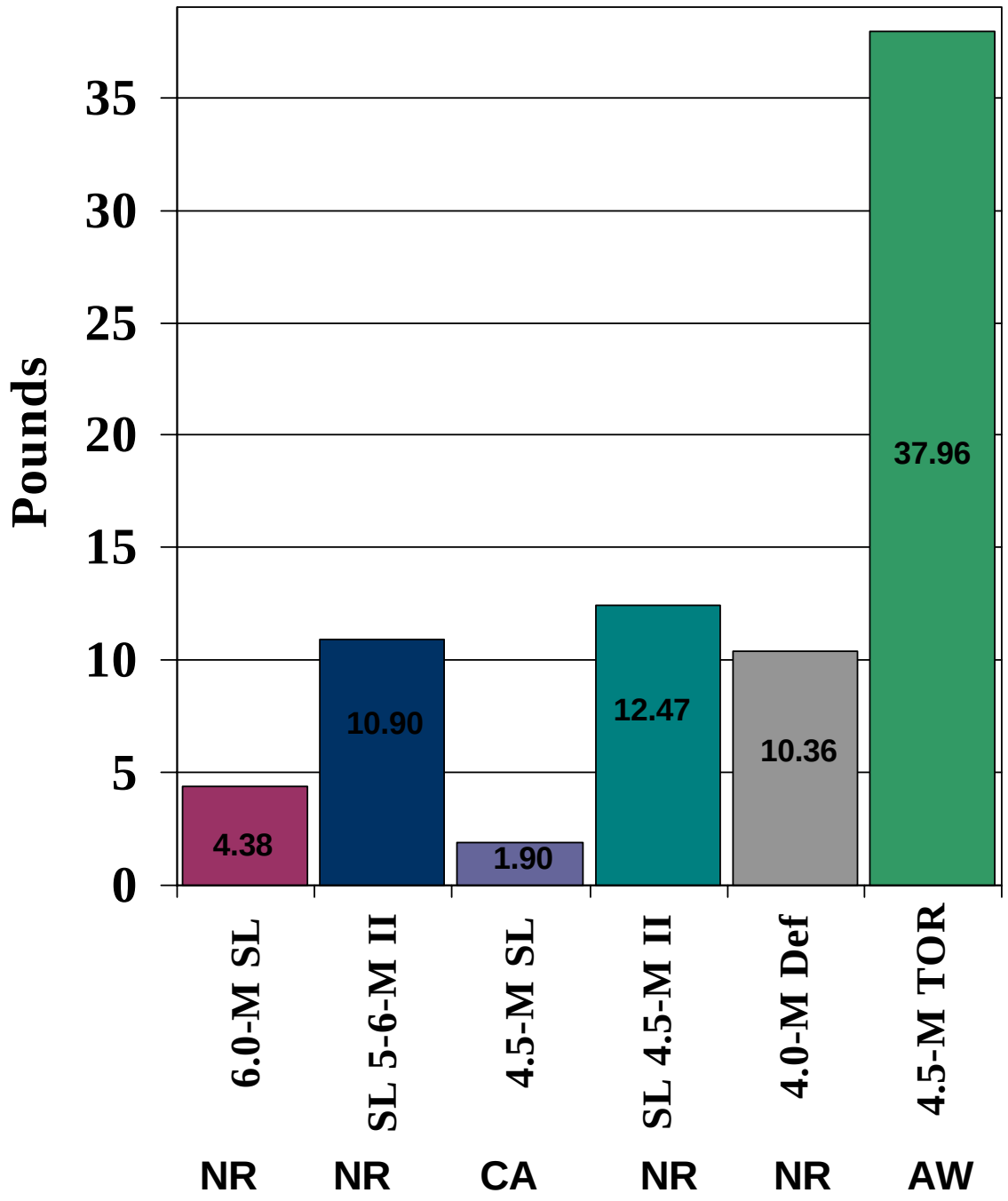


Fig. 5. Calf weight gain per acre on grazing management systems during the fall portion of the grazing season.

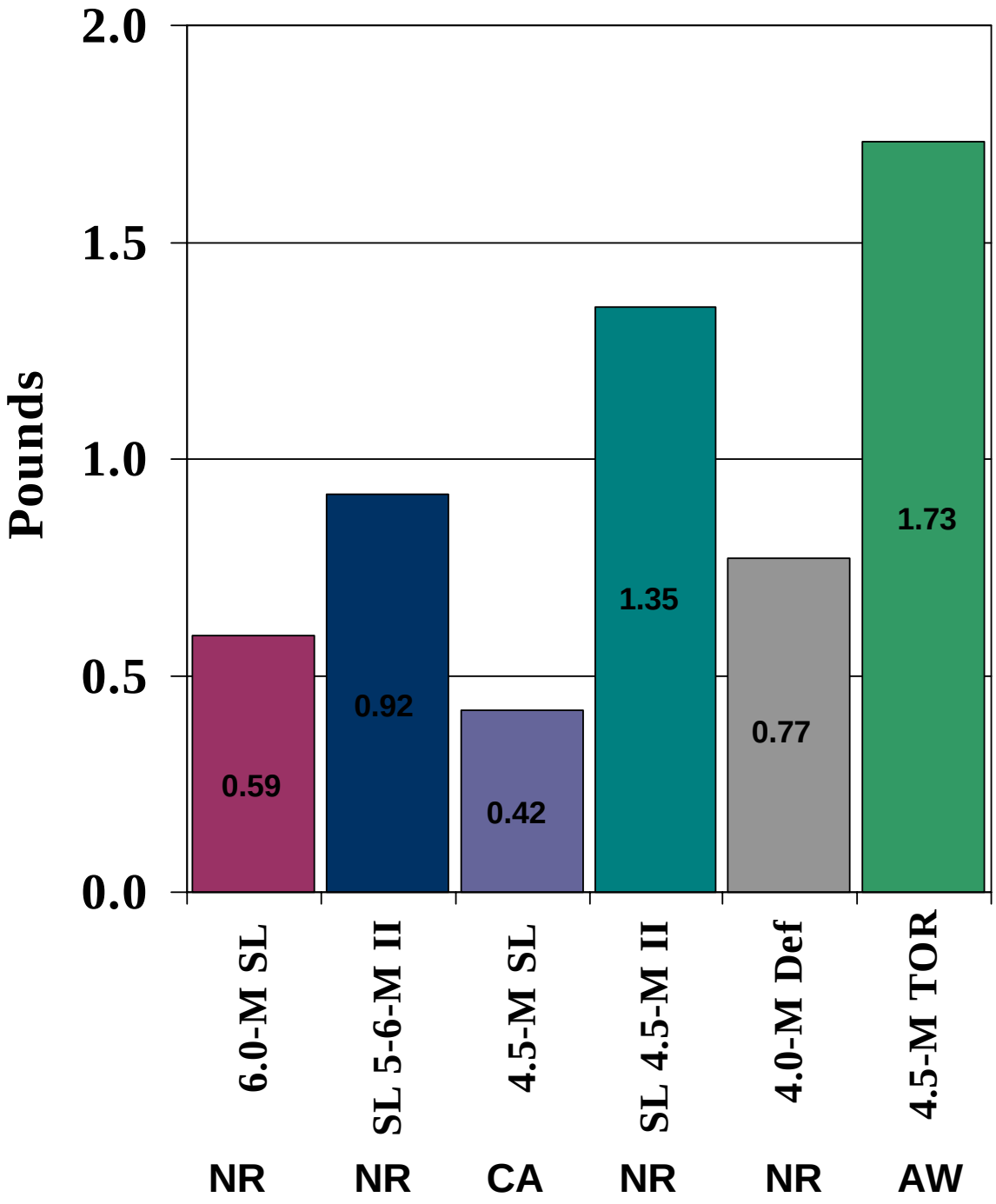


Fig. 6. Calf weight gain per day on grazing management systems during the fall portion of the grazing season.

Discussion

Extending the grazing season about a month beyond the end of the growing season for perennial plants, which usually occurs around mid October, requires use of pasture-forage types that have sufficient nutrient quality to meet livestock dietary requirements and sufficient herbage quantity to permit efficient capture of a relatively high proportion of the produced nutrients from the land base. Cow and calf weight performance should be near potential gains, and market value of calf accumulated weight during the fall portion of the grazing season should be greater than the rent and production costs of the fall pasture-forage.

Northern Plains cattle producers typically make management decisions about the fall portion of the grazing season with little solid information. Most beef producers can infer from experience a close approximation of the weight of calves when they go out to pasture in the spring, and, if the calves are sold at weaning, the producers know about the average weight of calves when they come off pasture in the fall. The difference between the two estimated weights gives producers a general idea of calf weight performance across the entire grazing season. When animal performance during spring, summer, and fall is averaged, cows appear to gain a small amount of weight and calf weight gains appear to be satisfactory only because comparisons to potential animal weight gains are not available. Most livestock producers know that animal weight gains are lower during the fall than during the early portion of the grazing season. The extent of this reduction in performance is not obvious, and the actual amount of the reduction in animal performance during the fall is not known from averaged seasonal gains. Lack of this information is easily dismissed as having little importance by producers making fall management decisions when it is viewed with the assumption that production costs are lower when cows and calves graze as long as possible.

Basing their management plans on the supposition that fall grazing reduces beef production costs, Northern Plains livestock producers attempt to extend the grazing season about a month beyond mid October. Traditional grazing management systems commonly graze native rangeland or cropland aftermath pasture-forage types during the fall portion of the grazing season. Grazing mature plant residue of these fall pasture-forage types is widely accepted to be low-cost and assumed to be considerably less expensive than feeding harvested forage. Few beef producers have questioned these presumptions, and very few beef producers weigh livestock mid season to separate the late-season weight performance from the early season weight performance.

Cow and calf weight gain performance during the fall portion of the grazing season on traditional grazing management systems is far below the animals' genetic growth potentials. Cows lose a great deal of weight--from around a quarter to two-thirds of a body condition score in a month. Calves gain very little weight--only around 25% to 40% of their potential weight gain. The reductions in weight performance of livestock grazing traditional pasture-forage types during the fall portion of the grazing season result from decreases in the quantity and nutritional quality of the herbage.

Cropland aftermath pastures almost always have low quantities of herbage present, and the nutrient content of stubble from annual cereals harvested for grain is extremely low. Unless the crop aftermath pasture contains a substantial quantity of spouted grain, lactating cows cannot find forage that meets their crude protein requirements, and the result is a loss of considerable weight and a great reduction in calf weight gain.

The weight of the fall herbage on native rangeland pastures that have not been previously grazed is only about 40% to 60% of the mid summer herbage weight on ungrazed grasslands. The weight of the fall herbage on previously grazed native rangeland pastures is considerably less than 50% of the potential peak herbage biomass. The summer stocking rates on traditional management systems are not adjusted after mid October to reflect the reduction in fall aboveground herbage biomass, and this failure causes part of the problem in reduced livestock weight performance during the fall portion of the grazing season.

Nutritional quality of native rangeland grasses decreases rapidly following the flowering stage, and the quality falls below the crude protein requirements of a lactating cow around mid July to early August. Nutritional quality of herbage consisting primarily of maturing lead tillers continues on a sharp decline until the end of the grazing season. Native rangeland herbage during the fall has a crude protein content of around 4.8%, about half the content of mid summer herbage. Cows grazing herbage with nutrient content below their dietary requirements draw on stored body fat to provide for a portion of their milk production, and their weight decreases. The loss of weight leads to decreased milk production, which results in reduced calf weight gain per day.

Grazing during the fall causes not only decreased livestock performance that season but also

biological problems for perennial plants and reduced pasture performance in the following growing season. Grazing that removes leaf area from overwintering tillers during the fall deprives tillers developing spring growth of a major source of nutrients and increases the demand on low levels of carbohydrate reserves. The result is a reduction of herbage weight produced during the succeeding growing season. Fall grazing damages perennial grasses, decreasing plant vigor and reducing leaf height 28% during the next growing season (Goetz 1963, Manske 2003b). The popular belief that perennial grasses will not be harmed by grazing after a frost is not consistent with the biology of grass growth and should not be used as a foundation for grazing management decisions because of the resulting reductions in grass production and increases in grazingland-forage costs the following year.

If grazing on native rangeland occurs after mid October, it should take place on reserve fall pastures that have been separated from the summer pasture system and have grasses with stimulated secondary tiller growth. Land area per month required for a range cow on reserve native rangeland pastures during the fall portion of the grazing season is about double the land area required per month during the growing season. Native rangeland that would require 2.5 acres per month for a lactating cow during the summer would require 4.2 acres per month during late October and 5.0 acres per month during early November.

Stimulation of secondary tillers by light grazing for 7 to 17 days on each pasture during the period between the third-leaf stage and the flowering stage (early June to mid July) can improve livestock weight performance on native rangeland two to two and a half months, until late September or mid October. The biology of native grass plants does not permit extending this improved performance beyond mid October, when nutritional quality of herbage on native rangeland falls too low to meet requirements of lactating cows.

Pasture-forage types that meet the nutritional requirements of lactating cows after mid October include Altai and Russian wildryes. The wildryes are the only perennial grasses that retain nutrient quality in the aboveground portions until around mid November. No perennial grass in the Northern Plains retains sufficient nutritional quality to dependably meet the nutritional requirements of lactating cows later than mid November. Cows grazing Altai wildrye pastures during mid October to mid November gained weight and the calves gained considerably more weight than calves on traditionally managed native rangeland and cropland aftermath pastures.

The traditional pasture-forage management strategies used in the Northern Plains were developed during the era of low-performance livestock. During the past several decades, the type of livestock in the region has shifted to a fast-growing, high-performance animal, but pasture-forage management practices have not been changed to meet the requirements of the modern livestock and take full advantage of their genetic growth potential. The use of slightly modified low-performance pasture-forage management strategies with high-performance livestock results in calves with weaning weights below potential and in high annual expenses for cow maintenance.

Biologically effective pasture-forage management strategies combine different pasture-forage types and graze each type at optimum times so that herbage production curves and nutritional quality curves coordinate with the dietary quantity and quality requirements of lactating cows during the entire grazing season. Such management strategies result in improved livestock weight performance, reduced livestock production costs, and increased profit margins.

Conclusion

Cows and calves do not gain weight at the same rate during the latter portion of the grazing season as they do during the early portion of the grazing season. Herbage quantity and quality decline as plants mature. The seasonal pattern of plant growth and maturity varies with pasture-forage types and can be modified by differing effects that grazing management practices have on plant growth.

Extending the grazing season one month beyond the end of the growing season for perennial plants on traditionally managed pasture-forage types does not reduce feed cost and greatly reduces livestock weight performance from potential weight gains. Grazing during the fall period on pasture-forage types that meet livestock dietary quantity and quality requirements produces near-potential animal weight gains.

Acknowledgment

I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the table and figures. I am grateful to Amy Kraus for assistance in the preparation of this manuscript.

Literature Cited

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Goetz, H. 1963. Growth and development of native range plants in the mixed prairie of western North Dakota. M.S. Thesis, North Dakota State University, Fargo, ND. 165p.

Manske, L.L. 1994a. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program. Regina, Saskatchewan, Canada.

Manske, L.L. 1994b. Grazing management for Northern Great Plains rangelands. NDSU Dickinson Research Extension Center. Range Research Report DREC 94-1004. Dickinson, ND. 11p.

Manske, L.L. 2003a. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1018f. Dickinson, ND. 37p.

Manske, L.L. 2003b. Effects of fall grazing on grass-leaf height. NDSU Dickinson Research Extension Center. Range Management Report DREC 03-1031b. Dickinson, ND. 7p.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Costs-Returns as Affected by Grazing Management Strategies

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

The type of grazing management strategy used in cow-calf production on native rangeland and domesticated grass pastures affects the biology of plant growth and the performance of cow-calf pairs. Grazing strategy effects on plant biology are shown as differences in stocking rate and acres required per cow-calf pair during the grazing season. These values affect the costs of pasture and forage per cow-calf pair and per acre. Grazing strategy effects on animal performance are shown as differences in cow and calf gain per day and gain per acre, and total cow and calf gain per grazing season. These values affect the cost per pound of calf weight gain. Together, these grazing strategy effects determine the net returns after pasture-forage costs per cow-calf pair and per acre at a given calf market value. Implementation of grazing management strategies that have biological and economical advantages improves the profit margin for beef production in the Northern Plains.

Procedure

This study was conducted at the NDSU Dickinson Research Extension Center, located in western North Dakota. Grazingland-forage costs were evaluated from data collected on grazing management treatments involved in pasture research projects conducted between 1983 and 1998. Grazingland-forage biomass values were based on the means of the average monthly herbage biomass data for the period grazed. Native rangeland herbage weight data used in the determination of stocking rate for the 12-month native range grazing strategy were collected monthly from ungrazed plots. The research data collected during severe water stress or drought periods were not included in this study. Range cow daily nutritional requirements, which change with cow size, level of milk production, and production period, were taken from NRC (1996). Dry matter and crude protein requirements were determined for cows with an average weight of 1200 pounds and a calf born in mid March.

Forage costs for harvested-forage types used as feed for range cows during the spring and fall portions of the lactation production period were evaluated from forage production data collected on harvested-forage types between 1995 and 1999. Forage dry matter yield per acre and percent crude protein data for perennial domesticated grass hay and annual cereal and annual legume hays were taken from a previous study (Manske and Carr 2000). Percent crude protein data for native range grasses were taken from Whitman et al. (1951) and Manske (1999a, b). Supplemental crude protein was provided as 20% crude protein range cake, at a cost of $120.00 per ton. Supplemental forage dry matter was provided as roughage, at a cost of $35.00 per ton.

Average production costs per acre for each forage type were determined by adding average custom farm work rates (Beard 1998), average land rent per acre (from western North Dakota), and average seed costs per acre (Swenson and Haugen 1999). The pasture rent value of $8.76 per acre was used to determine costs for native rangeland and domesticated grass pastures. One treatment of crested wheatgrass was fertilized annually with 50 pounds of nitrogen per acre, at an average cost of $12.50 per acre. The value of $2.00 per acre was used for cropland aftermath grazing costs. Land rent values of $22.07 per acre for cropland and $14.22 per acre for domesticated grass hayland were used in the determination of forage production costs for the harvested forages.

Several grazing management treatments and grazingland-forage types and harvested-forage types were evaluated during the grazing season, the period from early May to mid November, when perennial forage plants are growing and biologically active. Grazingland-forage and harvested-forage types were evaluated separately during the spring, summer, and fall portions of the lactation production period.

The lactation production period was 198 days from early May to mid November and was subdivided into three portions (fig. 1). The spring portion of the lactation period was 31 days from early to late May. During this portion of the lactation period, native rangeland was evaluated for 31 days of grazing on the 12-month repeated seasonal (12-m RS) treatment. Native rangeland was grazed for 16 days on the 6.0-month seasonlong (6.0-m SL) treatment. Unfertilized crested wheatgrass was grazed for 31 days on the 4.5-month seasonlong (4.5-m SL) and for 76 days on the 4.0-month deferred (4.0-m Def)

treatments. Fertilized crested wheatgrass was grazed for 31 days on the 4.5-month twice-over rotation (4.5-m TOR) treatment. Crested wheatgrass hay cut at the mature plant stage and crested wheatgrass hay cut at the boot stage were evaluated as feed during the 31-day spring portion of the lactation period.

The summer portion of the lactation period was 137 days from early June to mid October. Native rangeland was evaluated for 137 days of grazing on the 12-month repeated seasonal (12-m RS) treatment. Native rangeland was grazed for 137 days on the 6.0-month seasonlong (6.0-m SL), for 137 days on the 4.5-month seasonlong (4.5-m SL), for 92 days on the 4.0-month deferred (4.0-m Def), and for 137 days on the 4.5-month twice-over rotation (4.5-m TOR) treatments.

The fall portion of the lactation period was 30 days from mid October to mid November. Native rangeland was evaluated for two 15-day segments of grazing on the 12-month repeated seasonal (12-m RS) treatment. Native rangeland was grazed for 30 days on the 6.0-month seasonlong (6.0-m SL) and for 30 days on the 4.0-month deferred (4.0-m Def) treatments. Cropland aftermath was grazed for 30 days on the first version of the 4.5-month seasonlong (4.5-m SL) treatment. Native rangeland was grazed for 15 days on a second version of the seasonlong treatments with 4.5-month periods (SL 4.5-m) and for 30 days on seasonlong treatments with 5.0- and 6.0-month periods (SL 5.0-6.0-m). Altai wildrye was grazed for 30 days on the 4.5-month twice-over rotation (4.5-m TOR) treatment.

Harvested forages were evaluated as alternative feed sources during the 30-day fall portion of the lactation period. The harvested forages were evaluated as hay cut by swathing and rolled into large round bales. Late crested wheatgrass hay was cut at a mature plant stage. Early crested wheatgrass hay was cut at the boot stage. Forage barley hay was cut at the milk stage. Oat forage hay was cut at the milk stage. Pea forage hay was cut at a late plant stage. Forage lentil hay was cut at a late plant stage. Oat-pea forage was cut for hay.

Pasture and forage costs of feed to meet livestock dry matter and crude protein requirements were determined during this study. Production costs per acre were determined by adding average land rent per acre, custom farm work rates, seed costs per acre, and baling costs at per half ton rates. Costs per ton of forage dry matter (DM) were determined by dividing production costs per acre by pounds of forage dry matter yield per acre and multiplying the quotient by 2000 pounds. Costs per pound of crude protein (CP) were determined in two stages: first, pounds of forage dry matter per acre were multiplied by percentage of forage crude protein to derive pounds of crude protein per acre; then, production costs per acre were divided by pounds of crude protein per acre. Grazingland area per animal unit per month was determined in two stages: first, pounds of forage dry matter per acre were divided by pounds of forage dry matter required per animal unit per day to derive number of grazing days per acre; then, the average number of days per month was divided by the number of grazing days per acre. Harvested-forage land area per animal unit per month or per production period was determined in two stages: first, pounds of crude protein required per animal per day during a production period were divided by percentage of crude protein of forage type to derive pounds of forage dry matter to provide as feed per animal unit per day; then, pounds of forage dry matter to feed per day were divided by pounds of forage dry matter per acre, and the quotient was multiplied by 30 days per month, 30.5 days per month, or the number of days per production period. Forage-feed costs per animal per day (D), per month (Mo), or per production period (PP) were determined in three stages: first, production costs per acre were divided by pounds of forage dry matter per acre, and that quotient was divided by percentage of forage crude protein to derive cost per pound of crude protein; next, the cost per pound of crude protein was multiplied by pounds of crude protein required per animal per day during a production period; then, the forage costs per day were multiplied by 30 days per month, 30.5 days per month, or the number of days per production period. Costs per pound of calf weight gain were determined in two stages: first, accumulated calf weight gain was determined by subtracting calf live weight at the beginning of a growth period from calf live weight at the end of a growth period; then, total pasture costs or forage production costs for a calf growth period were divided by the accumulated calf weight for the growth period.

The terms “herbage” and “forage” are not synonymous. Herbage is the total amount of aboveground biomass of herbaceous plants like grasses and forbs. Forage is the portion of the herbage that can be removed without detriment to the plants and can provide feed for grazing animals or be harvested mechanically for feeding. About 50% of

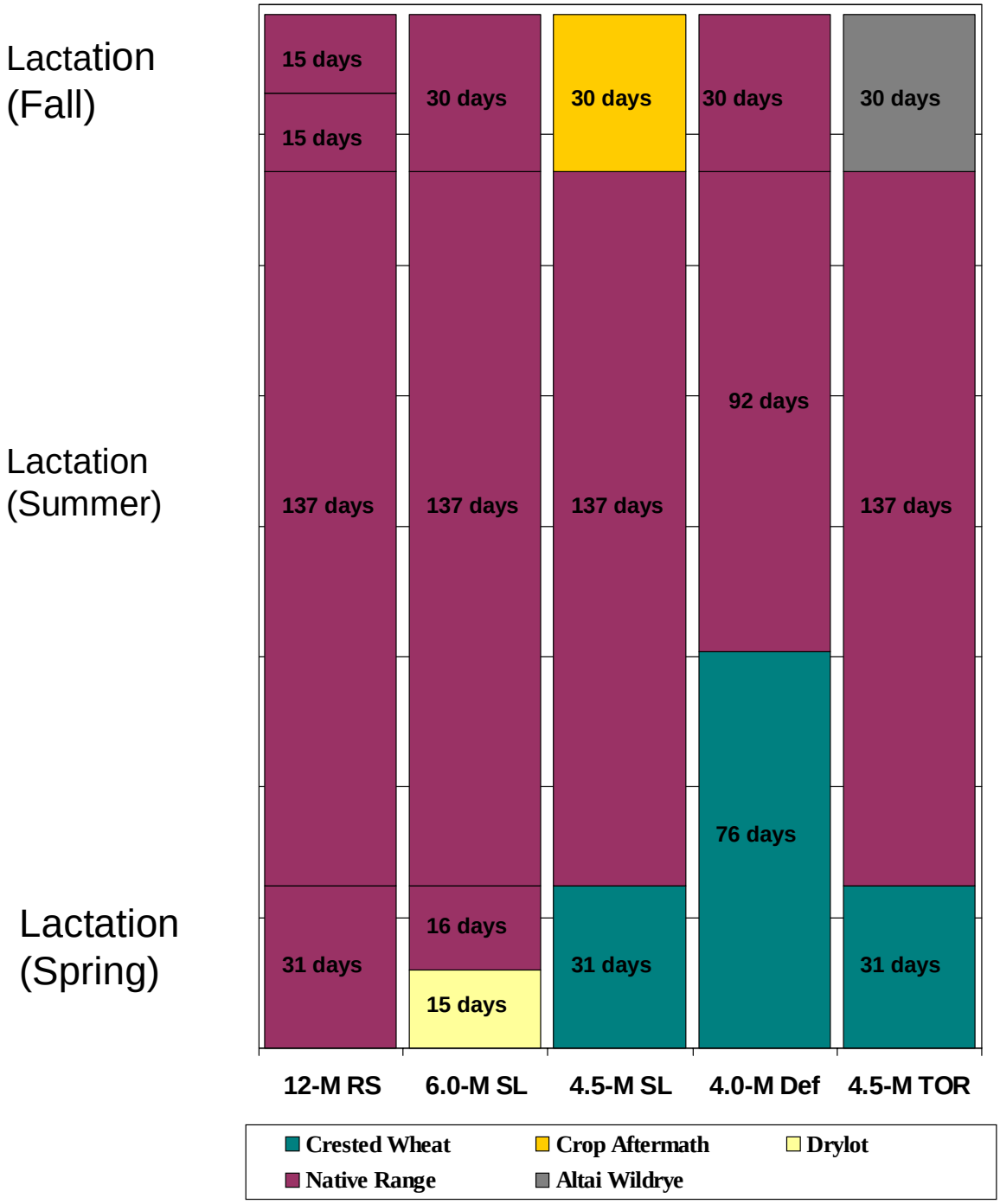


Fig. 1. Number of days per cow production period on grazing management strategies.

the herbage produced by a perennial plant on grazinglands must remain with the plant to sustain healthy and productive growth. About 50% of the herbage biomass produced during the growing season can be removed from the plant without harmful effects to plant health. The amount of forage ingested by grazing livestock is actually only about 50% of this quantity, or about 25% of the aboveground herbage biomass on seasonlong and single-grazing-period treatments. The remainder of the herbage that can be removed is broken from the plant, soiled by animal waste, consumed by insects and wildlife, and lost to other natural processes.

Results

Pasture-forage costs

Lactation (spring portion) Production Period

The spring portion of the lactation production period was 31 days from early May until late May. Costs of forage dry matter and crude protein (tables 1 and 2) to meet the requirements of a 1200-pound range cow with a calf during the spring portion of the lactation production period were determined. A cow with a calf requires 30 lbs of dry matter per day. The cow requires a daily intake of 27 lbs dry matter (DM) at 9.3% crude protein (CP) (2.51 lbs CP/day).

Native rangeland pasture forage during the spring has a crude protein content of around 16.3%. Native rangeland plants have not reached the third-leaf stage and are not physiologically ready for grazing during the spring portion of the lactation production period in May.

Spring native rangeland forage managed by the 12-month repeated seasonal (12-m RS) strategy has pasture rent value or production costs of $8.76 per acre, forage dry matter costs of $89.85 per ton, and crude protein costs of $0.28 per pound. A cow with a calf would require 4.62 acres per month, or 4.77 acres per period, at a cost of $41.85 for the 31-day period, or $1.35 per day.

Spring native rangeland forage managed by the 6.0-month seasonlong (6.0-m SL) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $77.52 per ton. A cow with a calf would require 4.04 acres per month, or 2.10 acres during the last 16 days of the period, at a cost of $18.40 for the 16-day period, or $1.15 per day.

Spring unfertilized crested wheatgrass complementary pasture grazed for 31 days during May by cattle on the 4.5-month seasonlong (4.5-m SL) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $35.39 per ton. A cow with a calf would require 1.82 acres per month, or 1.88 acres per period, at a cost of $16.47 for the 31-day period, or $0.52 per day.

Spring unfertilized crested wheatgrass complementary pasture grazed for 76 days from early May until mid July by cattle on the 4.0-month deferred (4.0-m Def) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $31.97 per ton. A cow with a calf would require 1.67 acres per month, or 4.16 acres for a period of 76 days from early May until mid July, at a cost of $36.44 for the 76-day period, or $0.48 per day.

Spring fertilized crested wheatgrass complementary pasture grazed for 31 days during May by cattle on the 4.5-month twice-over rotation (4.5-m TOR) strategy has pasture rent value of $8.76 per acre and fertilizer costs of $12.50 per acre; the resulting production costs are $21.26 per acre, and forage dry matter costs are $34.29 per ton. A cow with a calf would require 0.73 acres per month, or 0.75 acres per period, at a cost of $15.95 for the 31-day period, or $0.51 per day.

Crested wheatgrass hay cut late, at a mature plant stage, has a crude protein content of 6.4%. This crested wheatgrass hay has production costs of $28.11 per acre, forage dry matter costs of $34.80 per ton, and crude protein costs of $0.28 per pound. Mature crested wheatgrass hay would be fed at 27.0 lbs DM/day to provide 1.7 lbs CP/day. An additional 0.8 lbs of crude protein per day would need to be provided, at a cost of $7.27 per period. Production of mature crested wheatgrass hay to feed during the spring portion of the lactation period would require 0.58 acres, and the forage would cost $21.70 per period, or $0.70 per day. Total forage and supplement costs would be $28.97 per period, or $0.93 per day.

Crested wheatgrass hay cut early, at the boot stage, has a crude protein content of 14.5%. This crested wheatgrass hay has production costs of $26.50 per acre, forage dry matter costs of $40.80 per ton, and crude protein costs of $0.14 per pound. Early cut crested wheatgrass hay would be fed at 17.3 lbs DM/day to provide 2.5 lbs CP/day. An additional 12.7 lbs of roughage per day would need to be provided, at a cost of $6.88 per period. Production of early cut crested wheatgrass hay to feed during the spring portion of the lactation period would require 0.41 acres, and the forage would cost $10.85 per period, or $0.35 per day. Total forage and

Table 1. Pasture-forage costs of native rangeland and domesticated grass pastures to be grazed by range cows during the 31-day spring portion of the lactation production period.

		Native Rangeland (12-m RS)	Native Rangeland (6.0-m SL)	Crested Wheatgrass Unfertilized (4.5-m SL)	Crested Wheatgrass Unfertilized (4.0-m Def)	Crested Wheatgrass Fertilized (4.5-m TOR)
Days		31	16	31	76	31
Growth Stage		spring	spring	spring	spring	spring
Herbage Weight	lb/ac	780	906	1980	2192	4960
Forage DM Weight	lb/ac	195	226	495	548	1240
Costs/Acre						
Land Rent	$	8.76	8.76	8.76	8.76	8.76
Custom Work	$					12.50
Seed Cost	$					
Baling Cost	$					
Production Costs	$/ac	8.76	8.76	8.76	8.76	21.26
Forage DM Costs	$/ton	89.85	77.52	35.39	31.97	34.29
Land Area/Month	ac	4.62	4.04	1.82	1.67	0.73
Land Area/Period	ac	4.77	2.10	1.88	4.16	0.75
Land Cost/Period	$/pp	41.79	18.40	16.47	36.44	15.95
Forage Costs/Day	$/d	1.35	1.15	0.52	0.48	0.51
Forage Costs/Period	$/pp	41.85	18.40	16.47	36.44	15.95
Crude Protein	%	16.3				
Crude Protein Yield	lb/ac	31.79				
Crude Protein Cost	$/lb	0.28				
Supplementation						
Roughage/Day	lb/d					
Crude Protein/Day	lb/d					
Sup. Cost/Period	$/pp					
Total Feed Cost	$/pp	41.85	18.40	16.47	36.44	15.95
Cost/Day	$/d	1.35	1.15	0.52	0.48	0.51

Table 2. Forage costs of perennial grass hays to be fed to range cows during the 31-day spring portion of the lactation production period.

		Crested Wheatgrass Hay	Crested Wheatgrass Hay
Growth Stage		Mature	Boot stage
Herbage Weight	lb/ac	-	-
Forage DM Weight	lb/ac	1600	1300
Costs/Acre			
Land Rent	$	14.22	14.22
Custom Work	$	5.31	5.31
Seed Cost	$	-	-
Baling Costs	$	8.58	6.97
Production Costs	$/ac	28.11	26.50
Forage DM Costs	$/ton	34.80	40.80
Land Area /Month	ac	0.56	0.40
Land Area/Period	ac	0.58	0.41
Land Cost/Period	$/pp	8.25	5.83
Forage Costs/Day	$/d	0.70	0.35
Forage Costs/Period	$/pp	21.70	10.85
Crude Protein	%	6.4	14.5
Crude Protein Yield	lb/ac	102	189
Crude Protein Cost	$/lb	0.28	0.14
Supplementation			
Roughage/Day	lb/d		12.69
Crude Protein/Day	lb/d	0.78	
Sup. Cost/Period	$/pp	7.27	6.88
Total Feed Cost	$/pp	28.97	17.73
Cost/Day	$/d	0.93	0.57

supplement costs would be $17.73 per period, or $0.57 per day

Lactation (summer portion) Production Period

The summer portion of the lactation production period was 137 days from early June until mid October. Costs of forage dry matter and crude protein (table 3) to meet the requirements of a 1200-pound range cow with a calf during the summer portion of the lactation production period were determined. A cow with a calf requires 30 lbs of dry matter per day. The cow requires a daily intake of 27 lbs dry matter (DM) at 9.3% crude protein (CP) (2.51 lbs CP/day).

Native rangeland pasture forage has a crude protein content of around 9.6% during mid summer. The crude protein content of native range grasses decreases after mid summer and is below the requirements of a lactating cow by early August.

Summer native rangeland forage managed by the 12-month repeated seasonal (12-m RS) strategy has pasture rent value or production costs of $8.76 per acre, forage dry matter costs of $48.26 per ton, and crude protein costs of $0.25 per pound. A cow with a calf would require 2.52 acres per month, or 11.32 acres per period, at a cost of $98.64 for the 137-day period, or $0.72 per day.

Summer native rangeland forage managed by the 6.0-month seasonlong (6.0-m SL) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $77.50 per ton. A cow with a calf would require 4.04 acres per month, or 18.10 acres per period, at a cost of $158.55 for the 137-day period, or $1.16 per day.

Summer native rangeland forage managed by the 4.5-month seasonlong (4.5-m SL) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $54.75 per ton. A cow with a calf would require 2.86 acres per month, or 12.70 acres per period, at a cost of $111.25 for the 137-day period, or $0.81 per day.

Summer native rangeland forage managed by the 4.0-month deferred (4.0-m Def) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $42.52 per ton. A cow with a calf would require 2.22 acres per month, or 6.70 acres for a period of 92 days from mid July to mid October, at a cost of $58.26 for the 92-day period, or $0.63 per day.

Summer native rangeland forage managed by the 4.5-month twice-over rotation (4.5-m TOR) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $39.02 per ton. A cow with a calf would require 2.04 acres per month, or 9.00 acres per period, at a cost of $78.84 for the 137-day period, or $0.58 per day.

Table 3. Pasture-forage costs of native rangeland pastures to be grazed by range cows during the 137-day summer portion of the lactation production period.

		Native Rangeland (12-m RS)	Native Rangeland (6.0-m SL)	Native Rangeland (4.5-m SL)	Native Rangeland (4.0-m Def)	Native Rangeland (4.5-m TOR)
Days		137	137	137	92	137
Growth Stage		summer	summer	summer	summer	summer
Herbage Weight	lb/ac	1450	906	1280	1649	1794
Forage DM Weight	lb/ac	363	226	320	412	449
Costs/Acre						
Land Rent	$	8.76	8.76	8.76	8.76	8.76
Custom Work	$					
Seed Cost	$					
Baling Costs	$					
Production Costs	$/ac	8.76	8.76	8.76	8.76	8.76
Forage DM Costs	$/ton	48.26	77.50	54.75	42.52	39.02
Land Area/Month	ac	2.52	4.04	2.86	2.22	2.04
Land Area/Period	ac	11.32	18.10	12.70	6.70	9.00
Land Costs/Period	$/pp	99.16	158.55	111.25	58.26	78.84
Forage Costs/Day	$/d	0.72	1.16	0.81	0.63	0.58
Forage Costs/Period	$/pp	98.64	158.55	111.25	58.26	78.84
Crude Protein	%	9.6				
Crude Protein Yield	lb/ac	34.85				
Crude Protein Cost	$/lb	0.25				
Supplementation						
Roughage/Day	lb/d					
Crude Protein/Day	lb/d					
Sup. Cost/Period	$/pp					
Total Feed Cost	$/pp	98.64	158.55	111.25	58.26	78.84
Cost/Day	$/d	0.72	1.16	0.81	0.63	0.58

Lactation (fall portion) Production Period

The fall portion of the lactation production period was 30 days from mid October until mid November, with an early 15-day segment from mid to late October and a late 15-day segment from early to mid November. Costs of forage dry matter and crude protein (tables 4, 5, 6, and 7) to meet the requirements of a 1200-pound range cow with a calf during the fall portion of the lactation production period were determined. A cow with a calf requires 30 lbs of dry matter per day. The cow requires a daily intake of 27 lbs dry matter (DM) at 9.3% crude protein (CP) (2.51 lbs CP/day).

The costs of grazing native rangeland during the fall are considerably higher than the costs of grazing native rangeland during the summer. On grasslands that have had no grazing all growing season, the weight of the herbage on fall pastures is only about 40% to 60% of the mid summer herbage weight. Native rangeland pasture forage during the fall has a crude protein content of around 4.8%, about half the content of mid summer herbage.

Fall native rangeland forage managed by the 12-month repeated seasonal (12-m RS) strategy has pasture rent value or production costs of $8.76 per acre, forage dry matter costs of $80.37 per ton during the early segment and $97.33 per ton during the late segment of the fall period, and crude protein costs of $0.34 per pound during the early segment and $1.01 per pound during the late segment. A cow with a calf would require 4.20 acres per month during the early segment and 5.00 acres per month during the late segment, or 2.10 acres during the 15-day early segment and 2.50 acres during the 15-day late segment, at a cost of $18.40 for the 15-day early segment, or $1.21 per day, and $21.90 for the 15-day late segment, or $1.46 per day. The crude protein content of mature native rangeland forage is below the requirements of a lactating cow during the fall, and crude protein would need to be supplemented at 1.21 lbs per cow per day, at a cost of $10.90 per 30-day period. Total feed costs would be $23.85, or $1.59 per day, during the early fall lactation period and $27.35, or $1.82 per day, during the late fall lactation period.

Fall native rangeland forage managed by the 6.0-month seasonlong (6.0-m SL) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $78.57 per ton. A cow with a calf would require 4.04 acres per month, at a cost of $35.39 for the 30-day period, or $1.18 per day.

Fall native rangeland forage managed by seasonlong treatments with 5.0 or 6.0 months of grazing (SL 5.0-6.0-m) that end in mid November has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $49.21 per ton. The summer stocking rates used on these treatments are traditionally not adjusted to match the reduced fall herbage biomass, and a cow with a calf would graze 2.53 acres per month, at a cost of $22.16 for the 30-day period, or $0.74 per day.

Fall native rangeland forage managed by the 4.0-month deferred (4.0-m Def) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $42.52 per ton. The summer stocking rate of this strategy is traditionally not adjusted to match the reduced fall herbage biomass, and a cow with a calf would graze 2.22 acres per month, at a cost of $19.53 for the 30-day period, or $0.65 per day.

Cropland aftermath forage grazed during the fall by cattle from the first version of the 4.5-month seasonlong (4.5-m SL) strategy has production costs of $2.00 per acre and forage dry matter costs of $29.63 per ton. A cow with a calf would require 6.63 acres per month, at a cost of $13.26 for the 30-day period, or $0.44 per day.

Early fall native rangeland forage managed by the second version of the seasonlong treatments with 4.5 months of grazing (SL 4.5-m) that end in late October has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $72.10 per ton. A cow with a calf would require 3.26 acres per month, or 1.63 acres during the 15-day early segment, at a cost of $14.28 for the 15-day early segment, or $0.95 per day.

Altai wildrye complementary pasture forage grazed during the fall by cattle from the 4.5-month twice-over rotation (4.5-m TOR) strategy has pasture rent value or production costs of $8.76 per acre and forage dry matter costs of $27.04 per ton. A cow with a calf would require 1.39 acres per month, at a cost of $12.00 for the 30-day period, or $0.40 per day.

Crested wheatgrass hay cut late, at a mature plant stage, has a crude protein content of 6.4%. This crested wheatgrass hay has production costs of $28.11 per acre, forage dry matter costs of $34.80 per ton, and crude protein costs of $0.28 per pound. Mature crested wheatgrass hay would be fed at 27.0 lbs DM/day to provide 1.7 lbs CP/day. An additional 0.8 lbs of crude protein per day would need to be provided, at a cost of $7.02 per period. Production of

mature crested wheatgrass hay to feed during the fall portion of the lactation period would require 0.56 acres, and the forage would cost $21.00 per period, or $0.70 per day. Total forage and supplement costs would be $28.02 per period, or $0.93 per day.

Crested wheatgrass hay cut early, at the boot stage, has a crude protein content of 14.5%. This crested wheatgrass hay has production costs of $26.50 per acre, forage dry matter costs of $40.80 per ton, and crude protein costs of $0.14 per pound. Early cut crested wheatgrass hay would be fed at 17.3 lbs DM/day to provide 2.5 lbs CP/day. An additional 12.7 lbs of roughage per day would need to be provided, at a cost of $6.66 per period. Production of early cut crested wheatgrass hay to feed during the fall portion of the lactation period would require 0.40 acres, and the forage would cost $10.50 per period, or $0.35 per day. Total forage and supplement costs would be $17.16 per period, or $0.57 per day.

Forage barley hay cut early, at the milk stage, has a crude protein content of 13.0%. This forage barley hay has production costs of $68.21 per acre, forage dry matter costs of $28.80 per ton, and crude protein costs of $0.11 per pound. Early cut forage barley hay would be fed at 19.3 lbs DM/day to provide 2.5 lbs CP/day. An additional 10.7 lbs of roughage per day would need to be provided, at a cost of $5.62 per period. Production of early cut forage barley hay to feed during the fall portion of the lactation period would require 0.12 acres, and the forage would cost $8.40 per period, or $0.28 per day. Total forage and supplement costs would be $14.02 per period, or $0.47 per day.

Oat forage hay cut early, at the milk stage, has a crude protein content of 11.5%. This oat forage hay has production costs of $69.17 per acre, forage dry matter costs of $29.60 per ton, and crude protein costs of $0.13 per pound. Early cut oat hay would be fed at 21.8 lbs DM/day to provide 2.5 lbs CP/day. An additional 8.2 lbs of roughage per day would need to be provided, at a cost of $4.31 per period. Production of early cut oat hay to feed during the fall portion of the lactation period would require 0.14 acres, and the forage would cost $9.90 per period, or $0.33 per day. Total forage and supplement costs would be $14.21 per period, or $0.47 per day.

Pea forage hay cut at a late plant stage has a crude protein content of 14.4%. This pea forage hay has production costs of $86.87 per acre, forage dry matter costs of $37.40 per ton, and crude protein costs of $0.13 per pound. Late-cut pea forage hay would be fed at 17.4 lbs DM/day to provide 2.5 lbs CP/day. An additional 12.6 lbs of roughage per day would need to be provided, at a cost of $6.62 per period. Production of late-cut pea forage hay to feed during the fall portion of the lactation period would require 0.11 acres, and the forage would cost $9.90 per period, or $0.33 per day. Total forage and supplement costs would be $16.52 per period, or $0.55 per day.

Forage lentil hay cut at a late plant stage has a crude protein content of 14.7%. This forage lentil hay has production costs of $71.48 per acre, forage dry matter costs of $37.00 per ton, and crude protein costs of $0.13 per pound. Late-cut forage lentil hay would be fed at 17.1 lbs DM/day to provide 2.5 lbs CP/day. An additional 12.9 lbs of roughage per day would need to be provided, at a cost of $6.77 per period. Production of late-cut forage lentil hay to feed during the fall portion of the lactation period would require 0.13 acres, and the forage would cost $9.90 per period, or $0.33 per day. Total forage and supplement costs would be $16.67 per period, or $0.56 per day.

Oat-pea forage hay has a crude protein content of 12.5%. This oat-pea forage hay has production costs of $95.52 per acre, forage dry matter costs of $37.20 per ton, and crude protein costs of $0.16 per pound. Oat-pea forage hay would be fed at 20.1 lbs DM/day to provide 2.5 lbs CP/day. An additional 9.9 lbs of roughage per day would need to be provided, at a cost of $5.20 per period. Production of oat-pea forage hay to feed during the fall portion of the lactation period would require 0.12 acres, and the forage would cost $11.40 per period, or $0.38 per day. Total forage and supplement costs would be $16.60 per period, or $0.55 per day.

Table 4. Pasture-forage costs of native rangeland pastures to be grazed by range cows during the 30-day fall portion of the lactation production period.

		Native Rangeland (12-m RS) Early	Native Rangeland (12-m RS) Late	Native Rangeland (SL 4.5-m) Early	Native Rangeland (SL 5-6-m)	Native Rangeland (6.0-m SL)	Native Rangeland (4.0-m Def)
Days		15	15	15	30	30	30
Growth Stage		fall	fall	fall	fall	fall	fall
Herbage Weight	lb/ac	870	725	973	1423	891	1649
Forage DM Weight	lb/ac	218	180	243	356	223	412
Costs/Acre							
Land Rent	$	8.76	8.76	8.76	8.76	8.76	8.76
Custom Work	$						
Seed Cost	$						
Baling Costs	$						
Production Costs	$/ac	8.76	8.76	8.76	8.76	8.76	8.76
Forage DM Costs	$/ton	80.37	97.33	72.10	49.21	78.57	42.52
Land Area/Month	ac	4.20	5.00	3.26	2.53	4.04	2.22
Land Area/Period	ac	2.10	2.50	1.63	2.53	4.04	2.18
Land Costs/Period	$/pp	18.40	21.90	14.28	22.16	35.39	19.53
Forage Costs/Day	$/d	1.21	1.46	0.95	0.74	1.18	0.65
Forage Costs/Period	$/pp	18.40	21.90	14.28	22.16	35.39	19.53
Crude Protein	%	4.8	4.8				
Crude Protein Yield	lb/ac	10.46	8.64				
Crude Protein Cost	$/lb	0.34	1.01				
Supplementation							
Roughage/Day	lb/d						
Crude Protein/Day	lb/d	1.21	1.21				
Sup. Cost/Period	$/pp	5.45	5.45				
Total Feed Cost	$/pp	23.85	27.35	14.28	22.16	35.39	19.53
Cost/Day	$/d	1.59	1.82	0.95	0.74	1.18	0.65

Table 5. Pasture-forage costs of domesticated grass and cropland pastures to be grazed by range cows during the 30-day fall portion of the lactation production period.

		Altai Wildrye (4.5-m TOR)	Cropland Aftermath (4.5-m SL)
Days		30	30
Growth Stage		fall	fall
Herbage Weight	lb/ac	2590	270
Forage DM Weight	lb/ac	648	135
Costs/Acre			
Land Rent	$	8.76	2.00
Custom Work	$		
Seed Cost	$		
Baling Costs	$		
Production Costs	$/ac	8.76	2.00
Forage DM Costs	$/ton	27.04	29.63
Land Area/Month	ac	1.39	6.63
Land Area/Period	ac	1.39	6.63
Land Costs/Period	$/pp	12.18	13.26
Forage Costs/Day	$/d	0.40	0.44
Forage Costs/Period	$/pp	12.00	13.26
Crude Protein	%		
Crude Protein Yield	lb/ac		
Crude Protein Cost	$/lb		
Supplementation			
Roughage/Day	lb/d		
Crude Protein/Day	lb/d		
Sup. Cost/Period	$/pp		
Total Feed Cost	$/pp	12.00	13.26
Cost/Day	$/d	0.40	0.44

Table 6. Forage costs of perennial grass hays to be fed to range cows during the 30-day fall portion of the lactation production period.

		Crested Wheatgrass Hay	Crested Wheatgrass Hay
Growth Stage		Mature	Boot stage
Herbage Weight	lb/ac	-	-
Forage DM Weight	lb/ac	1600	1300
Costs/Acre			
Land Rent	$	14.22	14.22
Custom Work	$	5.31	5.31
Seed Cost	$	-	-
Baling Costs	$	8.58	6.97
Production Costs	$/ac	28.11	26.50
Forage DM Costs	$/ton	34.80	40.80
Land Area /Month	ac	0.56	0.40
Land Area/Period	ac	0.56	0.40
Land Cost/Period	$/pp	7.96	5.69
Forage Costs/Day	$/d	0.70	0.35
Forage Costs/Period	$/pp	21.00	10.50
Crude Protein	%	6.4	14.5
Crude Protein Yield	lb/ac	102	189
Crude Protein Cost	$/lb	0.28	0.14
Supplementation			
Roughage/Day	lb/d		12.69
Crude Protein/Day	lb/d	0.78	
Sup. Cost/Period	$/pp	7.02	6.66
Total Feed Cost	$/pp	28.02	17.16
Cost/Day	$/d	0.93	0.57

Table 7. Forage costs of annual cereal hays and annual legume hays to be fed to range cows during the 30-day fall portion of the lactation production period.

		Forage Barley Hay	Oat Forage Hay	Pea Forage Hay	Forage Lentil Hay	Oat-Pea Hay
Growth Stage		Milk	Milk	Late	Late	
Herbage Weight	lb/ac					
Forage DM Weight	lb/ac	4733	4667	4650	3867	5143
Costs/Acre						
Land Rent	$	22.07	22.07	22.07	22.07	22.07
Custom Work	$	16.08	16.08	16.08	16.08	16.08
Seed Cost	$	4.69	6.00	23.80	12.60	29.80
Baling Costs	$	25.37	25.02	24.92	20.73	27.57
Production Costs	$/ac	68.21	69.17	86.87	71.48	95.52
Forage DM Costs	$/ton	28.80	29.60	37.40	37.00	37.20
Land Area/Month	ac	0.12	0.14	0.11	0.13	0.12
Land Area/Period	ac	0.12	0.14	0.11	0.13	0.12
Land Costs/Period	$/pp	2.65	3.09	2.43	2.87	2.65
Forage Costs/Day	$/d	0.28	0.33	0.33	0.33	0.38
Forage Costs/Period	$/pp	8.40	9.90	9.90	9.90	11.40
Crude Protein	%	13.0	11.5	14.4	14.7	12.5
Crude Protein Yield	lb/ac	606	535	685	567	611
Crude Protein Cost	$/lb	0.11	0.13	0.13	0.13	0.16
Supplementation						
Roughage/Day	lb/d	10.7	8.2	12.6	12.9	9.9
Crude Protein/Day	lb/d					
Sup. Cost/Period	$/pp	5.62	4.31	6.62	6.77	5.20
Total Feed Cost	$/pp	14.02	14.21	16.52	16.67	16.60
Cost/Day	$/d	0.47	0.47	0.55	0.56	0.55

Summary of pasture-forage costs

Pasture and forage costs during the spring, summer, and fall portions of the lactation production period are shown in tables 8, 9, and 10.

Total feed costs during the 31-day spring portion of the lactation production period ranged between $15.95 per period, or $0.51 per day, and $41.85 per period, or $1.35 per day. Mature crested wheatgrass hay was expensive at $0.93 per day and had the highest harvested-forage hay costs. The costs of grazing native rangeland pastures before the plants reached the third-leaf stage were high at $1.15 and $1.35 per day. The costs of the forage from grazing unfertilized and fertilized crested wheatgrass pastures were reasonable, from $0.48 to $0.52 per day. The low cost of the forage from the unfertilized crested wheatgrass pasture of the deferred treatment cannot be maintained because the plants are grazed too heavily and too long and the amount of herbage produced each year will decrease. Fertilized crested wheatgrass pastures had the lowest costs. Total feed costs for crested wheatgrass hay cut early or cut late were considerably lower than the total feed costs for grazing native rangeland during May.

Total feed costs during the 137-day summer portion of the lactation production period ranged between $78.84 per period, or $0.58 per day, and $158.55 per period, or $1.16 per day. The cost of the forage from grazing native rangeland pastures on the twice-over rotation system was reasonable at $0.58 per day. The cost of the forage from the native range pasture of the deferred treatment will increase because the plants are grazed too heavily and the amount of herbage produced each year will decrease. The costs of grazing native rangeland pastures managed by traditional practices of repeated seasonal, 6.0-month seasonlong, 4.5-month seasonlong, and deferred grazing treatments were high, from $0.63 to $1.16 per day.

Total feed costs during the 30-day fall portion of the lactation production period ranged between $12.00 per period, or $0.40 per day, and $51.20 per period, or $1.71 per day. Mature crested wheatgrass hay was expensive at $0.93 per day and had the highest harvested-forage hay costs. Forage barley hay and early cut oat forage hay had the lowest harvested-forage hay costs. The cost of the forage from grazed Altai wildrye pastures was reasonable at $0.40 per day. The cost of the forage from grazing cropland aftermath appeared to be reasonable before cow and calf weight performance was considered. The costs of grazing native rangeland pastures during the nongrowing season were high, from $1.18 to $1.71 per day. Total feed costs for the harvested forages, except mature crested wheatgrass hay, were lower than the total feed costs for grazing native rangeland after mid October.

Some pasture forages and some harvested forages had high livestock feed costs because the quantity of nutrients captured per acre was relatively small. Some pasture forages and some harvested forages had low livestock feed costs because the quantity of nutrients efficiently captured per acre was high in relation to the forage production costs. Mature crested wheatgrass hay had the highest harvested-forage hay costs, and forage barley hay and early cut oat forage hay had the lowest harvested-forage hay costs.

Table 8. Pasture and forage costs during the spring portion of the lactation production period.

	Land Area ac/pp	Forage Dry Matter $/ton	Crude Protein $/lb	Forage Cost $/pp	Supplement Cost $/pp	Total Feed Cost $/pp	Cost per Day $/d
12-m RS Native Rangeland	4.77	89.85	0.28	41.85		41.85	1.35
6.0-m SL Native Rangeland	4.04	77.52		35.65		35.65	1.15
4.5-m SL Crested Wheatgrass	1.88	35.39		16.47		16.47	0.52
4.0-m Def Crested Wheatgrass	1.73	31.97		14.88		14.88	0.48
4.5-m TOR Crested Wheatgrass	0.75	34.29		15.95		15.95	0.51
Crested Wheatgrass Mature	0.58	34.80	0.28	21.70	7.27	28.97	0.93
Crested Wheatgrass Boot Stage	0.41	40.80	0.14	10.85	6.88	17.73	0.57

Table 9. Pasture and forage costs during the summer portion of the lactation production period.

	Land Area ac/pp	Forage Dry Matter $/ton	Crude Protein $/lb	Forage Cost $/pp	Supplement Cost $/pp	Total Feed Cost $/pp	Cost per Day $/d
12-m RS Native Rangeland	11.32	48.26	0.25	98.64		98.64	0.72
6.0-m SL Native Rangeland	18.10	77.50		158.55		158.55	1.16
4.5-m SL Native Rangeland	12.70	54.75		111.25		111.25	0.81
4.0-m Def Native Rangeland	9.99	42.52		86.31		86.31	0.63
4.5-m TOR Native Rangeland	9.00	39.02		78.84		78.84	0.58

Table 10. Pasture and forage costs during the fall portion of the lactation production period.

	Land Area ac/pp	Forage Dry Matter $/ton	Crude Protein $/lb	Forage Cost $/pp	Supplement Cost $/pp	Total Feed Cost $/pp	Cost per Day $/d
12-m RS							
Native Rangeland	4.60	88.85	0.68	40.30	10.90	51.20	1.71
6.0-m SL							
Native Rangeland	4.04	78.57		35.39		35.39	1.18
4.5-m SL							
Cropland Aftermath	6.63	29.63		13.26		13.26	0.44
4.0-m Def							
Native Rangeland	2.18	42.52		19.53		19.53	0.65
4.5-m TOR							
Altai Wildrye	1.39	27.04		12.00		12.00	0.40
Crested Wheatgrass							
Mature	0.56	34.80	0.28	21.00	7.02	28.02	0.93
Crested Wheatgrass							
Boot Stage	0.40	40.80	0.14	10.50	6.66	17.16	0.57
Forage Barley							
Milk	0.12	28.80	0.11	8.40	5.62	14.02	0.47
Oat Forage							
Milk	0.14	29.60	0.13	9.90	4.31	14.21	0.47
Pea Forage							
Late	0.11	37.40	0.13	9.90	6.62	16.52	0.55
Forage Lentil							
Late	0.13	37.00	0.13	9.90	6.77	16.67	0.56
Oat-Pea Forage							
Hay	0.12	37.20	0.16	11.40	5.20	16.60	0.55

Livestock Performance and Net Returns after Pasture-Forage Costs

The cow and calf weight performance and pasture-forage costs for the lactation (spring, summer, and fall portions) production period for grazingland-forage and harvested-forage management strategies were evaluated and compared. Range cow and calf performance on grazinglands is shown in tables 11-14 and figures 2-5. Pasture-forage costs and returns for management strategies are shown in tables 15-16.

12.0-month repeated seasonal management strategy

The 12.0-month repeated seasonal management strategy was developed from monthly herbage biomass data collected from ungrazed plots. The management strategy was evaluated as a system of separate native range pastures grazed at proper stocking rates, with each pasture grazed repeatedly during one livestock production period, at the same time each year. Calf weight and performance on this management strategy were estimated based on 1.80 lbs average daily gain and 95 lbs birth weight.

A native range pasture was evaluated for 31 days of grazing in May, during the spring portion of the lactation period. Spring native range forage has a crude protein content of around 16.3%. Calf weight gain was 1.80 lbs per day and 11.70 lbs per acre; accumulated weight gain was 55.80 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $39.06 per calf, and the net returns after pasture costs were a loss of $2.79 per cow-calf pair and a loss of $0.58 per acre on native range. The cost of calf weight gain was $0.75 per pound.

A native range pasture was evaluated for 137 days of grazing from early June to mid October, during the summer portion of the lactation period. Native range forage has a crude protein content of around 9.6% during mid summer. The crude protein content of native range grasses decreases after mid summer and is below the requirements of a lactating cow by early August. Calf weight gain was 1.80 lbs per day and 21.78 lbs per acre; accumulated weight gain was 246.60 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $172.62 per calf, and the net returns after pasture costs were $73.98 per cow-calf pair and $6.54 per acre. The cost of calf weight gain was $0.40 per pound.

Reserved native range pastures were evaluated for two 15-day segments of grazing, one from mid to late October and another from early to mid November, during the early and late segments of the fall portion of the lactation period. The costs of grazing native rangeland during the fall were determined separately for the early and late segments of the fall period. Calf weight gain was 1.80 lbs per day and 12.86 lbs per acre during the early 15-day segment and 10.80 lbs per acre during the late 15-day segment; accumulated weight gain was 54 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $37.80 per calf, and the net returns after pasture costs were a loss of $13.40 per cow-calf pair and a loss of $2.91 per acre. The cost of calf weight gain was $0.95 per pound.

The combined grazingland pastures for the 12.0-month repeated seasonal strategy yielded an accumulated calf weight gain of 356.40 lbs on 20.69 acres in 198 days at a cost of $191.69 per cow-calf pair. When calf accumulated weight was assumed to have a value of $0.70 per pound, the net returns after pasture costs were $57.79 per cow-calf pair and $2.79 per acre for all pastures during the 6.5-month grazing season. Grazing for 6.5 months on the 12.0-month repeated seasonal strategy, a lactating cow and her calf used 3.19 acres per month, at a cost of $29.49 per month, or $0.97 per day. Each accumulated pound of calf weight cost $0.54 on the grazinglands of the 12.0-month repeated seasonal strategy.

6.0-month seasonlong management strategy

The native range period of the 6.0-month seasonlong (6.0-m SL) treatment was 183 days, with 16 days during spring, 137 days during summer, and 30 days during fall portions of the lactation production period. Cow weight gain was 0.12 lbs per day and 0.91 lbs per acre; accumulated weight gain was 21.96 lbs. Calf weight gain was 1.80 lbs per day and 13.59 lbs per acre; accumulated weight gain was 329.40 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $230.58 per calf, and the net returns after pasture costs were $18.24 per cow-calf pair and $0.75 per acre. Each accumulated pound of calf weight cost $0.64 on the native range pasture of the 6.0-month seasonlong strategy.

Performance of animals grazing native rangeland on the 6.0-month seasonlong strategy declined considerably during the 30-day fall portion of the lactation period between mid October and mid November. Cows lost 1.74 lbs per day and 12.90 lbs per acre; accumulated weight loss was 52.20 lbs per month. Calf weight gain was 0.59 lbs per day and 4.38 lbs per acre; accumulated weight gain was 17.73 lbs. When calf accumulated weight was assumed to

have a value of $0.70 per pound, the gross return was $12.41 per calf, and the net returns after pasture costs were a loss of $22.98 per cow-calf pair and a loss of $5.69 per acre. Each accumulated pound of calf weight cost $1.99 on the 6.0-month seasonlong management strategy during mid October to mid November.

4.5-month seasonlong management strategy

The spring unfertilized crested wheatgrass complementary pasture period was 31 days during the spring portion of the lactation production period. Cow weight gain was 1.95 lbs per day and 32.15 lbs per acre; accumulated weight gain was 60.45 lbs. Calf weight gain was 1.91 lbs per day and 31.49 lbs per acre; accumulated weight gain was 59.21 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $41.45 per calf, and the net returns after pasture costs were $24.98 per cow-calf pair and $13.29 per acre on crested wheatgrass pasture. The cost of calf weight gain was $0.27 per pound.

The native range period of the first version of the 4.5-month seasonlong (4.5-m SL) treatment was 137 days during the summer portion of the lactation production period from early June to mid October. Cow weight gain was 0.34 lbs per day and 3.67 lbs per acre; accumulated weight gain was 46.58 lbs. Calf weight gain was 2.09 lbs per day and 22.55 lbs per acre; accumulated weight gain was 286.33 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $200.43 per calf, and the net returns after pasture costs were $89.18 per cow-calf pair and $7.02 per acre on native range. The cost of calf weight gain was $0.39 per pound.

A second version of the 4.5-month seasonlong (SL 4.5-m) management strategy grazed native rangeland from mid June until late October. During the 15-day period from mid to late October, cows grazing native rangeland lost 0.52 lbs per day and 4.75 lbs per acre; accumulated weight loss was 7.74 lbs in 15 days. Calf weight gain during the same period was 1.35 lbs per day and 12.47 lbs per acre; accumulated weight gain was 20.33 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $14.23 per calf, and the net returns after pasture costs were a loss of $0.05 per cow-calf pair and a loss of $0.03 per acre. Each accumulated pound of calf weight cost $0.70 on the second version of the 4.5-month seasonlong management strategy during mid to late October.

Livestock on the first version of the 4.5-month seasonlong (4.5-m SL) strategy grazed a cropland aftermath pasture during the fall portion of the lactation production period from mid October to mid November. Lactating cows that grazed cropland aftermath of annual cereal residue between mid October and mid November lost 1.61 lbs per day and 7.27 lbs per acre; accumulated weight loss was 48.17 lbs. Calf weight gain was 0.42 lbs per day and 1.90 lbs per acre; accumulated weight gain was 12.57 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $8.80 per calf, and the net returns after pasture costs were a loss of $4.46 per cow-calf pair and a loss of $0.67 per acre. Each accumulated pound of calf weight cost $1.05 on cropland aftermath during mid October to mid November.

The combined crested wheatgrass, native range, and cropland aftermath grazingland types for the 4.5-month seasonlong (4.5-m SL) strategy yielded an accumulated cow weight gain of 58.86 lbs and an accumulated calf weight gain of 358.11 lbs on 21.21 acres in 198 days at a cost of $140.98 per cow-calf pair. When calf accumulated weight was assumed to have a value of $0.70 per pound, the net returns after pasture costs were $109.70 per cow-calf pair and $5.17 per acre for portions of the year that cow-calf pairs were grazing pastures. Grazing for 6.5 months on the 4.5-month seasonlong strategy, a lactating cow and her calf used 3.27 acres per month, at a cost of $0.71 per day, or $21.72 per month. Each accumulated pound of calf weight cost $0.39 on the grazinglands of the 4.5-month seasonlong strategy.

4.0-month deferred management strategy

The spring unfertilized crested wheatgrass complementary pasture period was 76 days during the spring and early summer portions of the lactation production period. Cow weight gain was 0.91 lbs per day and 16.63 lbs per acre; accumulated weight gain was 69.16 lbs. Calf weight gain was 1.79 lbs per day and 32.70 lbs per acre; accumulated weight gain was 136.04 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $95.23 per calf, and the net returns after pasture costs were $58.78 per cow-calf pair and $14.13 per acre on crested wheatgrass pasture. The cost of calf weight gain was $0.27 per pound.

The native range period of the 4.0-month deferred (4.0-m Def) treatment was 122 days, with 92 days during summer and 30 days during fall portions of the lactation production period. Cow weight gain was 0.32 lbs per day and 4.40 lbs per acre; accumulated weight gain was 39.04 lbs. Calf weight

gain was 1.80 lbs per day and 24.73 lbs per acre; accumulated weight gain was 219.60 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $153.72 per calf, with $137.55 from the summer and $16.17 from the fall portions, and the net returns after pasture costs were $75.93 per cow-calf pair and $8.55 per acre on native range. The net returns during the summer portion were $79.29 per cow-calf pair and $11.83 per acre. The cost of calf weight gain on native rangeland was $0.35 per pound.

Performance of animals grazing on the 4.0-month deferred strategy declined considerably during the 30-day fall portion of the lactation production period between mid October and mid November. Cows lost 0.74 lbs per day and 9.96 lbs per acre; accumulated weight loss was 22.20 lbs. Calf weight gain was 0.77 lbs per day and 10.36 lbs per acre; accumulated weight gain was 23.10 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $16.17 per calf, and the net returns after pasture costs were a loss of $3.36 per cow-calf pair and a loss of $1.51 per acre. Each accumulated pound of calf weight cost $0.85 on the 4.0-month deferred management strategy during mid October to mid November.

The combined grazingland types for the 4.0-month deferred strategy yielded an accumulated cow weight gain of 108.20 lbs and an accumulated calf weight gain of 355.64 lbs on 13.04 acres in 198 days at a cost of $114.23 per cow-calf pair. When calf accumulated weight was assumed to have a value of $0.70 per pound, the net returns after pasture costs were $134.72 per cow-calf pair and $10.33 per acre for all portions of the grazing season. Grazing for 6.5 months on the 4.0-month deferred strategy, a lactating cow and her calf used 2.01 acres per month, at a cost of $0.58 per day, or $17.31 per month. Each accumulated pound of calf weight cost $0.32 on the grazinglands of the 4.0-month deferred strategy.

4.5-month twice-over rotation management strategy

The spring fertilized crested wheatgrass complementary pasture period was 31 days during the spring portion of the lactation production period. Cow weight gain was 2.68 lbs per day and 110.77 lbs per acre; accumulated weight gain was 83.08 lbs on 0.75 acres. Calf weight gain was 2.18 lbs per day and 90.11 lbs per acre; accumulated weight gain was 67.58 lbs on 0.75 acres. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $47.31 per calf, and the net returns after pasture costs were $31.36 per cow-calf pair and $41.82 per acre on fertilized crested wheatgrass pasture. The cost of calf weight gain was $0.24 per pound.

The native range period of the 4.5-month twice-over rotation (4.5-m TOR) treatment was 137 days during the summer portion of the lactation production period. Cow weight gain was 0.62 lbs per day and 9.44 lbs per acre; accumulated weight gain was 84.94 lbs. Calf weight gain was 2.21 lbs per day and 33.64 lbs per acre; accumulated weight gain was 302.77 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $211.94 per calf, and the net returns after pasture costs were $133.10 per cow-calf pair and $14.79 per acre on native rangeland. The cost of calf weight gain was $0.26 per pound.

Livestock grazed an Altai wildrye complementary pasture during the fall portion of the lactation production period. Lactating cows that grazed Altai wildrye pastures for 30 days between mid October and mid November gained 0.55 lbs per day and 11.87 lbs per acre; accumulated weight gain was 16.50 lbs. Calf weight gain was 1.73 lbs per day and 37.96 lbs per acre; accumulated weight gain was 52.77 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $36.94 per calf, and the net returns after pasture costs were $24.76 per cow-calf pair and $17.81 per acre on Altai wildrye pasture. The cost of calf weight gain was $0.23 per pound.

The combined grazingland types for the 4.5-month twice-over rotation strategy yielded an accumulated cow weight gain of 184.52 lbs and an accumulated calf weight gain of 423.12 lbs on 11.14 acres in 198 days at a cost of $106.79 per cow-calf pair. When calf accumulated weight was assumed to have a value of $0.70 per pound, the net returns after pasture costs were $189.39 per cow-calf pair and $17.00 per acre for all pastures during the grazing season. Grazing for 6.5 months on the 4.5-month twice-over rotation strategy, a lactating cow and her calf used 1.72 acres per month, at a cost of $0.54 per day, or $16.45 per month. Each accumulated pound of calf weight cost $0.25 on the grazinglands of the 4.5-month twice-over rotation strategy.

Table 11. Range cow and calf performance on native rangeland and domesticated grass pastures during the 31-day spring portion of the lactation production period.

		Native Rangeland (12-m RS)*	Native Rangeland (6.0-m SL)	Crested Wheatgrass Unfertilized (4.5-m SL)	Crested Wheatgrass Unfertilized (4.0-m Def)	Crested Wheatgrass Fertilized (4.5-m TOR)
Length of Period	days	31	16	31	76	31
Acres/Month	ac	4.62	4.04	1.82	1.67	0.75
Acres/Period	ac	4.77	2.10	1.88	4.16	0.75
Cow Gain/Day	lbs		0.12	1.95	0.91	2.68
Cow Gain/Acre	lbs		0.91	32.15	16.63	110.77
Cow Gain/Period	lbs		1.92	60.45	69.16	83.08
Calf Gain/Day	lbs	1.80	1.80	1.91	1.79	2.18
Calf Gain/Acre	lbs	11.70	13.64	31.49	32.70	90.11
Calf Gain/Period	lbs	55.80	28.80	59.21	136.04	67.58

*Based on estimated calf weight

Table 12. Range cow and calf performance on native rangeland pastures during the 137-day summer portion of the lactation production period.

		Native Rangeland (12-m RS)*	Native Rangeland (6.0-m SL)	Native Rangeland (4.5-m SL)	Native Rangeland (4.0-m Def)	Native Rangeland (4.5-m TOR)
Length of Period	days	137	183	137	122	137
Acres/Month	ac	2.52	4.04	2.86	2.22	2.04
Acres/Period	ac	11.32	24.24	12.70	8.88	9.00
Cow Gain/Day	lbs		0.12	0.34	0.32	0.62
Cow Gain/Acre	lbs		0.91	3.67	4.40	9.44
Cow Gain/Period	lbs		21.96	46.58	39.04	84.94
Calf Gain/Day	lbs	1.80	1.80	2.09	1.80	2.21
Calf Gain/Acre	lbs	21.78	13.59	22.55	24.73	33.64
Calf Gain/Period	lbs	246.60	329.40	286.33	219.60	302.77

*Based on estimated calf weight

Table 13. Range cow and calf performance on native rangeland pastures during the 30-day fall portion of the lactation production period.

		Native Rangeland (12-m RS)*		Native Rangeland (SL 4.5-m)	Native Rangeland (SL 5-6-m)	Native Rangeland (6.0-m SL)	Native Rangeland (4.0-m Def)
		Early	Late	Early			
Length of Period	days	15	15	15	30	30	30
Acres/Month	ac	4.20	5.00	3.26	2.53	4.04	2.22
Acres/Period	ac	2.10	2.50	1.63	2.53	4.04	2.18
Cow Gain/Day	lbs			-0.52	-0.82	-1.74	-0.74
Cow Gain/Acre	lbs			-4.75	-9.77	-12.90	-9.96
Cow Gain/Period	lbs			-7.74	-24.60	-52.20	-22.20
Calf Gain/Day	lbs	1.80	1.80	1.35	0.92	0.59	0.77
Calf Gain/Acre	lbs	12.86	10.80	12.47	10.90	4.38	10.36
Calf Gain/Period	lbs	27.00	27.00	20.33	27.60	17.73	23.10

*Based on estimated calf weight

Table 14. Range cow and calf performance on domesticated grass and cropland pastures during the 30-day fall portion of the lactation production period.

		Altai Wildrye (4.5-m TOR)	Crop Aftermath (4.5-m SL)
Length of Period	days	30	30
Acres/Month	ac	1.39	6.63
Acres/Period	ac	1.39	6.63
Cow Gain/Day	lbs	0.55	-1.61
Cow Gain/Acre	lbs	11.87	-7.27
Cow Gain/Period	lbs	16.50	-48.17
Calf Gain/Day	lbs	1.73	0.42
Calf Gain/Acre	lbs	37.96	1.90
Calf Gain/Period	lbs	52.77	12.57

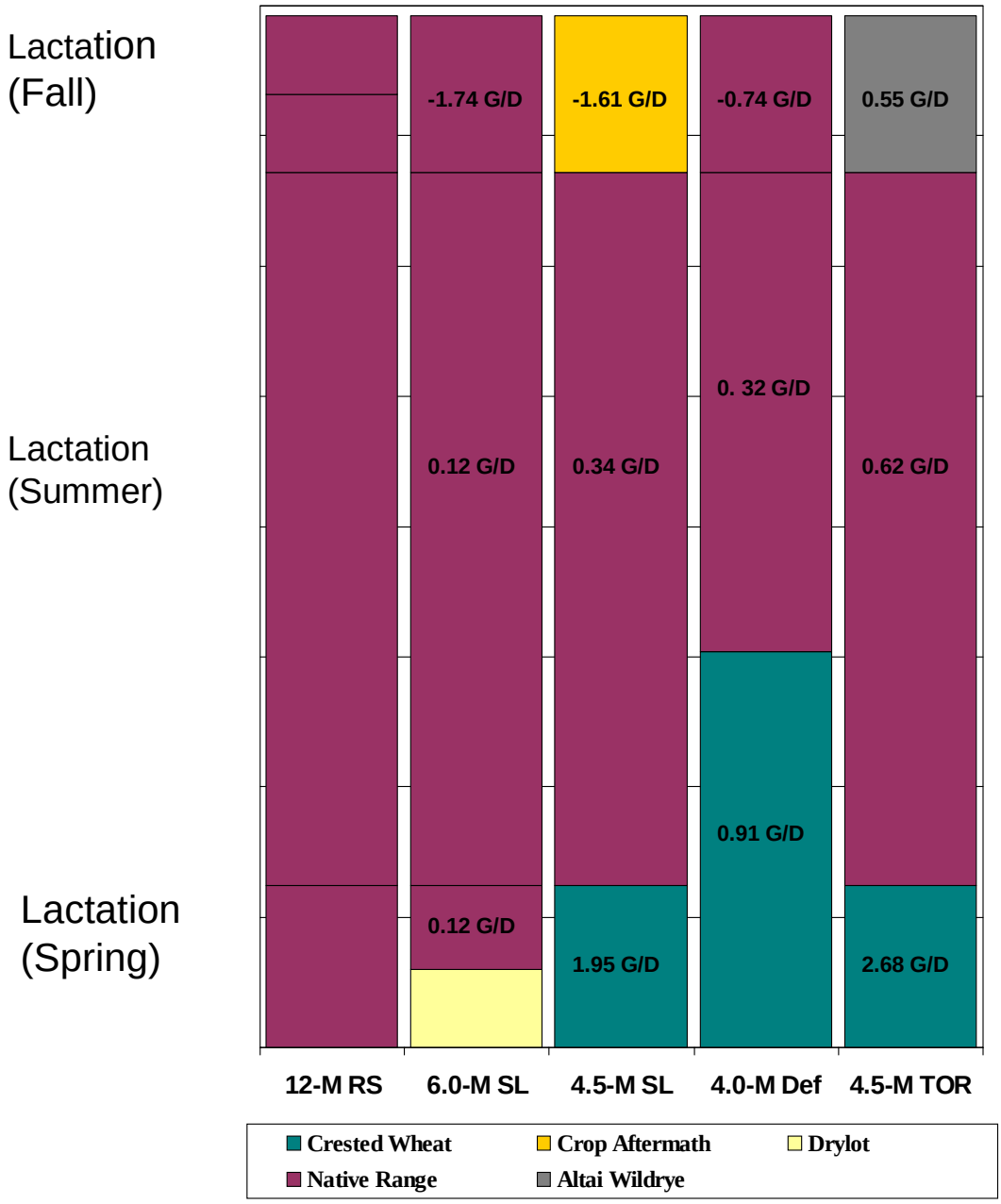


Fig. 2. Pounds of cow gain per day on grazing management strategies.

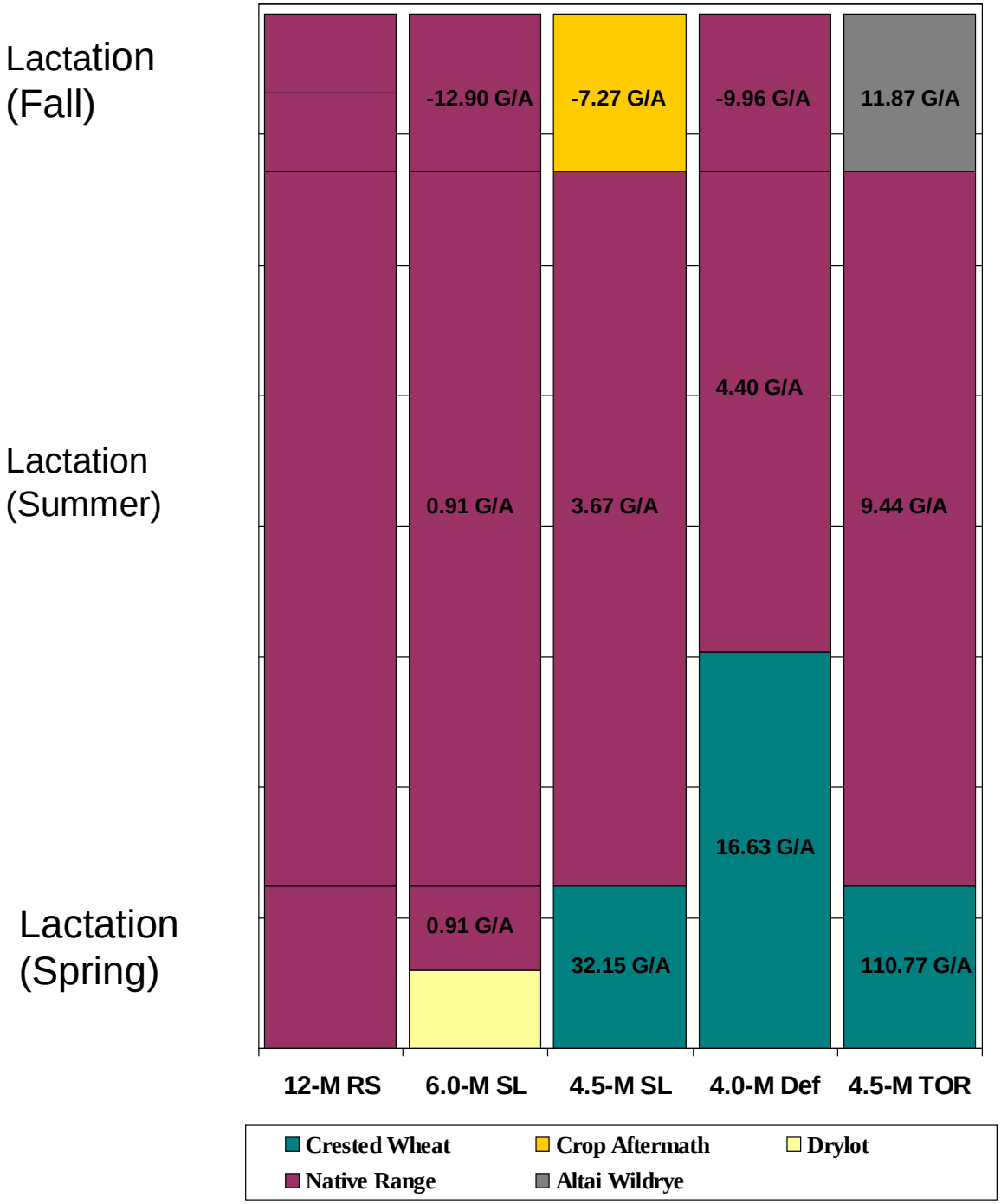


Fig. 3. Pounds of cow gain per acre on grazing management strategies.

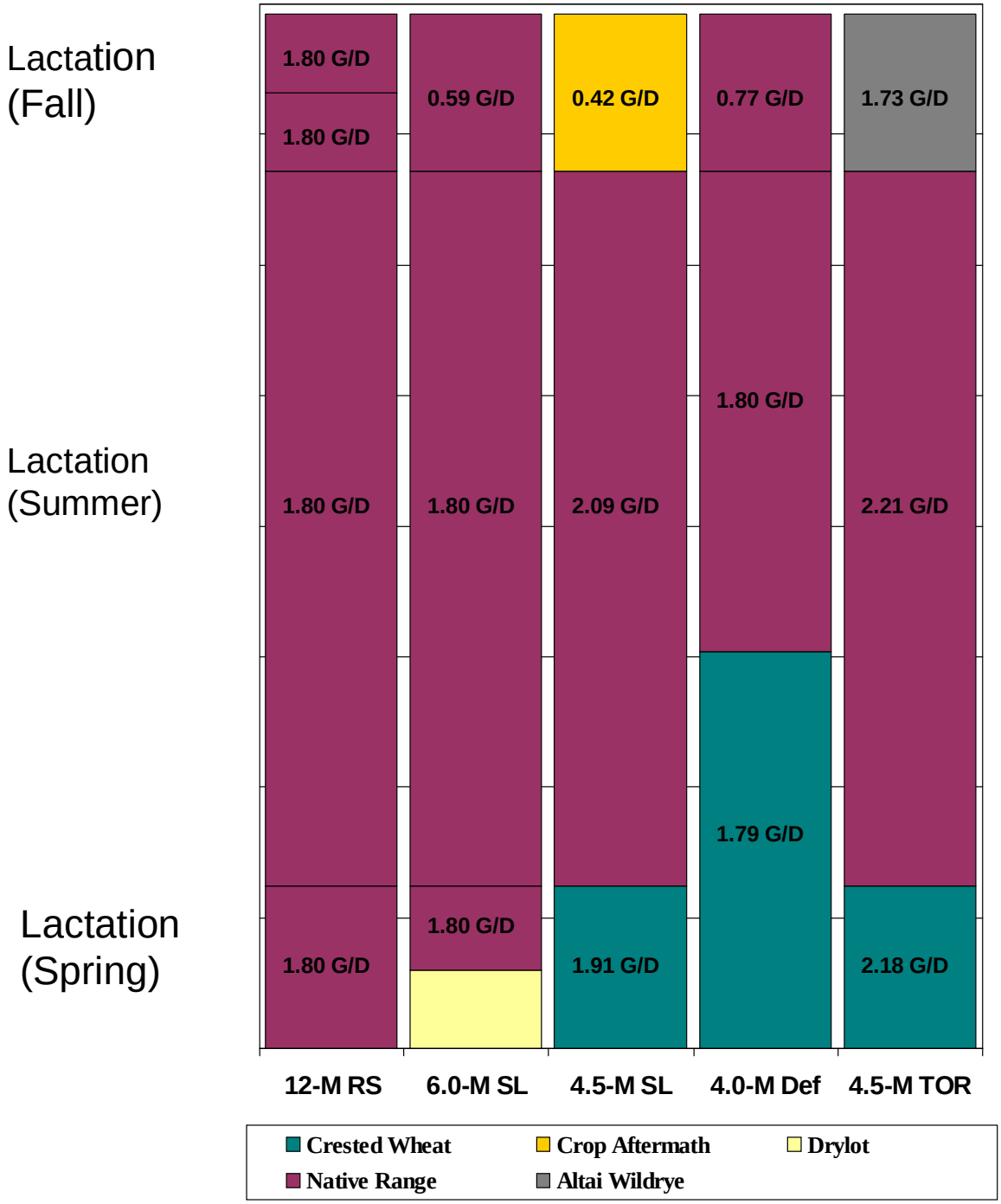


Fig. 4. Pounds of calf gain per day on grazing management strategies.

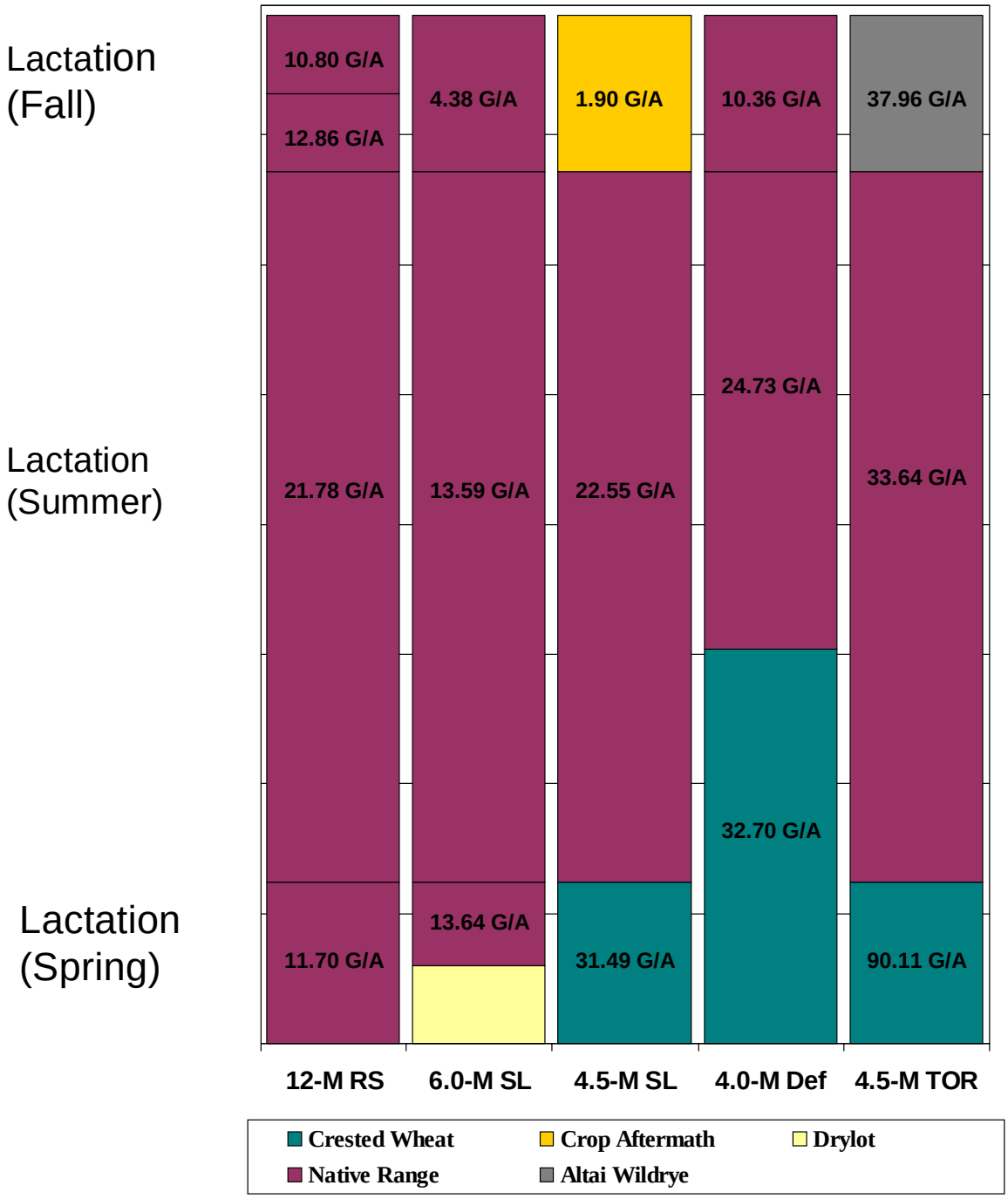


Fig. 5. Pounds of calf gain per acre on grazing management strategies.

Table 15. Costs and returns during the spring, summer, and fall portions of the lactation production period for grazing management strategies.

		12-M Repeated Seasonal*	6.0-M Seasonlong	4.5-M Seasonlong	4.0-M Deferred	4.5-M Twice-over Rotation
Spring Lactation Period		Native Rangeland	Native Rangeland	Crested Wheatgrass Unfertilized	Crested Wheatgrass Unfertilized	Crested Wheatgrass Fertilized
Accumulated Calf Wt.	lbs	55.80	28.80	59.21	136.04	67.58
Weight Value @ $0.70/lb	$	39.06	20.16	41.45	95.23	47.31
Pasture and Forage Costs	$	41.85	18.40	16.47	36.44	15.95
Net Return/c-c pr	$	-2.79	1.76	24.98	58.78	31.36
Net Return/acre	$	-0.58	0.83	13.29	14.13	41.82
Cost/lb of Calf Gain	$	0.75	0.64	0.27	0.27	0.24
Summer Lactation Period		Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland
Accumulated Calf Wt.	lbs	246.60	282.87	286.33	196.50	302.77
Weight Value @ $0.70/lb	$	172.62	198.01	200.43	137.55	211.94
Pasture and Forage Costs	$	98.64	158.55	111.25	58.26	78.84
Net Return/c-c pr	$	73.98	38.75	89.18	79.29	133.10
Net Return/acre	$	6.54	2.13	7.02	11.83	14.79
Cost/lb of Calf Gain	$	0.40	0.56	0.39	0.30	0.26
Fall Lactation Period		Native Rangeland	Native Rangeland	Cropland Aftermath	Native Rangeland	Altai Wildrye
Accumulated Calf Wt.	lbs	54.00	17.73	12.57	23.10	52.77
Weight Value @ $0.70/lb	$	37.80	12.41	8.80	16.17	36.94
Pasture and Forage Costs	$	51.20	35.39	13.26	19.53	12.00
Net Return/c-c pr	$	-13.40	-22.98	-4.46	-3.36	24.76
Net Return/acre	$	-2.91	-5.69	-0.67	-1.51	17.81
Cost/lb of Calf Gain	$	0.95	1.99	1.05	0.85	0.23

*Based on estimated calf weight

Table 16. Range cow and calf performance and costs and returns during the lactation production period for grazing management strategies.

		12-M Repeated Seasonal*	6.0-M Seasonlong	4.5-M Seasonlong	4.0-M Deferred	4.5-M Twice-over Rotation
Length of Season	days	198	183	198	198	198
Acres/Month	ac	3.19	4.04	3.27	2.01	1.72
Acres/Season	ac	20.69	24.24	21.21	13.04	11.14
Cow Gain/Day	lbs		0.12	0.30	0.55	0.93
Cow Gain/Acre	lbs		0.91	2.78	8.30	16.56
Cow Gain/Season	lbs		21.96	58.86	108.20	184.52
Calf Gain/Day	lbs	1.80	1.80	1.81	1.80	2.14
Calf Gain/Acre	lbs	17.23	13.59	16.88	27.27	37.98
Calf Gain/Season	lbs	356.40	329.40	358.11	355.64	423.12
Weight Value @ $0.70/lb	$	249.48	230.58	250.68	248.95	296.18
Pasture and Forage Costs	$	191.69	212.34	140.98	114.23	106.79
Net Return/c-c pr	$	57.79	18.24	109.70	134.72	189.39
Net Return/Acre	$	2.79	0.75	5.17	10.33	17.00
Cost/lb of Calf Gain	$	0.54	0.64	0.39	0.32	0.25

*Based on estimated calf weight

Projected pasture-forage costs and net returns

The individual cow-calf pair data for the grazing management strategies were projected to a beef herd of 100 cows and a herd of 300 cows (table 17). The differences in the land area required for forage nutrient production, in total feed costs, and in net returns after pasture-forage costs result from the differences in the biological effectiveness and the nutrient capture and conversion efficiency of the various grazing management strategies.

The land area required to produce the forage nutrients for 100 cows during the grazing season was 1114 acres for the 4.5-month twice-over rotation, 1304 acres for the 4.0-month deferred, 2121 acres for the 4.5-month seasonlong, 2069 acres for the 12-month repeated seasonal, and 2424 acres for the 6.0-month seasonlong treatments.

Total feed costs (pasture and harvested forages) for 100 cows during the grazing season were $10,679 for the 4.5-month twice-over rotation, $11,423 for the 4.0-month deferred, $14,098 for the 4.5-month seasonlong, $19,169 for the 12-month repeated seasonal, and $21,234 for the 6.0-month seasonlong treatments.

Net returns after pasture-forage feed costs for 100 cows during the grazing season were $18,939 from the 4.5-month twice-over rotation, $13,472 from the 4.0-month deferred, $10,970 from the 4.5-month seasonlong, $5,779 from the 12-month repeated seasonal, and $1,824 from the 6.0-month seasonlong treatments.

The land area required to produce the forage nutrients for 300 cows during the grazing season was 3342 acres for the 4.5-month twice-over rotation, 3912 acres for the 4.0-month deferred, 6363 acres for the 4.5-month seasonlong, 6207 acres for the 12-month repeated seasonal, and 7272 acres for the 6.0-month seasonlong treatments.

Total feed costs (pasture and harvested forages) for 300 cows during the grazing season were $32,037 for the 4.5-month twice-over rotation, $34,269 for the 4.0-month deferred, $42,294 for the 4.5-month seasonlong, $57,507 for the 12-month repeated seasonal, and $63,702 for the 6.0-month seasonlong treatments.

Net returns after pasture-forage feed costs for 300 cows during the grazing season were $56,817 from the 4.5-month twice-over rotation, $40,416 from the 4.0-month deferred, $32,910 from the 4.5-month seasonlong, $17,337 from the 12-month repeated seasonal, and $5,472 from the 6.0-month seasonlong treatments.

The net returns after pasture-forage costs were greatest on the biologically effective 4.5-month twice-over rotation grazing management system. The management strategies with moderate net returns were the 4.0-month deferred and 4.5-month seasonlong traditional systems. The management strategies with low net returns were the 12-month repeated seasonal and 6.0-month seasonlong traditional systems.

Table 17. Projection of net returns from 100-cow and 300-cow herds on grazing management strategies during the 6.5-month grazing season.

	100 Cows				**300 Cows**			
Grazing Management Strategies	Land Area	Total Feed Cost	Calf Weight Value @$0.70/lb	Net Return	Land Area	Total Feed Cost	Calf Weight Value @$0.70/lb	Net Return
	Acres	$	$	$	Acres	$	$	$
12-M Repeated Seasonal	2069	19,169	24,948	5779	6207	57,507	74,844	17,337
6.0-M Seasonlong	2424	21,234	23,058	1824	7272	63,702	69,174	5472
4.5-M Seasonlong	2121	14,098	25,068	10,970	6363	42,294	75,204	32,910
4.0-M Deferred	1304	11,423	24,895	13,472	3912	34,269	74,685	40,416
4.5-M Twice-over Rotation	1114	10,679	29,618	18,939	3342	32,037	88,854	56,817

Discussion

Today's fast-growing, high-performance cattle are genetically different from the old-style cattle and have higher rates of weight gain, produce greater quantities of milk, are larger, weigh more, and deposit less fat on their bodies. Because of the higher rates of production and larger size, modern animals require greater quantities of nutrients throughout the production year. A high-performance cow that has medium milk production and is 20% greater in size than an old-style animal requires 24% more energy and 34% more crude protein per year. During the 6.5-month grazing season from early May to mid November, this high-performance cow with a calf born in mid March requires 27% more energy and 41% more crude protein than an old-style cow-calf pair for production performances at their respective genetic potentials.

Old-style, traditional feed management systems are designed to provide forage to meet the dry matter requirements of old-style cattle and are usually evaluated by the cost per ton for harvested forages and by the cost per acre for pastures. Most pastures under traditional management practices cannot provide the 19% increase in dry matter needed to support high-performance cows at the stocking rate appropriate for old-style animals, and the forage produced fails to provide the greater quantities of nutrients. When high-performance livestock are fed forage from low-performance, old-style pasture-forage management systems, the forage crude protein levels are below livestock requirements during 40% to 60% of the days in a production year and the deficiency results in animal performance below potential, in high forage-feed costs, and in low profit margins.

Adjustments of old-style management practices to provide greater amounts of dry matter per cow and appropriate additions of crude protein supplement will improve animal performance. Profit margins will not improve, however, as long as the value of the increases in pasture and forage provided per cow is greater than the value of increases in production per cow.

Modern high-performance cow-calf pairs have greater pasture-forage costs and lower net returns after pasture-forage costs on old-style traditional management systems like the 12-month repeated seasonal, 6.0-month seasonlong, 4.5-month seasonlong, and 4.0-month deferred grazing practices than on biologically effective management systems like the 4.5-month twice-over rotation grazing practice.

Grazing native rangeland pastures during May is expensive, costing even more than feeding mature crested wheatgrass hay during the same period. Rangeland plants are not physiologically ready for grazing prior to the third-leaf stage, and grazing prior to plant readiness causes a reduction in herbage biomass production (Campbell 1952, Rogler et al. 1962, Manske 2000a). Delaying grazing on native rangeland until grass plants have reached the third-leaf stage, in early June, requires the use of another forage type for earlier grazing. Some domesticated perennial cool-season grasses like crested wheatgrass and smooth bromegrass reach the third-leaf stage three to five weeks earlier than native cool-season grasses and are dependable as spring pastures from early May until early June. Crested wheatgrass is an excellent early season spring pasture forage. The start of the grazing season on domesticated grass pastures is restricted to very late April or early May because no perennial grass in the Northern Plains reaches the third-leaf stage before late April.

Unfertilized crested wheatgrass pastures provide forage at reasonable costs during May and early and mid June, but in late June the crude protein content drops below the requirements for lactating cows. Fertilized crested wheatgrass pastures provide forage at reasonable costs during May and early June. Fertilization of crested wheatgrass pastures during the first week of April increased the amount of herbage produced, and the costs per ton for forage dry matter on fertilized pastures were about the same as the costs per ton for forage dry matter on unfertilized pastures, even though the cost of the fertilizer more than doubled the production costs per acre. Fertilization shortened by several weeks the effective period of use of domesticated grass spring complementary pastures by grazing livestock.

Cow and calf performance was strong on unfertilized crested wheatgrass during May and early and mid June but decreased considerably when grazing continued until mid July. Fertilization on crested wheatgrass pastures shortened the period during which livestock performed well. Weight performance for cows and calves during May and early June was greater on fertilized crested wheatgrass pastures than on unfertilized pastures, but livestock performance on fertilized crested wheatgrass pastures decreased earlier, in mid June.

Grazed native rangeland pastures provide forage dry matter and crude protein at lower costs during the summer portion of the lactation production period from early June to mid October than during other times of the year. The native rangeland

pastures of the 4.5-month seasonlong and 4.5-month twice-over rotation strategies were grazed only within this portion of the growing season and had forage dry matter costs that ranged between $39 and $55 per ton and crude protein costs of around $0.25 per pound. The twice-over rotation system had the lowest native rangeland pasture-forage costs because the management strategy does not start grazing on any forage type until the grass plants have reached the third-leaf stage, so the system avoids negative effects on plant biological processes and resulting reductions in herbage biomass production (Manske 2000c).

Cow and calf weight performance generally did not differ among native range treatments during the early grazing period of June and July, but during the latter portion of the grazing period, after early August, animal weight performance was greater on the twice-over rotation treatment than on the traditional seasonlong and deferred treatments.

Cow gain per day on the seasonlong and deferred treatments decreased successively as the grazing period progressed. Cows gained weight during the early portion of the grazing period but lost weight during the latter portion. Weight loss during the latter portion of the grazing season occurred at a greater rate on the deferred treatment. Cows on the twice-over rotation treatment gained weight at a greater rate than did cows on the seasonlong and deferred treatments. Cows on the twice-over rotation treatment gained weight during the early and middle portions of the grazing period and lost a small amount of weight at the end of the grazing period. Cow gain per day, accumulated weight, and gain per acre were greater on the twice-over rotation treatment than on the seasonlong and deferred treatments.

The greatest differences in calf performance on the native range treatments occurred during the later portions of the grazing period. Calf gain per day on the seasonlong and deferred treatments decreased as the grazing season progressed. The decrease in calf gain per day was greater on the 6.0-month seasonlong than on the deferred treatment and greater on the deferred treatment than on the 4.5-month seasonlong treatment. Calf accumulated weight was greater on the 4.5-month seasonlong treatment than on the deferred treatment and greater on the deferred treatment than on the 6.0-month seasonlong treatment. The decrease in calf gain per day during the latter portion of the grazing period was smaller on the twice-over rotation treatment than on the seasonlong and deferred treatments. Calf accumulated weight gain was greater on the twice-over rotation treatment than on the 4.5-month seasonlong, the 4.0-month deferred, and the 6.0-month seasonlong treatments.

The native rangeland pasture of the 6.0-month seasonlong strategy had grazing during the summer portion of the lactation production period from early June to mid October and during periods before and after the summer period. The higher forage costs of this strategy reflect the reduced levels of herbage production caused by the decreased plant density and plant size that result from grazing prior to the third-leaf stage in the spring and from grazing fall tillers in the late season.

The deferred grazing treatment withholds grazing from one or two pastures until the lead tillers of grass plants develop through the vegetative and sexually reproductive stages. Early rangeland managers believed that grass seed production was necessary for grassland health, and they developed deferred rotation grazing treatments specifically to allow grasses to flower and set seed. However, very few young grass plants mature from seed in an established grassland: almost all young grass plants are formed vegetatively. A major problem with the deferred management treatments that start grazing after grass seed development is that native-grass basal cover is reduced (Sarvis 1941, Manske et al. 1988). Another problem is that the nutritional quality of the native rangeland grasses on deferred grazing treatments is below the crude protein requirements of lactating cows. Nutritional quality of native rangeland grasses decreases rapidly following the seed development stage, and the quality falls below 9.6% crude protein around mid July to early August (Manske 1999a, b).

Nutritional quality of forage on native rangeland after mid August is below the requirements of lactating cows, and the weight performance of cows and calves diminishes greatly unless vegetative reproduction of secondary tillers is stimulated, as it is on the twice-over rotation system. Manipulation of secondary tiller growth of native rangeland grasses with light defoliation by grazing on each pasture for 7 to 17 days during the period between the third-leaf stage and the flowering stage (early June to mid July) can improve livestock performance for two to two and a half months at the end of the grazing season, until late September or mid October, but the biology of native grass plants does not permit extending this improved performance longer (Manske 2000c). Nutritional quality of herbage on native rangeland grazed after mid October is insufficient to meet requirements of lactating cows.

Forages that meet the nutritional requirements of lactating cows after mid October include Altai and Russian wildryes. The wildryes are the only perennial grasses that retain nutrient quality in the aboveground portions of the plant until about mid November. Altai wildrye complementary pastures with grazing during the fall portion of the lactation production period from mid October to mid November provided forage at reasonable costs. Forage dry matter costs were around $27 per ton. No perennial grass in the Northern Plains retains sufficient nutritional quality to dependably meet the nutritional requirements of lactating cows later than mid November.

Cow and calf weight performance on Altai wildrye pastures between mid October and mid November was favorable, but not as impressive as livestock weight performance on fertilized crested wheatgrass during May. Weight gains of cows and calves grazing Altai wildrye were considerably greater than those of livestock grazing native range or crop aftermath during the same period. Lactating cows on 6.0-month seasonlong and deferred native range grazing treatments and on crop aftermath of annual cereal stubble treatments lost weight during the period between mid October and mid November, and calves with those cows gained little weight.

Native rangeland pastures with grazing during the nongrowing season have high forage dry matter and crude protein costs. The aboveground herbage on native rangeland pastures averages less than 800 pounds per acre from November to April. The amount of forage available for ingestion by grazing animals is less than 200 pounds per acre on native rangeland pastures that have not been previously grazed during the growing season. Forage dry matter costs range between $97 and $140 per ton, and crude protein costs range between $0.76 and $1.26 per pound.

Both the 6.0-month seasonlong and the 4.0-month deferred treatments extend the grazing period on native rangeland past mid October. The weight of the fall herbage on pastures that have not been previously grazed is only about 40% to 60% of the midsummer herbage weight on ungrazed grasslands. The weight of the fall herbage on pastures that have been previously grazed is considerably less than 50% of the potential peak herbage biomass. The stocking rates of these two treatments are not adjusted after mid October to reflect late-season reductions in aboveground herbage biomass. The amount of aboveground herbage that remains at the end of the grazing period is only about 200 to 300 pounds per acre. This small amount of herbage catches very little snow and provides little insulation for overwintering perennial plants. The amount of insulation affects the rate of carbohydrate respiration that occurs in the crowns of the perennial plants. When the amount of insulation is low, plants respire rapidly and the stored carbohydrate reserves can be reduced or depleted before spring. Depletion of reserves causes plant death called "winter kill", and reduction of reserves causes reduced herbage biomass production the following season.

