Nebraska Lincoln EXTENSION

EC158

Integrating Management Objectives and Grazing Strategies on Semi-arid Rangeland

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Rangelands account for about half of Nebraska's total land area or about 24 million acres. Much of these expansive natural resource areas are in the semi-arid climatic region of Nebraska where grazing management decisions have a profound effect on ranch survival. The educational objective of this circular is to explain management practices that optimize the sustainability of rangeland-based enterprises. Additionally a decision-support tool is provided for selecting grazing systems best suited to livestock production and natural resource management objectives.

A **grazing strategy** is a plan for accomplishing a set of objectives based on comprehensive knowledge of available resources and the production and marketing environment. Management can be greatly simplified when grazing strategies are based on clearly stated and prioritized resource-management and livestock-production objectives *(Figure 1)*. Decisions on when and how to use plant resources have profound effects on the success of grazing strategies. Plant resources can be used for livestock production or wildlife cover and ecosystem functions such as hydrologic condition and site stability.

While most rangelands in the central and northern Great Plains are dominated by grasses and grass-like species, shrubs and forbs also are potentially valuable sources of nutrients and cover in these ecosystems. All above-ground, non-woody plant growth is collectively called **herbage**, regardless of palatability. Livestock and wildlife also may consume **browse**, defined as the palatable portions of woody plant growth. **Forage** is composed of palatable herbage and woody plant growth that are accessible to the grazing animal.

Efficient use of herbage and woody plant growth can be evaluated only when all management objectives related to plant resources are clearly understood *(Figure 1)*. For example, if sustaining a prairie-grouse population is one of the resource-management objectives, uneven distribution of grazing may leave enough standing herbage in parts of pastures to provide adequate nesting cover. In contrast, if livestock production is the major objective, uniform grazing distribution becomes important. If adequate distribution cannot be accomplished with strategically placed water or salting locations, cross fencing areas into smaller pastures and/or increasing livestock density with rotational grazing systems may be effective methods of accomplishing livestock production objectives. **Grazing systems** define periods of grazing and non-grazing and are important tools for executing grazing strategies. When different grazing systems have a similar likelihood of accomplishing a prioritized set of objectives, the simplest system generally is the most economically and ecologically efficient.

Semi-arid climates are characterized by relatively high evaporation rates and wide swings in temperature between day and night during the summer. Lines between semi-arid and sub-humid climatic zones are transitional because of year-to-year variation in precipitation and corresponding duration of cloud cover *(Figure 2)*. Contrasts between day and night temperatures decline as cloud cover increases. Semi-arid climates occur continuously in Nebraska where long-term average annual precipitation ranges from 12 to 22 inches. Climates are continuously sub-humid where average annual precipitation is greater than 24 inches. Central Nebraska is a climatic transition zone *(Figure 2)*. Semi-arid climatic conditions generally occur in central Nebraska when growing-season precipitation is below average.

Base decisions on when and where to graze on clearly defined animal-production and resource-management objectives.

Best Management Practices

Decisions on when and where to graze plant resources should be based on clearly defined animal-production and resource-management objectives *(Figure 1)*. Production objectives for growing livestock should be defined in terms of target weights at a future date that reflect future ownership and production plans. Target cow condition scores at selected points during the annual reproductive schedule should be based on knowledge of seasonal patterns in nutritive value of available forage resources. Relatively low cow condition scores may be acceptable during the

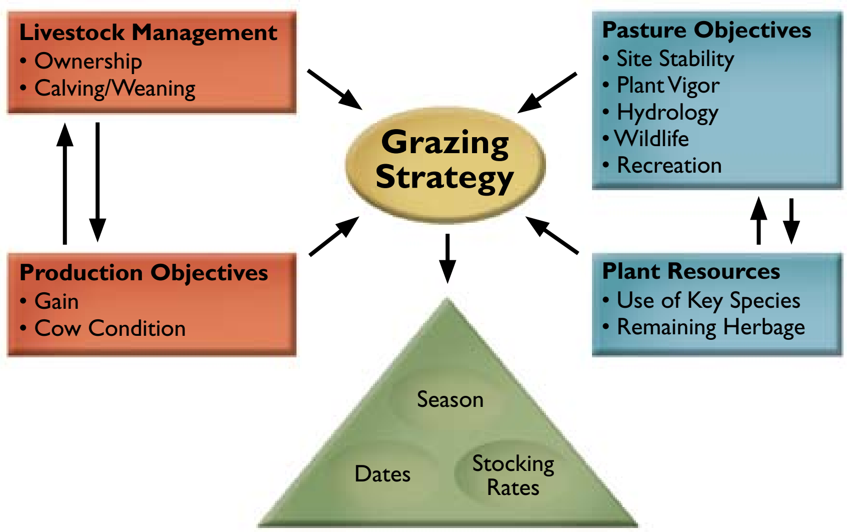

Figure 1. *Grazing strategies should be based on prioritized livestock-production and natural resource-management objectives. These overall plans provide clear guidelines for herbage allocation and selection of an efficient grazing system.*

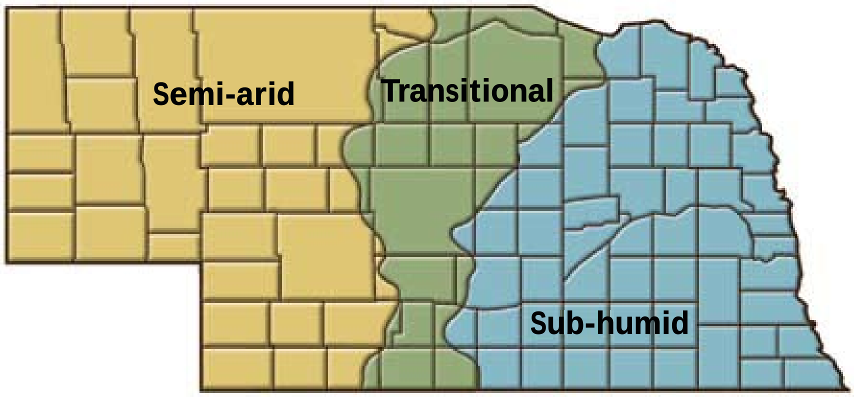

Figure 2. *Climatic zones in Nebraska based on weather records from 1961-1990.*

second trimester of pregnancy if highly nutritious forage will be available during much of the third trimester as with summer calving herds. If livestock ownership will be retained, less than maximum potential gains by growing cattle on rangeland may be acceptable if natural resource management objectives are not compromised *(Figure 1)*. Cattle sold off grass generally are most profitable when average daily gains are near the maximum potential for the available forage resources.

Grazing management, the manipulation of grazing animals to accomplish desired results, should be based on probable plant and animal responses. Air temperature and soil moisture change as the growing season progresses in semi-arid environments. Consequently, the opportunity for relatively rapid plant growth and recovery from grazing is limited to only a portion of what we typically call the growing season. Plants may remain green throughout the growing season; however, 75 percent to 100 percent of herbage production of individual species occurs during 45 to 60 days when soil moisture and air temperatures are simultaneously favorable *(Figure 3)*. Sedges and cool-season grasses such as needlegrass, prairie junegrass, and western wheatgrass produce most of their herbage in the spring and may produce additional herbage in the fall if soil moisture is available. In contrast, warm-season grasses such as prairie sandreed, bluestems, switchgrass, and grama grasses produce the bulk of their herbage during the summer. Removing more than 60 percent of the current year herbage during a species' primary growth period precludes its ability to capitalize on the limited number of days with favorable growing conditions in semi-arid regions.

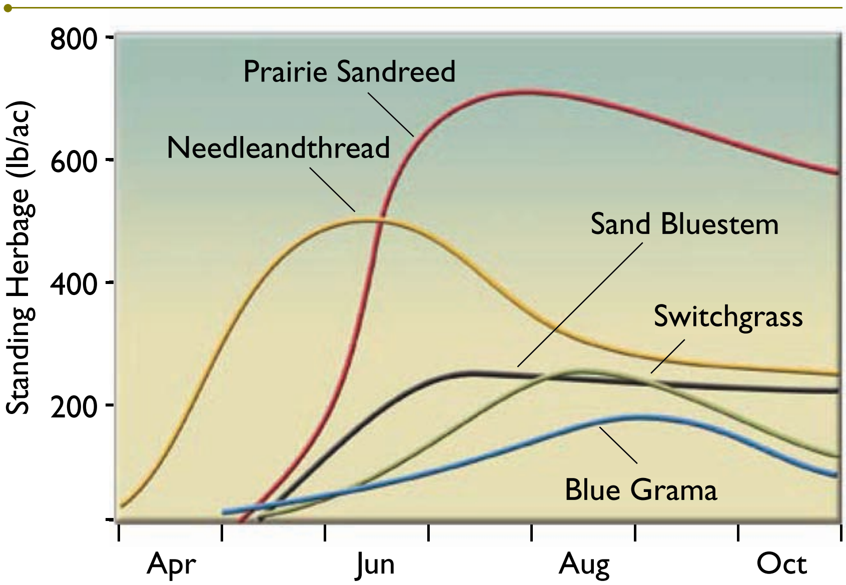

Figure 3. *Seasonal distribution of current-year herbage by species on sandy range sites in good to excellent range condition with average precipitation (Nosal 1983).*

The average amount of herbage from which each animal in a pasture selects a daily diet declines and the likelihood of overgrazing preferred plant species increases as grazing pressure increases. **Grazing pressure** is the demand/supply ratio between dry matter requirements of livestock and the quantity of forage available in a pasture at a specific time. Reducing the length of the summer-grazing season and increasing herd size to obtain the same end-of-season stocking rate increases grazing pressure regardless of grazing system. **Cumulative grazing pressure** (CGP) is expressed as animal unit demand per ton of forage over a period of time, e.g., **animal-unit days** of grazing per ton of forage (AUD/ton). During the summer, an AUD of grazing is equivalent to about 26 lb of air-dry forage. Based on a standard of 30 days per month, each **animal-unit month** (AUM) is equivalent to about 780 lb of air-dry forage. For cattle, animal-unit equivalents (AUE) can be estimated by dividing the average weight of pairs or individuals by 1,000 lb *(Table 1)*. Therefore, AUE increases as cattle gain weight.

Stocking rate is the number of animal units per acre for a specified amount of time without regard to the amount of forage, e.g., AUD/ac or AUM/ac. Consequently, cumulative grazing pressure (AUD/ton) influences plant and animal interactions more than stocking rate (AUD/acre). However, within a given time, stocking rate is directly related to cumulative grazing pressure. Several years of stocking rate, animal performance, and precipitation records can be used to identify levels of stocking beyond which undesirable plant and animal responses begin to occur. Stocking rate is a unit of measure that represents the amount of AU demand placed on an acre, or the amount of forage that would be removed per acre, over a specified time. In Nebraska, stocking rate is commonly expressed as AUD/acre or AUM/acre.

Stocking-Rate Adjustments

Reasonable AUE, total days of grazing, and number of grazable acres should be known for each pasture to calculate stocking rate *(Table 1)*. When livestock do not uniformly graze a pasture, excessive grazing pressure will occur on preferred areas if stocking rates are based on similar use in all areas. Livestock may completely avoid or make only partial use of forage in some areas. Additionally, grazing distribution may differ over time or by kind and class of livestock. Consequently, location and acreage of under utilized forage should be a part of each year's grazing records. This information can be used to determine grazable acres and proper stocking rates when similar conditions occur in the future.

Slope has a greater effect on grazing distribution of cattle than on sheep or goats. Cattle prefer to graze flat to gently rolling topography. Use of palatable herbage by beef cattle declines as much as 30 percent when slopes are 10-30 percent and may be nonexistent on slopes exceeding 60 percent *(Figure 4)*. Actual reductions in grazing will be affected by length of slope, diversity of range sites, topography, and distance to water. AUDs should be reduced by 50 percent for locations one to two miles from water and areas more than two miles away from water often are not grazed (Holechek 1988).

Determining the appropriate herd size to achieve a proper stocking rate depends on kind, class, and weight of grazing animals. Livestock forage requirements can change measurably with changes in weight and/or reproductive status. Ecologically and economically efficient management depends on properly balancing total forage requirements of the herd with available forage resources. Historically, the average weight of livestock on many ranches changed due to selection

Table 1.

Examples of how differences in reproduction schedules, initial livestock weight, and/or average daily gain (ADG) affect animal-unit equivalents (AUE) in cow-calf and yearling enterprises.

Cow-calf Enterprises

To estimate AUE: For dry cows or until the average age of the calf crop exceeds three months, divide the average weight (lb) of the cows by 1000 lb.

When the average age of the calf crop reaches three months, add the average weight (lb) of calves to the average cow weight (lb) and divide by 1000 lb.

Cow Weight	1200 lb
Calving Season	May-Jun
Birth Weight	80 lb
ADG of Calves	2.2 lb/day

Monthly AUE

	May	Jun	Jul	Aug	Sep	Oct
Calf	0	0	0	0	.31	.38
Cow	1.2	1.2	1.2	1.2	1.2	1.2
Pair	**1.2**	**1.2**	**1.2**	**1.2**	**1.51**	**1.58**

Six-month average = 1.32 AUE/Pair

Cow Weight	1400 lb
Calving Season	Jan-Feb
Birth Weight	90 lb
ADG of Calves	2.0 lb/day, Mar-May 2.3 lb/day, Jun-Oct

Monthly AUE

	May	Jun	Jul	Aug	Sep	Oct
Calf	.30	.37	.44	.50	.57	.63
Cow	1.4	1.4	1.4	1.4	1.4	1.4
Pair	**1.7**	**1.77**	**1.84**	**1.9**	**1.97**	**2.03**

Six-month average = 1.87 AUE/Pair

Yearling Enterprises

To estimate AUE: Divide the average weight (lb) of yearlings by 1000 lb.

		ADG (lb/day)	
Class	Initial Weight	May-Sep	May-Oct
Steers	650 lb	2.20	0.40
Heifers	500 lb	1.75	0.32

Monthly AUE

	May 15 Jun 15	Jun 15 Jul 15	Jul 15 Aug 15	Aug 15 Sep 15	Sep 15 Oct 15
Steers	.68	.75	.82	.89	.93
Heifers	.53	.58	.63	.69	.72

Five-month average = .82 AUE/Steer; .63 AUE/Heifer

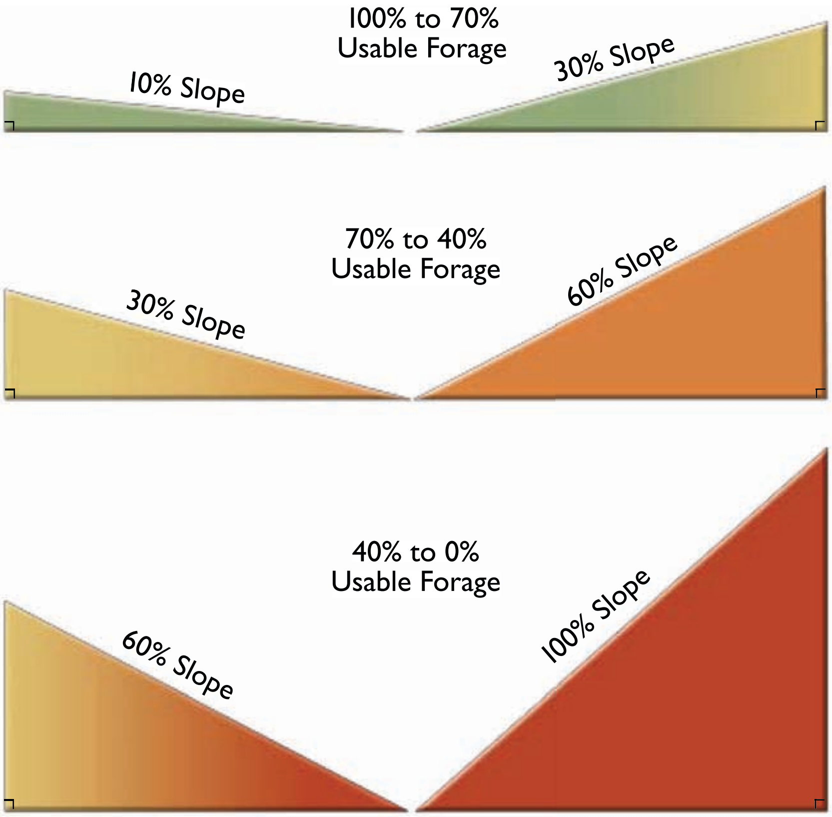

Figure 4. *General percentages of forage resources that will likely be used by beef cattle when topography varies within three ranges of slope (modified from Holechek 1988).*

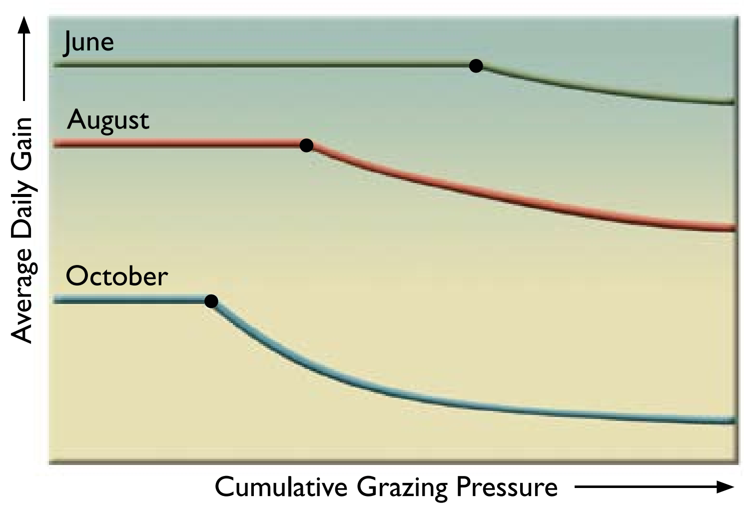

Figure 5. *Seasonal declines in critical grazing pressure (•) for animal performance as vegetation matures and forage quality declines (modified from Hart 1978).*

and breeding programs. These changes were most notable during the 1970s and 1980s when increased weaning weights were emphasized. Increases in average mature cow weights and calf weights caused by genetics and earlier calving dates increased animal-unit equivalents per cow-calf pair by 30 percent to 50 percent. With no reduction in herd size, these changes increased stocking rate by 30 percent to 50 percent *(Table 2, Question 2)*.

Critical cumulative grazing pressure is the level where the average performance of all animals in the herd declines with each additional AUD of grazing *(Figure 5)*. For example, when the growth of calves on rangeland is repeatedly below expected progeny differences (EPD), cumulative grazing pressure has increased enough to limit the full expression of their genetic growth potential. Growth of these calves in the feedlot is often excellent; but when increased forage demand by cows results in little increase in weaning weights or increased costs of supplementation, commercial cow-calf enterprises that sell weaned calves off grass are hurt economically. Stocking rates must be reduced to lower the cumulative grazing pressure before expected progeny difference can be fully expressed on grass in these situations.

Seasonal declines in critical cumulative grazing pressure are related to the leaf/stem ratios of forage. A high percentage of the current-year herbage is composed of leaf tissue early in the growing season. Development of new leaves on individual grass tillers ends when stems begin to elongate (Waller et al. 1985). Consequently, leaf/stem ratios, potential average daily gains, and critical cumulative grazing pressure *(Figure 5)* decline as the growing season progresses. Livestock can severely graze plants and continue to gain weight at maximum rates when a high percentage of the forage is leafy and immature. In contrast, animal performance will decline before excessive removal of herbage occurs late in the growing season or after killing frost because little high quality leaf material exists.

Critical Plant and Animal Interactions

Season of grazing and cumulative grazing pressure are the two most important variables

Table 2.

Commonly asked questions about stocking rates.

Question 1: How many animals can be placed on a specific land area and not exceed a moderate stocking rate?

Assumptions: Land area and moderate stocking rate are known: for example **640 acres**, **18 AUD/acre**, **180 days**, and **1.32 AUE per pair**.

	Number	Class	AUE	Season
a.	**48**	Pairs	1.32	180 days
b.	**34**	Pairs	1.87	180 days
c.	**117**	Steers	0.82	120 days
d.	**152**	Heifers	0.63	120 days

Calculations for a:

Step 1: Total available forage
(640 acres)(18 AUD/acre) =11,520 AUD

Step 2: Number of AU for the grazing season
11,520 AUD/180 days= 64 AU

Step 3: Number of pairs for the grazing season
64 AU/1.32 AUE= 48 pairs

Question 2: With no changes in the number of animals or length of grazing season, what is the effect of different AUE on stocking rate?

Assumptions: The land area and stocking rate at which animal numbers can be sustained under moderate drought are known: for example **800 acres** and **15 AUD/acre**.

	Number	Class	AUE	Season	Stocking Rate
a.	**50**	Pairs	1.32	180 days	**15** AUD/acre
b.	**50**	Pairs	1.87	180 days	**21** AUD/acre
c.	**160**	Steers	0.82	120 days	**20** AUD/acre
d.	**160**	Heifers	0.63	120 days	**15** AUD/acre

Calculations comparing a and b:

Step 1: Stocking rates for different cows and reproductive schedules

for a: (50 pair)(1.32 AU/pair)(180 days)/(800 acres) = 15 AUD/acre
for b: (50 pair)(1.87 AU/pair)(180 days)/(800 acres) = 21 AUD/acre

Step 2: Increase above historically appropriate stocking rate
(21 AUD/acre - 15 AUD/acre)/(15 AUD/acre) = 40%

Note: Not adjusting animal numbers for differences in AUE in these examples (a vs. b and c vs. d) would increase stocking rates by 40 percent and 33 percent above the historically sustainable stocking rate of 15 AUD/acre. These increases are large enough to cause measurable reductions in animal performance and/or vigor of preferred plant species.

in plant and animal responses to grazing management. Management decisions affect plant vigor, herbage production, and diet quality of grazing animals the most during the growing season. Forage quality declines in all plants as they mature as reflected in the progressive declines in daily gains of growing cattle during the "summer" grazing season *(Figure 6)*. Seasonal declines in nutritive value of green plants correspond to the aging of leaves and decline in leaf/stem ratios.

Nutritive value of plants is high during periods of rapid growth which occur only when temperatures and soil moisture are simultaneously favorable for growth of a particular species *(Figure 3)*. Since rangeland in good to excellent condition has many plant species, the time when high quality forage is available is extended because of overlapping periods of rapid growth for different plant species. Species diversity also increases the likelihood of some herbage being produced when precipitation is unevenly distributed during the growing season in dry years.

Degree of defoliation of key species increases as cumulative grazing pressure increases. The percentage of prairie sandreed tillers grazed in the Sandhills during June and July increases from 50 percent to 90 percent as cumulative grazing pressure increases *(Figure 7a)*. Concurrently, the average amount of herbage removed from individual tillers increases from 50 percent to 74 percent *(Figure 7b)*. When 74 percent of the herbage has been removed from 90 percent of all prairie sandreed tillers in the pasture, total use of prairie sandreed in the pasture is about 67 percent *(Figure 7c)*. At this level, prairie sandreed has been heavily grazed. If heavy grazing occurs before or during drought, the stored energy reserves of this species will be reduced by 40 percent (Reece et al. 1996).

When relatively small quantities of current-year herbage occur early in the growing season *(Figure 3)*, concentrating cattle for rotation-grazing

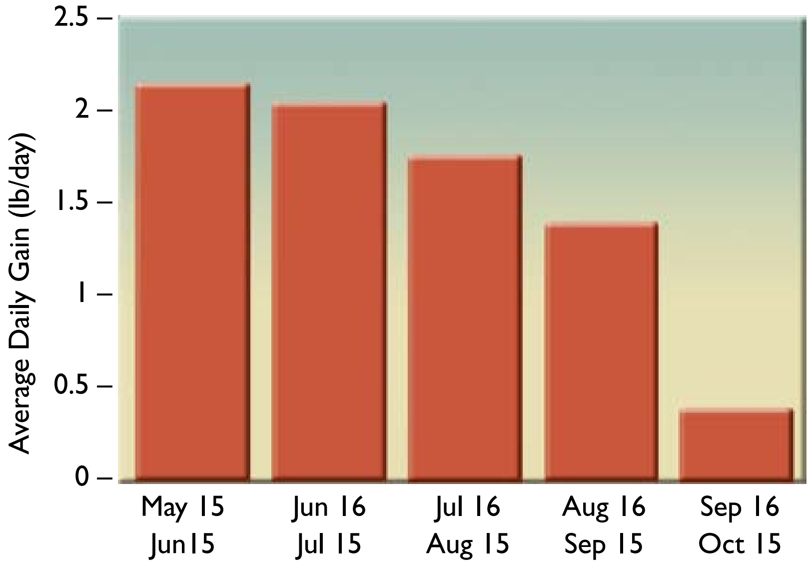

***Figure 6.** Average daily gains of yearling steers during a 10-year study from 1958 to 1967 in Sioux County, Nebraska (Burzlaff and Harris 1969).*

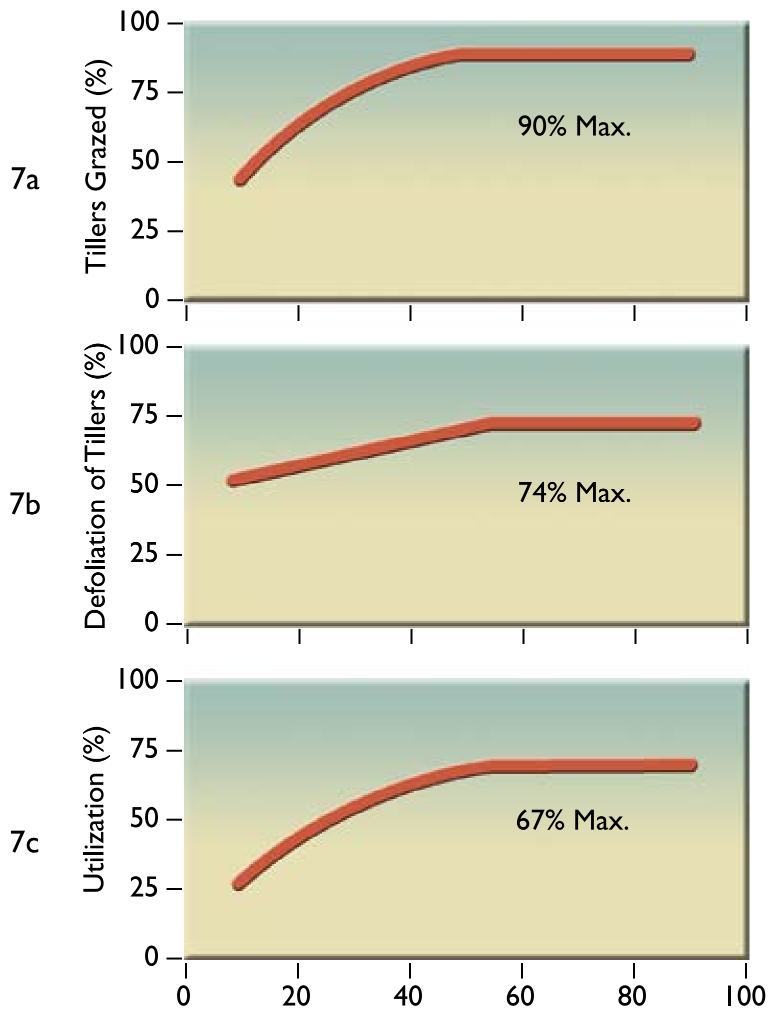

***Figure 7.** Effect of grazing pressure on (a) the percentage of tillers grazed, (b) degree of defoliation of grazed tillers, and (c) overall use of prairie sandreed herbage during June and July (Cullan et al. 1999).*

systems can result in relatively high grazing pressure. Progressively increasing stocking rates from light to full seasonal levels as plants grow will reduce the amount of herbage removed per acre early in the summer grazing season and reduce the risk of overgrazing key species when they are most susceptible to heavy defoliation.

Under season-long continuous grazing, low stocking densities minimize the likelihood of high grazing pressure early in the growing season in properly stocked pastures. **Stocking density**, the concentration of livestock at a given point in time, is expressed as AU/ac. The amount of herbage removed per acre in a single day increases as stocking density increases. When stocking density is low during the growing season, grazing pressure (AUD/ton) often declines because plant growth exceeds dry matter intake by livestock. The likelihood of overgrazing or reducing diet quality before cattle are moved to another pasture increases as stocking density increases.

Many range ecosystems in Nebraska tolerate heavy grazing until drought occurs. The combination of heavy grazing and drought is the primary cause of decline in range condition; however, rangelands in good to excellent condition are resilient and often recover rapidly when properly managed. The most effective way to maintain high levels of vigor in key plant species is to periodically provide full growing-season deferment from spring green-up to killing frost. It generally is not possible for cattle to overgraze semi-arid rangelands during the dormant season unless they receive supplemental feed. The likelihood of pastures being deferred for a full growing season declines as relatively inexpensive crop residue becomes more available; however, corn stalks generally are not available until October or early November, providing 30 to 45 days of opportunity for full growing-season deferment in at least one pasture each year.

