SEMIARID LANDS AND DESERTS

SOIL RESOURCE AND RECLAMATION

edited by

J. Skujiņš

Department of Biology
Utah State University
Logan, Utah

Marcel Dekker, Inc. New York • Basel • Hong Kong

11

Grazing Management

CARLTON H. HERBEL and REX D. PIEPER *U.S. Department of Agriculture and New Mexico State University, Las Cruces, New Mexico*

I. INTRODUCTION

A major use of semiarid and arid lands ("rangelands" in this chapter) is grazing or browsing by livestock and wild herbivores. Rangelands also provide habitat for wildlife, recreational opportunities, water, and aesthetic values. Animal production on rangelands reduces the requirements for nonrenewable fossil fuels and utilizes resources not readily usable by other means.

Semiarid and arid rangelands are often fragile and subject to accelerated soil erosion if not managed appropriately. If rangelands are mismanaged so that plants fail to provide sufficient soil cover, the composition of the plant community changes, with the result that productivity is reduced and erosion increases. Continued abuse of the rangeland system can result in severe soil degradation. This does not imply that proper grazing is destructive; some plants produce more biomass with moderate livestock grazing than with protection from livestock grazing. Some native plant communities evolved with grazing use by native animals, whereas other communities evolved with little or no utilization by herbivores. However, native plant communities are not always the most productive under intensive animal grazing (Herbel, 1982). Revegetation with introduced or improved plant species may dramatically increase the productivity of rangelands (Herbel, 1983).

Grazing of livestock is controlled to some degree by range managers and pastoralists around the world. However, many important environmental factors are beyond control of the manager, but these factors need to be considered in planning grazing management and future research on the subject.

Such terms as carrying capacity, animal distribution, management plans, grazing preference, stocking pressure, grazing system, continuous grazing, rotational grazing, grazing utilization, grazing intensity, and flexibility are used to describe various aspects of grazing management (Society for Range

Management, 1974). These terms are addressed in this chapter. *Grazing management* is planned grazing or browsing of plants (native or introduced) by animals (livestock and/or wildlife) to accomplish the objectives of the land manager.

II. PRINCIPLES AND CONCEPTS

Grazing management uses some of the concepts of applied ecology, with emphasis on plant-animal-environment interactions. These involve the temporal and spatial distribution of animals, the kinds and numbers of animals, and animal effects on range plants (Heady, 1971, 1984; Heitschmidt, 1988; Kothmann, 1980). Utilization of plants by animals may affect the quantity and quality of range forage, and the quantity and quality of range forage affect animal production from a unit of rangeland. The environment (soil and climatic components) also affects range forage and, therefore, animal performance.

The performance of grazing animals is determined by (1) animal potential, (2) forage quantity, (3) forage quality, and (4) feeding to supplement range forage. Furthermore, animals often graze the plants and parts of plants having the highest nutrient value (Torell and Hart, 1988).

A. Continuous Grazing

There is a considerable contrast between extensive and intensive grazing management (Table 1). Long-duration or continuous use may involve grazing periods of several months to more than a year—*extensive grazing management*. The periods of deferment from grazing may be zero or extend from several months to more than a year. One or more groups of animals may be used. A relatively small amount of capital expenditure is required for fence and water development. Management input and the risks involved are relatively minor. Decisions on animal numbers and when to move livestock to another range unit are not critical unless the permanent range resource, plants and soils, is in danger of irreversible damage (Herbel, 1982).

McIlvain and Shoop (1969) concluded that a number of rotational schemes they studied were inferior to yearlong continuous grazing at the same stocking rates at Woodward, Oklahoma. They cited some major reasons for the success of continuous yearlong grazing in the southern Great Plains: (1) forage production is primarily dependent on warm-season rainfall, and there can be a 30-fold variation in monthly forage production within a year; (2) most plants are useful to cattle; (3) many of the plants that increase after a drought are excellent grazing plants; (4) cattle grazing competes with forage losses as a plant matures and also with other consumers; (5) young and regrowth forage is more palatable and nutritious than more mature forage; (6) grazed plants conserve soil water for subsequent growth; and (7) favorable precipitation combined with proper grazing management allows rangelands to recover a desirable species composition following drought. Herbel (1973) gave some additional reasons for the success of yearlong continuous grazing: (1) use is light when the plants are actually growing and (2) lighter stocking per unit area means less compaction of the soil by livestock.

TABLE 1 Concept of Grazing Management

Extensive	Intensive
Low risk	High risk
Low cost	High cost
Low management inputs	High management inputs

B. Specialized Grazing Systems

Van Poollen and Lacey (1979) reported that herbage production was 13% higher under specialized grazing system compared to production under continuous grazing on 14 separate studies in U.S. rangeland. On the other hand, gain of individual animals is often reduced by specialized grazing systems since livestock are concentrated on smaller units and lack the opportunity to select a diet as high in nutritive content as they might under continuous grazing (Malechek, 1984; Pieper, 1980). However, in many cases there has been little difference in either vegetational or livestock response between continuous grazing and specialized grazing systems (Driscoll, 1967; Shiflet and Heady, 1971).

C. Short-Duration Grazing

Short-duration grazing use involves one or more groups of domesticated animals that are moved from one unit to an ungrazed unit every 2-28 days (Savory, 1979). Deferment from grazing use varies from a relatively short time during the growing season of plants to a longer period when plants are dormant. This is an intensive system. Short-duration grazing requires a relatively large capital expenditure for fences and water development. Decisions on the movement of livestock must be made daily during the growing season because immature plants are supposed to be grazed only once before they are deferred from grazing. Therefore, the risk and the management inputs are high with the more intensive short-duration grazing system. However, high inputs do not necessarily guarantee high net returns to the operator (Herbel, 1982).

In evaluating grazing systems in South Africa, Roberts (1967) reported: (1) slow rotation systems do not eliminate selective grazing; (2) using 16 units in a high-intensity, short-duration system, 12 are grazed once each for about 2 weeks each 6 months, and the 4 units not in the regular rotation may be used as reserve grazing in droughty years or given a full year's rest if not needed; (3) high-intensity, short-duration grazing combined sufficient rests with efficient grazing use to allow rapid restoration of denuded rangelands but high-intensity, short-duration grazing was less beneficial on rangelands in good condition; (4) restoration of rangelands may be retarded, and intensified abuse may occur, if the stocking rate is increased more rapidly than indicated by range conditions; (5) with variable precipitation, no system can eliminate selective grazing if set grazing periods and stocking rates are maintained, but high-intensity, short-duration reduces selective grazing; and (6) the relatively high capital investment required to implement high-intensity, short-duration grazing can be justified by the increased carrying capacity. Short-duration grazing may also detrimentally influence cryptogamic crusts on many rangelands (Brotherson et al., 1983; Johansen, 1986).

III. GRAZING OPTIMIZATION

Many range workers have noticed that areas protected from grazing by large herbivores often tend to become somewhat stagnant. Early work on grazing influences indicated that grazing was detrimental, despite such observations on vegetation in exclosures. Indeed, Caldwell (1984) has indicated that even low levels of herbivory may reduce the ability of an individual plant to compete successfully in the plant community. Recent research, however, suggests that some degree of defoliation may be beneficial to individual plants in the community.

McNaughton (1979), working in the extremely productive Seregenti Plains in eastern Africa, has studied plant-animal relations in some detail. He developed a series of curves to demonstrate the relationship between the level of defoliation and plant fitness or productivity. Some plants are detrimentally impacted by defoliation, others little impacted until defoliation reaches a certain level and then are detrimentally impacted, but a third group is stimulated by defoliation until a certain level of defoliation is reached, at which point fitness or productivity is reduced until the point of actual death. Others have also expanded on the theory (Hilbert et al., 1981; Dyer et al., 1982; Paige and Whitham, 1987). The basic idea behind the theory is that grazing or herbivory acts as a selective force and that plants continually subjected to herbivory develop adaptations that allow them to survive herbivory. Grasses have long been considered as having special adaptations for grazing, but such a theory was not developed formally. Some workers (Owen and Wiegert, 1976, 1981) have even expressed the view that grasses depend on the herbivores for their survival and evolution. Others have argued against the close relationship between plants and herbivores (Belsky, 1986). Belsky (1986) stated that "None of the grass traits presented as examples of grass mutualism have been shown to encourage herbivory, although they certainly lessen its deleterious effects. In fact, most studies of natural systems show that grazing reduces or has no effect on the productivity of the plants. If this is universally the case, mutualisms could not have evolved."

These arguments have relevance to rangelands in the United States. Bison (*Bison bison* L.) were present in large numbers in the Great Plains prior to settlement. Blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] and buffalo grass [*Buchloe dactyloides* (Nutt.) Engelm.], two dominant grass species of the Great Plains, are very resistant to grazing. Do they owe this resistance to grazing pressure imposed by large concentrations of bison? In contrast are conditions in the Intermountain Region, which supported mainly pronghorn antelope (*Antilocapra americana* Ord) and mule deer (*Odocoileus heminonus* Rafinesque) (Platou and Tueller, 1985), and desert grassland regions of the Southwest, which supported populations of pronghorn antelope but few other large herbivores (Martin, 1968). In these regions some of the major grass species are not resistant to grazing. Notable among these are bluebunch wheatgrass [*Agropyron spicatum*

(Pursh) Scribn. and Smith] in the Intermountain Region (Caldwell et al., 1981) and black grama [*Bouteloua eriopoda* (Torr.) Torr.] in the Southwest. These two grass species may owe their lack of grazing resistance to the absence of grazing pressure before the introduction of domestic livestock into these areas.

IV. STOCKING RATE

Stocking rate is the number of animals grazing on rangeland per unit area. The decision on the stocking rate is the most important made by the land manager. A heavy stocking rate may lead to a change in plant species and increased soil erosion eventually leading to permanent damage to the system. Conversely, a light stocking rate for a number of years often leads to a reduced economic return to the operator. In large units with a poor distribution of grazing animals, it is nearly impossible to prevent areas of heavy utilization near watering points, *sacrifice zones*. In this situation, there is an area of heavy utilization of plants, an area of light utilization at a distance from water, and an area of moderate utilization in between. It is a great challenge to the operator to use techniques that increase the area of moderate use considering a forage crop and economic conditions that vary from year to year. We estimate that proper stocking rates throughout all range units would double animal production in the western United States.

A. Stocking Rate Theory

Proper stocking rate is essential to the successful management of rangeland. To establish the proper stocking rate, Hart (1980) suggested the following determinations:

1. Animal and plant responses.
   a. Achieve maximum gain per animal or per area?
   b. Achieve maximum profit per animal or per area?
   c. Achieve greatest reproductive efficiency of plants and animals?
   d. Maximize use of available forage?
   e. Maximize the improvement of range conditions?
2. Determine the relationship between stocking rate and the desired plant or animal response.
3. Calculate the stocking rate to achieve the desired results.
4. Are there constraints to using the calculated stocking rate?

Answering the questions posed in part 1 will assist in developing goals. Some land managers use experience in developing guides to determine stocking rates. Other land managers determine stocking rate by allocating available forage to animals, using feed requirements for each class of animal.

Under range conditions, gain per grazing animal remains constant below a critical stocking rate and decreases linearly as stocking rate increases above the critical level (Hart, 1978). It is a land manager's duty to determine the critical stocking rate. A guide was developed by Bement

(1969) for grazing rangeland dominated by blue grama in the central Great Plains. Gain per animal and gain per unit area are related to the amount of herbage left ungrazed at the end of the growing season. Maximum returns from yearling cattle were obtained when 336 kg ha^{-1} of herbage was left at the end of the growing season. This figure can be approximated for rangelands grazed only during the growing season by taking 50% of the long-term herbage. For example, if the long-term herbage production on a range unit is 2000 kg ha^{-1}, maximum returns from yearling cattle can be obtained when 1000 kg ha^{-1} of herbage is left at the end of the growing season. The plant and soil resources are maintained, or gradually improved, when 1000 kg ha^{-1} of herbage remains at the end of the growing season. In a droughty year when only 1500 kg ha^{-1} herbage is produced, only 500 kg ha^{-1} herbage should be harvested by the cattle. Conversely, when herbage production is 2500 kg ha^{-1}, 1500 kg ha^{-1} can be harvested. This illustrates the difficulty encountered by land managers because they make decisions on a stocking rate before herbage production is known. In practice, stocking rate decisions are based on the long-term performance of the vegetation on a range unit.

B. Economic Considerations

Economic considerations in determining the stocking rate are important if the land manager wishes to produce the highest profit. If fixed carrying costs per animal (interest, veterinary costs, death loss, and initial costs of land and animals) are high relative to selling price, then profits are greater if gain per animal is maximized. However, if carrying costs are low relative to selling price of animals, profits are greater if gain per unit area is maximized at a reduction in gain per animal (Torell and Hart, 1988; Hart, 1980). In the latter, care must be taken not to abuse the resource.

V. DISTRIBUTION OF GRAZING ANIMALS

Domesticated animals traverse any range unit in response to the number and location of watering places, the distribution of plant species within the unit, topography, the size of the unit, and various other attractants (Herbel and Gould, 1980). Improved distribution of grazing animals over the large units prevalent in the western United States will result in a higher number of animals using range vegetation properly.

A. Water

Domesticated animals must have enough water. Minimum daily requirements for water are as follows: cow with calf, 38 L; ewe with lamb, 4 L; and horse, 45 L (Holechek et al., 1989). Variations in environmental conditions may alter water requirements. In range units with more than one watering point, periodic opening and closing of these points can be used to rotate grazing pressure to different portions of the unit (Martin and Ward, 1970).

In a comparison of wildlife use of water with short-duration and continuous livestock grazing, Prasad and Guthery (1986) showed that water at the center of a short-duration cell may be largely unavailable to white-tailed deer (*Odocoileus virginianus* Zimmermann), collared peccaries

(*Tayassu tajacu* L.), and wild turkeys (*Meleagris gallopavo* Nelson). However, most species of birds made about the same number of visits to water regardless of grazing system. Prasad and Guthery (1986) concluded that peripheral water facilities should be maintained with cell grazing to maintain a maximum diversity of wildlife. The waterers could be fenced to minimize effects on the rotation of livestock even though the outlying water may attract livestock.

B. Location of Plants

Plants that are palatable during a certain part of the year attract animals to the part of the range unit where they occur even though these plant species occur at a distance from water. In the Southwest and other areas, Russian thistle (*Salsola iberica* Sennen and Pau) is palatable and nutritious when young. It can be encouraged to grow with a soil disturbance, such as disking.

C. Topography

In rolling terrain, it is common to see rangelands with bottoms showing the effects of heavy grazing but with light grazing on the adjacent slopes. On a 10% slope, about 75% of the grazing use occurs within 0.8 km of the watering point. Some animals, such as sheep and goats, utilize vegetation on rough terrain better than cattle.

D. Other Structures

Placing salt and supplemental feed away from permanent watering points also helps to distribute domestic animals to areas that otherwise would be lightly utilized (Ares, 1953). Shade and rubbing posts located away from watering points also attract domesticated animals to undergrazed areas. Construction of "drift" fences to prevent livestock from continually grazing in certain favored places within a range unit also helps with distribution problems. Fencing to create smaller units, trails, and roads may be useful in obtaining better livestock distribution under some circumstances.

VI. FLEXIBILITY IN GRAZING

There is a large variation, temporally and spatially, in forage production. Table 2 shows the precipitation and perennial grass yields for three sites on an experimental range in southern New Mexico (Herbel and Gibbens, 1981). The average annual precipitation in this area is 230 mm. The Reagan and Stellar sites, about 50 m apart, are on plains that are occasionally flooded. Both of these sites have clay loam soils. The Cacique site is 13 km from the Reagan and Stellar sites and is a loamy sand soil on a flat, upland area. The average yield of perennial grasses at the Reagan site, primarily burro grass (*Scleropogon brevifolius* Phil.), for 1957-1977 was 950 kg ha^{-1}, but it was 88 kg ha^{-1} in 1960 and 3017 kg ha^{-1} in 1959. The Stellar site was dominated by tobosa [*Hilaria mutica* (Buckl.) Benth.], and the average yield of perennial grasses for 1957-1977 was 1662 kg ha^{-1}; in 1965 it was 15 kg ha^{-1}, and in 1972 it was 3718 kg ha^{-1}.

TABLE 2 Precipitation (mm, October-September) and Dry Weight (kg ha^{-1}) of Perennial Grasses for Selected Years at Three Sites, Jornada Experimental Range, New Mexico

	Reagan[a]		Stellar[b]		Cacique[c]	
Year	Ppt	Yield	Ppt	Yield	Ppt	Yield
1959	216	3017	216	1846	188	428
1960	130	88	130	390	104	63
1963	236	1745	236	1665	122	99
1965	152	69	152	15	140	174
1966	170	719	170	782	229	323
1972	356	1314	356	3718	257	419
1977	203	492	203	541	262	501

[a]Primarily burro grass (*Scleropogon brevifolius*).

[b]Primarily tobosa (*Hilaria mutica*).

[c]Primarily black grama (*Bouteloua eriopoda*) and mesa dropseed (*Sporobolus flexuosus*).

Source: From Herbel and Gibbens, 1981.

Black grama and mesa dropseed [*Sporobolus flexuosus* (Thurb.) Rydb.] dominate the Cacique site and the average yield for 1959-1977 was 321 kg ha^{-1}, but in 1960 it was 63 kg ha^{-1} and in 1977 it was 501 kg ha^{-1}. Table 2 illustrates the tremendous variability that occurs in the forage crop at the same site from year to year and at different sites within the same year (Herbel and Gibbens, 1981). If a constant stocking rate is maintained, it must be low enough to maintain proper utilization when forage production is considerably below average or there will be destructive grazing in drought years (Pieper, 1981). Much of the permanent damage to rangelands has occurred when the stocking rate was considerably higher than indicated by the forage crop. Some flexibility in the stocking rate permits the operator to stock animals according to the variability encountered in the quantity of forage produced.

Most grazing studies have been established at a fixed stocking rate. Downward adjustments in livestock numbers were made only in severe droughts, but adjustments in numbers should be part of the plan for the grazing study (Herbel, 1973). Flexible herd management has been suggested by several workers as the best method for maximizing livestock production without damaging the range resource during droughty periods (Ares, 1952; Boykin, 1967; Jardine and Forsling, 1922; Reynolds, 1954; Stubblefield, 1956). During years when the forage crop is about average, the livestock group is composed of 55-60% breeding animals. The remainder of the herd is composed of young animals. In years of low forage production, adjustments in the size and composition of the group of animals are planned to bring the group within the capacity of the range. For example, in the arid portions of the Southwest, the primary production of perennial grasses occurs in the summer. Therefore, the number of animals relying on this forage can be adjusted in the fall to meet the forage conditions from fall until the following summer. It is an unwise practice to supplement the quantity of forage while the animals are grazing on rangelands. Rather, the surplus animals should be sold or fed in a lot (Herbel et al., 1984). Readily salable animals are marketed, and the breeding-age animals are culled more deeply than normally. In the years with above-average forage production, part or all of the natural increase from the breeding group can be held over until spring or fall, depending on market and forage conditions. Martin (1975) advocated stocking at 90% of estimated carrying capacity to provide a cushion for maximum flexibility.

The cattle herd that grazed on the Jornada Experimental Range in southern New Mexico from 1927 to 1934 averaged 80% cows and 6% yearlings (Paulsen and Ares, 1962). The remaining 14% of the herd was calves and bulls. From 1940 to 1951, when the system of flexible herd management was in effect, cows averaged 61% and yearlings 30% of the total herd. Using the same sale prices for comparison, the average annual gross income was slightly higher in the 1940-1951 period although there were 30% fewer animal units grazing the range than in 1927-1934 (Paulsen and Ares, 1962).

Low forage quality and poor animal growth in Colorado coupled with decreasing prices near the end of the fall grazing season favor the early sale of cattle (Rodriguez and Jameson, 1988). The early sale of domestic livestock and/or harvesting wildlife are also techniques useful in reducing the pressure on rangelands when there is a reduced forage crop. Risk is reduced by using flexible marketing dates.

VII. SOIL PROPERTIES

Johnston (1961) and Johnston et al. (1971) reported that a heavy rate of cattle grazing *Festuca* grasslands in Canada reduced soil organic matter (OM) and total phosphorus (P) content but increased $NaHCO_3$-soluble P compared to a lighter stocking rate. Smoliak et al. (1972) reported that *Stipa-Bouteloua* grasslands in Canada grazed by sheep at a heavy rate had increased soil organic carbon (C) but there was no effect on total and available P and nitrogen (N) content compared to soils with a lighter stocking rate. Organic C and total P content were greater, but total N was lower in soils of ungrazed grassland in the northern Great Plains in central North Dakota when compared to soils of grazed grasslands (Bauer et al., 1987). Bulk densities were highest in surface soils of grazed grassland. Continuous, rotationally deferred, and short-duration rotation grazing systems did not affect soil bulk density in trials in southeastern Wyoming (Abdel-Magid et al., 1987). Van Haveren (1983) found that the degree of soil compaction, as measured by bulk density, depended on the texture, water content, and organic matter.

VIII. GRAZING EFFECTS ON WATERSHEDS

The hydrological impacts of animal grazing result primarily from the interactions of weather, vegetation, soil, topography, and intensity of animal utilization. Blackburn (1984) cited several authors who recognized that heavy continuous grazing accelerated erosion and runoff. Hydrological characteristics are generally not different among ungrazed range units and those that are continuously grazed lightly or moderately.

A. Grazing Systems

Gifford and Hawkins (1976, 1978) found no evidence that any single grazing system consistently increased plant and litter cover on watersheds. Range units grazed under a four-unit, three-herd deferred rotation system in Texas were hydrologically similar to those of a livestock exclosure (Blackburn, 1984; McGinty et al., 1978; Wood and Blackburn, 1981a, b). Range units grazed under a high-intensity, low-frequency grazing system (eight units, one herd with 17 day graze and 119 day rest) were superior or similar hydrologically to moderate continuously grazed units. Conversely, units under a short-duration scheme (14 units, one herd with a 4 day graze and 50 day rest) at double the recommended stocking rate were similar hydrologically to those under heavy continuous grazing (McCalla et al., 1984a, b). Hydrologic conditions under short-duration grazing responded favorably during years of average or higher precipitation; however, during drought the short-duration system rapidly displayed adverse impacts on infiltration rates, roughness, and soil aggregates. After 2 years of above-average precipitation, the hydrological conditions of the short-duration units had not overcome the adverse effects of a single drought year.

Thurow et al. (1988) assessed the hydrological responses of units moderately stocked under continuous and high-intensity, low-frequency grazing systems, and heavily stocked under continuous and short-duration grazing near Sonora, Texas. Moderate stocking maintained infiltration rates, whereas heavy stocking resulted in decreased infiltration rate and increased erosion. The heavy stocking rate and weather, rather than grazing strategy, were the primary factors influencing hydrological responses.

B. Water Quality

Sediment is the major pollutant from rangeland watersheds. Moderate continuous grazing or specialized grazing systems should reduce sediment losses from most watersheds. However, if watersheds have been severely overgrazed, instituting moderate continuous or specialized grazing systems may not reduce sediment losses. Bacteria or nutrients as potential pollutants from livestock grazing are not a serious problem on areas not in riparian zones (Blackburn, 1984; Buckhouse and Gifford, 1976). However, Gary et al. (1983) found that the number of fecal coliform organisms in streamwater were increased when livestock grazed on adjacent rangeland. The numbers of these organisms remain elevated several months after cattle are removed (Stephenson and Street, 1978). Sediments serve as a reservoir of coliform and *Salmonella* organisms (Stephenson and Rychert, 1982). Fecal coliform levels tend to increase as stocking rates increase, as with specialized grazing systems (Tiedemann et al., 1987).

IX. GRAZING EFFECTS ON RIPARIAN ZONES

The direct effects of animal grazing on riparian zones are (1) change, reduction, or elimination of vegetation; (2) higher stream temperatures from a reduction in woody streamside cover; (3) excessive sediment in the channel from streambank and upland erosion; (4) high coliform bacterial counts from upper watershed sources; (5) channel widening from hoof action on streambanks and water erosion; (6) change in the structure of the water column and channel; and (7) elimination of riparian areas by channel degradation and/or lowering of the water table (Skovlin, 1984; Platts and Raleigh, 1984). In a Montana study, there was no correlation between riparian condition and the type of grazing system. Grazing intensity was an important factor in the riparian condition, but not as important as the amount of vegetation utilized by domestic animals during part of the growing season (Platts and Raleigh, 1984). Riparian zones are highly preferred by some classes of domestic animals and must be managed separately from adjacent areas. Specialized systems can protect and enhance riparian habitats, but these have not been identified.

X. GAME RANCHING

Some of the rangelands have been dedicated to producing both wildlife and livestock or, increasingly, wildlife only. Wildlife are used to enhance the beauty of the unit and the opportunity for recreational hunting. In the United States and other countries throughout the world, increased emphasis is placed on wildlife for a source of income (Henderson, 1988).

Generally, sufficient forage remains for wildlife, such as deer or other browsers that have different grazing habits than cattle, when proper utilization of forage species is maintained in the diet of domestic livestock, such as cattle (Smith and Rodgers, 1988). However, dietary overlaps between wildlife and livestock require an allocation of the forage resource. Additionally, proper utilization leaves greater amounts of cover required by ground-nesting birds, such as ducks or grouse.

One or more species of livestock can be used to produce a vegetation community suitable for various species of wildlife. Cattle often have a diet high in grasses with the result that the plant community may have a higher proportion of forbs and shrubs. Deer and pronghorn antelope prefer forbs and shrubs. Upland game birds, such as quail, use forb seeds. Therefore, cattle grazing may improve the habitat for deer, antelope, quail, and other animals that need some forbs and shrubs (Smith and Rodgers, 1988).

Watering locations influence animal selection of foraging areas if preferred vegetation is available. Plant species and location of water wells and drinking troughs can be altered to achieve more uniform distribution of grazing. However, improved distribution can also be obtained by emphasizing cattle in relatively level areas and wildlife in hilly areas and riparian zones.

There are six ways in which wildlife can benefit the land manager increase economic returns (Knight, 1988):

1. Exchange of entry rights for protection from further ingress

2. Exchange of entry rights for the performance of wildlife-enhancing practices
3. Fee areas for nonconsumptive use of wildlife, such as aesthetics
4. Granting entry rights without direct compensation, particularly where wildlife species are a problem
5. Having the wildlife for the land manager's hunting or viewing pleasure
6. Granting hunting rights, as through a lease for a specified purpose

XI. GRAZING SYSTEMS

Environmental conditions vary considerably on rangelands around the world. Consequently, grazing systems should be designed to meet the specific conditions of each area and management condition. In this section, we review grazing studies for major range regions with emphasis on rangelands in the United States.

A. California Annual Rangeland

Studies at the San Joaquin Experimental Range in central California showed a consistent advantage of yearlong continuous grazing over seasonal grazing in breeding cow performance and calf weaning weights (Duncan and Heady, 1969). The best balance of seasonally preferred plant species occurred on ranges grazed continuously yearlong. Similar results with sheep were obtained at Hopland, about 160 km north of San Francisco. Deferred rotation grazing was compared to yearlong continuous grazing. The average weaning weight of lambs was consistently higher with yearlong continuous grazing. The grazing treatment did not affect species composition of plants, density of plants, or herbage production. Heady (1961) concluded that "Yearlong grazing at reasonable stocking rates is the best way to manage the California annual type because it pays primary attention to the day by day animal needs and because yearlong grazing amounts to a partial deferment every year."

B. The Pacific Bunchgrass Region

Hormay and Talbot (1961) described rest rotation grazing for this region as (1) graze a unit all season for maximum livestock production, which may reduce the vigor of the grazed plants; (2) after step 1, rest that unit one or two seasons, until the plants' vigor is restored and litter accumulates; (3) defer grazing in the unit rested in step 2 until seed is ripe, then graze for the remainder of season to trample the seed into the soil and for maximum livestock production; and (4) rest one or two seasons to permit the establishment of new plants. The time required for each step depends on the growth requirements of the major plants. This grazing system reduces selective grazing and improves the reproduction of grazed plants.

Ratliff (1962) used a combination of fencing, salting, water development, and horseback riding to reduce selective grazing at Harvey Valley in northeastern California. After 13 years, Ratcliff and Reppert (1968) concluded that the performance of individual animals was about the same with rest rotation grazing as with season long grazing. In some years, there was an increase in the length of the grazing season but no change in the

E. Intermountain Shrub Region

Season long grazing was compared with deferred rotation grazing in southeastern Oregon (Hyder and Sawyer, 1951). Cow weight gains were greater under season long grazing than deferred rotation grazing. Concentrating the cattle in the deferred rotation system for 2 consecutive years reduced plant vigor.

The important management point on the desert rangelands of southwestern Utah is to occasionally defer key species during late winter (Blaisdell and Holmgren, 1984). Most of this area serves as winter range for sheep. Studies in Nevada also showed that rest rotation grazing failed to improve the sagebrush-grass range, presumably because of heavy grazing during the growing season (Eckert and Spencer, 1986, 1987).

F. Northern Great Plains

Deferred rotation and season long grazing were compared in central North Dakota (Rogler, 1951). Steer gains were not increased with a rotation system when there was sufficient forage for season long grazing. There seemed to be merit in a rotation system for improving range damaged by overgrazing. However, complete deferment until the recovery of range condition was a more rapid method of range improvement (Rogler, 1951). A rotation system can be used when it is necessary to stock at a high rate during occasional years and with older cattle. Younger cattle were less likely to gain weight under a rotation system because they did not use the mature forage in summer and fall as well as older cattle. Lodge (1970) reviewed other grazing studies on native rangelands in the northern Great Plains in Canada and United States and concluded that specialized grazing systems were no better than continuous grazing.

G. Central Great Plains

Hart et al. (1988) compared continuous, four-unit rotationally deferred and eight-unit short-duration grazing for 6 years on a mixed grass range near Cheyenne, Wyoming. The three grazing systems did not affect steer gains differentially. The basal cover of vegetation was not affected by grazing treatment.

H. True Prairie Region

Deferred rotation grazing was compared with season long grazing near Manhattan, Kansas. On the major range site, there was a slightly greater reduction in range condition under deferred rotation grazing than with moderate season long grazing during a 6 year period (Herbel and Anderson, 1959). Moderate season long grazing gave a higher steer gain than deferred rotation grazing (E. F. Smith et al., 1967). Intensive early-season grazing proved beneficial to both livestock and vegetation in the Flint Hills of Kansas (Smith and Owensby, 1978).

I. Southern Great Plains

A number of deferred rotation schemes were studied near Woodward, Oklahoma (McIlvain and Shoop, 1969; McIlvain and Savage, 1951; McIlvain et al. (1955). No rotation system was superior to yearlong continuous grazing.

J. Edwards Plateau

Merrill (1954) compared continuous yearlong grazing at three intensities with deferred rotation grazing at a moderate rate on the Edwards Plateau near Sonora, Texas. After 11 years, the stocking rate in the units in the deferred rotation system was increased 33% (Merrill, 1969). Those units made greater improvement than any of the units grazed continuously. Herbage production was 2458 kg ha^{-1} on the four-pasture, three-herd rotation system compared to 1073 kg ha^{-1} under continuous grazing after 20 years (Reardon and Merrill, 1976).

Near Barnhart, Texas, average annual net returns per animal unit for 7 years were \$30.63, \$39.03, and \$41.71 for continuous, four-unit rotation, and two-unit rotation, respectively (Huss and Allen, 1969). Combination stocking with cattle and sheep; cattle, sheep, and goats; or cattle and goats was more profitable than using cattle or sheep alone (Merrill, 1969; Huss and Allen, 1969).

K. Southern Rolling Plains

Fisher and Marion (1951) compared rotation and continuous grazing at a moderate rate near Spur, Texas, concluding that (1) rotation grazing did not improve the vegetational composition during a 6 year study, (2) rotation grazing increased differential grazing use of the major plants as the season progressed or during drought, and (3) gains of yearling steers grazing on the rotation units were slightly lower than gains of steers grazing on the continuous units. Calf production per animal unit averaged 200, 208, and 221 kg for moderate continuous, two-unit rotation, and a four-unit rotation, respectively, during an 8 year study near Throckmorton, Texas (Kothmann et al., 1970).

Heitschmidt (1986) concluded that production per cow was lower in rotational grazing than moderate continuous grazing at Throckmorton, Texas, because conception rates, weaned calf weights, and calf weaning weights were reduced by rotational grazing. Diet quality and intake were lower with rotation grazing than continuous grazing when forage availability was low, but the opposite occurred when forage availability was high. Overall, sediment production was greater and infiltration rates were lower with rotation grazing than with continuous grazing.

L. Semidesert Grassland of the Southwest

A number of studies near Las Cruces, New Mexico, have contributed to developing the best pasture grazing system and the closely related seasonal suitability grazing system (Paulsen and Ares, 1962; Valentine, 1967; Beck, 1978; Herbel, 1974; Herbel and Nelson, 1969; Holechek and Herbel, 1982).

There were two major vegetation types on the Jornada Experimental Range near Las Cruces 60 years ago, one dominated by black grama and the other dominated by tobosa and burro grass. The grazing system consisted of grazing the tobosa-burro grass type in summer and early fall, and grazing the black grama type for the remainder of the year (Paulsen and Ares, 1962). However, the stand of black grama was depleted because of the severe drought of 1951-1956 (Herbel et al., 1972) and the rapid increase of shrubs (Buffington and Herbel, 1965). The grasses, forbs, and shrubs have a high nutritive value (Nelson et al., 1970). Nearly all species available were grazed to some extent during the year (Herbel and Nelson, 1966). In a 20 year study on a black grama type, Beck et al. (1987) reached the following conclusions:

1. Seasonal suitability grazing system did not improve forage conditions or livestock performance over yearlong continuous grazing.
2. Herbage biomass production is related more to annual and growing season precipitation patterns than to stocking rate.
3. Livestock performance is related more to herbage availability than to either grazing system.

Martin and Severson (1988) compared yearlong grazing with the Santa Rita grazing system for 13 years near Tucson, Arizona. The Santa Rita grazing system is a one-herd, three-unit, 3 year rotation scheme that may improve deteriorated rangelands in the Southwest (Martin, 1978). Martin and Severson (1988) concluded that herbage yields were not related to grazing treatment on rangeland in good condition.

M. North Africa and the Middle East

Grazing studies in northern Africa are limited. Many livestock herders practice some form of nomadic or seminomadic (transhumant) system. These systems usually involve livestock movement away from permanent water during the rainy season and toward permanent water during the dry season (Breman et al., 1978; Holechek et al., 1989; Sandford, 1983). These systems provide maximum flexibility for the herders to meet varying forage and water needs for their livestock.

Heavy stocking on annual grassland rangeland in Niger increased standing plant biomass compared to that under moderate stocking (Wylie et al., 1985). However, animal weight gains were inversely related to stocking rate during the dry season. Heifers lost less weight under a rotational grazing system than under continuous grazing when they were watered on alternate days, but not when watered daily (Wylie and Pieper, 1990). Opportunities for specialized grazing systems appear limited in developing countries, but when animals are under the close control of a herder, some grazing systems could be implemented without extensive fencing and other developments.

In Israel, rotational grazing schemes favored grasses over forbs, which increased under continuous grazing and heavy stocking (Gutman and Seligman, 1979; Seligman and Gutman, 1978). The response of legumes was similar under rotation and continuous stocking with both moderate and heavy stocking. Individual animal performance was also adversely affected by rotational and heavy stocking whereby individual animal selectivity was restricted.

Annual grasslands respond differently than perennial grasslands since seed reproduction is the key rather than the impact of grazing on individual plants. In many cases management suitable for perennial grasslands are misapplied to annual grasslands.

XII. CONCLUSIONS

We have reviewed the literature on grazing management and have reached the following conclusions.

Universal conclusions are inappropriate, because the results of a grazing study are specific to a given site and are closely related to rate of stocking (Gammon, 1978b). The performance of animals on rangelands is related to the quality and quantity of forage available to the animal and the harvesting efficiency of the grazing animal (Heitschmidt, 1988).

Most studies indicate a moderate stocking rate, particularly during the growing season. Grazing at a moderate or lighter rate on key plants provides optimum animal performance. An occasional period of heavy grazing in the dormant season reduces unpalatable or ungrazed plants and promotes more uniform grazing.

Favorable weather is more effective than a specialized grazing system in providing a rapid improvement in species composition.

Fluctuation in the quantity of the forage crop is a frequent occurrence and must be considered in setting a stocking rate.

Any range improvement that increases livestock distribution results in greater livestock production from that unit.

A rapid rotation system may result in improvement in range condition with proper stocking, but once the desired condition has been achieved, a slower rotation or continuous grazing gives the highest animal production.

Ephemeral grasses and forbs may contribute much to animal performance for a brief, but critical, part of the year.

The evolutionary history of a plant species is critical. Some of the major species in the Rocky Mountains, some areas west of the Rocky Mountains, and some desert areas did not evolve under grazing pressure. Species that are not adapted to grazing often do not survive moderate grazing.

Stocking with a variety of animals increases the productivity of rangelands. Rabbits, rodents, insects, and other wildlife, however, consume forages that may be useful to domestic livestock and other animals.

Supplemental feeding to animals grazing range forage should supplement the *quality* of forage, not the *quantity*.

A cell arrangement may improve livestock management (Dahl, 1986).

Heavy trampling may damage beneficial algal crusts and soil microbes.

Intensive grazing requires more management input.

Besides additional research on these principles mentioned, other questions are related to the site-specific importance of (1) seed production, (2) seed planting by trampling, (3) seedling establishment, and (4) trampling effects on soils. Considerable funds have been expended on studying grazing systems, but continuous grazing at a moderate rate will maximize sustained production of animals from most range resources.

CAVEAT

The views expressed in this chapter are those of the authors and do not reflect the official policies of the U.S. Department of Agriculture.

REFERENCES

Abdel-Magid, A. H., Schuman, G. E., and Hart, R. H. (1987). Soil bulk density and water infiltration as affected by grazing systems. *J. Range Manag. 40*: 307-309.

Ares, F. N. (1952). Size and composition of the herd. *Am. Cattle Prod. 34*(7): 14, 16, 18.

Ares, F. N. (1953). Better cattle distribution through the use of meal-salt mix. *J. Range Manag. 6*: 341-346.

Bauer, A., Cole, C. V., and Black, A. L. (1987). Soil property comparisons in virgin grasslands between grazed and nongrazed management systems. *Soil Sci. Soc. Am. J. 51*: 176-182.

Beck, R. F. (1978). A grazing system for semiarid lands. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 569-572.

Beck, R. F., McNeely, R. P., and Kiesling, H. E. (1987). Seasonal grazing on black grama grasslands. In *Livestock Research Briefs and Cattle Growers' Short Course*, New Mexico Agr. Exp. Sta., Las Cruces, pp. 85-88.

Belsky, A. J. (1986). Does herbivory benefit plants? A review of the evidence. *Am. Naturalist 127*: 871-891.

Bement, R. E. (1969). A stocking-rate guide for beef production on blue-grama range. *J. Range Manag. 22*: 83-86.

Blackburn, W. H. (1984). Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences.* Westview Press, Boulder, Colorado, pp. 927-983.

Blaisdell, J. P., and Holmgren, R. C. (1984). Managing intermountain rangelands—salt-desert shrub ranges. U.S. Department of Agriculture General Technical Report INT 163.

Booysen, P., and Tainton, N. M. (1978). Grassland management: Principles and practice in South Africa. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 551-554.

Boykin, C. C. (1967). Profitability and flexibility of two range cattle systems in the Rolling Plains of Texas. *J. Range Manag. 20*: 375-379.

Breman, H., Diallo, A., Traore, G., and Djiteye, M. M. (1978). The ecology of the annual migrations of cattle in the Sahel. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 592-595.

Brotherson, J. D., Rushforth, S. R., and Johansen, J. R. (1983). Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Ariz. *J. Range Manag. 36*: 579-581.

Buckhouse, J. C., and Gifford, G. F. (1976). Sediment production and infiltration rates as affected by grazing and debris burning on chained and seeded pinyon-juniper. *J. Range Manag. 29*: 83-85.

Buffington, L. C., and Herbel, C. H. (1965). Vegetational changes on a semidesert grassland range from 1858 to 1963. *Ecol. Monogr. 35*: 139-164.

Caldwell, M. M. (1984). Plant requirements for prudent grazing. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences.* Westview Press, Boulder, Colorado, pp. 117-152.

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

Clatworthy, J. N. (1984). The Charter Estate grazing trial—results of botanical analysis. *Zimbabwe Agr. J. 81*: 49-52.

Dahl, B. E. (1986). The West Texas experience in short duration grazing. In *Short Duration Grazing*, J. A. Tiedeman (Ed.). Washington State University, Pullman, pp. 103-116.

Driscoll, R. S. (1967). Managing public rangelands: Effective livestock grazing practices and systems for national forests and national grasslands. U.S. Department of Agriculture, AIB 315.

Duncan, D. A., and Heady, H. F. (1969). Grazing systems in the California annual type (abstract). *Am. Soc. Range Manag. 22*: 23-24.

Dyer, M. I., Detling, J. K., Coleman, D. C., and Hilbert, D. W. (1982). The role of herbivores in grasslands. In *Grasses and Grasslands*, J. R. Estes, R. J. Tyrl, and J. N. Brunken (Eds.). University of Oklahoma Press, Norman, pp. 255-295.

Eckert, R. E., Jr., and Spencer, J. S. (1986). Vegetation response on allotments grazed under rest-rotation management. *J. Range Manag. 39*: 166-174.

Eckert, R. E., Jr., and Spencer, J. S. (1987). Growth and reproduction of grasses heavily grazed under rest-rotation management. *J. Range Manag. 40*: 156-159.

Fisher, C. E., and Marion, P. T. (1951). Continuous and rotation grazing on buffalo and tobosa grassland. *J. Range Manag. 4*: 48-51.

Gammon, D. M. (1978a). Patterns of defoliation during continuous and rotational grazing of rangeland by cattle. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 603-605.

Gammon, D. M. (1978b). A review of experiments comparing systems of grazing management on natural pastures. *Proc. Grassl. Soc. S. Afr. 13*: 75-82.

Gammon, D. M. (1984). An appraisal of short-duration grazing as a method of veld management. *Zimbabwe Agr. J. 81*: 59-64.

Gary, H. L., Johnson, S. R., and Ponce, S. L. (1983). Cattle grazing impact on surface water quality in a Colorado Front Range stream. *J. Soil Water Conserv. 38*: 124-128.

Gifford, G. F., and Hawkins, R. H. (1976). Grazing systems and watershed management: A look at the record. *J. Soil Water Conserv. 31*: 281-283.

Gifford, G. F., and Hawkins, R. H. (1978). Hydrologic impact of grazing on infiltration: A critical review. *Water Resources Res. 14*: 305-313.

Goodloe, S. (1969). Short duration grazing in Rhodesia. *J. Range Manag. 22*: 369-373.

Gutman, M., and Seligman, N. (1979). Grazing management of Mediterranean foothill range in the Upper Jordan Valley. *J. Range Manag. 32*: 86-92.
Harris, R. W. (1954). Fluctuations in forage of ponderosa pine ranges in eastern Oregon. *J. Range Manag. 7*: 250-255.
Hart, R. H. (1978). Stocking rate theory and its application to grazing on rangelands. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 547-550.
Hart, R. H. (1980). Determining a proper stocking rate for a grazing system. In *Proceedings, Grazing Management Systems for Southwest Rangelands Symposium*, K. C. McDaniel and C. Allison (Eds.). New Mexico State University, Las Cruces, pp. 49-64.
Hart, R. H., Samuel, M. J., Test, P. S., and Smith, M. A. (1988). Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *J. Range Manag. 41*: 282-286.
Heady, H. F. (1961). Continuous vs. specialized grazing systems: A review and application to the California annual type. *J. Range Manag. 14*: 182-193.
Heady, H. F. (1971). Management of grazing animals based upon consequences of grazing. In *The Impact of Herbivores on Arid and Semiarid Rangelands*. Australian Rangelands Society, Perth, Western Australia, pp. 299-309.
Heady, H. F. (1984). Concepts and principles underlying grazing systems. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences*. Westview Press, Boulder, Colorado, pp. 885-902.
Heitschmidt, R. K. (1986). Short duration grazing at the Texas Experimental Ranch. In *Short Duration Grazing*, J. A. Tiedeman (Ed.). Washington State University, Pullman, pp. 91-102.
Heitschmidt, R. K. (1988). Intensive grazing in arid regions. In *Forage and Grassland Conference, American Forage and Grassland Council*, Baton Rouge, Louisiana, pp. 340-349.
Henderson, F. R. (Ed.) (1988). *Guidelines for Increasing Wildlife on Farms and Ranches*. Wildlife Resources Committee, Great Plains Agricultural Council, Kansas Cooperative Extension Service S-25.
Herbel, C. H. (1973). Grazing systems on native range. In Great Plains Beef Symposium, F. H. Baker (Ed.). Great Plains Agricultural Council Publ. 63, Lincoln, Nebraska, pp. K-1 to K-19.
Herbel, C. H. (1974). A review of research related to development of grazing systems on native ranges of the western United States. In Plant morphogenesis as the basis for scientific management of range resources, K. W. Kreitlow and R. H. Hart (coord.). U.S. Department of Agriculture Misc. Publ. No. 1271, pp. 138-149.
Herbel, C. H. (1982). Grazing management on rangelands. *J. Soil Water Conserv. 37*: 77-79.
Herbel, C. H. (1983). Principles of intensive range improvements. *J. Range Manag. 36*: 140-144.

Herbel, C. H., and Anderson, K. L. (1959). Response of true prairie vegetation on mjaor Flint Hills range sites to grazing treatments. *Ecol. Monogr. 29*: 171-186.

Herbel, C. H., and Gibbens, R. P. (1981). Drought and grazing management decisions. In *Proceedings, International Rancher's Roundup*, L. D. White and A. L. Hoermann (Eds.). Texas Agricultural Extension Servide, Uvalde, pp. 187-192.

Herbel, C. H., and Gould, W. L. (1980). Managing semidesert ranges of the Southwest. New Mexico Extension Circ. 456.

Herbel, C. H., and Nelson, A. B. (1966). Species preference of Hereford and Santa Gertrudis cattle on a southern New Mexico range. *J. Range Manag. 19*: 177-181.

Herbel, C. H., and Nelson, A. B. (1969). Grazing management on semidesert ranges in southern New Mexico. Jornada Exp. Range Rep. No. 1.

Herbel, C. H., Ares, F. N., and Wright, R. A. (1972). Drought effects on a semidesert range. *Ecology 53*: 1084-1093.

Herbel, C. H., Wallace, J. D., Finkner, M. D., and Yarbrough, C. C. (1984). Early weaning and part-year confinement of cattle on arid rangelands of the Southwest. *J. Range Manag. 37*: 127-130.

Hilbert, D. W., Swift, D. M., Detling, J. K., and Dyer, M. I. (1981). Relative growth rates and the grazing optimization hypothesis. *Oecologia (Berl.) 51*: 14-18.

Holechek, J. L., and Herbel, C. H. (1982). Seasonal suitability grazing in the western United States. *Rangelands 4*: 252-255.

Holechek, J. L., Pieper, R. D., and Herbel, C. H. (1989). *Range Management Principles and Practices*. Prentice Hall, Englewood Cliffs, New Jersey.

Hormay, A. L., and Talbot, M. W. (1961). Rest-rotation grazing—a new management system for perennial bunchgrass ranges. U.S. Department of Agriculture Prod. Res. Rep. 51.

Howell, L. N. (1978). Development of multi-camp grazing systems in the southern Orange Free State, Republic of South Africa. *J. Range Manag. 31*: 459-465.

Huss, D. L., and Allen, J. V. (1969). Livestock production and profitability comparisons of various grazing systems, Texas Range Station. Texas Agr. Exp. Sta. Bull. B-1089.

Hyder, D. N., and Bement, R. E. (1977). The status of seasons of grazing and rest in grazing management. In *The Impact of Herbivores on Arid and Semi-arid Rangelands*. Australian Rangelands Society, Perth, Western Australia, pp. 73-82.

Hyder, D. N., and Sawyer, W. A. (1951). Rotation-deferred grazing as compared to season-long grazing on sagebush-bunchgrass ranges in Oregon. *J. Range Manag. 4*: 30-34.

Jardine, J. T., and Forsling, C. L. (1922). Range and cattle management during drought. U.S. Department of Agriculture Bull. 1031.

Johansen, J. R. (1986). Importance of cryptogamic soil crusts to arid rangelands: Implications for short-duration grazing. In *Short Duration Grazing*, J. A. Tiedeman (Ed.). Washington State University, Pullman, pp. 127-136.

Johnston, A. (1961). Comparison of lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta. *Can. J. Plant Sci. 41*: 615-622.
Johnston, A., Dormaar, J. F., and Smoliak, S. (1971). Long-term grazing effect on fescue grassland soils. *J. Range Manag. 24*: 185-188.
Knight, J. E. (1988). Landowner management opportunities. In *Guidelines for Increasing Wildlife on Farms and Ranches*, F. R. Henderson (Ed.). Kansas Cooperative Extensive Service S-25, pp. 1D-31D.
Kothmann, M. M. (1980). Integrating livestock needs to the grazing system. In *Proceedings, Grazing Management Systems for Southwest Rangelands Symposium*, K. C. McDaniel and C. Allison (Eds.). New Mexico State University, Las Cruces, pp. 65-83.
Kothmann, M. M., Mathis, G. W., Marion, P. T., and Waldrip, W. J. (1970). Livestock production and economic returns from grazing treatments on the Texas Experimental Ranch. Texas Agr. Exp. Sta. Bull. B-1100.
Lodge, R. W. (1970). Complimentary grazing systems for the northern Great Plains. *J. Range Manag. 23*: 268-271.
Malechek, J. C. (1984). Impacts of grazing intensity and specialized grazing systems on livestock response. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences*. Westview Press, Boulder, Colorado, pp. 1129-1158.
Martin, P. S. (1968). The meaning of empty niches. In *AIBS Pleistocene Man-Environment Relationships Symposium*, Columbus, Missouri, pp. 85-94.
Martin, S. C. (1975). Stocking strategies and net cattle sales on semidesert range. U.S. Department of Agriculture Forest Service RM-146.
Martin, S. C. (1978). The Santa Rita grazing system. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 573-575.
Martin, S. C., and Severson, K. E. (1988). Vegetation response to the Santa Rita grazing system. *J. Range Manag. 41*: 291-295.
Martin, S. C., and Ward, D. E. (1970). Rotating access to water to improve semidesert cattle range near water. *J. Range Manag. 23*: 22-26.
McCalla, G. R., II, Blackburn, W. H., and Merrill, L. B. (1984a). Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. *J. Range Manag. 37*: 265-269.
McCalla, G. R., II, Blackburn, W. H., and Merrill, L. B. (1984b). Effects of livestock grazing on sediment production, Edwards Plateau of Texas. *J. Range Manag. 37*: 291-294.
McGinty, W. A., