ERM-056 05/21

Grazing Principles for Profitable and Regenerative Resource Management Series:

II. GRAZING MANAGEMENT AND ITS EFFECTS ON PLANT COMPETITION AT DIFFERENT SCALES

Tim Steffens* and Morgan Treadwell**

This is the second in a series of Texas A&M AgriLife Extension Service publications to help readers better understand the ecology of grazed lands, the way plants grow, develop, and react to **defoliation** by **herbivores**, how to manage forage quality and quantity, management of stocking rate to improve grazing profitability, essential concepts related to proper grazing management, and how to apply these concepts successfully using adaptive grazing management strategies. We suggest you read these in order, but each can be read separately if you already have a firm background in these topics. A complete glossary of technical terms used throughout all of the publications can be found at the back of each publication. Several of these terms were supplied by the Society for Range Management, and their definitions are placed in quotes.[1] When needed, additional clarification is provided. When a technical term is used for the first time in each publication, it is shown in boldface type.

Other Titles in the Principles of Regenerative Grazing Management Series

I. **Ecological Concepts in an Economic Context**

III. **Factors Affecting the Magnitude of Grazing Effects on Plant Responses and Forage Quality**

IV. **Stocking Rate: The Essential Concept for Profitable and Regenerative Grazing Management**

V. **Essential Concepts Necessary for Adaptive Multi-paddock Grazing Management to Achieve Desired Livestock and Landscape Goals**

VI. **Using Essential Grazing Concepts to Properly Implement Successful Adaptive, Multi-paddock Grazing Strategies**

*Assistant Professor and Extension Rangeland

**Associate Professor and Extension Range Specialist

Animals interact with plants in ways that maximize benefits and minimize detrimental conditions for themselves. They tend to select plants across the landscape that allow them to increase the rate of nutrient intake. So, in general, they tend to prefer high-quality plant species that grow densely on parts of the landscape that are easily reached and have a growth form that makes it easy to get a full bite. Since they also prefer a high percentage of succulent material and less fiber, they also select live plants over dead, green plants over brown, young plants over old, and leaf rather than stem.

Detrimental effects of plant defoliation are the result of 1) loss of leaves (photosynthetic capacity); 2) loss of roots (absorptive capacity); and 3) loss of growing points, or **meristems** (reproductive capacity). Plants sacrifice roots, change their growth form, growth rate, or chemistry to react to the challenge of being grazed. The growing points are found at three primary locations on the plant. The apical meristem at the tip of the stem, may actually be near the soil surface in the early stages of growth, but then begins to elevate as the plant prepares to set seed. Other growing points are at the collar of the leaf and allow the plant to regrow leaf after the tips have been removed, provided that these growing points are not removed also. If both of these growing points are removed, plants must regrow from growing points on buds at the base of the plant. Figure 1 provides a visual way to understand these growing points and where they are located.

When plants cannot cope well enough to compensate for the timing, frequency, and intensity with which they are defoliated, they die. Plants with high proportions of leaf that are palatable and easily consumed, young plants or taller grasses with growing points that are easily removed by grazers, and those that stay green longer than their neighbors may be affected especially adversely by grazing because they are defoliated more severely or often than less palatable or less susceptible neighbors.

[1](Society for Range Management, 2005)

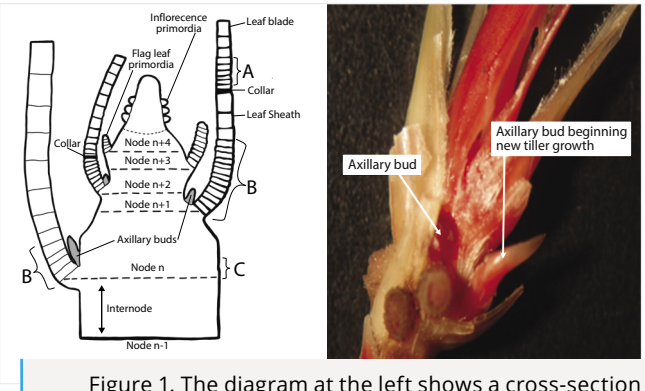

Figure 1. The diagram at the left shows a cross-section of a young crown and tillers. "Node n" is the oldest, and "Node n+4" is just forming. (A) Blade intercalary meristem, where leaf blade cells divide and elongate. (B) Sheath intercalary meristem, where sheath cells divide and elongate. The shoot apex (inflorescence primordia) lays down cells that can form into a variety of structures. Axillary buds are where new tillers form in response to removal of the growing point at the apex of the tiller, which hormonally suppresses growth of these buds. The photo on the right shows an actual dormant blue grama axillary bud with another axillary bud that has initiated growth of a new tiller. *Diagram by Hendrickson and Briske.*[2] *Photo courtesy of Morgan Treadwell.*

By knowing how plants react to defoliation and how long it takes for them to fully recover, we can be better informed regarding how our grazing management will affect the plants we want to promote or discourage.

EFFECTS OF GRAZING ON A LANDSCAPE SCALE

Animals affect their environment on a landscape scale both directly by removing vegetation and indirectly through other activities. The latter factor is one reason why the results of some studies differ when evaluating the effects of clipping on plants versus grazing. Indirect effects of grazing by large animals include trampling and soil compaction, defecation and urination, seed dispersal, and seedbed preparation.

Potentially beneficial effects of short-term trampling followed by a period of recovery with no animals present include enhanced contact of dead plant material with the soil. This **litter** can better protect the soil surface from the force of falling rain and be more readily decomposed by soil microbes. Trampling may also temporarily break up soil crusts that form between plants where splash erosion breaks down soil surface **structure**. It may also increase soil-seed contact and create small depressions to hold water after a rain, which may increase the opportunity for seed germination and survival.

[2](Hendrickson and Briske, 1997)

Animals also may enhance seed germination and survival in other ways. They disperse seeds (both desirable and undesirable) in their wool and hair and ingest then deposit them in dung. Germination may be increased in some instances when a hard seed coat is softened or removed in the digestive tract of animals. The dung may then reduce temperature extremes and provide a moister environment for the seed and seedling. Seed germination is enhanced for many plant species by these processes. If these seedlings are palatable, they will likely require a period for them to establish without being grazed to help ensure their long-term survival.

Figure 2. Grazing animals affect plant communities by trampling standing plant material, which can compact soils, but also can improve soil-seed contact, provide small divots to hold moisture for a longer period, and put plant litter in contact with the soil, where it can act as a mulch to decrease evaporative losses. In these photos from South Texas, animal impacts created an ideal environment for seedlings to survive, and the 4 months without grazing after this event provided the seedlings an opportunity to establish. Note the prickly pear clump and live oak tree in the background for reference. *Photos courtesy of Tim Steffens.*

Figure 3. The area at top was dominated by annual grasses, such as little barley and cheatgrass utilized at high stocking density with sheep. In doing so, they ate some of the forage, trampled the rest in contact with the soil, and mixed it with their own manure. Notice the complete ground cover and mulch that improve the water cycle. The following year, this area had perennial warm-season grasses beginning to establish. 3 years later, with about 11-month recovery periods between short graze periods in a 12-inch rainfall area, the picture at bottom was taken in the same area. *Photo courtesy of Tim Steffens.*

However, when trampling occurs for long periods of time, without sufficient recovery, soils can become compacted, and surface **aggregate** stability can be destroyed. This breakdown of soil structure increases soil **bulk density**, decreases water infiltration, and increases the opportunity for soil erosion. These detrimental effects are intensified by short recovery periods, animals with heavier body weights compared to hoof size, and wet soils.

Heavy concentrations of dung in areas where animals congregate also redistribute plant nutrients on a landscape. In areas where animals concentrate, such as those around watering points, shade, and fence lines, soil disturbance and nutrient levels may be increased. Higher nutrient and disturbance levels may cause species like cheatgrass, mustards, pigweed, and annual broomweed (generally lower **seral** plants that respond to higher nutrient concentrations and **disturbance**) to dominate. High levels of surface water contamination may also occur.