Cropland aftermath is a common pasture type used just prior to weaning and then later for dry cows. The amount of forage present on most aftermath pastures was low, and even with very low production costs per acre, the forage dry matter costs were around $30 per ton. The nutrient content of stubble of annual cereals harvested for grain is extremely low. Unless the crop aftermath contains a substantial amount of sprouted grain, lactating and dry cows cannot find forage that meets their crude protein requirements. The loss of animal weight on this pasture type should be considered as a cost.

Most livestock producers assume that beef production costs will be lower if cows graze as long as possible because it seems reasonable that allowing a cow to graze her own food is more economical than harvesting and feeding hay. When the forage costs for grazing during the fall are averaged with the costs during the summer period for such treatments as the 6.0-month seasonlong and 4.0-month deferred, the costs during the fall do not appear to be high. However, when the forage costs during the fall period are separated from those of the summer period, the greater expense of fall grazing becomes evident. The 15-day period from mid to late October had forage dry matter costs of over $80 per ton and crude protein costs around $0.34 per pound. The 15-day period from early to mid November had forage dry matter costs of over $97 per ton and crude protein costs of over $1.00 per pound. If grazing on native rangeland occurs after mid October, it should be on fall pastures separated from the summer pasture system, and the stocking rate should allot about double the number of acres per animal unit that summer seasonlong grazing treatments would require.

The costs per acre for pasture and the costs per ton for harvested forages are not directly comparable. However, the cost per pound or ton of ingested forage crude protein and dry matter from pastures and the cost per pound or ton of forage crude protein and dry matter from harvested forages can be compared. Perennial grass hay has been the major harvested-forage type used as winter feed for beef cows in the Northern Plains. Traditionally, crested

wheatgrass and smooth bromegrass--domesticated perennial grass hays--are cut late, after the seed heads have developed and plants have reached maximum height. This practice yields about the year's potential amount of forage dry matter per acre, about 300 pounds per acre more dry matter than harvesting at the boot stage. However, the quantity of crude protein captured per acre in mature hay is only a little more than half the quantity of crude protein captured per acre in hay cut at the boot stage. Forage dry matter costs were $34.80 per ton for mature hay and $40.80 per ton for hay cut at the boot stage. Crude protein costs were $0.28 per pound for mature hay and $0.14 per pound for early cut hay. Mature domesticated perennial grass hay is expensive livestock feed because it has high costs per pound of crude protein.

Annual cereal hays of forage barley and oat forage cut at the milk stage had high production costs that ranged from $68 to $70 per acre. However, the forage dry matter costs and crude protein costs were relatively low. Forage dry matter costs ranged between $28 and $30 per ton and crude protein costs ranged between $0.11 and $0.13 per pound. Early cut annual cereal hays capture greater pounds of crude protein per acre than the late-cut hays, and the cost per pound of crude protein is lower for the early cut annual cereal hays.

Annual legume hays of pea forage and forage lentil cut at late plant growth stages and oat-pea forage had high production costs that ranged from $71 to $96 per acre. The forage dry matter costs ranged from $37 to $38 per ton. The late-cut annual legume hays had lower dry matter costs than the early cut legume hays. Crude protein costs were relatively low for all annual legume hays and ranged from $0.13 to $0.16 per pound. Late-cut annual legume hays capture greater pounds of crude protein per acre and have lower crude protein costs than the early cut hays.

Traditionally, beef producers have based evaluations of animal production costs on the rent value per acre for pasture and the production costs per acre or the market value per ton for harvested forages. Traditional comparisons of pasture or land rent values, forage production costs per acre, and forage dry matter bulk weight costs do not accurately reflect livestock production costs and the effectiveness of pasture-forage management strategies. Calculations using these traditional market values can result in misleading assessments of forage costs. The cost of grazingland forage and harvested forage is affected by the efficiency of the harvest strategy and by the quantity of nutrients captured relative to the potential quantity of nutrients produced. Therefore, determination of the profit or loss from forages is more accurately made from calculations based on the costs and returns per unit of nutrients. Total profits from forages and beef animals can be determined from the quantities of nutrients required by the livestock. Substantial reduction in beef production costs can be achieved by producers who change to forage management strategies that efficiently capture low-cost nutrients produced on a land base.

Conclusion

Increasing the value captured from grassland pastures and haylands is the key to improving profit margins for the beef production industry. The improved efficiency of biologically effective pasture-forage management strategies results in increased value captured from resources on a land base. Just as adding value to a commodity at each stage of production provides economic benefit, increasing the value captured from the land base reduces costs and strengthens profit margins.

Some production costs for the beef industry in the Northern Plains are unnecessarily high because livestock producers tend to rely on traditional pasture-forage management practices that inefficiently capture the nutrients produced on a land base. These practices result in higher costs for the nutrients ingested by the animals, increased annual production costs per animal, and low profit margins.

Pasture-forage management systems for beef production in the Northern Plains need improved efficiency to increase the value captured from the land. During the past several decades the type of livestock in the region has shifted from a low-performance to a fast-growing, high-performance animal that produces most efficiently when its diet meets nutrient requirements during each production period. Traditional pasture-forage management practices do not provide diets that meet livestock immediate nutrient demand, and attempts to produce high-performance livestock by using slightly modified traditional low-performance management strategies have led to high production costs and low profit margins.

Pasture-forage management strategies that increase value captured place the biological requirements of the plants and the ecosystem processes as the highest priority. Those systems coordinate grazing and harvest periods with plant growth stages to remove greater amounts of nutrients rather than greater amounts of dry matter and to

provide adequate nutrients throughout the cows' 12-month production cycle. Implementing biologically effective pasture-forage management strategies increases the quantity of forage nutrients produced and improves the efficiency of forage nutrient capture and the conversion of forage nutrients into saleable commodities. An increased quantity of forage nutrients produced and captured as a commodity reduces livestock production costs and improves profit margins.

Efficient pasture-forage management strategies for high-performance livestock provide pasture and forage types to meet the nutritional requirements of high-performance livestock during each production period at low costs per unit of saleable product. Evaluation of the effectiveness of management strategies in reducing livestock pasture-forage production costs can be accomplished through comparisons of costs per unit of nutrient, land area per animal unit, forage feed costs per day or per production period, and costs per pound of calf weight gain. Implementation of efficient pasture-forage management strategies will result in improved livestock weight performance, reduced livestock production costs, and increased profit margins.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in the preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables and figures.

Literature Cited

Campbell, J.B. 1952. Farming range pastures. Journal of Range Management 5:252-258.

Beard, L.W. 1998. 1998 North Dakota custom rates. North Dakota Agricultural Statistics Service. http://www.nass.usda.gov/nd/cus

Manske, L.L., W.T. Barker, and M.E. Biondini. 1988. Effects of grazing management treatments on grassland plant communities and prairie grouse habitat. USDA. Forest Service. General Technical Report RM-159. p. 58-72.

Manske, L.L. 1999a. Annual nutritional quality curves for native range cool season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1026. Dickinson, ND. 16p.

Manske, L.L. 1999b. Annual nutritional quality curves for native range warm season grasses. NDSU Dickinson Research Extension Center. Range Management Report DREC 99-1027. Dickinson, ND. 13p.

Manske, L.L., and P.M. Carr. 2000. Determination of costs of harvested forage types to help reduce beef production costs. NDSU Dickinson Research Extension Center. Range Research Report DREC 00-1029. Dickinson, ND. 18p.

Manske, L.L. 2000a. Grazing before grass is ready. NDSU Dickinson Research Extension Center. Range Management Report DREC 00-1032. Dickinson, ND. 6p.

Manske, L.L. 2000b. Fall grazing affects grass leaf height. NDSU Dickinson Research Extension Center. Range Management Report DREC 00-1031. Dickinson, ND. 9p.

Manske, L.L. 2000c. Management of prairie in the Northern Great Plains based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 12p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Rogler, G.A., R.J. Lorenz, and H.M. Schaaf. 1962. Progress with grass. North Dakota Agricultural Experiment Station. Bulletin 439. Fargo, ND. 15p.

Sarvis, J.T. 1941. Grazing investigations on the Northern Great Plains. North Dakota Agricultural Experiment Station. Bulletin 308. Fargo, ND. 110p.

Swenson, A., and R. Haugen. 1999. Projected 2000 crop budgets for southwest North Dakota. NDSU Extension Service. http://www.ext.nodak.edu/extpubs/agecon/

Whitman, W.C., D.W. Bolin, E.W. Klosterman, H.J. Klostermann, K.D. Ford, L. Moomaw, D.G. Hoag, and M.L. Buchanan. 1951. Carotene, protein, and phosphorus in range and tame grasses of western North Dakota. North Dakota Agricultural Experiment Station. Bulletin 370. Fargo, ND. 55p.

Costs-Returns of Forage Management Strategies for Range Cows during the Nongrazing Season

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

Most beef producers view feeding livestock during the nongrazing season as a major expense. However, economical forage sources can turn feeding livestock during this time from expense into income. The weight added to a calf during the dry gestation, third trimester, and early lactation production periods has economic value when the calf is sold. If the value of the calf weight is less than the cost of forage during the nongrazing season, the forage costs are an expense, but if the value of the calf weight is greater than the costs of the forage, the difference is income. The costs of forage types used for feed during the nongrazing season vary greatly, and the use of the most economical feed is critical to ensuring positive profit margins. This study evaluated fourteen forage types used to feed range cows during the nongrazing season and determined whether feeding each type was an expense or yielded income.

Procedure

This study was conducted at the NDSU Dickinson Research Extension Center, located in western North Dakota. Forage types were evaluated as livestock feed during the nongrazing season, a period of about 5.5 months from mid November to late April, when air temperatures are low, liquid water is scarce, physiological plant processes are slow, foliage production is minimal in dormant perennial plants, and biologically active grass material is unavailable as livestock feed. The harvested-forage treatments were identified by the forage type fed during the nongrazing season: forage barley hay, oat forage hay, pea forage hay, forage lentil hay, oat-pea forage hay, and crested wheatgrass hay. The pasture-forage treatments were reserved native rangeland and cropland aftermath pastures. Pasture and forage costs were evaluated against calf weight value to determine the profit or loss. Pasture and forage costs evaluated were production costs per acre, forage dry matter costs per ton, crude protein yield and cost per pound, land area per animal unit, and livestock forage, supplement, and total feed costs. Forage dry matter yield per acre and percent crude protein data for annual cereal and annual legume hays and perennial domesticated grass hays were taken from forage production data collected on harvested-forage types between 1995 and 1999 and reported in a previous study (Manske and Carr 2000a). Pasture rent value of $8.76 per acre was used to determine costs of native rangeland pastures. The value of $2.00 per acre was used for cropland aftermath grazing costs. Land rent values of $22.07 per acre for cropland and $14.22 per acre for domesticated grass hayland were used in the determination of production costs for forage types. Supplemental crude protein was added as 20% crude protein range cake, at a cost of $120.00 per ton. Supplemental forage dry matter was added as roughage, at a cost of $35.00 per ton. Production costs per acre, forage dry matter costs per ton, and crude protein yield and cost per pound were taken from Manske (2002a). Livestock forage costs, crude protein supplementation costs, and roughage supplementation costs were taken from Manske (2002b).

Range cow daily nutritional requirements, which change with cow size and production period, were taken from NRC (1996). An average 1200-pound range cow with a calf born in mid March requires 4143 pounds of dry matter, 2202 pounds of energy (TDN), and 339 pounds of crude protein during the 167-day (5.5-month) nongrazing season from mid November until late April. The dry matter and nutrients need to be provided from the forage type selected.

An assumed price of $0.70 per pound was used to determine the economic value of calf weight for both the birth weight and the accumulated weight. The pasture and forage costs for the third trimester and for the early lactation production periods were used to determine cost per pound for the calf birth weight and for the calf accumulated weight, respectively. The pasture and forage costs for the dry gestation, third trimester, and early lactation production periods were used to determine cost per pound for the nongrazing-season calf weight. A positive profit margin can be achieved for beef production during a low market with calf weight value at $0.70 per pound at weaning time when the average forage-feed costs are $0.62 or less per day,

forage dry matter costs are $48.00 or less per ton, and crude protein costs are $0.25 or less per pound.

Pasture and forage costs of feed to meet livestock dry matter and crude protein requirements were determined during this study. Production costs per acre were determined by adding average land rent per acre, custom farm work rates, seed costs per acre, and baling costs at per half ton rates. Costs per ton of forage dry matter (DM) were determined by dividing production costs per acre by pounds of forage dry matter yield per acre and multiplying the quotient by 2000 pounds. Costs per pound of crude protein (CP) were determined in two stages: first, pounds of forage dry matter per acre were multiplied by percentage of forage crude protein to derive pounds of crude protein per acre; then, production costs per acre were divided by pounds of crude protein per acre. Grazingland area per animal unit per month was determined in two stages: first, pounds of forage dry matter per acre were divided by pounds of forage dry matter required per animal unit per day to derive number of grazing days per acre; then, the average number of days per month was divided by the number of grazing days per acre. Harvested-forage land area per animal unit per month or per production period was determined in two stages: first, pounds of crude protein required per animal per day during a production period were divided by percentage of crude protein of forage type to derive pounds of forage dry matter to provide as feed per animal unit per day; then, pounds of forage dry matter to feed per day were divided by pounds of forage dry matter per acre, and the quotient was multiplied by 30 days per month, 30.5 days per month, or the number of days per production period. Forage-feed costs per animal per day (D), per month (Mo), or per production period (PP) were determined in three stages: first, production costs per acre were divided by pounds of forage dry matter per acre, and that quotient was divided by percentage of forage crude protein to derive cost per pound of crude protein; next, the cost per pound of crude protein was multiplied by pounds of crude protein required per animal per day during a production period; then, the forage costs per day were multiplied by 30 days per month, 30.5 days per month, or the number of days per production period. Costs per pound of calf weight gain were determined in two stages: first, accumulated calf weight gain was determined by subtracting calf live weight at the beginning of a growth period from calf live weight at the end of a growth period; then, total pasture costs or forage production costs for a calf growth period were divided by the accumulated calf weight for the growth period.

Nongrazing-season production periods

Grazingland-forage types and harvested-forage types were evaluated during the 167-day nongrazing season, the period from mid November to late April. The dry gestation production period was 32 days from mid November to mid December. The third trimester production period was 90 days from mid December to mid March. The calves were born in mid March, at an average weight of 95 pounds. The early lactation production period was 45 days from mid March to late April.

Harvested-forage types

The harvested forages were evaluated as hay cut by swathing and rolled into large round bales. One forage barley hay treatment was cut at the milk stage and another was cut at the hard dough stage. One oat forage hay treatment was cut at the milk stage and another was cut at the hard dough stage. One pea forage hay treatment was cut at an early plant growth stage and another was cut at a late plant stage. One forage lentil hay treatment was cut at an early plant growth stage and another was cut at a late plant stage. Oat-pea forage was cut for hay. Late crested wheatgrass hay was cut at a mature plant stage. Early crested wheatgrass hay was cut at the boot stage.

Pasture and harvested-forage treatments

Reserved native rangeland pasture with range cake

Grazed forage from separate reserved native rangeland pastures stocked at proper rates was evaluated as livestock feed during each of the three production periods of the nongrazing season. Crude protein was supplemented with range cake as required during the dry gestation, third trimester, and early lactation production periods.

Cropland aftermath pasture; mature crested wheatgrass hay with range cake

Grazed forage from cropland aftermath pastures was evaluated as livestock feed during the dry gestation production period and crude protein was not supplemented. A harvested forage consisting of crested wheatgrass hay cut late, at the mature plant stage, was evaluated as livestock feed during the third trimester and early lactation production periods. Crude protein was supplemented with range cake as required during these two production periods.

Mature crested wheatgrass hay with range cake

A harvested forage consisting of crested wheatgrass hay cut late, at the mature plant stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented during the dry gestation production period, and crude protein was supplemented with range cake as required during the third trimester and early lactation production periods.

Mature crested wheatgrass hay with range cake and alfalfa-corn silage

A harvested forage consisting of crested wheatgrass hay cut late, at the mature plant stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented during the dry gestation production period. Crude protein was supplemented with range cake as required during the third trimester production period. The mature crested wheatgrass hay was supplemented with alfalfa hay and corn silage to meet cow nutrient requirements during the early lactation production period.

Crested wheatgrass hay cut early

A harvested forage consisting of crested wheatgrass hay cut early, at the boot stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Forage barley hay cut early

A harvested forage consisting of forage barley hay cut early, at the milk stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Forage barley hay cut late

A harvested forage consisting of forage barley hay cut late, at the hard dough stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented during the dry gestation and third trimester production periods, and crude protein was supplemented with range cake as required during the early lactation production period.

Oat forage hay cut early

A harvested forage consisting of oat forage hay cut early, at the milk stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Oat forage hay cut late

A harvested forage consisting of oat forage hay cut late, at the hard dough stage, was evaluated as livestock feed during the nongrazing season. Roughage was supplemented during the dry gestation production period, no supplementation was required during the third trimester production period, and crude protein was supplemented with range cake as required during the early lactation production period.

Pea forage hay cut early

A harvested forage consisting of pea forage hay cut at an early plant stage was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Pea forage hay cut late

A harvested forage consisting of pea forage hay cut at a late plant stage was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Forage lentil hay cut early

A harvested forage consisting of forage lentil hay cut at an early plant stage was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Forage lentil hay cut late

A harvested forage consisting of forage lentil hay cut at a late plant stage was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as required during the dry gestation, third trimester, and early lactation production periods.

Oat-pea forage hay

A harvested forage consisting of oat-pea forage hay was evaluated as livestock feed during the nongrazing season. Roughage was supplemented as

required during the dry gestation, third trimester, and early lactation production periods.

The terms “herbage” and “forage” are not synonymous. Herbage is the total amount of aboveground biomass of herbaceous plants like grasses and forbs. Forage is the portion of the herbage that can be removed without detriment to the plants and can provide feed for grazing animals or be harvested mechanically for feeding.

Forage plants in pastures saved for grazing during fall and winter are categorized as reserve forage in this study. Some articles in the popular press have incorrectly used the term “stockpiled forage” to refer to late-season pastures. The word “stockpile” is not correctly used to refer to natural resources or living organisms. Manufactured products, like steel pipe, charcoal briquets, diesel fuel, lumber, and processed food, can be stockpiled at storage locations during periods of surplus and used later in their original stored condition during periods of deficiency. Natural resources, like iron ore, lignite coal, and crude oil deposits, that are left in place as raw material until needed for manufacturing products are reserves, not stockpiles. Living organisms, like trees in a forest and fish in the ocean, that are left in place until needed and continue biological processes of life, growth, and death are reserves, not stockpiles. Perennial grass resources that are left in place and saved as unprocessed pasture forage until needed in fall and winter are living organisms that continue to change their dry matter weight and nutritional quality during the growing season and the nongrowing season and are, therefore, reserves, not stockpiles. The term “stockpiled forage” can correctly be used to refer only to processed forages that do not change in dry matter or nutrient content during storage.

Results

This study evaluated and compared two pasture-forage and twelve harvested-forage treatments for the forage costs and the total feed costs for the dry gestation, third trimester, and early lactation production periods. Costs related to forage production are taken from Manske and Carr 2000b. Total livestock feed costs for pasture-forage and harvested-forage management strategies are taken from Manske 2001. Forage costs for pasture-forage and harvested-forage treatments are shown in tables 1-7.

Pasture-forage costs

Reserved native rangeland pasture

Reserved native rangeland pasture during the 32-day dry gestation production period has a crude protein content of around 4.8%. Late-season native range forage has pasture rent costs of $8.76 per acre, forage dry matter costs of $97.33 per ton, and crude protein costs of $1.01 per pound. A cow grazing reserved native rangeland pasture would require 4.00 acres per month, or 4.27 acres during the dry gestation production period. The reserved pasture forage would cost $37.44 per production period. An additional 0.34 lbs of crude protein per day would need to be supplemented, at a cost of $3.26 per period. Total forage and supplement costs during the dry gestation period would be $40.70, or $1.27 per day.

Reserved native rangeland pasture during the 90-day third trimester production period has a crude protein content of around 4.8%. Late-season native range forage has pasture rent costs of $8.76 per acre, forage dry matter costs of $120.83 per ton, and crude protein costs of $1.26 per pound. A cow grazing reserved native rangeland pasture would require 4.97 acres per month, or 14.90 acres during the third trimester production period. The reserved pasture forage would cost $130.50 per production period. An additional 0.72 lbs of crude protein per day would need to be supplemented, at a cost of $19.44 per period. Total forage and supplement costs during the third trimester period would be $149.94, or $1.67 per day.

Reserved native rangeland pasture during the 45-day early lactation production period has a crude protein content of around 9.2%. Early spring native range forage has pasture rent costs of $8.76 per acre, forage dry matter costs of $140.16 per ton, and crude protein costs of $0.76 per pound. A cow grazing reserved native rangeland pasture would require 6.48 acres per month, or 9.72 acres during the early lactation production period. The reserved pasture forage would cost $85.05 per production period. An additional 0.25 lbs of crude protein per day would need to be supplemented, at a cost of $3.38 per period. Total forage and supplement costs during the early lactation period would be $88.43, or $1.97 per day.

The reserved native rangeland treatment would require 28.89 acres to produce forage to feed during the three production periods of the nongrazing season. Reserved forage would cost $252.99 and supplementation would cost $26.08 per season. Total

feed costs for this treatment would be $279.07 per season, or $1.67 per day.

Cropland aftermath pasture and mature crested wheatgrass hay

Crop aftermath pasture of annual cereal stubble has very low crude protein content during the 32-day dry gestation production period. Cropland aftermath forage has pasture rent costs of $2.00 per acre and forage dry matter costs of $29.63 per ton. A cow grazing cropland aftermath pasture would require 6.63 acres per month, or 7.10 acres during the dry gestation production period. The crop aftermath forage would cost $14.20 per production period. Additional crude protein was not supplemented even though the forage was below the requirements of a dry gestating cow. Total forage and supplement costs during the dry gestation period would be $14.20, or $0.44 per day.

Mature crested wheatgrass hay has a crude protein content of 6.4%. During the 90-day third trimester production period, crested wheatgrass hay cut late would be fed at 24.0 lbs DM/day to provide 1.5 lbs CP/day. An additional 0.3 lbs of crude protein per day would need to be provided, at a cost of $9.02 per period. Production of mature crested wheatgrass hay to feed during the third trimester production period would require 0.45 acres per month, or 1.35 acres per period. The mature forage would cost $46.80 per production period. Total forage and supplement costs during the third trimester period would be $55.82, or $0.62 per day.

Mature crested wheatgrass hay has a crude protein content of 6.4%. During the 45-day early lactation production period, crested wheatgrass hay cut late would be fed at 27.0 lbs DM/day to provide 1.7 lbs CP/day. An additional 1.01 lbs of crude protein per day would need to be provided, at a cost of $13.50 per period. Production of mature crested wheatgrass hay to feed during the early lactation production period would require 0.51 acres per month, or 0.76 acres per period. The mature forage would cost $33.75 per production period. Total forage and supplement costs during the early lactation period would be $47.25, or $1.05 per day.

The cropland aftermath pasture and mature crested wheatgrass hay treatment would require 9.21 acres to produce forage to feed during the three production periods of the nongrazing season. Forage would cost $94.75 and supplementation would cost $22.52 per season. Total feed costs for this treatment would be $117.27 per season, or $0.70 per day.

Harvested-forage costs

Forage barley hay cut early

Forage barley hay cut early, at the milk stage, has a crude protein content of 13.0%. This forage barley hay has production costs of $68.21 per acre, forage dry matter costs of $28.80 per ton, and crude protein costs of $0.11 per pound.

The dry gestation production period was 32 days. Early cut forage barley hay would be fed at 11.5 lbs DM/day to provide 1.5 lbs CP/day. An additional 12.5 lbs of roughage per day would need to be provided, at a cost of $7.00 per period. Production of early cut forage barley hay to feed during the dry gestation period would require 0.07 acres per month, and the forage would cost $5.12 per production period. Total forage and supplement costs during the dry gestation period would be $12.12, or $0.38 per day.

The third trimester production period was 90 days. Early cut forage barley hay would be fed at 14.4 lbs DM/day to provide 1.9 lbs CP/day. An additional 9.6 lbs of roughage per day would need to be provided, at a cost of $14.96 per period. Production of early cut forage barley hay to feed during the third trimester period would require 0.09 acres per month, and the forage would cost $18.90 per production period. Total forage and supplement costs during the third trimester period would be $33.86, or $0.38 per day.

The early lactation production period was 45 days. Early cut forage barley hay would be fed at 21.0 lbs DM/day to provide 2.7 lbs CP/day. An additional 6.0 lbs of roughage per day would need to be provided, at a cost of $4.73 per period. Production of early cut forage barley hay to feed during the early lactation period would require 0.13 acres per month, and the forage would cost $13.50 per production period. Total forage and supplement costs during the early lactation period would be $18.23, or $0.41 per day.

The early cut forage barley hay treatment would require 0.54 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $37.52 and supplementation would cost $26.69 per season. Total feed costs for this treatment would be $64.21 per season, or $0.38 per day.

Forage barley hay cut late

Forage barley hay cut late, at the hard dough stage, has a crude protein content of 9.2%. This forage barley hay has production costs of $70.35 per acre, forage dry matter costs of $27.40 per ton, and crude protein costs of $0.15 per pound.

The dry gestation production period was 32 days. Late-cut forage barley hay would be fed at 16.2 lbs DM/day to provide 1.5 lbs CP/day. An additional 7.8 lbs of roughage per day would need to be provided, at a cost of $4.37 per period. Production of late-cut forage barley hay to feed during the dry gestation period would require 0.09 acres per month, and the forage would cost $7.04 per production period. Total forage and supplement costs during the dry gestation period would be $11.41, or $0.36 per day.

The third trimester production period was 90 days. Late-cut forage barley hay would be fed at 20.3 lbs DM/day to provide 1.9 lbs CP/day. An additional 3.7 lbs of roughage per day would need to be provided, at a cost of $5.83 per period. Production of late-cut forage barley hay to feed during the third trimester period would require 0.12 acres per month, and the forage would cost $26.10 per production period. Total forage and supplement costs during the third trimester period would be $31.93, or $0.35 per day.

The early lactation production period was 45 days. Late-cut forage barley hay would be fed at 27.0 lbs DM/day to provide 2.48 lbs CP/day. An additional 0.25 lbs of crude protein per day would need to be provided, at a cost of $3.38 per period. Production of late-cut forage barley hay to feed during the early lactation period would require 0.16 acres per month, and the forage would cost $18.45 per production period. Total forage and supplement costs during the early lactation period would be $21.83, or $0.49 per day.

The late-cut forage barley hay treatment would require 0.70 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $51.59 and supplementation would cost $13.58 per season. Total feed costs for this treatment would be $65.17 per season, or $0.39 per day.

Oat forage hay cut early

Oat hay cut early, at the milk stage, has a crude protein content of 11.5%. This oat hay has production costs of $69.17 per acre, forage dry matter costs of $29.60 per ton, and crude protein costs of $0.13 per pound.

The dry gestation production period was 32 days. Early cut oat hay would be fed at 13.0 lbs DM/day to provide 1.5 lbs CP/day. An additional 11.0 lbs of roughage per day would need to be provided, at a cost of $6.16 per period. Production of early cut oat hay to feed during the dry gestation period would require 0.08 acres per month, and the forage would cost $6.08 per production period. Total forage and supplement costs during the dry gestation period would be $12.24, or $0.38 per day.

The third trimester production period was 90 days. Early cut oat hay would be fed at 16.3 lbs DM/day to provide 1.9 lbs CP/day. An additional 7.7 lbs of roughage per day would need to be provided, at a cost of $12.13 per period. Production of early cut oat hay to feed during the third trimester period would require 0.10 acres per month, and the forage would cost $21.60 per production period. Total forage and supplement costs during the third trimester period would be $33.73, or $0.37 per day.

The early lactation production period was 45 days. Early cut oat hay would be fed at 23.7 lbs DM/day to provide 2.7 lbs CP/day. An additional 3.3 lbs of roughage per day would need to be provided, at a cost of $2.60 per period. Production of early cut oat hay to feed during the early lactation period would require 0.15 acres per month, and the forage would cost $15.75 per production period. Total forage and supplement costs during the early lactation period would be $18.35, or $0.41 per day.

The early cut oat forage hay treatment would require 0.63 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $43.43 and supplementation would cost $20.89 per season. Total feed costs for this treatment would be $64.32 per season, or $0.39 per day.

Oat forage hay cut late

Oat hay cut late, at the hard dough stage, has a crude protein content of 7.8%. This oat forage hay has production costs of $74.53 per acre, forage dry matter costs of $26.40 per ton, and crude protein costs of $0.17 per pound.

The dry gestation production period was 32 days. Late-cut oat hay would be fed at 19.1 lbs DM/day to provide 1.5 lbs CP/day. An additional 4.9 lbs of roughage per day would need to be provided, at a cost of $2.74 per period. Production of late-cut oat

hay to feed during the dry gestation period would require 0.10 acres per month, and the forage would cost $8.00 per production period. Total forage and supplement costs during the dry gestation period would be $10.74, or $0.34 per day.

The third trimester production period was 90 days. Late-cut oat hay would be fed at 24.0 lbs DM/day to provide 1.9 lbs CP/day. Production of late-cut oat hay to feed during the third trimester period would require 0.13 acres per month, and the forage would cost $28.80 per production period. Total forage and supplement costs during the third trimester period would be $28.80, or $0.32 per day.

The early lactation production period was 45 days. Late-cut oat hay would be fed at 27.0 lbs DM/day to provide 2.1 lbs CP/day. An additional 0.6 lbs of crude protein per day would need to be provided, at a cost of $8.37 per period. Production of late-cut oat hay to feed during the early lactation period would require 0.14 acres per month, and the forage would cost $20.70 per production period. Total forage and supplement costs during the early lactation period would be $29.07, or $0.65 per day.

The late-cut oat forage hay treatment would require 0.70 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $57.50 and supplementation would cost $11.11 per season. Total feed costs for this treatment would be $68.61 per season, or $0.41 per day.

Pea forage hay cut early

Pea forage hay cut at an early plant stage has a crude protein content of 18.9%. This pea forage hay has production costs of $79.96 per acre, forage dry matter costs of $55.00 per ton, and crude protein costs of $0.15 per pound.

The dry gestation production period was 32 days. Early cut pea forage hay would be fed at 7.9 lbs DM/day to provide 1.5 lbs CP/day. An additional 16.1 lbs of roughage per day would need to be provided, at a cost of $9.02 per period. Production of early cut pea forage hay to feed during the dry gestation period would require 0.08 acres per month, and the forage would cost $7.04 per production period. Total forage and supplement costs during the dry gestation period would be $16.06, or $0.50 per day.

The third trimester production period was 90 days. Early cut pea forage hay would be fed at 9.9 lbs DM/day to provide 1.9 lbs CP/day. An additional 14.1 lbs of roughage per day would need to be provided, at a cost of $22.21 per period. Production of early cut pea forage hay to feed during the third trimester period would require 0.11 acres per month, and the forage would cost $25.20 per production period. Total forage and supplement costs during the third trimester period would be $47.41, or $0.53 per day.

The early lactation production period was 45 days. Early cut pea forage hay would be fed at 14.4 lbs DM/day to provide 2.7 lbs CP/day. An additional 12.6 lbs of roughage per day would need to be provided, at a cost of $9.92 per period. Production of early cut pea forage hay to feed during the early lactation period would require 0.15 acres per month, and the forage would cost $18.45 per production period. Total forage and supplement costs during the early lactation period would be $28.37, or $0.63 per day.

The early cut pea forage hay treatment would require 0.64 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $50.69 and supplementation would cost $41.15 per season. Total feed costs for this treatment would be $91.84 per season, or $0.55 per day.

Pea forage hay cut late

Pea forage hay cut at a late plant stage has a crude protein content of 14.4%. This pea forage hay has production costs of $86.87 per acre, forage dry matter costs of $37.40 per ton, and crude protein costs of $0.13 per pound.

The dry gestation production period was 32 days. Late-cut pea forage hay would be fed at 10.3 lbs DM/day to provide 1.5 lbs CP/day. An additional 13.7 lbs of roughage per day would need to be provided, at a cost of $7.67 per period. Production of late-cut pea forage hay to feed during the dry gestation period would require 0.07 acres per month, and the forage would cost $6.08 per production period. Total forage and supplement costs during the dry gestation period would be $13.75, or $0.43 per day.

The third trimester production period was 90 days. Late-cut pea forage hay would be fed at 13.0 lbs DM/day to provide 1.9 lbs CP/day. An additional 11.0 lbs of roughage per day would need to be provided, at a cost of $17.33 per period. Production of late-cut pea forage hay to feed during the third trimester period would require 0.08 acres per month, and the forage would cost $21.60 per production

period. Total forage and supplement costs during the third trimester period would be $38.93, or $0.43 per day.

The early lactation production period was 45 days. Late-cut pea forage hay would be fed at 19.0 lbs DM/day to provide 2.7 lbs CP/day. An additional 8.0 lbs of roughage per day would need to be provided, at a cost of $6.30 per period. Production of late-cut pea forage hay to feed during the early lactation period would require 0.12 acres per month, and the forage would cost $15.75 per production period. Total forage and supplement costs during the early lactation period would be $22.05, or $0.49 per day.

The late-cut pea forage hay treatment would require 0.50 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $43.40 and supplementation would cost $31.30 per season. Total feed costs for this treatment would be $74.70 per season, or $0.45 per day.

Forage lentil hay cut early

Forage lentil hay cut at an early plant stage has a crude protein content of 21.8%. This forage lentil hay has production costs of $59.69 per acre, forage dry matter costs of $71.60 per ton, and crude protein costs of $0.17 per pound.

The dry gestation production period was 32 days. Early cut forage lentil hay would be fed at 6.8 lbs DM/day to provide 1.5 lbs CP/day. An additional 17.2 lbs of roughage per day would need to be provided, at a cost of $9.63 per period. Production of early cut forage lentil hay to feed during the dry gestation period would require 0.12 acres per month, and the forage would cost $8.00 per production period. Total forage and supplement costs during the dry gestation period would be $17.63, or $0.55 per day.

The third trimester production period was 90 days. Early cut forage lentil hay would be fed at 8.6 lbs DM/day to provide 1.9 lbs CP/day. An additional 15.4 lbs of roughage per day would need to be provided, at a cost of $24.26 per period. Production of early cut forage lentil hay to feed during the third trimester period would require 0.15 acres per month, and the forage would cost $28.80 per production period. Total forage and supplement costs during the third trimester period would be $53.06, or $0.59 per day.

The early lactation production period was 45 days. Early cut forage lentil hay would be fed at 12.5 lbs DM/day to provide 2.7 lbs CP/day. An additional 14.5 lbs of roughage per day would need to be provided, at a cost of $11.42 per period. Production of early cut forage lentil hay to feed during the early lactation period would require 0.23 acres per month, and the forage would cost $20.70 per production period. Total forage and supplement costs during the early lactation period would be $32.12, or $0.71 per day.

The early cut forage lentil hay treatment would require 0.93 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $57.50 and supplementation would cost $45.31 per season. Total feed costs for this treatment would be $102.81 per season, or $0.62 per day.

Forage lentil hay cut late

Forage lentil hay cut at a late plant stage has a crude protein content of 14.7%. This forage lentil hay has production costs of $71.48 per acre, forage dry matter costs of $37.00 per ton, and crude protein costs of $0.13 per pound.

The dry gestation production period was 32 days. Late-cut forage lentil hay would be fed at 10.1 lbs DM/day to provide 1.5 lbs CP/day. An additional 13.9 lbs of roughage per day would need to be provided, at a cost of $7.78 per period. Production of late-cut forage lentil hay to feed during the dry gestation period would require 0.08 acres per month, and the forage would cost $6.08 per production period. Total forage and supplement costs during the dry gestation period would be $13.86, or $0.43 per day.

The third trimester production period was 90 days. Late-cut forage lentil hay would be fed at 12.7 lbs DM/day to provide 1.9 lbs CP/day. An additional 11.3 lbs of roughage per day would need to be provided, at a cost of $17.80 per period. Production of late-cut forage lentil hay to feed during the third trimester period would require 0.10 acres per month, and the forage would cost $21.60 per production period. Total forage and supplement costs during the third trimester period would be $39.40, or $0.44 per day.

The early lactation production period was 45 days. Late-cut forage lentil hay would be fed at 18.6 lbs DM/day to provide 2.7 lbs CP/day. An additional 8.4 lbs of roughage per day would need to be provided, at a cost of $6.62 per period. Production of

late-cut forage lentil hay to feed during the early lactation period would require 0.14 acres per month, and the forage would cost $15.75 per production period. Total forage and supplement costs during the early lactation period would be $22.37, or $0.50 per day.

The late-cut forage lentil hay treatment would require 0.61 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $43.43 and supplementation would cost $32.20 per season. Total feed costs for this treatment would be $75.63 per season, or $0.45 per day.

Oat-pea forage hay

Oat-pea forage hay has a crude protein content of 12.5%. Oat-pea forage hay has production costs of $95.52 per acre, forage dry matter costs of $37.20 per ton, and crude protein costs of $0.15 per pound.

The dry gestation production period was 32 days. Oat-pea forage hay would be fed at 11.9 lbs DM/day to provide 1.5 lbs CP/day. An additional 12.1 lbs of roughage per day would need to be provided, at a cost of $6.78 per period. Production of oat-pea forage hay to feed during the dry gestation period would require 0.07 acres per month, and the forage would cost $7.04 per production period. Total forage and supplement costs during the dry gestation period would be $13.82, or $0.43 per day.

The third trimester production period was 90 days. Oat-pea forage hay would be fed at 15.0 lbs DM/day to provide 1.9 lbs CP/day. An additional 9.0 lbs of roughage per day would need to be provided, at a cost of $14.18 per period. Production of oat-pea forage hay to feed during the third trimester period would require 0.09 acres per month, and the forage would cost $25.20 per production period. Total forage and supplement costs during the third trimester period would be $39.38, or $0.44 per day.

The early lactation production period was 45 days. Oat-pea forage hay would be fed at 21.8 lbs DM/day to provide 2.7 lbs CP/day. An additional 5.2 lbs of roughage per day would need to be provided, at a cost of $4.10 per period. Production of oat-pea forage hay to feed during the early lactation period would require 0.13 acres per month, and the forage would cost $18.45 per production period. Total forage and supplement costs during the early lactation period would be $22.55, or $0.50 per day.

The oat-pea forage hay treatment would require 0.52 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $50.69 and supplementation would cost $25.06 per season. Total feed costs for this treatment would be $75.75 per season, or $0.45 per day.

Crested wheatgrass hay cut late

Crested wheatgrass hay cut late, at a mature plant stage, has a crude protein content of 6.4%. This crested wheatgrass hay has production costs of $28.11 per acre, forage dry matter costs of $34.80 per ton, and crude protein costs of $0.28 per pound.

The dry gestation production period was 32 days. Mature crested wheatgrass hay would be fed at 23.4 lbs DM/day to provide 1.5 lbs CP/day. An additional 0.6 lbs of roughage per day would need to be provided, at a cost of $0.34 per period. Production of mature crested wheatgrass hay to feed during the dry gestation period would require 0.44 acres per month, and the forage would cost $13.12 per production period. Total forage and supplement costs during the dry gestation period would be $13.46, or $0.42 per day.

The third trimester production period was 90 days. Mature crested wheatgrass hay would be fed at 24.0 lbs DM/day to provide 1.5 lbs CP/day. An additional 0.3 lbs of crude protein per day would need to be provided, at a cost of $9.02 per period. Production of mature crested wheatgrass hay to feed during the third trimester period would require 0.45 acres per month, and the forage would cost $46.80 per production period. Total forage and supplement costs during the third trimester period would be $55.82, or $0.62 per day.

The early lactation production period was 45 days. Mature crested wheatgrass hay would be fed at 27.0 lbs DM/day to provide 1.7 lbs CP/day. An additional 1.0 lbs of crude protein per day would need to be provided, at a cost of $13.50 per period. Production of mature crested wheatgrass hay to feed during the early lactation period would require 0.51 acres per month, and the forage would cost $33.75 per production period. Total forage and supplement costs during the early lactation period would be $47.25, or $1.05 per day.

The mature crested wheatgrass hay treatment would require 2.58 acres to produce forage to feed during the three production periods of the nongrazing season. Harvested forage would cost $93.67 and supplementation would cost $22.86 per

season. Total feed costs for this treatment would be $116.53 per season, or $0.70 per day.

Crested wheatgrass hay cut early

Crested wheatgrass hay cut early, at the boot stage, has a crude protein content of 14.5%. This crested wheatgrass hay has production costs of $26.50 per acre, forage dry matter costs of $40.80 per ton, and crude protein costs of $0.14 per pound.

The dry gestation production period was 32 days. Early cut crested wheatgrass hay would be fed at 10.3 lbs DM/day to provide 1.5 lbs CP/day. An additional 13.7 lbs of roughage per day would need to be provided, at a cost of $7.68 per period. Production of early cut crested wheatgrass hay to feed during the dry gestation period would require 0.24 acres per month, and the forage would cost $6.72 per production period. Total forage and supplement costs during the dry gestation period would be $14.40, or $0.45 per day.

The third trimester production period was 90 days. Early cut crested wheatgrass hay would be fed at 12.9 lbs DM/day to provide 1.9 lbs CP/day. An additional 11.1 lbs of roughage per day would need to be provided, at a cost of $17.48 per period. Production of early cut crested wheatgrass hay to feed during the third trimester period would require 0.30 acres per month, and the forage would cost $23.40 per production period. Total forage and supplement costs during the third trimester period would be $40.88, or $0.45 per day.

The early lactation production period was 45 days. Early cut crested wheatgrass hay would be fed at 18.8 lbs DM/day to provide 2.7 lbs CP/day. An additional 8.2 lbs of roughage per day would need to be provided, at a cost of $6.43 per period. Production of early cut crested wheatgrass hay to feed during the early lactation period would require 0.43 acres per month, and the forage would cost $17.10 per production period. Total forage and supplement costs during the early lactation period would be $23.53, or $0.52 per day.

The early cut crested wheatgrass hay treatment would require 1.80 acres to produce forage to feed during the three production periods of the nongrowing season. Harvested forage would cost $47.22 and supplementation would cost $31.59 per season. Total feed costs for this treatment would be $78.81 per season, or $0.47 per day.

Supplementation

Most of the harvested-forage types evaluated had levels of crude protein greater than the amount required by range cows, and additional dry matter was needed. Roughage supplementation was required during the three production periods with early cut forage barley, early cut oat forage, early cut pea forage, late-cut pea forage, early cut forage lentil, late-cut forage lentil, oat-pea forage, and early cut crested wheatgrass hays. A few of the forage types had levels of crude protein lower than the amount required by range cows. Crude protein supplementation was required with late-cut forage barley hay during the early lactation period, late-cut oat forage hay during the early lactation period, late-cut crested wheatgrass hay during the third trimester and early lactation periods, and reserved native rangeland pastures during the dry gestation, third trimester, and early lactation periods. Standard sources of roughage and crude protein supplementation were used in this study in order to evaluate the differences among the forage types. Not all types of supplements have these same costs, and selective substitution could reduce the supplementation expenses.

Table 1. Forage costs for the pasture-forage treatments.

		Reserved Native Rangeland			Crop Aftermath, Mature Hay		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac	725	580	480	270		
Forage Wt	lb/ac	180	145	125	135	1600	1600
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	8.76	8.76	8.76	2.00	28.11	28.11
Forage DM Cost	$/ton	97.33	120.83	140.16	29.63	34.80	34.80
Land Area/Mo	ac	4.00	4.97	6.48	6.63	0.45	0.51
Land Area/PP	ac	4.27	14.90	9.72	7.10	1.35	0.76
Land Cost/Mo	$/mo	35.04	43.54	56.76	13.26	6.40	7.25
Land Cost/PP	$/pp	35.41	130.52	85.15	14.20	19.20	10.81
Feed Cost/D	$/d	1.17	1.45	1.89	0.44	0.52	0.75
Feed Cost/Mo	$/mo	35.10	43.50	56.70	13.26	15.60	22.50
Feed Cost/PP	$/pp	37.44	130.50	85.05	14.20	46.80	33.75
Crude Protein	%	4.8	4.8	9.2		6.4	6.4
Crude Protein	lb/ac	8.64	6.96	11.50		102	102
Cost CP	$/lb	1.01	1.26	0.76		0.28	0.28
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d						
CP/D	lb/d	0.34	0.72	0.25		0.33	1.00
Sup. Cost/PP	$/pp	3.26	19.44	3.38		9.02	13.50
Total Feed Cost	$/pp	40.70	149.94	88.43	14.20	55.82	47.25
Cost/D	$/d	1.27	1.67	1.97	0.44	0.62	1.05

Table 2. Forage costs for the forage barley harvested-forage treatments.

		Early Cut			Late Cut		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac						
Forage Wt	lb/ac	4733	4733	4733	5133	5133	5133
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	68.21	68.21	68.21	70.35	70.35	70.35
Forage DM Cost	$/ton	28.80	28.80	28.80	27.40	27.40	27.40
Land Area/Mo	ac	0.07	0.09	0.13	0.09	0.12	0.16
Land Area/PP	ac	0.07	0.27	0.20	0.10	0.36	0.24
Land Cost/Mo	$/mo	1.54	1.99	2.87	1.99	2.65	3.53
Land Cost/PP	$/pp	1.54	5.96	4.41	2.21	7.95	5.30
Feed Cost/D	$/d	0.16	0.21	0.30	0.22	0.29	0.41
Feed Cost/Mo	$/mo	4.80	6.30	9.00	6.60	8.70	12.30
Feed Cost/PP	$/pp	5.12	18.90	13.50	7.04	26.10	18.45
Crude Protein	%	13.0	13.0	13.0	9.2	9.2	9.2
Crude Protein	lb/ac	606	606	606	468	468	468
Cost CP	$/lb	0.11	0.11	0.11	0.15	0.15	0.15
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d	12.5	9.6	6.0	7.8	3.7	
CP/D	lb/d						0.25
Sup. Cost/PP	$/pp	7.00	14.96	4.73	4.37	5.83	3.38
Total Feed Cost	$/pp	12.12	33.86	18.23	11.41	31.93	21.83
Cost/D	$/d	0.38	0.38	0.41	0.36	0.35	0.49

Table 3. Forage costs for the oat harvested-forage treatments.

		Early Cut			Late Cut		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac						
Forage Wt	lb/ac	4667	4667	4667	5667	5667	5667
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	69.17	69.17	69.17	74.53	74.53	74.53
Forage DM Cost	$/ton	29.60	29.60	29.60	26.40	26.40	26.40
Land Area/Mo	ac	0.08	0.10	0.15	0.10	0.13	0.14
Land Area/PP	ac	0.09	0.31	0.23	0.11	0.38	0.21
Land Cost/Mo	$/mo	1.77	2.21	3.31	2.21	2.87	3.09
Land Cost/PP	$/pp	1.99	6.84	5.08	2.43	8.39	4.63
Feed Cost/D	$/d	0.19	0.24	0.35	0.25	0.32	0.46
Feed Cost/Mo	$/mo	5.70	7.20	10.50	7.50	9.60	13.80
Feed Cost/PP	$/pp	6.08	21.60	15.75	8.00	28.80	20.70
Crude Protein	%	11.5	11.5	11.5	7.8	7.8	7.8
Crude Protein	lb/ac	535	535	535	435	435	435
Cost CP	$/lb	0.13	0.13	0.13	0.17	0.17	0.17
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d	11.0	7.7	3.3	4.9		
CP/D	lb/d					0.0	0.62
Sup. Cost/PP	$/pp	6.16	12.13	2.60	2.74	0.0	8.37
Total Feed Cost	$/pp	12.24	33.73	18.35	10.74	28.80	29.07
Cost/D	$/d	0.38	0.37	0.41	0.34	0.32	0.65

Table 4. Forage costs for the pea harvested-forage treatments.

		Early Cut			Late Cut		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac						
Forage Wt	lb/ac	2800	2800	2800	4650	4650	4650
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	79.96	79.96	79.96	86.87	86.87	86.87
Forage DM Cost	$/ton	55.00	55.00	55.00	37.40	37.40	37.40
Land Area/Mo	ac	0.08	0.11	0.15	0.07	0.08	0.12
Land Area/PP	ac	0.09	0.32	0.23	0.07	0.25	0.18
Land Cost/Mo	$/mo	1.77	2.43	3.31	1.54	1.77	2.65
Land Cost/PP	$/pp	1.99	7.09	5.08	1.54	5.52	3.97
Feed Cost/D	$/d	0.22	0.28	0.41	0.19	0.24	0.35
Feed Cost/Mo	$/mo	6.60	8.40	12.30	5.70	7.50	10.50
Feed Cost/PP	$/pp	7.04	25.20	18.45	6.08	21.60	15.75
Crude Protein	%	18.9	18.9	18.9	14.4	14.4	14.4
Crude Protein	lb/ac	526	526	526	685	685	685
Cost CP	$/lb	0.15	0.15	0.15	0.13	0.13	0.13
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d	16.1	14.1	12.6	13.7	11.0	8.0
CP/D	lb/d						
Sup. Cost/PP	$/pp	9.02	22.21	9.92	7.67	17.33	6.30
Total Feed Cost	$/pp	16.06	47.41	28.37	13.75	38.93	22.05
Cost/D	$/d	0.50	0.53	0.63	0.43	0.43	0.49

Table 5. Forage costs for the forage lentil harvested-forage treatments.

		Early Cut			Late Cut		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac						
Forage Wt	lb/ac	1667	1667	1667	3867	3867	3867
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	59.69	59.69	59.69	71.48	71.48	71.48
Forage DM Cost	$/ton	71.60	71.60	71.60	37.00	37.00	37.00
Land Area/Mo	ac	0.12	0.15	0.23	0.08	0.10	0.14
Land Area/PP	ac	0.13	0.46	0.34	0.09	0.30	0.22
Land Cost/Mo	$/mo	2.65	3.31	5.08	1.77	2.21	3.09
Land Cost/PP	$/pp	2.87	10.15	7.50	1.99	6.62	4.86
Feed Cost/D	$/d	0.25	0.32	0.46	0.19	0.24	0.35
Feed Cost/Mo	$/mo	7.50	9.60	13.80	5.70	7.20	10.50
Feed Cost/PP	$/pp	8.00	28.80	20.70	6.08	21.60	15.75
Crude Protein	%	21.8	21.8	21.8	14.7	14.7	14.7
Crude Protein	lb/ac	361	361	361	567	567	567
Cost CP	$/lb	0.17	0.17	0.17	0.13	0.13	0.13
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d	17.2	15.4	14.5	13.9	11.3	8.4
CP/D	lb/d						
Sup. Cost/PP	$/pp	9.63	24.26	11.42	7.78	17.80	6.62
Total Feed Cost	$/pp	17.63	53.06	32.12	13.86	39.40	22.37
Cost/D	$/d	0.55	0.59	0.71	0.43	0.44	0.50

Table 6. Forage costs for oat-pea harvested-forage treatment.

		Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring
Days		32	90	45
Herbage Wt	lb/ac			
Forage Wt	lb/ac	5143	5143	5143
Forage DM/AU	lb/d	24	24	27
Production Cost	$/ac	95.52	95.52	95.52
Forage DM Cost	$/ton	37.20	37.20	37.20
Land Area/Mo	ac	0.07	0.09	0.13
Land Area/PP	ac	0.07	0.26	0.19
Land Cost/Mo	$/mo	1.54	1.99	2.87
Land Cost/PP	$/pp	1.54	5.74	4.19
Feed Cost/D	$/d	0.22	0.28	0.41
Feed Cost/Mo	$/mo	6.60	8.40	12.30
Feed Cost/PP	$/pp	7.04	25.20	18.45
Crude Protein	%	12.5	12.5	12.5
Crude Protein	lb/ac	611	611	611
Cost CP	$/lb	0.15	0.15	0.15
Cow CP/D	lb/d	1.49	1.87	2.73
Supplementation				
Roughage/D	lb/d	12.1	9.0	5.2
CP/D	lb/d			
Sup. Cost/PP	$/pp	6.78	14.18	4.10
Total Feed Cost	$/pp	13.82	39.38	22.55
Cost/D	$/d	0.43	0.44	0.50

Table 7. Forage costs for crested wheatgrass harvested-forage treatments.

		Mature			Early		
		Dry Gestation	Third Trimester	Early Lactation	Dry Gestation	Third Trimester	Early Lactation
Season		Late Fall	Winter	Early Spring	Late Fall	Winter	Early Spring
Days		32	90	45	32	90	45
Herbage Wt	lb/ac						
Forage Wt	lb/ac	1600	1600	1600	1300	1300	1300
Forage DM/AU	lb/d	24	24	27	24	24	27
Production Cost	$/ac	28.11	28.11	28.11	26.50	26.50	26.50
Forage DM Cost	$/ton	34.80	34.80	34.80	40.80	40.80	40.80
Land Area/Mo	ac	0.44	0.45	0.51	0.24	0.30	0.43
Land Area/PP	ac	0.47	1.35	0.76	0.26	0.89	0.65
Land Cost/Mo	$/mo	6.26	6.40	7.25	3.41	4.27	6.11
Land Cost/PP	$/pp	6.68	19.20	10.81	3.64	12.66	9.24
Feed Cost/D	$/d	0.41	0.52	0.75	0.21	0.26	0.38
Feed Cost/Mo	$/mo	12.30	15.60	22.50	6.30	7.80	11.40
Feed Cost/PP	$/pp	13.12	46.80	33.75	6.72	23.40	17.10
Crude Protein	%	6.4	6.4	6.4	14.5	14.5	14.5
Crude Protein	lb/ac	102	102	102	189	189	189
Cost CP	$/lb	0.28	0.28	0.28	0.14	0.14	0.14
Cow CP/D	lb/d	1.49	1.87	2.73	1.49	1.87	2.73
Supplementation							
Roughage/D	lb/d	0.6			13.72	11.10	8.17
CP/D	lb/d		0.33	1.00			
Sup. Cost/PP	$/pp	0.34	9.02	13.50	7.68	17.48	6.43
Total Feed Cost	$/pp	13.46	55.82	47.25	14.40	40.88	23.53
Cost/D	$/d	0.42	0.62	1.05	0.45	0.45	0.52

Summary of pasture-forage and harvested-forage costs

Pasture and forage costs during the dry gestation, third trimester, and early lactation production periods during the nongrazing season are shown in tables 8-11.

Total feed costs during the 32-day dry gestation production period ranged between $10.74 per period, or $0.34 per day, and $40.70 per period, or $1.27 per day. Reserved native rangeland pasture had the highest costs. Forage barley hay and oat forage hay had the lowest costs. Early cut pea forage hay and early cut forage lentil hay had costs greater than $15.00 per period or $0.47 per day. The other forage types had costs lower than $14.50 per period or $0.45 per day.

Total feed costs during the 90-day third trimester production period ranged between $28.80 per period, or $0.32 per day, and $149.94 per period, or $1.67 per day. Reserved native rangeland pasture had the highest costs. Mature crested wheatgrass hay had the highest harvested-forage costs, and forage barley hay and oat forage hay had the lowest costs. Early cut pea forage hay and early cut forage lentil hay had costs greater than $45.00 per period or $0.50 per day. The other forage types had costs $0.45 or lower per day and less than $41.00 per period.

Total feed costs during the 45-day early lactation production period ranged between $18.23 per period, or $0.41 per day, and $88.43 per period, or $1.97 per day. Reserved native rangeland pasture had the highest costs. Mature crested wheatgrass hay had the highest harvested-forage costs, and early cut forage barley hay and early cut oat forage hay had the lowest costs. Late-cut oat forage hay, early cut pea forage hay, and early cut forage lentil hay had costs greater than $28.00 per period or $0.62 per day. The other forage types had costs lower than $25.00 per period or $0.55 per day.

Total feed costs for the pasture-forage and harvested-forage treatments during the nongrazing season ranged between $64.21 per season, or $0.38 per day, and $279.07 per season, or $1.67 per day. Reserved native rangeland pasture had the highest costs. Mature crested wheatgrass hay had the highest harvested-forage costs, and early cut forage barley hay had the lowest costs. Early cut pea forage hay and early cut forage lentil hay had costs greater than $90.00 per season or $0.54 per day. The other forage types had costs lower than $79.00 per season or $0.47 per day.

Harvested forages cut at plant stages that yield greater amounts of crude protein per acre have lower costs per unit of nutrient and are relatively low-cost forages that help reduce livestock production costs. Early crested wheatgrass, early forage barley, early oat forage, late pea forage, late forage lentil, and oat-pea forage hays have crude protein costs below $0.25 per pound and feed costs below $0.62 per day. Use of these forages reduces livestock feed costs so that profit margins are positive even when calves are sold at $0.70 per pound.

Forage costs during the nongrazing season

Forage costs of pasture-forage and harvested-forage management treatments for range cows during the 167-day nongrazing season are shown in table 12.

Production costs per acre for annual cereal and annual legume hays were considerably greater than those for perennial grass hays and pasture forages. Production costs per acre for harvested forages cut late were greater than production costs per acre for the same forage type cut early because the greater forage dry matter yield of the late-cut forages resulted in increased baling costs. The relationships among forage production costs of pasture forage, perennial hays, and annual hays are often interpreted to indicate that feeding livestock annual cereal and annual legume hays is more expensive than feeding livestock perennial grass hays or grazing late-season pastures. This interpretation of forage production costs per acre has been the basis for numerous management strategies for range cows during the nongrazing season. However, neither production costs per acre nor rent per acre accurately reflects livestock production costs because forage dry matter weight per acre and nutrient weight per acre captured through grazing and haying vary with forage type and plant growth stage, and the variations are not proportional to these per acre costs.

The costs per unit of forage dry matter reflect the relationships between the production costs per acre and the amount of dry matter cut for hay. The forage dry matter costs for perennial grass hays ($34.80 and $40.80/ton), annual cereal ($26.40 to $29.60/ton), and annual legume ($37.00 to $71.60/ton) hays express this relationship. Forage dry matter costs per ton were greater for harvested forages cut early than for the same forage type cut late because the production costs per acre were shared by fewer pounds of forage dry matter yield for the early cut forages.

Cost of harvested forage per unit of weight is commonly used to compare different forage types. Most harvested forages intended as feed for beef cattle are still bought and sold by some measure of forage weight, like pounds, tons, or bales. Placing priority on the cost of forage weight has led to the common practice of comparing harvested-forage costs by the forage cost per ton and to the development of the misconception that the harvested forage with the lowest cost per ton is the lowest-cost livestock feed. Forage dry matter costs per unit of weight do not accurately reflect livestock production costs because of the variable quantity of nutrients contained within the dry matter and the resulting differences in the amount of dry matter needed to provide adequate quantities of nutrients for livestock.

Cost per unit of nutrient is an important indicator of livestock forage costs. Nutrient cost per unit of weight is related to the forage dry matter cost and the quantity of nutrients per unit of forage weight. Crude protein costs for early cut perennial grass hay ($0.14/lb) and annual cereal hays ($0.11 and $0.13/lb) were lower than crude protein costs for the same forage types cut late ($0.28, $0.15 and $0.17/lb, respectively). Crude protein costs for late-cut annual legume hays ($0.13 and $0.13/lb) were lower than crude protein costs for the same forage types cut early ($0.15 and $0.17/lb). High-quality forages have lower costs per unit of nutrient than low-quality forages at the same cost per unit of dry matter weight. Even high-quality forages with a higher cost per unit of dry matter weight may actually be less costly feed because less of the high-quality forage is needed to meet the nutritional requirements of the livestock.

Land area per animal unit, an important factor in beef production costs, is related to the amount of nutrients captured per acre and the amount of nutrients required by a cow. Land area required to produce forage nutrients to feed a 1200-pound cow during the three production periods of the nongrazing season was 0.50 to 0.61 acres for oat-pea and late-cut legume hays, 0.54 to 0.63 acres for early cut cereal hays, 0.70 acres for late-cut cereal hays, 0.64 to 0.93 acres for early cut legume hays, 1.80 acres for early cut crested wheatgrass hay, 2.58 acres for late-cut crested wheatgrass hay, 9.21 acres for crop aftermath, and 28.89 for reserved native rangeland pastures. Reserved native rangeland and crop aftermath pastures required the largest land area. Crested wheatgrass hay cut at a mature plant stage required the largest harvested-forage land area, and forage barley cut at the milk stage, pea forage cut late, and oat-pea hay required the smaller land areas. Costs of the land area required to provide adequate quantities of forage nutrients for a cow contribute substantially to total production costs. When the amount of the produced nutrients captured from a land base is greater, the land area required by each animal unit will be smaller and the production costs will be lower.

During the nongrazing season, livestock forage-feed costs per day and per season for early cut crested wheatgrass hay ($0.47/day and $78.81/season) were a little more than half the feed costs for mature-cut crested wheatgrass hay ($0.70/day and $116.53/season). The feed costs for early cut annual cereal hays ($0.38 and $0.39/day) were lower than the feed costs for late-cut annual cereal hays ($0.39 and $0.41/day). The feed costs for late-cut annual legume hays ($0.45 and $0.45/day) were lower than the feed costs for early cut annual legume hays ($0.55 and $0.62/day). The feed costs for annual cereal and late-cut annual legume hays were less than $0.45 per day and $76.00 per season. The feed costs for oat-pea hay ($0.45/day) were similar to the feed costs for late-cut legume hays. Reserved native rangeland pastures ($1.67/day and $279.07/season) and cropland aftermath pastures ($0.70/day and $117.27/season) had the highest livestock feed costs.

Perennial grass hays yield greater pounds of crude protein per acre when harvested during early developmental stages, around the boot stage to the flowering stage. Annual cereal hays yield greater pounds of crude protein per acre when harvested during early developmental stages, around the flowering stage to milk stage. Annual legume hays generally yield greater pounds of crude protein per acre when harvested during the middle and late stages of development. Cereal-legume mixed hays have generally not produced greater quantities of forage dry matter or pounds of crude protein per acre than have annual cereals or annual legumes seeded separately, because of the differences in the optimum times to harvest annual cereals and annual legumes. Cutting forage hays at their optimum harvest times reduces livestock feed costs per day and per month because the cost per pound of crude protein is lower when greater pounds of crude protein per acre are captured during harvest. Mature crested wheatgrass hay had the highest livestock forage-feed costs (greater than $0.62/day and $105.00/season). Forage barley cut at the milk stage had the lowest feed costs ($0.38/day and $64.00/season) for range cows during the nongrazing season.

Table 8. Forage and supplement costs for pasture-forage treatments.

		Reserved Native Rangeland	Cropland Aftermath and Mature Crested Wheatgrass Hay
Dry Gestation			
Land Area	ac/pp	4.27	7.10
Forage	$/pp	37.44	14.20
Supplement	$/pp	3.26	
Feed Cost	$/pp	40.70	14.20
Third Trimester			
Land Area	ac/pp	14.90	1.35
Forage	$/pp	130.50	46.80
Supplement	$/pp	19.44	9.02
Feed Cost	$/pp	149.94	55.82
Early Lactation			
Land Area	ac/pp	9.72	0.76
Forage	$/pp	85.05	33.75
Supplement	$/pp	3.38	13.50
Feed Cost	$/pp	88.43	47.25
Nongrazing Season			
Total Land Area	acres	28.89	9.21
Total Forage	$	252.99	94.75
Total Supplement	$	26.08	22.52
Total Feed Cost	$	279.07	117.27
Cost/Day	$	1.67	0.70

Table 9. Forage and supplement costs for annual cereal hay treatments.

		Forage Barley Hay Early Cut	Forage Barley Hay Late Cut	Oat Hay Early Cut	Oat Hay Late Cut
Dry Gestation					
Land Area	ac/pp	0.07	0.10	0.09	0.11
Forage	$/pp	5.12	7.04	6.08	8.00
Supplement	$/pp	7.00	4.37	6.16	2.74
Feed Cost	$/pp	12.12	11.41	12.24	10.74
Third Trimester					
Land Area	ac/pp	0.27	0.36	0.31	0.38
Forage	$/pp	18.90	26.10	21.60	28.80
Supplement	$/pp	14.96	5.83	12.13	0.0
Feed Cost	$/pp	33.86	31.93	33.73	28.80
Early Lactation					
Land Area	ac/pp	0.20	0.24	0.23	0.21
Forage	$/pp	13.50	18.45	15.75	20.70
Supplement	$/pp	4.73	3.38	2.60	8.37
Feed Cost	$/pp	18.23	21.83	18.35	29.07
Nongrazing Season					
Total Land Area	acres	0.54	0.70	0.63	0.70
Total Forage	$	37.52	51.59	43.43	57.50
Total Supplement	$	26.69	13.58	20.89	11.11
Total Feed Cost	$	64.21	65.17	64.32	68.61
Cost/Day	$	0.38	0.39	0.39	0.41

Table 10. Forage and supplement costs for annual legume hay treatments.

		Pea Hay Early Cut	Pea Hay Late Cut	Forage Lentil Hay Early Cut	Forage Lentil Hay Late Cut	Oat-Pea Hay
Dry Gestation						
Land Area	ac/pp	0.09	0.07	0.13	0.09	0.07
Forage	$/pp	7.04	6.08	8.00	6.08	7.04
Supplement	$/pp	9.02	7.67	9.63	7.78	6.78
Feed Cost	$/pp	16.06	13.75	17.63	13.86	13.82
Third Trimester						
Land Area	ac/pp	0.32	0.25	0.46	0.30	0.26
Forage	$/pp	25.20	21.60	28.80	21.60	25.20
Supplement	$/pp	22.21	17.33	24.26	17.80	14.18
Feed Cost	$/pp	47.41	38.93	53.06	39.40	39.38
Early Lactation						
Land Area	ac/pp	0.23	0.18	0.34	0.22	0.19
Forage	$/pp	18.45	15.75	20.70	15.75	18.45
Supplement	$/pp	9.92	6.30	11.42	6.62	4.10
Feed Cost	$/pp	38.37	22.05	32.12	22.37	22.55
Nongrazing Season						
Total Land Area	acres	0.64	0.50	0.93	0.61	0.52
Total Forage	$	50.69	43.40	57.50	43.43	50.69
Total Supplement	$	41.15	31.30	45.31	32.20	25.06
Total Feed Cost	$	91.84	74.70	102.81	75.63	75.75
Cost/Day	$	0.55	0.45	0.62	0.45	0.45

Table 11. Forage and supplement costs for domesticated grass hay treatments.

		Crested Wheatgrass Hay Late Cut	Crested Wheatgrass Hay Early Cut
Dry Gestation			
Land Area	ac/pp	0.47	0.26
Forage	$/pp	13.12	6.72
Supplement	$/pp	0.34	7.68
Feed Cost	$/pp	13.46	14.40
Third Trimester			
Land Area	ac/pp	1.35	0.89
Forage	$/pp	46.80	23.40
Supplement	$/pp	9.02	17.48
Feed Cost	$/pp	55.82	40.88
Early Lactation			
Land Area	ac/pp	0.76	0.65
Forage	$/pp	33.75	17.10
Supplement	$/pp	13.50	6.43
Feed Cost	$/pp	47.25	23.53
Nongrazing Season			
Total Land Area	acres	2.58	1.80
Total Forage	$	93.67	47.22
Total Supplement	$	22.86	31.59
Total Feed Cost	$	116.53	78.81
Cost/Day	$	0.70	0.47

Table 12. Forage costs of pasture-forage and harvested-forage management treatments for range cows during the 167-day nongrazing season.

	Production Costs	Forage Dry Matter Costs	Crude Protein Costs	Land Area per nongrazing season	Feed Costs per nongrazing season	Feed Costs per day
	$/ac	$/ton	$/lb	ac	$	$
Forage Barley Milk Stage Hay	68.21	28.80	0.11	0.54	64.21	0.38
Forage Barley Hard Dough Stage Hay	70.35	27.40	0.15	0.70	65.17	0.39
Oat Milk Stage Hay	69.17	29.60	0.13	0.63	64.32	0.39
Oat Hard Dough Stage Hay	74.35	26.40	0.17	0.70	68.61	0.41
Pea Forage Early Stage Hay	79.96	55.00	0.15	0.64	91.84	0.55
Pea Forage Late Stage Hay	86.87	37.40	0.13	0.50	74.70	0.45
Forage Lentil Early Stage Hay	59.69	71.60	0.17	0.93	102.81	0.62
Forage Lentil Late Stage Hay	71.48	37.00	0.13	0.61	75.63	0.45
Oat-Pea Hay	95.52	37.20	0.15	0.52	75.75	0.45
Crested Wheatgrass Mature Hay	28.11	34.80	0.28	2.58	116.53	0.70
Crested Wheatgrass Early Hay	26.50	40.80	0.14	1.80	78.81	0.47
Reserved Native Range	8.76	122.13	1.04	28.89	279.07	1.67
Crop Aftermath and Mature Crested Wheatgrass Hay	7.98	43.72		9.21	117.27	0.70

Calf weight value and net returns after pasture-forage costs

Costs-returns of forage-type treatments for range cows during the nongrazing season are shown in tables 13-16.

Reserved native rangeland pasture with range cake

Reserved native rangeland pasture had production costs of $8.76 per acre and forage dry matter costs of $122.13 per ton. A 1200-pound cow would require 28.89 acres of properly stocked native range pasture for the 167-day nongrazing season, and the forage to feed the animal would cost $252.99. Crude protein supplementation with range cake would cost $26.08. Total forage and supplement costs would be $279.07 per nongrazing season, or $1.67 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $1.58 per pound. Calf weight gain during the early lactation production period was 1.80 pounds per day, and accumulated weight gain was 81 pounds, at a cost of $1.09 per pound. Total calf weight was 176 pounds, at a cost of $1.59 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $123.20 per calf. The net returns after pasture-forage costs were a loss of $155.87 per cow-calf pair grazing reserved native rangeland pastures.

Cows grazing reserved native rangeland pastures would capture 8.74 pounds of crude protein per acre; the prorated cost of the nutrient would be $1.04 per pound. This high cost of crude protein would produce pasture-forage costs greater than the calf weight value. Reserved native range pastures supplemented with range cake would return a loss of $5.40 per acre.

Grazed cropland aftermath; mature crested wheatgrass hay with range cake

Cropland aftermath and mature crested wheatgrass hay had production costs of $7.98 per acre and forage dry matter costs of $43.72 per ton. Production of cropland aftermath and mature crested wheatgrass hay to feed a 1200-pound cow during the 167-day nongrazing season would require 9.21 acres, and the forage would cost $94.75. Forage from cropland aftermath pastures was not supplemented with crude protein, even though the forage was below the crude protein requirements of a dry gestating cow. Dry cows grazing cropland aftermath lost an average of 1.14 lbs per day and an average of 4.82 lbs per acre; accumulated weight loss was 36.48 lbs per period, which is about half of one body condition score. This weight loss is an additional cost for thin cows and cows in moderate condition but not for heavy cows. Crude protein supplementation with range cake while mature crested wheatgrass hay is fed would cost $22.52. Total forage and supplement costs would be $117.27 per nongrazing season, or $0.70 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.59 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.55 per pound. Total calf weight was 180.5 pounds, at a cost of $0.65 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $9.08 per cow-calf pair grazing cropland aftermath and fed mature crested wheatgrass hay.

Haying crested wheatgrass at the mature stage captured 102 pounds of crude protein per acre; the prorated cost of the nutrient was $0.28 per pound. Grazing cropland aftermath and feeding mature crested wheatgrass hay supplemented with range cake returned $0.99 per acre above pasture-forage costs.

Mature crested wheatgrass hay with range cake

Mature crested wheatgrass hay had production costs of $28.11 per acre and forage dry matter costs of $34.80 per ton. Production of mature crested wheatgrass hay to feed a 1200-pound cow during the 167-day nongrazing season would require 2.58 acres, and the forage would cost $93.67. Roughage supplementation would cost $0.34 and crude protein supplementation with range cake would cost $22.52. Total forage and supplement costs would be $116.53 per nongrazing season, or $0.70 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.59 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.55 per pound. Total calf weight was 180.5 pounds, at a cost of $0.65 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $9.82 per cow-calf pair fed mature crested wheatgrass hay supplemented with range cake.

Haying crested wheatgrass at the mature stage captured 102 pounds of crude protein per acre; the prorated cost of the nutrient was $0.28 per pound. Mature crested wheatgrass hay supplemented with range cake returned $3.81 per acre above pasture-forage costs.

Mature crested wheatgrass hay with range cake and alfalfa-corn silage

Mature crested wheatgrass hay had production costs of $28.11 per acre and forage dry matter costs of $34.80 per ton. Production of mature crested wheatgrass hay to feed a 1200-pound cow during the 167-day nongrazing season would require 2.72 acres, and the forage would cost $77.92. Nutrient supplementation would cost $11.50 for range cake and $15.75 for alfalfa-corn silage. Total forage and supplement costs would be $105.17 per nongrazing season, or $0.63 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.59 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.42 per pound. Total calf weight was 180.5 pounds, at a cost of $0.58 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $21.18 per cow-calf pair fed mature crested wheatgrass hay.

Haying crested wheatgrass at the mature stage captured 102 pounds of crude protein per acre; the prorated cost of the nutrient was $0.28 per pound. Mature crested wheatgrass hay supplemented with range cake and alfalfa-corn silage returned $7.79 per acre above pasture-forage costs.

Crested wheatgrass hay cut early

Crested wheatgrass hay cut early, at the boot stage, had production costs of $26.50 per acre and forage dry matter costs of $40.80 per ton. Production of early cut crested wheatgrass hay to feed a 1200-pound cow during the 167-day nongrazing season would require 1.80 acres, and the forage would cost $47.22. Roughage supplementation would cost $31.59. Total forage and supplement costs would be $78.81 per nongrazing season, or $0.47 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.43 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.28 per pound. Total calf weight was 180.5 pounds, at a cost of $0.44 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $47.54 per cow-calf pair fed early cut crested wheatgrass hay.

Haying crested wheatgrass at the boot stage captured 189 pounds of crude protein per acre; the prorated cost of the nutrient was $0.14 per pound. Early cut crested wheatgrass hay returned $26.14 per acre above pasture-forage costs.

Forage barley hay cut early

Forage barley hay cut early, at the milk stage, had production costs of $68.21 per acre and forage dry matter costs of $28.80 per ton. Production of early cut forage barley hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.54 acres, and the forage would cost $37.52. Roughage supplementation would cost $29.69. Total forage and supplement costs would be $64.21 per nongrazing season, or $0.38 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.36 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.21 per pound. Total calf weight was 180.5 pounds, at a cost of $0.36 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $62.14 per cow-calf pair fed early cut forage barley hay.

Haying forage barley at the milk stage captured 606 pounds of crude protein per acre; the prorated cost of the nutrient was $0.11 per pound. Early cut forage barley hay returned $115.07 per acre above pasture-forage costs.

Forage barley hay cut late

Forage barley hay cut late, at the hard dough stage, had production costs of $70.35 per acre and forage dry matter costs of $27.40 per ton. Production of late-cut forage barley hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.70 acres, and the forage would cost $51.59. Crude protein supplementation would cost $3.38 and roughage supplementation would cost $10.20. Total forage and supplement costs would be $65.17 per

nongrazing season, or $0.39 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.34 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.26 per pound. Total calf weight was 180.5 pounds, at a cost of $0.36 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $61.18 per cow-calf pair fed late-cut forage barley hay.

Haying forage barley at the hard dough stage captured 468 pounds of crude protein per acre; the prorated cost of the nutrient was $0.15 per pound. Late-cut forage barley hay returned $87.49 per acre above pasture-forage costs.

Oat forage hay cut early

Oat forage hay cut early, at the milk stage, had production costs of $69.17 per acre and forage dry matter costs of $29.60 per ton. Production of early cut oat forage hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.63 acres, and the forage would cost $43.43. Roughage supplementation would cost $20.89. Total forage and supplement costs would be $64.32 per nongrazing season, or $0.39 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.36 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.21 per pound. Total calf weight was 180.5 pounds, at a cost of $0.36 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $62.03 per cow-calf pair fed early cut oat forage hay.

Haying oat forage at the milk stage captured 535 pounds of crude protein per acre; the prorated cost of the nutrient was $0.13 per pound. Early cut oat forage hay returned $98.46 per acre above pasture-forage costs.

Oat forage hay cut late

Oat forage hay cut late, at the hard dough stage, had production costs of $74.53 per acre and forage dry matter costs of $26.40 per ton. Production of late-cut oat forage hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.70 acres, and the forage would cost $57.50. Crude protein supplementation would cost $8.37 and roughage supplementation would cost $2.74. Total forage and supplement costs would be $68.61 per nongrazing season, or $0.41 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.30 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.34 per pound. Total calf weight was 180.5 pounds, at a cost of $0.38 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $57.74 per cow-calf pair fed late-cut oat forage hay.

Haying oat forage at the hard dough stage captured 435 pounds of crude protein per acre; the prorated cost of the nutrient was $0.17 per pound. Late-cut oat forage hay returned $82.49 per acre above pasture-forage costs.

Pea forage hay cut early

Pea forage hay cut at an early plant stage had production costs of $79.96 per acre and forage dry matter costs of $55.00 per ton. Production of early cut pea forage hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.64 acres, and the forage would cost $50.69. Roughage supplementation would cost $41.15. Total forage and supplement costs would be $91.84 per nongrazing season, or $0.55 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.50 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.33 per pound. Total calf weight was 180.5 pounds, at a cost of $0.51 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $34.51 per cow-calf pair fed early cut pea forage hay.

Haying pea forage at an early plant stage captured 526 pounds of crude protein per acre; the prorated cost of the nutrient was $0.15 per pound. Early cut pea forage hay returned $53.92 per acre above pasture-forage costs.

Pea forage hay cut late

Pea forage hay cut at a late plant stage had production costs of $86.87 per acre and forage dry matter costs of $37.40 per ton. Production of late-cut pea forage hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.50 acres, and the forage would cost $43.40. Roughage supplementation would cost $31.30. Total forage and supplement costs would be $74.70 per nongrazing season, or $0.45 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.41 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.26 per pound. Total calf weight was 180.5 pounds, at a cost of $0.41 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $51.65 per cow-calf pair fed late-cut pea forage hay.

Haying pea forage at a late plant stage captured 685 pounds of crude protein per acre; the prorated cost of the nutrient was $0.13 per pound. Late-cut pea forage hay returned $103.30 per acre above pasture-forage costs.

Forage lentil hay cut early

Forage lentil hay cut at an early plant stage had production costs of $59.69 per acre and forage dry matter costs of $71.60 per ton. Production of early cut forage lentil hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.93 acres, and the forage would cost $57.50. Roughage supplementation would cost $45.31. Total forage and supplement costs would be $102.81 per nongrazing season, or $0.62 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.56 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.38 per pound. Total calf weight was 180.5 pounds, at a cost of $0.57 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $23.54 per cow-calf pair fed early cut forage lentil hay.

Haying forage lentil at an early plant stage captured 361 pounds of crude protein per acre; the prorated cost of the nutrient was $0.17 per pound. Early cut forage lentil hay returned $25.31 per acre above pasture-forage costs.

Forage lentil hay cut late

Forage lentil hay cut at a late plant stage had production costs of $71.48 per acre and forage dry matter costs of $37.00 per ton. Production of late-cut forage lentil hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.61 acres, and the forage would cost $43.43. Roughage supplementation would cost $32.20. Total forage and supplement costs would be $75.63 per nongrazing season, or $0.45 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.41 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.26 per pound. Total calf weight was 180.5 pounds, at a cost of $0.42 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $50.72 per cow-calf pair fed late-cut forage lentil hay.