Pasture-use sequences in summer-grazed rotation systems should be changed by 30 to 60 days each year to enhance species diversity. Grazing upland pastures during the primary growing season of key forage species in consecutive years or grazing pastures two or more times during the growing season maximizes the risk of reducing vigor and a downward trend in range condition on semi-arid rangeland. For example, sand bluestem plants that were heavily defoliated in mid-June and in mid-August during a single growing season had 43 percent less total root length compared to plants defoliated only after killing frost in October *(Figure 8)*.

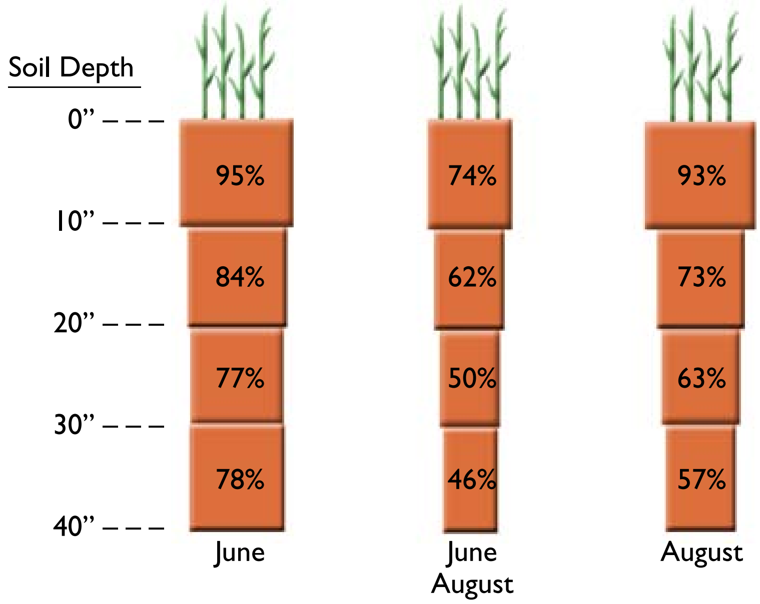

Figure 8. *Percent of total sand bluestem root length in each 10-inch increment of soil compared to plants not clipped until October, after killing frost. Total length of all roots the following spring was 286 feet after heavy defoliation in June, 196 feet after heavy defoliation in June and August, and 240 feet for August compared to 341 feet for plants clipped only in October (modified from Engel et al. 1998).*

Critical Evaluation

Many factors affect animal production besides CGP including stage of plant maturity and animal condition. "Green" cattle may gain more than 3.0 lb/head/day on lush early-summer forage. Growing cattle will lose weight on dormant-forage resources without supplements. Dry cows could gain weight during late summer and early fall where lactating cows would lose condition. Additionally, animal performance can be affected by animal health, genetics, implants, and environmental variables.

Accurate grazing, precipitation, and animal performance records are needed to critically evaluate grazing management effects on animal production and natural resources to correctly determine the effectiveness of management decisions. Animal performance records should include beginning and ending weights and/or cow condition scores for critical intervals of the production cycle. The effects of changes in stocking rates or grazing systems on animal performance are most discernable when all other variables are relatively similar among years and locations. If large numbers of animals are involved, consider weighing a representative subset of the same animals at the beginning and end of each grazing season. Livestock should be weighed on site and under the same conditions each time. The most accurate weights occur after an overnight stand without food and water. Livestock scales are one of the best investments in the range livestock industry. Managers cannot efficiently change what they cannot measure. Vegetation responses can be monitored with photographs taken on clear days at permanently marked locations at one- to five-year intervals, using the same camera settings and focal points each time. Photographs taken during the morning or late afternoon provide the best contrast in shades and colors. Visual contrasts are minimal near solar noon, 11 a.m. to 2 p.m. Photographs should be filed with date, location, weather, grazing information, and a list of species that are heading or flowering when photos are taken. Additionally, managers should periodically evaluate range condition using guidelines in the University of Nebraska–Lincoln Extension circular, *Range Judging Handbook* (EC150). Requests for rangeland inventories also can be submitted to local Natural Resources Conservation Service offices. Population census procedures, available from the Nebraska Game and Parks Commission, can be used to monitor wildlife populations.

Livestock scales are one of the best investments in the range livestock industry. Managers cannot efficiently change what they cannot measure.

Livestock Production Criterion

Should herd size be based on production per acre or individual animal performance *(Figure 9)*? Production per acre has advantages when land costs are relatively high, but higher stocking rates increase cumulative grazing pressure and increase the risk of damage to vegetation. Also, animal performance is less certain, especially with variable precipitation. Therefore maximizing yield of animal product per acre (Point 2) requires relatively high levels of ecological and economic risk. As stocking rates increase, the critical cumulative grazing pressure (Point 1) will be exceeded and average animal performance will begin to decline while production per acre continues to increase

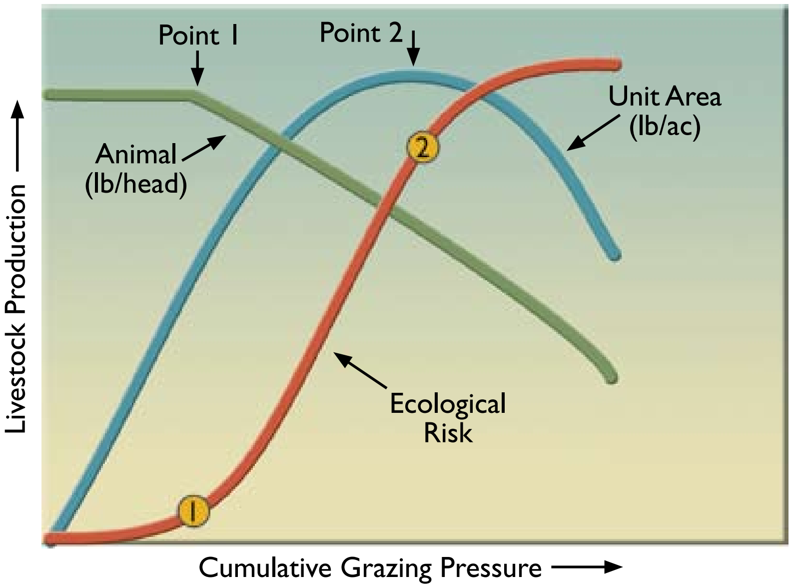

Figure 9. *Effects of cumulative grazing pressure on average animal performance (green), total livestock production per acre (blue), and ecological risk (red) at the end of the "summer" grazing season. Maximum production per unit land area (Point 2) is always associated with relatively low average animal performance which begins to decline at the critical cumulative grazing pressure (Point 1).*

(Figure 9). However, increases in production per acre become increasingly smaller beyond this point because of declining individual animal performance. Consequently, the top of most rangeland production-per-acre curves is relatively flat, indicating that considerable variation can occur in individual animal performance as cumulative grazing pressure changes with no measurable change in production per acre *(Figure 9)*.

If animal performance is too low to recover the purchase and/or production cost of each animal, return to land becomes a moot point. It would be prudent to use moderation in selecting stocking rates if maximizing production per acre is an objective. Additionally, up to 40 percent of the rangeland in some Nebraska counties is leased. Most lease rates are well below the cost of buying and owning the land, which should further diminish attempts to maximize production per acre. Moderate stocking rates reduce ecological risks by leaving more herbage for ecosystem functions and increase the likelihood of optimizing net return per animal sold off grass. When ownership is retained in a later production stage, higher stocking rates may be justified if compensatory growth reduces the cost per pound of gain on feed and rangeland resources are not jeopardized.

Hydrologic Condition of Rangeland

Soil moisture is the primary factor that limits plant growth on upland range sites. The **hydrologic cycle** is the process by which energy from the sun vaporizes water from land and oceans into the atmosphere then returns the condensed water vapor to the earth as precipitation *(Figure 10)*. Movement of precipitation into, through, or over the landscape is controlled by hydrologic condition.

The hydrologic condition of rangelands is a function of vegetation, soil, topography, and climate. Standing herbage and plant litter on the soil surface reduce the physical impact of raindrops on bare soil and retard surface flow of water when heavy rains occur. Decreases in protective plant cover result in increased runoff and exposure of soil aggregates to the destructive force of raindrops. Soil particles that are dislodged by raindrops or surface flow can plug openings in the soil or form crusts, reducing **infiltration**, the movement of water into the soil. Decreases in above-ground plant biomass eventually reduce the amount of organic matter entering the soil, which leads to reduced soil aggregate formation and stability. Reduced herbage production limits root production. Grass roots create a network that physically binds soil particles together. Additionally, roots induce soil aggregation by exuding organic chemicals that bind individual mineral particles. Improved soil structure and pores, created by root penetration of the soil, enhance **percolation**, the movement of water through the soil profile.

Sound management minimizes the negative effects of grazing on infiltration and optimizes the ability of desirable plants to use soil moisture. Downward cyclic interactions of hydrologic condition and plant vigor can be insidious *(Figure 11)*. It is easy to assume that below-average precipitation causes delayed green-up in the spring or reduced herbage production during the growing season. Hydrologic condition and plant growth are inseparable and both are directly affected by herbage allocation decisions *(Figure 1)*. On well managed upland range sites, standing herbage should include both carryover herbage from past years and current-year growth. The amount of herbage remaining after grazing and the amount of plant growth before heavy precipitation events occur are key elements for hydrologic condition, regardless of grazing system. When little or no standing herbage is left on rangeland because of fire, severe hail, severe drought, or abusive grazing, the most effective way to improve hydrologic condition and plant vigor is to exclude grazing animals for an entire year before grazing is resumed.

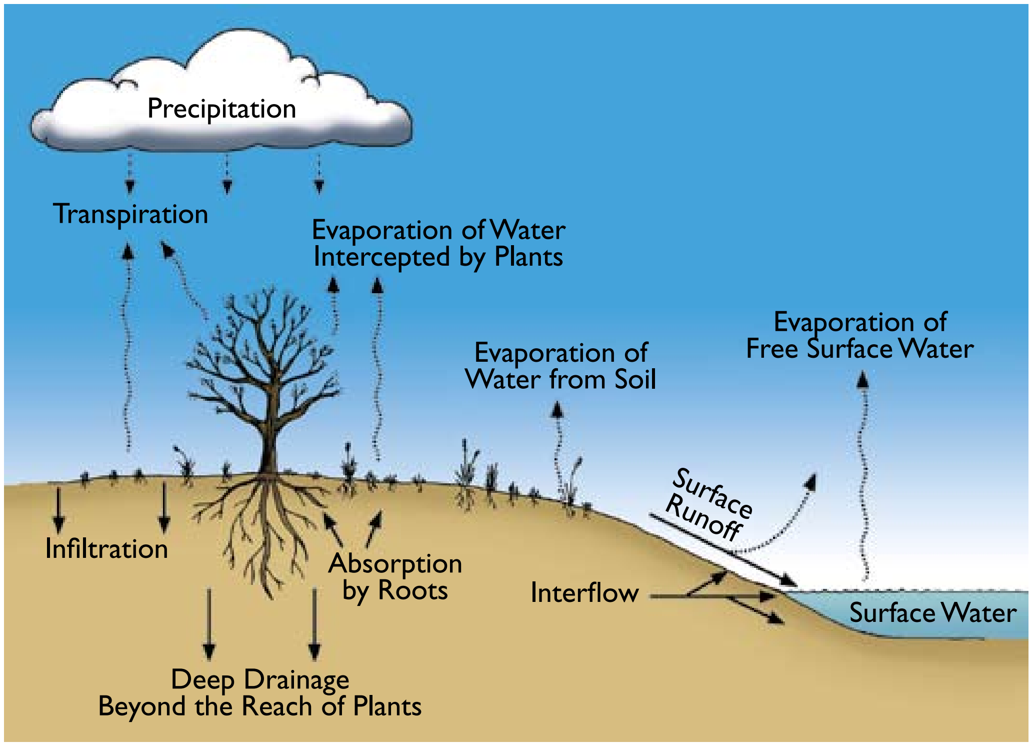

***Figure 10.** The water cycle showing major processes and pathways of water movement through a watershed. Water inf ow = water outf ow ± storage (Thurow 1991).*

Grazing by herds of domestic or native **ungulates**, hoofed animals, is inherently detrimental to hydrologic condition because of herbage consumption and soil compaction. Livestock tracks on clayey or silty sites create small pockets and barriers that may retard surface flow during light precipitation; however, soil compaction and reduced protective plant cover generally reduce infiltration and increase runoff during heavy precipitation. The potential for damaging soil structure or compacting soil generally is greater on wet compared to dry soils and greater on fine textured clayey or silty soils compared to coarse textured sandy soils. Numerous studies of livestock effects on rangeland watersheds conclude the following:

- Non-grazed areas have higher infiltration rates than grazed areas.
- Moderate and light grazing intensities produce similar infiltration rates.
- Heavy grazing reduces infiltration more than moderate or light grazing.

Range sites differ in the degree to which grazing may affect infiltration. Soil texture causes large differences in infiltration rates. With little or no soil aggregation or structure, infiltration rates may be 6.0 to 10.0 inches per hour on sandy soils compared to 0.2 to 0.8 inch per hour on clay loam soils. Grazing has relatively little effect on hydrologic condition on level to gently rolling sands or sandy range sites. With little or no slope and very high infiltration rates, potential damage to hydrologic condition on these sites is generally limited to how grazing affects the ability of plant roots to reach and absorb soil moisture.

Management practices that maintain high levels of plant vigor in key grass species and good to excellent range condition are optimal for hydrologic condition on grazed rangeland. Plant vigor and species composition affect the soil depth from which vegetation uses moisture. Reduction in root length often corresponds to decline in plant vigor. Losses of deep roots are measurably greater than loss of shallow roots

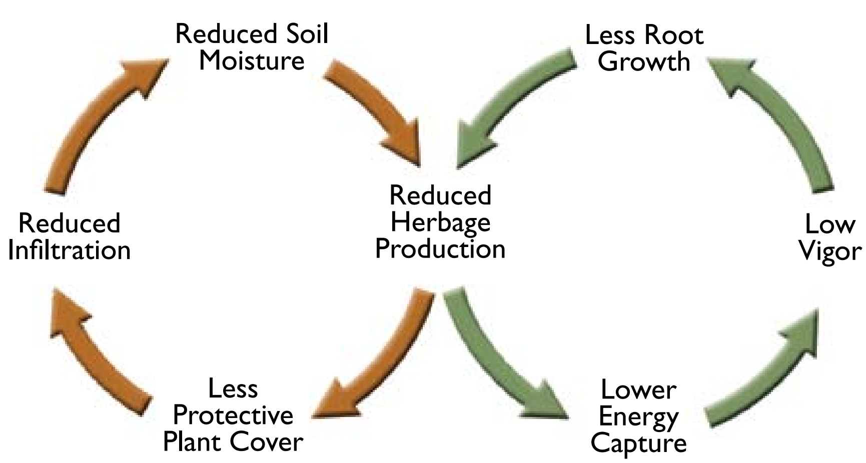

***Figure 11.** Cyclic interaction of hydrologic condition (brown) and plant growth (green) on rangelands (modified from a personal communications with R.L. Gillen, 1996).*

in tallgrasses such as sand bluestem *(Figure 8)*. In contrast, more than 70 percent of the total root length of shortgrasses such as blue grama and buffalograss is normally located in the top foot of soil *(Figure 12)*. Shortgrasses often increase as range condition declines. Reduced plant vigor and increased percentage composition of shortgrasses are most likely to occur on tall- and mixed-grass prairie when overgrazing precedes or occurs during drought.

Optimizing Hydrologic Condition on Grazed Rangeland

- Periodically provide full growing-season deferment to improve vigor of preferred plant species and increase the amount of litter and standing dead herbage.

- Shift the date of grazing in each pasture used for rotation grazing by 30 days or more each year. Change the sequence of pasture use by 60 days for pastures grazed in June or July when prairie sandreed is, or has the potential to be, a codominant species.

- On range sites prone to erosion, manage for adequate amounts of protective plant cover during July, August, and September when thunderstorms are most likely to produce high precipitation rates.

Upland Game Birds

Most wildlife species are characterized by cyclic high and low populations, often in response to consecutive years of above or below average habitat conditions. Wildlife populations are affected by all aspects of their ecosystem. Ecosystems of migratory species are often transcontinental. Non-migratory species frequently are affected by landscape characteristics well beyond the boundaries of a single ranch or resource management unit. Consequently, to be most effective, wildlife management should be based on critical habitat needs of selected species over an appropriate scale of land area. The minimum acreage of high quality cover and the probable number of nests established per unit area differ among game birds. Pheasants benefit from relatively diverse land use that provides a mosaic of 40- to 160-acre cover and food resource areas. In contrast, sharp-tailed grouse prefer thousands of acres of grassland where only two to six successful nests per section may occur even with an abundance of high quality cover. Sharp-tailed grouse and other upland game birds may be drawn from large surrounding areas into seasonally limited resource areas, such as hayland or cropland, especially when high quality cover occurs on nearby rangeland or seeded grasslands.

Nesting cover is the most limiting habitat requirement for most upland game bird species in Nebraska. About 94 percent of the land in Nebraska is privately owned. Cultivated land and urban areas rarely provide safe nesting sites. Consequently, adequate nesting cover for upland game birds is most likely to occur on rangeland or seeded grassland. Historically, the need to generate income for tax and land payments and enterprise and family expenses has caused most landowners to optimize beef production. The high priority of beef production and limited use of dormant-season grazing near areas with abundant crop residues often minimize the availability of nesting cover in grazed pastures.

Distribution and architecture of plant cover on grasslands is directly related to accumulation of standing herbage. Consequently, the ability of wildlife to carry out daily and seasonal activities without being observed by predators declines as stocking rates increase. The highest quality nesting cover for prairie grouse generally will not occur until pastures have been rested for one or two years. Most upland and migratory game birds will select nesting sites during March or April if adequate cover exists. Given the limited amount of current-year plant growth in early spring, the accumulation of residual herbage from preceding years is critical

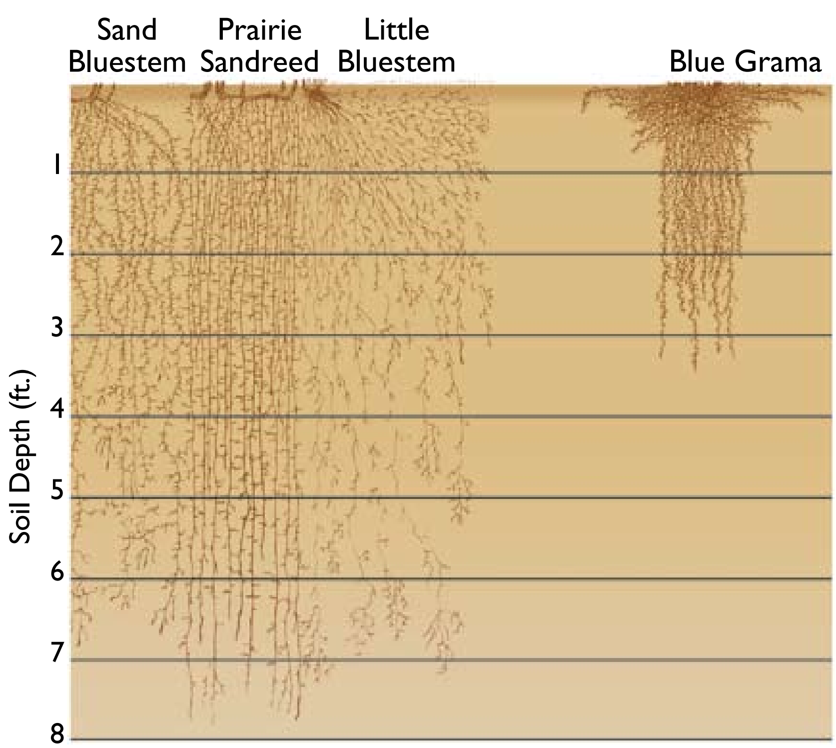

Figure 12. *Root distribution patterns for sand bluestem, prairie sandreed, little bluestem, and blue grama (modified from Weaver 1965 and Weaver and Clements 1938).*

for early nesting. Inadequate residual herbage will cause birds to delay nesting until May or June and result in correspondingly smaller clutches.

Plant growth after grazing in June or July may provide minimal levels of cover needed for some safe nesting sites for sharp-tailed grouse in the subsequent spring (Reece et al. 2001). In most years Sandhills pastures in good to excellent range condition can produce enough cover after light or moderate stocking rates in June to provide safe nesting next spring *(Figure 13)*. If cattle are not moved until late July, the limited amount of plant growth after grazing provides safe nesting cover only after low levels of cumulative grazing pressure. While plant growth after heavy grazing in June may provide enough cover for some safe nest sites, high cumulative grazing pressures at this time are potentially detrimental to the vigor of prairie sandreed *(Figures 3 and 7)*. Provision of safe nesting sites and brood-rearing cover for sharp-tailed grouse in every pasture would require measurable reductions in stocking rates compared to grazing strategies that give highest priority to livestock production; however, grouse populations can be sustained when high quality cover is well distributed within their home range of 4 to 19 square miles.

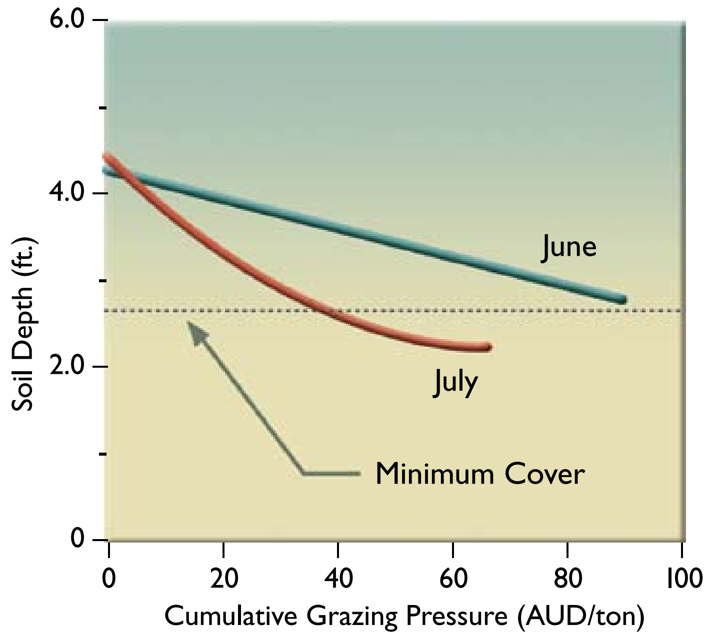

Figure 13. *Average cover during September after pastures were grazed only in mid-June and mid-July. Minimum average visual obstruction needed to just sustain prairie grouse populations in the Sandhills is about 2.7 inches. The number and quality of safe nesting sites increase as mean values of visual obstruction increase (Reece et al. 2001).*

Relative Value of Pastures

Rangeland commonly is divided into pastures to facilitate separation of livestock for breeding and/or nutritional management and to provide control over the time and extent to which plants are grazed. Cross fencing is often used to separate range sites with measurable differences in plant species or herbage production. In addition to minimizing the opportunity for livestock to concentrate on preferred range sites, multiple pastures can be used to enhance vigor of preferred plant species. The sequence or season in which pastures are used can be changed enough each year to avoid having consecutive years of heavy defoliation of plants during rapid growth.

The relative value of dividing a given land area progressively into more pastures to reduce the average number of days each pasture is grazed during the growing season declines as the number of pastures increases. Assuming similar grazing capacity among pastures, dividing rangeland into four pastures reduces the average time plants in any pasture are exposed to grazing under deferred rotation by 75 percent, from 150 to 38 days during a five-month grazing season *(Figure 14)*. Dividing the same area into eight pastures reduces the average time cattle are present in each pasture to 19 days. This is a 100 percent increase in cross-fencing costs for an additional 19-day reduction in the time plants are exposed to grazing compared to the initial reduction of 112 days from the first four pastures. After eight pastures, adding each additional pasture reduces the average time plants are exposed to grazing by less than one day. Cross fencing a given rangeland area into more than eight pastures become increasingly more difficult to justify biologically and economically. Consolidating livestock into a single herd and capitalizing on existing pastures may warrant the use of more than eight pastures if an adequate water supply is available. When calculating livestock water supply needs, use 20 gallons per pair day and four to seven days of storage capacity to account for potentially high heat stress and evaporation losses during July and August.

Nesting cover is the most limiting habitat requirement for most upland game bird species in Nebraska.

The inherent productivity of rangeland is the primary factor determining the economically prudent limit to downsizing pastures. For example, subirrigated meadows may be five times more productive than adjacent upland range sites. If the economical limit for recovering fence costs on upland range sites is 320 acres, the smallest prudent pasture size on subirrigated sites may be 60 acres.

Characteristics of Grazing Systems

Because grazing systems simply define periods of grazing and non-grazing, there can be an overwhelming number of potential grazing systems; however, environmental, economic, and resource constraints limit the number of acceptable systems. Conceptually, most feasible grazing systems fit into the following four categories: season-long continuous grazing, rest-rotation grazing; deferred rotation grazing; and intensively managed grazing.

Season-long Continuous Grazing

Compared to multiple-pasture grazing systems, the risk of management mistakes are minimized with only one decision on when to begin and one decision on when to end grazing each year under season-long continuous grazing. Daily rates of herbage removal per acre are relatively small because cattle are dispersed over the entire acreage in contrast to one-fourth or less of the total acreage in most rotation systems. Livestock have the greatest possible opportunity to select a high quality diet under continuous grazing. Light to moderate stocking rates can be used to optimize gains on replacement heifers or first-calf heifers. While costs for fence and water are lowest for continuous grazing, more labor may be required to check widely dispersed cattle. Uneven distribution of grazing at light to moderate stocking rates can provide adequate cover for wildlife in little used areas of the pasture. Blowouts or other disturbed areas likely will not heal regardless of lowered stocking rates or delayed entry dates. Consequently, risk of damage to vegetation under drought conditions can be very high in preferred areas. To reduce potential problems shift a pasture from season-long continuous grazing to rotation grazing for several years. When it is not possible to shift from continuous to rotation grazing, periodically switching use of individual pastures from growing-season to dormant-season use (seasonal rotation) will enhance plant vigor.

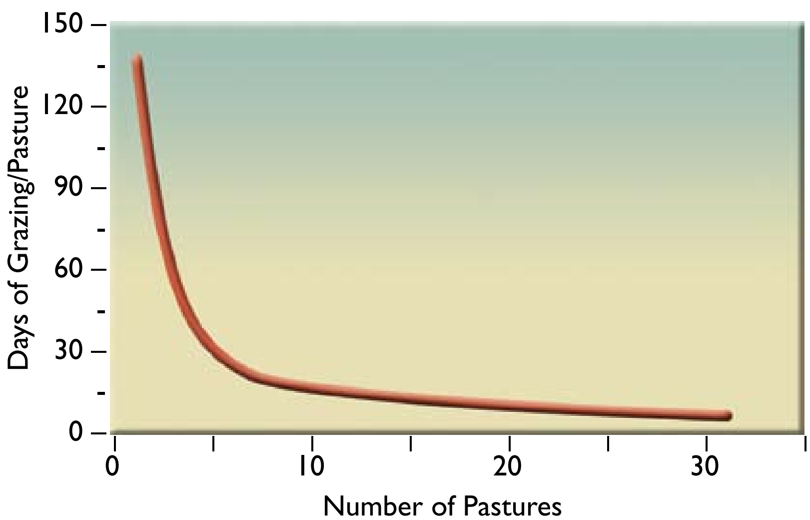

Figure 14. *The average number of days plants could be defoliated during a 150-day grazing season declines as the number of pastures used for rotation grazing increases. However, the relationship is one of diminishing returns. The greatest benefits occur from the first several pastures, and reductions in the average number of days vegetation is exposed to grazing become relatively small after eight pastures.*

Rest-Rotation Grazing

This grazing system was initially developed to improve range condition by resting one or more pastures for a minimum of one year. Stocking rates in grazed pastures are traditionally increased to compensate for non-use in the rested pasture(s). Concentrating livestock into remaining pastures will facilitate livestock management and may improve distribution of grazing within pasture; however, because stocking rate is increased in grazed pastures to offset non-use in the rested pasture(s), higher cumulative grazing pressure is expected to reduce animal performance in the last one or two pastures grazed each year compared to other rotation systems. Each spring the rested pasture and the pasture grazed first during the preceding year will provide the greatest amount of nesting cover for upland game birds. Deferring grazing in these pastures until mid-June or early July will ensure optimal use of nesting or brood-rearing cover.

Rest-rotation systems are more likely to succeed when used for relatively long "summer" grazing seasons. Spreading the same end-of-season stocking rate over six compared to four months would reduce stocking density and daily removal of forage by 33 percent. Fewer cattle would stay in pastures for more days, removing less forage per day when key forage species are growing rapidly. The likelihood of sustaining higher stocking rates in grazed pastures increases the more frequently pastures receive full growing-season deferment.

If nesting cover was a relatively high ranking objective, a six-pasture, rest-rotation system might be used to provide good cover on 33 percent of the land area by resting two pastures and using four pastures for grazing each year *(Figure 15)*. A staggered schedule of resting pastures with a six-pasture system would provide year-to-year continuity of high quality cover and a sequence of four years of grazing followed by two years of rest. Stocking rates would traditionally increase by 33 percent in grazed pastures in this six-pasture rest-rotation system which may be excessive for a relatively short "summer" grazing season. Reducing the stocking rate and/or increasing the length of the grazing season increases the likelihood of accomplishing natural-resource management objectives.

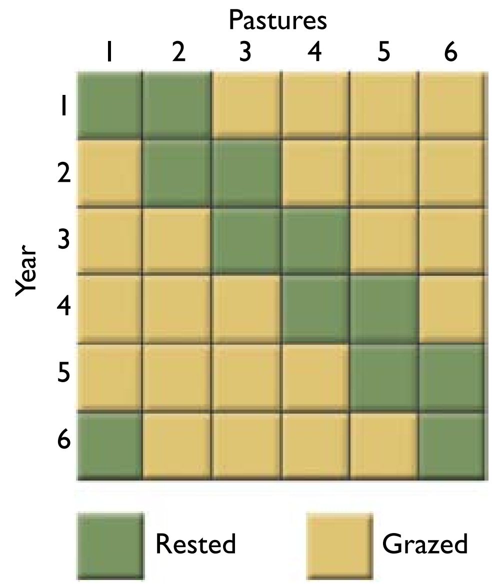

Figure 15. *An example of a rest/graze schedule for a six-pasture, rest-rotation grazing system with two consecutive years of rest applied to each pasture.*

Deferred-Rotation Grazing

The combination of using four or more pastures with one grazing period per pasture and moderate stocking rates is often a relatively efficient method of maintaining high levels of vigor in key plant species, improving range condition, and healing disturbed areas *(Figure 16, Tables 3 and 4)*. Dividing an area into four or more pastures can improve the distribution of grazing by reducing diversity of range sites within pastures. Distribution of grazing also may become more uniform because of reduced distance to water or increased stocking densities; however, improving grazing distribution will limit the availability of cover for wildlife in most pastures. Generally each pasture in a deferred-rotation system is only grazed one time each year and the grazing period is relatively long compared to intensively managed systems. During five- to six-month "summer" grazing seasons, 50 percent to 70 percent of the pastures in deferred-rotation systems are not grazed when dominant forage species are growing rapidly compared to some use in most pastures during this time in intensively managed grazing systems. Advanced plant maturity in the last pasture(s) under deferred-rotation may reduce animal performance late in summer grazing seasons compared to season-long continuous or intensively managed grazing.

Pasture sizes and grazing-management practices used for deferred-rotation grazing systems are well suited for seasonal rotation. Dormant-season and growing-season use can be rotated among pastures where logistically feasible. Inadequate protection from storms, use of crop residue for winter grazing, or short-term livestock ownership plans may reduce the feasibility of dormant season grazing. If little opportunity exists for seasonal rotation, plant vigor can be maintained in most grasses by delaying the initial turnout date until key species have begun rapid growth and providing periodic deferment of each pasture until September or October.

Understanding attributes of various grazing systems is critical for determining which system is best suited for a prioritized set of objectives.

Intensively Managed Grazing

The smaller pastures and shorter distances to water commonly associated with intensively managed grazing systems improve grazing distribution compared to the other systems. The highest possible fence and water costs are associated with intensively managed grazing; however, the large number of pastures used for these systems provides maximum flexibility for accomplishing individual pasture-management objectives. Grazing plans can be designed to alter stocking rates, provide rest, or reduce the number of grazing periods in selected pastures. The potentially negative effects of high grazing pressure on animal performance *(Figures 5 and 9)* can be partially offset by rapidly moving livestock among pastures to capitalize on forage resources before seasonal declines in nutritive value occur *(Figures 3 and 6)*. Consistently high

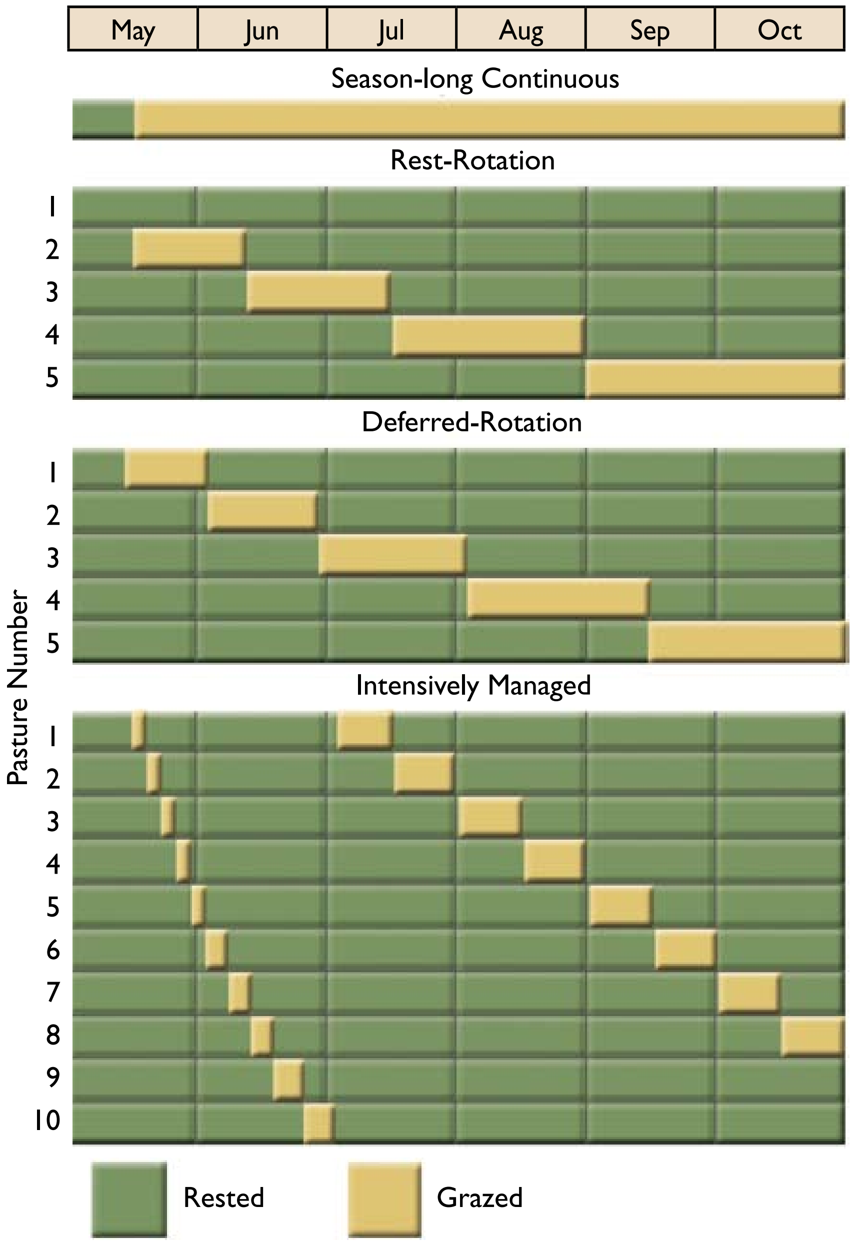

Figure 16. *Seasonal distribution of grazing for systems that are compared in Tables 3 and 4.*

cumulative grazing pressure when dominant forage species normally grow rapidly can cause measurable reductions in the vigor of key grasses such as prairie sandreed *(Figure 7)*. Multiple grazing periods, more uniform distribution of grazing, and commonly high grazing pressure during the growing season preclude the provision of adequate nesting cover for upland game birds when intensively managed grazing systems are restricted to the "summer" grazing season. Sustainable prairie grouse populations have been observed when moderate stocking rates were applied over 8 to 12 months with a large number of pastures, often more than 20. Relatively high grazing pressure and numerous decisions of when to begin and end grazing in individual pastures, inherent with intensively managed grazing, require a relatively high level of commitment to monitoring and management.

Selecting a Grazing System

The relative likelihood of accomplishing 11 objectives with four hypothetical grazing systems in the Nebraska Sandhills is presented in *Table 3*. The general seasonal distribution of grazing and non-grazing days for each grazing system selected and graphically summarized for this decision making process *(Figure 16)* may be considerably different from one ranch to another as land, livestock, labor, and financial resources change. Information in this circular and other university publications can be used to determine the relative likelihood of accomplishing specific objectives for different sets of grazing systems.

Stocking rate is a critical variable in grazing management because it is directly related to cumulative grazing pressure which affects livestock-production and natural-resource-management objectives *(Figures 1, 5, 7, 9, and 13)*, regardless of grazing system. Comparisons of grazing systems should be based on similar end-of-season stocking rates.

Key Points of the Example

- Stocking rates in the grazed pastures of the rest-rotation system are 20 percent higher compared to the other three grazing systems in *Figure 16* to compensate for non-use in the rested pasture.
- Total end-of-season stocking rates averaged over the entire land area are moderate for each of the four hypothetical systems compared in *Table 3*.
- Differences in the length of grazing periods (yellow bars) in the rotation and intensively managed systems *(Figure 16)* indicate progressively higher stocking rates for individual pastures that correspond to increasing amounts of available forage as the growing season progresses *(Figure 3)*.

Comparison Index (CI) values in *Table 3* indicate the likelihood of each grazing system to accomplish an objective compared to the other systems. Numerical values do not indicate that a grazing system is good or bad. Differences in herbage allocation, controlled by stocking rate and date of grazing *(Figure 1)*, may change the Comparison Index (CI) values. For example, if the stocking rate in the rest-rotation system *(Figure 16)* was reduced by 20 percent, Comparison Index values for plant and animal responses would be similar to deferred rotation *(Table 3)*. Under intensively managed grazing, skipping several pastures during the first cycle and delaying grazing until after mid-September *(Figure 16)* would increase the Comparison Index values for plant responses.

Once resource-management and livestock-production objectives *(Figure 1)* have been clearly defined *(Table 3)*, they need to be ranked. The relative value (RV) of a given objective compared to each of the other objectives can be indicated with a simple weighting method. Divide 10 points among the objectives, giving the most important objective(s) the highest value(s) and the least important objective(s) the lowest value(s) *(Table 4)*. Using whole numbers, move points among the objectives until the values correctly represent the relative importance in most two- and three-way comparisons of objectives. For example, in Scenario 1 *(Table 4)* improving range condition is more important than any other objective. Ownership of growing cattle will be retained, good sources of water are readily available, and if needed, electric fence will be used to divide pastures. Consequently, maximizing average daily gains and minimizing fence and water costs are least important and similar in relative value. Labor is a limited resource and intermediate in value (RV=3) between the animal performance and infrastructure objectives (RV=1) and improving range condition (RV=5).

The relative value of each objective is multiplied by the Comparison Index values *(Table 3)*. The sum of these scores [(RV) x (CI)] indicates which grazing system *(Figure 16)* is most likely to accomplish a given set of ranked objectives. Total scores *(Table 4)* in this process do not indicate that a grazing system is good or bad. They simply help identify the most effective grazing system for a given set of prioritized objectives.

Clearly one system is not best for all grazing strategies. Changing objectives and/or relative importance of objectives can change the most suitable grazing system as demonstrated by the three scenarios in *Table 4*. Total scores for Scenario 1

Table 3.

Relative likelihood of accomplishing management objectives on upland range sites during the growing season with different grazing systems *(Figure 16)* **when stocking rate**, averaged over all pastures, **is moderate for each system**.

Controlling Variable(s) and Management Objectives	**Grazing Systems**			
	"Season-long Continuous"	"5-pasture Rest-rotation" 1 pasture rested, balance grazed once	"5-pasture Deferred-rotation" each pasture grazed once	"10-pasture, Intensively Managed Grazing," most pastures grazed twice
	Comparison Index Values[1] (5 = most likely, 1 = least likely)			
Stocking Rate and Date of Grazing				
• Provide nesting cover for prairie grouse	3	5	3	1
• Maximize average daily gains	5	1	4	4
Number of Pastures				
• Minimize fence and water expenses	5	3	3	1
• Improve grazing distribution	1	3	3	5
• Minimize risk of mistakes on selecting a turn-out date and making pasture moves	5	3	3	1
• Facilitate livestock management	1	4	4	5
• Minimize time required to monitor herbage resources	5	3	3	1
• Flexibility in accomplishing individual pasture management objectives	1	2	4	5
Date of Grazing and Stocking Rate				
• Improve range condition	1	2	5	3
• Increase vigor of preferred plant species	1	3	5	4
• Heal disturbed sites	1	3	5	5

[1]Comparison Index Values in this example are based on observations and published studies in the Nebraska Sandhills.

Table 4.

Examples of livestock production and natural-resource management objectives and use of indices to determine the relative likelihood of different grazing systems to accomplish prioritized sets of objectives when grazing occurs only during the "summer" grazing season. Scores are derived by multiplying relative values of objectives for each scenario by the estimated comparison index values in *Table 3*.

Objectives	Relative Value of Objectives (1 to 10, ∑ = 10)	Continuous		Rest Rotation		Deferred Rotation		Intensively Managed	
		Index	Score	Index	Score	Index	Score	Index	Score
Scenario 1									
Improve range condition	5	1	5	2	10	5	25	3	15
Reduce time checking livestock	3	1	3	4	12	4	12	5	15
Minimize fence and water costs	1	5	5	3	3	3	3	1	1
Maximize average daily gains	1	5	5	1	1	4	4	4	4
			18		**26**		**44**		**35**
Scenario 2									
Maximize average daily gains	4	5	20	1	4	4	16	4	16
Flexibility for pasture management objectives	3	1	3	2	6	4	12	5	15
Uniform use of forage	2	1	2	3	6	3	6	5	10
Improve range condition	1	1	1	2	2	5	5	3	3
			26		**18**		**39**		**44**
Scenario 3									
Provide nesting cover for grouse	7	3	21	5	35	3	21	1	7
Minimize risk of grazing management mistakes	2	5	10	3	6	3	6	1	2
Heal disturbed sites	1	1	1	3	3	5	5	5	5
			32		**44**		**32**		**14**

(Table 4) indicate that the deferred-rotation system described in *Figure 16* is most likely to accomplish that set of ranked objectives. Continuous and rest-rotation grazing are much less likely to be effective. The intensively managed system has intermediate potential to accomplish the objectives.

When range condition has improved to target levels in all pastures, the relative value of this objective may be reduced or the objective may be deleted as long as condition does not decline. In Scenario 2, the relative values of improving range condition and maximizing average daily gains are reversed compared to Scenario 1, and two objectives are different *(Table 4)*. Additionally, less distinction occurs among objectives in Scenario 2 compared to Scenario 1 with only a one-point separation compared to a two-point separation between each of the top three objectives. Consequently, intermediately ranked objectives may have a greater cumulative effect on the grazing system selection process than the highest ranked objective. Continuous and rest-rotation grazing are least likely to accomplish the prioritized objectives of Scenario 2, even though average daily gains are likely to be highest under continuous grazing compared to the other systems. The intensively managed (IMG) and deferred-rotation grazing systems have a relatively high likelihood of accomplishing ranked objectives in Scenario 2. If existing pastures and livestock water are adequate for intensively managed grazing, the decision is relatively easy. If the cost for needed infrastructure is relatively high, the deferred-rotation grazing system may be the prudent choice.

It is often assumed that the best or only way to recover the cost of additional fence and water is to increase stocking rate. Increasing stocking rate at this point in the decision-making process has two potentially negative consequences. First, doing so invalidates the decision making process. A new set of Comparison Index values *(Table 3)* should be estimated and used for comparing all systems at the proposed increased stocking level. Secondly, the first objective in Scenario 2 is to maximize average daily gains. The potential of exceeding critical cumulative grazing pressure and reducing average daily gains increases as stocking rate increases. Measurable increases in stocking rate will compromise the most important objective in Scenario 2, especially when drought occurs.

Placing a relatively high value on the highest ranked objective, as demonstrated by placing 7 of 10 possible points on nesting cover in Scenario 3, increases the likelihood of a single objective dominating the decision-making process *(Table 4)*. When stocking rate, averaged over all pastures, is moderate for each system, the rest-rotation system is most likely and the intensively managed grazing system is least likely to accomplish the prioritized objectives in Scenario 3. Continuous and deferred-rotation grazing have intermediate potential to accomplish this set of prioritized objectives.

Over time, modifying or changing grazing systems to account for changes in objectives and resources may be beneficial. The preceding discussion of the decision-making process for selecting grazing systems was based on scenarios in which the selected rangeland area is grazed only during the "summer" grazing season. Many ranches in the semi-arid region of the Great Plains have cow-calf enterprises and often have a herd of livestock on the ranch throughout the year. Providing full growing-season deferment to every pasture every two to four years frequently increases sustainable stocking rates compared to pastures grazed only during the summer.

Assess and Modify

Initial records of range condition, livestock performance, and/or wildlife populations provide valuable baseline information for long-term assessments. Grazing, precipitation, and livestock-performance records are critical for annually evaluating the effectiveness of grazing systems, and for planning turn-out dates and/or pasture use sequences in each subsequent year. Guidelines for

grazing records are available from the University of Nebraska–Lincon and the Natural Resources Conservation Service. Cumulative precipitation from the preceding October to killing frost of the current year is essential for understanding plant and animal responses. Precipitation information can be collected from on-site rain gauges or purchased from the regional High Plains Regional Climate Center (online at hprcc.unl.edu; phone (402) 472-6706; or fax (402) 472-8763).

Glossary

Animal-unit days (AUD) - AUD of grazing is equivalent to about 26 lb of air-dry forage

Animal-unit equivalents (AUE) - estimated by dividing the average weight of pairs or an individual by 1,000 lb

Animal-unit month (AUM) - equivalent to about 780 lb of air-dry forage

Browse - palatable portions of woody plant growth

Critical cumulative grazing pressure - level of CGP where the average performance of all animals in the herd declines with each additional AUD of grazing

Cumulative grazing pressure (CGP) - animal unit demand per ton of forage over a period of time

Forage - palatable herbage and woody plant growth that are available and acceptable to the grazing animal

Grazing management - manipulation of grazing animals to accomplish desired results

Grazing pressure - demand/supply ratio between dry matter requirements of livestock and the quantity of forage available in a pasture at a specific time

Grazing strategy - a plan for accomplishing a set of objectives based on comprehensive knowledge of available resources, and the production and marketing environment

Grazing system - periods of grazing and non-grazing

Herbage - all of the above-ground, non-woody growth of plants

Hydrologic cycle - the process by which energy from the sun vaporizes water from land and oceans into the atmosphere and the return of condensed water vapor to the earth as precipitation

Infiltration - movement of water into the soil

Percolation - movement of water through the soil profile

Semi-arid - climates characterized by relatively high evaporation rates and wide swings in temperature between day and night

Stocking density - concentration of livestock at a given point in time, expressed as AU/ac

Stocking rate - number of AU per acre for a specified amount of time without regard to the amount of forage

Ungulates - hoofed animals

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