Landscape-scale effects vary with the animal species and management. For instance, an animal's forage preferences and ability to selectively graze affect the plant species chosen and, in some cases, the intensity with which they are grazed. **Defoliation** affects a plant's ability to obtain nutrients from the environment and to manufacture compounds needed for survival through **photosynthesis**. If some plants are defoliated more severely than their neighbors, their ability to compete for resources will be decreased, and species composition can change over time, causing less palatable or less productive plants to increase. An in-depth discussion of defoliation effects on individual plants follows in the section about grazing effects on an individual plant.

We generally consider that sheep prefer high-quality **forbs** as a major part of their diet. Deer also select forbs preferentially, as well as significant amounts of **browse** in their diet. Goats also select high proportions of browse when available. Horses and cattle eat higher proportions of coarser grasses under most circumstances compared to other **ruminants**, such as sheep, goats, or deer, but will repeatedly use these plants to maintain them in a less mature, higher-quality stage of growth. This preference for certain forage species, however, does not keep them from eating other types of food. Even in high-quality habitats, when grass is available, about 50 percent of a goat's diet may contain grasses. We also know that deer and antelope will utilize cool-season grasses, such as small grain fields, in the fall and winter. Alfalfa is a preferred species by almost all grazing or browsing animals. Furthermore, when forage is limited, the variety of plant species is low, or mobility of the animals is limited so that different species of grazers are forced onto the same area at the same time, diets of different grazing species will be more similar than when the opposite conditions are true.

Mobility and size, as well as grazing habits, will influence the effect that grazing animals have on the landscape. For instance, sheep prefer higher elevations when bedding down and will use slopes and broken country more effectively than cattle. Therefore, hilltops will often be the most heavily utilized part of a landscape by sheep, whereas the lower areas, especially those near water, will usually receive the greatest grazing pressure when cattle are the primary grazing species. Likewise, the ability of a goat or deer to stand on its back legs while browsing gives areas that are heavily utilized by these species a characteristic "browse line." This browse line may be more pronounced on the side of the pasture from which prevailing winds blow, since they also prefer to feed into the wind.

One factor that will modify the behaviors of a species of grazing animal is learning in response to management. If animals are consistently herded out of a critical area where they tend to congregate, or replacements are selected from offspring of animals that avoid these areas, grazing behavior and land-use patterns of the group may eventually change to some degree in desirable ways. Likewise, strategic placement of water, nutrient supplements, supplemental feeding areas, fencing, and shade will influence animal distribution over the landscape.

EFFECTS OF GRAZING ON AN INDIVIDUAL PLANT SCALE

This section deals primarily with the effects of defoliation by grazing animals on an individual plant and that plant's ability to compete with its neighbors as a result. The ability of palatable forage species to compete with neighboring plants that are less desirable is important to maintain forage quality over time.

Most reproduction of **perennial** herbaceous species in North America is **vegetative**, that is, from **stolons**, **rhizomes**, or an increase in the number of stems from buds at the base of the plant. Seed recruitment is generally rare in most existing stands of native, perennial vegetation. Therefore, it is important to maintain the vigor and reproductive capacity of vegetative parts of preferred species by leaving these reproductive structures intact to the greatest extent possible and by leaving enough leaf material for the plant to support new growth.

This does not mean that allowing plants to make seed periodically is unnecessary or that seedling recruitment is unimportant. What it *does* mean is that **vegetative reproduction** is normally the most rapid means of increasing the percentage of total production represented by preferred species. However, in low seral communities, seedling recruitment is often the only means desirable species have available to reproduce themselves. Likewise, allowing a plant to set seed is one way to ensure that enough recovery has been provided following defoliation for the plant to maintain its competitive capacity. Plants should also be allowed to set seed at least often enough to ensure that a viable seed bank is maintained in the soil. Due to insect or rodent consumption or microbial attack, many species have relatively short periods when their seeds remain viable in the soil while others, like mesquite and many of the annual weeds and grasses, have seeds that may last several years.

The harmful effects of defoliation for an individual plant include a decrease in leaf area that diminishes photosynthetic capacity. If defoliation is too severe (common wisdom says 50 percent of leaf surface, but this figure may actually range from about 30 percent to about 60 percent, depending on the species), it also temporarily stops root growth. The plant must then reallocate energy from roots to shoots to survive until enough leaf grows to produce more energy than the plant uses to maintain itself. This interruption of root growth and decrease in photosynthetic activity puts that plant at a disadvantage compared to its neighbors that were not defoliated as severely, allowing its competitors to capture more of the limited nutrients, water, or sunlight available. Since the roots of other plants may simply occupy the space vacated by the damaged plant, total production of the community may not decrease significantly. However, these other plants are often less palatable, such as threeawn and many of the weedy forbs and shrubs. These changes in species composition would cause *palatable* production as well as livestock and wildlife productivity to decrease.

Figure 4. When plants are defoliated too severely and too often, their growth is affected. This four-wing saltbush is chronically and severely browsed, exhibiting a "hedged" appearance. If provided a period of regrowth between defoliations, the twigs will begin to elongate and grow leaves that are better able to capture sunlight and easier for browsing animals to eat. *Photo courtesy of Tim Steffens.*

When a grass plant is in the early stages of growth, the growing point is near or below the soil surface. As the plant matures, the growing point elevates, generally just prior to producing a seed head. If the growing point is removed at that time, further stem growth stops, and growth must begin again from the axillary buds near the base of the plant. The recruitment of new stems from these basal buds may increase the number of tillers making up the plant, given adequate time and conditions for regrowth. However, the plant must survive until this growth begins again and then produce enough foliage before dormancy to grow sufficient

roots to effectively compete for soil moisture. In drier environments, or when the growing point at the tip of a grass stem is removed later in the season, there may not be time for the plant to grow enough new tillers and roots to compete effectively for moisture.

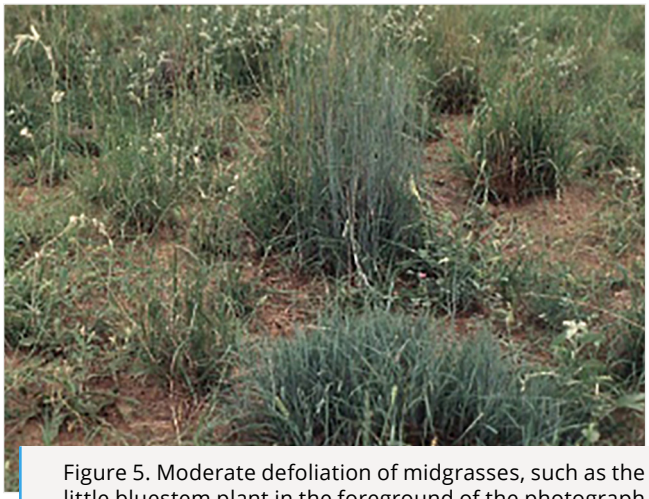

Figure 5. Moderate defoliation of midgrasses, such as the little bluestem plant in the foreground of the photograph compared to the undefoliated little bluestem behind it, followed by enough time for regrowth of a full complement of leaves ensures that they can maintain their competitive ability with less desirable plants in the community.
Photo courtesy of Tim Steffens.

Therefore, removal of the growing point may actually decrease the number of stems produced by a plant when poor growing conditions prevail—another reason why some species disappear while others become more abundant under heavy grazing.

Taller growth habits with high leaf areas give plants possessing these characteristics an advantage in ungrazed to moderately grazed situations, since they can more effectively compete for light and often have deeper root systems. However, continuous heavy grazing creates a difference in selection pressure on species with erect growth forms and those that grow closer to the ground, have larger numbers of shorter tillers, and reduced leaf numbers and leaf areas. It is easier for grazers to remove too much leaf material from taller, leafier plants than those with lower growth forms. Therefore, the shorter plants are more competitive compared to their erect, leafy cousins in situations where heavy grazing is common.

Finally, some possible positive effects of defoliation include opening the canopy to allow earlier soil warming in the spring, decrease moisture losses from **transpiration**, and initiate growth from dormant axillary buds at the base of grass plants. Removal of dead or older leaves that may be inefficient at photosynthesis would promote growth in moister environments and decrease interception of rainfall where low-volume precipitation events are common.

The next publication in this series discusses how plants change with growth and maturity and how that affects forage quality.

GLOSSARY

Aggregate A cluster of soil particles held together in a single group such as a clod or crumb. The more stable and rounder in appearance, the more desirable the aggregate **structure**.

Animal Unit Day (AUD) "The forage demand (amount of forage) on an oven-dry basis required by one animal unit for a period of one day."[1]

Animal Unit Month (AUM) "The amount of oven-dry forage (forage demand) required by one animal unit for a standardized period of 30 animal-unit-days."[1]

Animal Unit Year-long (AUY) "Equal to 12 AUMs."[1]

Area Allowance A measure of area/animal at a given point in time. It is measured in units of area/animal with no measure of time. It is the inverse of stocking density and changes linearly with increasing paddock numbers on the same land area with animal numbers remaining constant.

Biomass The amount of living material.

Browse The part of shrubs, woody vines, and trees available for animal consumption composed of leaves and small, soft twigs of palatable shrubs.[1]

Bulk Density The mass per unit of volume (e.g., pounds/cubic foot) of undisturbed soil, including air space. Within a particular soil type, lower bulk density will allow more rapid moisture infiltration and movement through the profile.

Capital Assets In the context of a business, capital assets are things with a useful life longer than a year that are used to make the products of the business. They are not intended for sale in the regular course of business operations such as machinery, buildings, or the real property where the business is located. In the case of the range resource, they would be things like seedbanks, soil organic matter, perennial plants, and water resources.

Carnivore An animal that eats other animals.

Carrying Capacity "The average number of livestock and/or wildlife that may be sustained on a management unit compatible with management objectives for the unit. In addition to site characteristics, it is a function of management goals and management intensity."[1]

Climax "The final or stable biotic community in a successional series; it is self-perpetuating and in equilibrium with the physical habitat."[1] Stress or disturbance as a result of excessive levels of grazing or other factors would cause the community to revert to a lower **successional state**. With removal of the stressor, the community would then progress through the same stages back to the stable climax community. This view of **successional** processes, however, has been unsuccessful in explaining **plant community** changes in some circumstances, particularly those where "naturalized" alien species have become an important part of the plant community, on areas where extreme degradation of the soil has occurred, or where other environmental influences like pollution or species extinction have changed the productive potential of the site.

Cycle Length The length of time required to graze all paddocks in a unit, i.e., the recovery period plus the grazing period.

Deferment "The delay of grazing to achieve a specific management objective. A strategy aimed at providing time for plant reproduction, establishment of new plants, restoration of plant vigor, a return to environmental conditions appropriate for grazing, or the accumulation of forage for later use."[1]

Defoliation "The removal of plant leaves, i.e., by grazing or browsing, cutting, chemical defoliant, or natural phenomena such as hail, fire, or frost."[1]

Disturbance A change in conditions, processes, or a stress that causes some plants to die in an area. Examples include fire, drought, excessive grazing, floods, etc.

Dormancy The period when the plant is no longer growing, usually after frost, but may also be due to drought.

Ecological Site "A kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management."[1]

Ecological Threshold A threshold of soil or other degradation that, once crossed, changes the potential plant community for a site irreversibly on management-level time scales without high levels of management input or extended periods of time.

Ecosystem "Organisms together with their abiotic environment, forming an interacting system, inhabiting an identifiable space."[1] I.e., the plants, animals, soils, climate, and other living and non-living things that affect each other through a series of chemical and physical feedbacks.

Forb A broadleaf herbaceous plant (not a grass, sedge, or rush); often referred to as a weed.

Herbaceous Plant Plants that are not woody.

Herbage Allowance The amount of forage on offer compared to the amount that the animals can consume.

Herbivore "An animal that subsists principally or entirely on plants or plant materials."[1]

Litter "The uppermost layer of organic debris on the soil surface; essentially the freshly fallen or slightly decomposed vegetal material."[1]

Meristem A region of plant tissue—found chiefly at the growing tips of roots and shoots, at the nodes, and in grasses, at the collar of leaves and at the base of the plant—consisting of actively dividing cells forming new tissue. The growth points of the plant.

Omnivore An animal that eats both plants and animals.

Organism Any living thing.

Overgrazing "Continued heavy grazing which exceeds the recovery capacity of the plant and creates a deteriorated range."[1] It happens to individual plants and is caused by inadequate opportunity for regrowth following defoliation that weakens, and if continued, can kill that plant. Overgrazing can occur even with low stocking rates.

Overhead cost The costs, usually associated with land, facilities, or labor, that do not increase directly with the number of animals.

Overstocking "Placing a number of animals on a given area that will result in overuse if continued to the end of the planned grazing period."[1] That is, forage demand in excess of that which will meet animal production and resource goals. Overstocking will always cause one or more of the following: 1) overgrazing; 2) increased variable costs; 3) decreased animal performance; 4) lower profitability.

Paddock "A grazing area that is a subdivision of a grazing management unit and is enclosed and separated from other areas by a fence or barrier."[1] The term "pasture" is also used in the United States. However, "paddock" is used in this case because it is most often used in conjunction with controlled grazing management, whereas pasture is a term more commonly used in areas where season-long or year-long grazing is common.

Perennial A plant that has a life span of 3 or more years that regrows each year from existing crowns, stems, or roots.[1]

Photosynthesis The chemical reaction carried on by green plants in which they change carbon dioxide from the air and water absorbed from its roots to form simple compounds used for energy using the light from the sun.

Plant Community "An assemblage of plants occurring together at any point in time, thus denoting no particular successional status."[1]

Recovery Regrowth following **defoliation** sufficient for a plant to fully regain its vigor so that it can retain its competitive ability in relation to neighboring plants. With regard to a plant community, recovery may also require additional time for plants to produce reproductive parts and then germinate and establish new plants, if more desirable plants are wanted. In order to ensure recovery, a period of grazing **deferment** is usually required.

Revenue The total amount of money received as a result of doing business.

Rhizome A horizontal underground stem, usually sending out roots and aboveground shoots from the nodes that is responsible for vegetative reproduction in some plants like Johnsongrass and Tobosa.[1]

Ruminant "Even-toed, hoofed mammals that chew the cud and have a 4-chamber stomach."[1] These animals also have a dental pad in the upper jaw instead of incisor teeth, such as a cow, sheep, goat, or deer, but not a horse.

Seral "Refers to species or communities that are eventually replaced by other species or communities within a sere."[1] It is sometimes used to refer to the **successional state** of a community growing on an **ecological site.** A high seral community would have a high proportion of species that are long-lived, use resources efficiently (e.g., conserve them with little waste), and are adapted to lower levels of disturbance. Low or mid-seral communities would have a higher proportion of plants that were shorter-lived, more opportunistic, and possibly less efficient in their resource use. High, mid-, and low seral may also refer to plants characteristically found in these respective communities.

Seral Community "The relatively transitory communities that develop under plant succession. Syn. seral stage"[1]

Stocking Density "The relationship between number of animals and the specific unit of land being grazed at any one point in time. May be expressed in animal units per unit of land area (animal units at a specific time/area of land)."[1] It is the inverse of area allowance and changes asymptotically with increasing paddock numbers on the same land area when animal numbers remain constant.

Stocking Intensity The total forage demand per unit area in a paddock for a grazing period.

Stocking Rate "The relationship between the number of animals and the grazing management unit utilized over a specified time period."[1] This will be expressed in terms of animal units of forage demand over a described time period per unit of land area such as acres/cow/year, acres/animal unit × month, animal unit × days/acre, etc.[1] Therefore, it is an indirect measure of forage demand on a management unit for a grazing season or year. With continuous grazing, stocking rate and stocking intensity will be the same.

Stolon "A horizontal stem which grows along the surface of the soil and roots at the nodes."[1] These are the "runners" commonly seen in species like Buffalograss, Curly mesquite, and Bermudagrass.

Structure The characteristic size and shape of the soil aggregates.

Succession "The progressive replacement of plant communities on a site which leads to the potential natural plant community."[1]

Successional State "The present state of vegetation and soil protection of an ecological site in relation to the potential natural community for the site. Successional status is the expression of the relative degree to which kinds, proportions, and amounts of plants in a community resemble that of the potential natural community."[1] Generally, in higher seral communities, species are usually longer-lived, reproduce less often, and are generally better adapted to conditions where competition is high for limited resources and the plants are generally assumed to be better adapted to moister conditions and are more productive, though there is often much of the energy lost to respiration, such that net productivity approaches respiration.

Transpiration The loss of moisture through the leaves of plants.

Turnover The number of units produced from a given area over a period of time.

Variable costs Those costs that increase with each additional unit of production. In livestock production, usually associated with feed, veterinary costs, shearing, interest, depreciation on the livestock, etc.

Vegetative "Non-reproductive plant parts (i.e., leaf and stem) in contrast to reproductive plant parts (i.e., flower and seed) in developmental stages of plant growth. Also, the non-reproductive stage in plant development."[1] This term also may be used for classes of plants that are not woody—that is, not shrubs or trees.

Vegetative Reproduction "Production of new plants by any asexual method,"[1] e.g., from **stolons** or **rhizomes**.

BIBLIOGRAPHY

Beierlein, J. G., Schneeberger, K. C., and Osburn, D. D. (2014). *Principles of agribusiness management.* Ed. 5. Waveland Press Inc. Long Grove, IL.

Caldwell, M. M., Richards, J. H., Johnson, D. A., Nowak, R. S., and Dzurec, R. S. (1981). *Coping with herbivory: Photosynthetic capacity and resource allocation in two semiarid Agropyron bunchgrasses.* Oecologia. Vol. 50, 14–24.

Frasier, W. M., and Steffens, T. (2013). *Stocking rate decisions are not related to what you paid for your land or pickup.* Rangelands. Vol. 35, 14–21.

Gammon, D. M., and Roberts, B. R. (1978). *Patterns of defoliation during continuous and rotational grazing of the Matopos sandveld of Rhodesia.* 1. Selectivity of grazing. Rhodesia Journal of Agricultural Research. Vol. 16, 117–131.

Hart, R. H. (1986). *How important are stocking rates in grazing management?* Proceedings, The Ranch Management Symposium. November 5–7, 1986. University of Nebraska Agricultural Extension Service. Lincoln, NE. 77–87.

Hendrickson, J. R., and Briske, D. D. (1997). *Axillary bud banks of two semiarid perennial grasses: Occurrence, longevity, and contribution to population persistence.* Oecologia. Vol. 110, Iss. 4, 584–591.

Jones, R. J., and Sandland, R. L. (1974). *The relation between animal gain and stocking rate.* Journal of Agricultural Science. Vol. 83, 335–342.

Limb, R. F., Fuhlendorf, S. D., Engle, D. M., and Kerby, J. D. (2011). *Growing-season disturbance in tallgrass prairie: Evaluating fire and grazing on Schizachyrium scoparium.* Rangeland Ecology & Management. Vol. 64, 28–36.

Reed, F., Roath, R., and Bradford, D. (1999). *The grazing response index: A simple and effective method to evaluate grazing impacts.* Rangelands. Vol. 21, Iss. 4, 3–6.

Rittenhouse, L. R. and Bailey, D. W. (1996). *Spatial and temporal distribution of nutrients: Adaptive significance to free-grazing herbivores.* Proceedings of the 3rd Grazing Livestock Nutrition Conference. July 18–19, 1996. Proceedings Western Section American Society for Animal Science. Custer, SD. 47, Supp 1, 51–61.

Rittenhouse, L. R., and Roath, L. R. (1987). *Forage quality: primary chemistry of grasses.* Integrated pest management on rangeland a shortgrass prairie perspective. Westview Press. Boulder, CO. 25–37.

Smith, B., Leung, P., and Love, G. (1986). *Intensive grazing management: Forage, animals, men, profits.* The Graziers Hui. Kamuela, HI.

Society for Range Management. (1998). *Glossary of terms used in range management.* Ed. 4. Retrieved from: *http://globalrangelands.org/glossary*.

Steffens, T., Grissom, G., Barnes, M., Provenza, F., and Roath, R. (2013). *Adaptive grazing management for recovery: Know why you're moving from paddock to paddock.* Rangelands. Vol. 35, 28–34.

Villalba, J. J., and Provenza, F. D. (2009). *Learning and dietary choice in herbivores.* Rangeland Ecology and Management. Vol. 62, 399–406.

Voisin, A. (1988). *Grass productivity.* Island Press. Covelo, CA.