Haying forage lentil at a late plant stage captured 567 pounds of crude protein per acre; the prorated cost of the nutrient was $0.13 per pound. Late-cut forage lentil hay returned $83.15 per acre above pasture-forage costs.

Oat-pea forage hay

Oat-pea forage hay had production costs of $95.52 per acre and forage dry matter costs of $37.20 per ton. Production of oat-pea forage hay to feed a 1200-pound cow during the 167-day nongrazing season would require 0.52 acres, and the forage would cost $50.69. Roughage supplementation would cost $25.06. Total forage and supplement costs would be $75.75 per nongrazing season, or $0.45 per day during that 167-day period.

Calves were born in mid March, with an average weight of 95 pounds at a cost of $0.41 per pound. Calf weight gain during the early lactation production period was 1.90 pounds per day, and accumulated weight gain was 85.5 pounds, at a cost of $0.26 per pound. Total calf weight was 180.5 pounds, at a cost of $0.42 per pound. When calf weight was assumed to have a value of $0.70 per pound, the gross value was $126.35 per calf. The net returns after pasture-forage costs were $50.60 per cow-calf pair fed oat-pea forage hay.

Haying oat-pea forage captured 611 pounds of crude protein per acre; the prorated cost of the nutrient was $0.15 per pound. Oat-pea forage returned $97.31 per acre above pasture-forage costs.

Table 13. Pasture and forage costs during the 167-day nongrazing season.

Forage-Type Treatments	Forage Dry Matter Cost $/ton	Forage Cost $	Supplement Cost $	Total Feed Cost $	Cost per Day $/d
Reserved Native Range with cake	122.13	252.99	26.08	279.07	1.67
Cropland Aftermath and Mature Crested Wheatgrass with cake	43.72	94.75	22.52	117.27	0.70
Mature Crested Wheatgrass with cake	34.80	93.67	22.86	116.53	0.70
Mature Crested Wheatgrass with cake and alfalfa-silage	34.80	77.92	27.25	105.17	0.63
Crested Wheatgrass, Early	40.80	47.22	31.59	78.81	0.47
Forage Barley, Early	28.80	37.52	26.69	64.21	0.38
Forage Barley, Late	27.40	51.59	13.58	65.17	0.39
Oat Forage, Early	29.60	43.43	20.89	64.32	0.39
Oat Forage, Late	26.40	57.50	11.11	68.61	0.41
Pea Forage, Early	55.00	50.69	41.15	91.84	0.55
Pea Forage, Late	37.40	43.40	31.30	74.70	0.45
Forage Lentil, Early	71.60	57.50	45.31	102.81	0.62
Forage Lentil, Late	37.00	43.43	32.20	75.63	0.45
Oat-Pea Forage	37.20	50.69	25.06	75.75	0.45

Table 14. Costs-returns per cow-calf pair during the 167-day nongrazing season.

Forage-Type Treatments	Calf Weight lbs	Pasture-forage Cost per pound Calf Weight $/lb	Gross Value Calf Weight @$0.70/lb $	Forage and Supplement Cost per Cow-Calf Pair $	Net Return per Cow-Calf Pair $
Reserved Native Range with cake	176.0	1.59	123.20	279.07	-155.87
Cropland Aftermath and Mature Crested Wheatgrass with cake	180.5	0.65	126.35	117.27	9.08
Mature Crested Wheatgrass with cake	180.5	0.65	126.35	116.53	9.82
Mature Crested Wheatgrass with cake and alfalfa-silage	180.5	0.58	126.35	105.17	21.18
Crested Wheatgrass, Early	180.5	0.44	126.35	78.81	47.54
Forage Barley, Early	180.5	0.36	126.35	64.21	62.14
Forage Barley, Late	180.5	0.36	126.35	65.17	61.18
Oat Forage, Early	180.5	0.36	126.35	64.32	62.03
Oat Forage, Late	180.5	0.38	126.35	68.61	57.74
Pea Forage, Early	180.5	0.51	126.35	91.84	34.51
Pea Forage, Late	180.5	0.41	126.35	74.70	51.65
Forage Lentil, Early	180.5	0.57	126.35	102.81	23.54
Forage Lentil, Late	180.5	0.42	126.35	75.63	50.72
Oat-Pea Forage	180.5	0.42	126.35	75.75	50.60

Table 15. Costs-returns per acre during the 167-day nongrazing season.

Forage-Type Treatments	Production Cost $/ac	Acres per Nongrazing Season ac	Crude Protein Yield lb/ac	Crude Protein Cost $/lb	Net Return per Acre $
Reserved Native Range with cake	8.76	28.89	8.74	1.04	-5.40
Cropland Aftermath and Mature Crested Wheatgrass with cake	7.98	9.21	102	0.28	0.99
Mature Crested Wheatgrass with cake	28.11	2.58	102	0.28	3.81
Mature Crested Wheatgrass with cake and alfalfa-silage	28.11	2.72	102	0.28	7.79
Crested Wheatgrass, Early	26.50	1.80	189	0.14	26.41
Forage Barley, Early	68.21	0.54	606	0.11	115.07
Forage Barley, Late	70.35	0.70	468	0.15	87.40
Oat Forage, Early	69.17	0.63	535	0.13	98.46
Oat Forage, Late	74.53	0.70	435	0.17	82.49
Pea Forage, Early	79.96	0.64	526	0.15	53.92
Pea Forage, Late	86.87	0.50	685	0.13	103.30
Forage Lentil, Early	59.69	0.93	361	0.17	25.31
Forage Lentil, Late	71.48	0.61	567	0.13	83.15
Oat-Pea Forage	95.52	0.52	611	0.15	97.31

Table 16. Cost per pound of calf weight during nongrazing season.

Forage-Type Treatments	Birth Weight Cost per Pound $/lb	Accumulated Weight Cost per Pound $/lb	Calf Weight Cost per Pound $/lb
Forage Barley, Early	0.36	0.21	0.36
Oat Forage, Early	0.36	0.21	0.36
Forage Barley, Late	0.34	0.26	0.36
Oat Forage, Late	0.30	0.34	0.38
Pea Forage, Late	0.41	0.26	0.41
Oat-Pea Forage	0.41	0.26	0.42
Forage Lentil, Late	0.41	0.26	0.42
Pea Forage, Early	0.50	0.33	0.51
Forage Lentil, Early	0.56	0.38	0.57
Crested Wheatgrass, Early	0.43	0.28	0.44
Mature Crested Wheatgrass with cake and alfalfa-silage	0.59	0.42	0.58
Mature Crested Wheatgrass with cake	0.59	0.55	0.65
Cropland Aftermath and Mature Crested Wheatgrass with cake	0.59	0.55	0.65
Reserved Native Range with cake	1.58	1.09	1.59

Summary of net returns per acre and per cow-calf pair

Net returns after pasture-forage costs per acre and per cow-calf pair are shown in table 17. Forage types with high net returns were forage barley hay cut early, at $115.07/acre and $62.14/cow-calf pair; pea forage hay cut late, at $103.30/acre and $51.65/cow-calf pair; oat forage hay cut early, at $98.46/acre and $62.03/cow-calf pair; oat-pea forage hay, at $97.31/acre and $50.60/cow-calf pair; forage barley hay cut late, at $87.40/acre and $61.18/cow-calf pair; forage lentil hay cut late, at $83.15/acre and $50.72/cow-calf pair; and oat forage hay cut late, at $82.49/acre and $57.74/cow-calf pair. Forage types with moderate net returns were pea forage hay cut early, at $53.92/acre and $34.51/cow-calf pair; crested wheatgrass hay cut early, at $26.41/acre and $47.54/cow-calf pair; and forage lentil hay cut early, at $25.31/acre and $23.54/cow-calf pair. Forage types with low net returns were mature crested wheatgrass hay with range cake and alfalfa-corn silage, at $7.79/acre and $21.18/cow-calf pair; mature crested wheatgrass hay with range cake, at $3.18/acre and $9.82/cow-calf pair; and cropland aftermath and mature crested wheatgrass hay with range cake, at $0.99/acre and $9.08/cow-calf pair. The forage type with negative net returns was reserved native range with range cake, at -$5.40/acre and -$155.87/cow-calf pair.

The plant growth stage at which the forages were grazed or hayed affected the net returns. Late-cut forage lentil hay returned $57.84/acre and $27.18/cow-calf pair more than early cut forage lentil hay. Late-cut pea forage hay returned $49.38/acre and $17.14/cow-calf pair more than early cut pea forage hay. Early cut forage barley hay returned $27.67/acre and $0.96/cow-calf pair more than late-cut forage barley hay. Early cut oat forage hay returned $15.97/acre and $4.29/cow-calf pair more than late-cut oat forage hay. Early cut crested wheatgrass hay returned $22.60/acre and $37.72/cow-calf pair more than mature crested wheatgrass hay. Summer-grazed native range pastures managed with the twice-over system returned $20.19/acre and $288.97/cow-calf pair more than reserved native range pastures grazed during the nongrowing season.

Annual legume hays harvested during the middle and late plant stages of development yielded a greater weight of crude protein per acre than the same hay harvested at early stages. The late-cut annual legume hays had lower forage costs and livestock feed costs and greater net returns than early cut annual legume hays.

Annual cereal hays and perennial grass hays harvested during early stages of development yielded greater weight of crude protein per acre than the same hay harvested at late and mature stages. The early cut annual cereal hays and perennial grass hays had lower forage costs and livestock feed costs and greater net returns than late-cut annual cereal hays and mature perennial grass hays.

Cereal-legume hays have a mixture of forage types with different optimum harvest times. The mixed hays generally have greater forage costs and lower net returns per acre than the cereal and legume hays seeded separately and harvested at their respective optimum plant stages. Oat-pea forage hay returned $1.15/acre less than early cut oat forage hay and $5.99/acre less than late-cut pea forage hay. The opposite relationships occur when the separately seeded cereal and legume hays are harvested at plant stages different from their optimum growth stage. Oat-pea forage hay returned $14.82/acre more than late-cut oat forage hay and $43.39/acre more than early cut pea forage hay.

The three mature crested wheatgrass hay treatments with different combinations of nutrient supplements returned low value per acre and per cow-calf pair, with values ranging from $7.79 to $0.99 per acre and $21.18 to $9.08 per cow-calf pair. Traditionally, domesticated perennial grass hays like crested wheatgrass and smooth bromegrass are harvested at the mature plant stage after the seed heads have developed and plants have reached maximum height. This practice yields high forage dry matter weight per acre but low crude protein weight per acre. Mature domesticated perennial grass hays have high forage costs and livestock feed costs and low net returns per acre and per cow-calf pair.

The extended grazing treatment, reserved native rangeland with range cake, used no harvested forages. The production costs were low, but the forage costs and livestock feed costs were extremely high. The net returns were a loss of $5.40/acre and a loss of $155.87 per cow-calf pair. The herbage biomass per acre during the nongrowing season was less than 33% to 50% of the summer herbage biomass. The crude protein captured per acre during the nongrowing season was less than 20% to 33% of the amount available for capture during the summer.

Table 17. Net returns after pasture-forage costs per acre and per cow-calf pair for forage types.

Forage-Type Treatments	Net Return per Acre $/acre	Net Return per Cow-Calf Pair $/c-c pr
Forage Barley, Early	115.07	62.14
Oat Forage, Early	98.46	62.03
Forage Barley, Late	87.40	61.18
Oat Forage, Late	82.49	57.74
Pea Forage, Late	103.30	51.65
Oat-Pea Forage	97.31	50.60
Forage Lentil, Late	83.15	50.72
Pea Forage, Early	53.92	34.51
Forage Lentil, Early	25.31	23.54
Crested Wheatgrass, Early	26.41	47.54
Mature Crested Wheatgrass with cake and alfalfa-silage	7.79	21.18
Mature Crested Wheatgrass with cake	3.81	9.82
Cropland Aftermath and Mature Crested Wheatgrass with cake	0.99	9.08
Summer Native Range with Twice-Over System	14.79	133.10
Reserved Native Range with cake	-5.40	-155.87

Projected pasture-forage costs and net returns

The individual cow-calf pair data for the pasture-forage and harvested-forage treatments were projected to a herd of 100 cows and a herd of 300 cows (table 18). The differences in the land area required for forage nutrient production, in the total feed costs, and in net returns among the treatments result from the differences in the biological effectiveness and the nutrient capture and conversion efficiency of the various forage management strategies.

The land area required to produce the forage nutrients for 100 cows during the nongrazing season was 54 to 70 acres for annual cereal hays; 50 to 93 acres for annual legume hays; 180 acres for early crested wheatgrass hay; 272 acres for mature crested wheatgrass hay, alfalfa hay, and corn silage; 258 acres for mature crested wheatgrass hay; 921 acres for cropland aftermath pasture; and 2889 acres for reserved native rangeland pasture.

Total feed costs (forage and supplement) for 100 cows during the nongrazing season were $6,421 to $6,861 for annual cereal hays; $7,470 to $10,281 for annual legume hays; $7,881 for early crested wheatgrass hay; $10,517 for mature crested wheatgrass hay, alfalfa hay, and corn silage; $11,653 for mature crested wheatgrass hay; $11,727 for cropland aftermath pasture; and $27,907 for reserved native rangeland pasture.

Net returns after pasture-forage feed costs for 100 cows during the nongrazing season were $5,774 to $6,214 from annual cereal hays; $2,354 to $5,165 from annual legume hays; $4,754 from early crested wheatgrass hay; $2,118 from mature crested wheatgrass hay, alfalfa hay, and corn silage; $982 from mature crested wheatgrass hay; $908 from cropland aftermath pasture; and a loss of $15,587 from reserved native rangeland pasture.

The land area required to produce the forage nutrients for 300 cows during the nongrazing season was 162 to 210 acres for annual cereal hays; 150 to 279 acres for annual legume hays; 540 acres for early crested wheatgrass hay; 816 acres for mature crested wheatgrass hay, alfalfa hay, and corn silage; 774 acres for mature crested wheatgrass hay; 2763 acres for cropland aftermath pasture; and 8667 acres for reserved native rangeland pasture.

Total feed costs (forage and supplement) for 300 cows during the nongrazing season were $19,263 to $20,583 for annual cereal hays; $22,410 to $30,843 for annual legume hays; $23,643 for early crested wheatgrass hay; $31,551 for mature crested wheatgrass hay, alfalfa hay, and corn silage; $34,959 for mature crested wheatgrass hay; $35,181 for cropland aftermath pasture; and $83,721 for reserved native rangeland pasture.

Net returns after pasture-forage feed costs for 300 cows during the nongrazing season were $17,322 to $18,642 from annual cereal hays; $7,062 to $15,495 from annual legume hays; $14,262 from early crested wheatgrass hay; $6,354 from mature crested wheatgrass hay, alfalfa hay, and corn silage; $2,946 from mature crested wheatgrass hay; $2,724 from cropland aftermath pasture; and a loss of $46,761 from reserved native rangeland pasture.

Mature crested wheatgrass hay required 40% more land area than early cut crested wheatgrass hay and more than four times the land area that early cut annual cereal hays and late-cut annual legume hays required to produce adequate forage. Cropland aftermath pasture and reserved native rangeland pasture required a great deal more land area than the harvested-forage types.

Early cut annual legume hays, mature crested wheatgrass hay, cropland aftermath pasture, and reserved native rangeland pasture were expensive forage for beef cows during the nongrazing season. Feed costs for forage barley hays and early cut oat forage hays were less than half the feed costs for mature crested wheatgrass hay. Feed costs for late-cut legume hay, late-cut oat forage hay, and oat-pea forage hay management strategies were less than 60% of the feed costs for mature crested wheatgrass hay.

Net returns after pasture-forage costs were high from annual cereal hays, late-cut annual legume hays, and oat-pea hay. Early crested wheatgrass hay and pea forage hay cut early had moderate net returns. Forage lentil hay cut early, mature crested wheatgrass hay with alfalfa hay and corn silage, mature crested wheatgrass hay, and crop aftermath pasture had low net returns. Reserved native rangeland pasture had negative net returns.

Table 18. Projection of net returns from 100-cow and 300-cow herds on forage management strategies during the 5.5-month nongrazing season.

Forage Management Strategies	100 Cows				300 Cows			
	Land Area	Total Feed Cost	Calf Weight Value @$0.70/lb	Net Return	Land Area	Total Feed Cost	Calf Weight Value @$0.70/lb	Net Return
	Acres	$	$	$	Acres	$	$	$
Reserved Native Range	2889	27,907	12,320	-15,587	8667	83,721	36,960	-46,761
Cropland Aftermath	921	11,727	12,635	908	2763	35,181	37,905	2724
Mature Crested Wheatgrass	258	11,653	12,635	982	774	34,959	37,905	2946
Mature Crested Wheatgrass, alfalfa hay, corn silage	272	10,517	12,635	2118	816	31,551	37,905	6354
Crested Wheatgrass, Early	180	7881	12,635	4754	540	23,643	37,905	14,262
Forage Barley, Early	54	6421	12,635	6214	162	19,263	37,905	18,642
Forage Barley, Late	70	6517	12,635	6118	210	19,551	37,905	18,354
Oat Forage, Early	63	6432	12,635	6203	189	19,296	37,905	18,609
Oat Forage, Late	70	6861	12,635	5774	210	20,583	37,905	17,322
Pea Forage, Early	64	9184	12,635	3451	192	27,552	37,905	10,353
Pea Forage, Late	50	7470	12,635	5165	150	22,410	37,905	15,495
Forage Lentil, Early	93	10,281	12,635	2354	279	30,843	37,905	7062
Forage Lentil, Late	61	7563	12,635	5072	183	22,689	37,905	15,216
Oat-Pea Forage	52	7575	12,635	5060	156	22,725	37,905	15,180

Discussion

Harvested forages are usually viewed as expensive feeds because the production costs per acre are greater than pasture rent per acre and a high percentage of the harvested-forage production costs consist of labor and equipment costs. Some harvested forages are expensive, but not all harvested forages are high-cost feeds. Harvested forages cut at optimum plant stages that yield great amounts of crude protein per acre have low costs per unit of nutrient and are forages that provide low-cost feeds. Harvested forages cut at plant stages that yield great amounts of dry matter and low amounts of crude protein per acre have high costs per unit of nutrient and generally are expensive forages that increase livestock production costs.

Traditionally, crested wheatgrass and smooth bromegrass--domesticated perennial grass hays--are cut late, after the seed heads have developed and plants have reached maximum height. This practice yields about the year's potential amount of forage dry matter per acre at a moderately low cost per ton, but the low yield in weight of nutrients per acre causes high nutrient costs. The land costs, production costs, equipment costs, and labor costs per acre were lower for mature crested wheatgrass hay than for annual cereal and annual legume forages. However, livestock feed costs for the mature crested wheatgrass forage treatment were considerably greater than feed costs for the annual cereal and annual legume forage management treatments. Mature crested wheatgrass hay is expensive livestock feed because it has high costs per pound of crude protein.

The cost of livestock feed is regulated primarily by the cost per unit of weight of the nutrients contained in the forage. The nutrient cost per unit of weight is determined by the weight of the nutrients harvested per acre prorated against the land costs, production costs, equipment costs, and labor costs per acre.

The weight of nutrients harvested per acre is related to the percent nutrient content and the weight of the forage dry matter at the time of cutting. The percent crude protein content and dry matter weight of the forage first increase and then decrease as the growing season progresses and plants mature. These changes are reflected in the quantity curves for the two factors. The percent crude protein content and dry matter weight curves for a single forage type differ from each other throughout the growing season, and curves of various types of forage plants have different shapes. The greatest percent crude protein occurs during early plant growth stages, and then the quality level declines as the plants develop. Percent nutrient content declines at a greater rate in grasses than in legumes. The weight of the forage dry matter per acre increases during the early growth stages until the maximum plant height is reached, and then the dry matter weight decreases as the plants dry during senescence. The rate of growth to peak dry matter weight is greater in grasses than in legumes. The greatest amount of crude protein per acre does not occur at the peak percent crude protein or the peak dry matter weight per acre but at the plant growth stage during which the curves for percent nutrient content and weight of forage dry matter cross.

The two curves cross at the flowering growth stage for grass plants, including perennial grasses and annual cereal grasses. The cost per pound of crude protein is lower for perennial grasses and annual cereal forages when plants are cut early, between the boot stage and the early milk stage. Crested wheatgrass cut at the boot stage had lower costs per pound of crude protein than crested wheatgrass cut at a mature stage of growth. Forage barley and oat forage hay cut early, at the milk stage, had lower costs per pound of crude protein than their respective forage types cut later, at the hard dough stage.

The two curves for legumes cross at a later growth stage, when the plants are at full growth but before the leaves start drying from senescence. The cost per pound of crude protein is lower for annual legume forages when plants are cut one time during a late full-growth stage. Early cut forage lentil hay and early cut pea forage hay were cut prior to the plant growth stage with the greatest amount of crude protein per acre, so these hays had greater costs per pound of crude protein than the same legume forage types cut at later plant growth stages.

Generally, the lowest-cost livestock feed from a harvested-forage type is the hay with the lowest cost per pound of nutrient, which results from harvesting at the plant growth stage when that forage type yields its greatest weight of nutrients per acre. Evaluation of harvested forages should be based on costs per unit of weight of the nutrients.

Grazing domesticated grassland and native rangeland pastures during the growing season provides low-cost forage for lactating beef cows because the amount of nutrients captured per acre is high in relation to forage production costs and because the animals' dietary requirements are met. Pasture-forage costs start to increase when the forage nutrient quality drops below the livestock

requirements--sometime between mid July and early August on traditionally managed pastures. Pasture-forage costs increase dramatically after mid October because the amount of nutrients captured per acre from the mature forage is low.

Extending the grazing season beyond mid October requires the use of forage types with low nutrient costs per pound. Such forages have a relatively high amount of nutrients captured per acre in proportion to forage production costs and are of sufficient quality to meet livestock dietary requirements. Of perennial grasses, only the wildryes retain nutrients in the aboveground parts of lead tillers into the fall and provide an economical forage for grazing after mid October. Altai wildrye provides low-cost forage for lactating beef cows from mid October to mid November. No perennial grass efficiently provides low-cost grazed forage beyond mid November, which is the end of the grazing season because perennial forage plants have low levels of biological activity and foliage growth is minimal.

Today's fast-growing, high performance cattle are genetically different from the old-style cattle and require greater quantities of nutrients throughout the production year. During the 5.5-month nongrazing season, from mid November to late April, the high-performance cow requires 20% more energy and 24% more crude protein than the old-style cow.

Extending grazing into the nongrowing season has traditionally been regarded as less expensive than feeding harvested forages; however, because of the high nutrient costs, having cows graze their own feed is not a low-cost strategy. Domesticated grass hay harvested at the mature stage is expensive feed because of the low quantity of nutrients captured per acre. Low-cost forages to feed beef cows during the nongrazing season, from mid November to late April, are provided from forage types when a high proportion of the produced nutrients are captured by efficient harvest management that results in low-cost nutrients. Several harvested annual cereal and annual legume hays cut at their optimum growth stage can be fed economically to range cows during the fall and winter.

Harvested forages cut at the growth stage that yields the greatest weight of nutrients per acre have low prorated costs per pound of nutrient and are low-cost forage. When the livestock feed costs are lower than the economic value of calf weight, the forage becomes a source of substantial income.

Conclusion

The feed costs from harvested forage fed during the nongrazing season are widely assumed to be the cause of high beef production costs. Domesticated perennial grass hay harvested by the traditional practice of cutting plants late, at a mature growth stage, is, without a doubt, expensive livestock feed. Traditional comparisons of labor costs and cash-flow costs are the basis for the long-held belief that grazed native rangeland during the nongrowing season is a less costly feed source than harvested forages. Popular slogans like "Graze longer and save money" are used as management guidelines because it seems reasonable that to let a cow graze her own feed would be cheaper than to run a swather, baler, and feed wagon. The logic of this argument is valid only when or if the effectiveness of nutrient capture for the grazing method and the effectiveness of nutrient capture for the haying method are nearly the same. The problem is that these methods of harvesting forage for use during the nongrazing season differ greatly in their effectiveness of nutrient capture. Grazing cows capture only about 8.7 pounds of crude protein per acre during the nongrowing season; with this practice crude protein costs are over $1.00 per pound and livestock feed costs are $1.67 per day. Cutting forage barley at the milk stage is a more effective method of harvesting nutrients; it captures 606 pounds of crude protein per acre at a prorated cost of $0.11 per pound and results in livestock feed costs of $0.38 per day.

The effectiveness of nutrient capture by various forage harvest methods can be evaluated and compared through determination of the cost per pound of nutrient captured. The cost of forage weight does not reflect the cost of livestock feed from harvested forages. Land costs, production costs, equipment costs, and labor costs per acre are important, but these costs do not regulate the costs of livestock feed. The nutrient content of the forage at the growth stage when plants are cut affects the costs of the harvested forage as livestock feed. Cutting forage at the optimum growth stage reduces the nutrient cost per unit of weight and the cost of livestock feed. Generally, the forage harvest methods that capture crude protein at $0.25 or less per pound and provide feed for livestock at $0.62 or less per day will permit positive net returns from beef production when the value of the calf weight produced is $0.70 or greater per pound.

The valuable product from pastures and haylands is the nutrients, not the dry matter weight. The major factor determining pasture-forage costs is the cost per pound of crude protein from a forage

type. The cost per pound of crude protein is determined by the efficiency of nutrient capture for the harvest management of the forage type. The amount of income from or expense for a forage type is determined by the difference between the value of calf weight and the pasture-forage costs. Beef producers who determine the prorated costs per pound of nutrient and select a forage type that has lower feed costs than the value of calf weight have changed feeding beef cows during the nongrazing season from a major expense into a source of substantial income.

Acknowledgment

I am grateful to Amy M. Kraus for assistance in preparation of this manuscript. I am grateful to Sheri Schneider for assistance in production of this manuscript and for development of the tables.

Literature Cited

Manske, L.L. 2001. Pasture and forage costs-returns of management strategies for range cows. NDSU Dickinson Research Extension Center. Range Research Report DREC 01-1040. Dickinson, ND. 22p.

Manske, L.L. 2002a. Pasture and forage costs of grazingland and harvested forages for range cows. NDSU Dickinson Research Extension Center. Range Research Report DREC 02-1045. Dickinson, ND. 11p.

Manske, L.L. 2002b. Pasture and forage costs during the production periods of range cows. NDSU Dickinson Research Extension Center. Range Research Report DREC 02-1046. Dickinson, ND. 51p.

Manske, L.L., and P.M. Carr. 2000a. Determination of costs of harvested-forage types to help reduce beef production costs. NDSU Dickinson Research Extension Center. Range Research Report DREC 00-1029. Dickinson, ND. 18p.

Manske, L.L., and P.M. Carr. 2000b. Feeding harvested annual forages to reduce beef production costs. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 00-3018. Dickinson, ND. 12p.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.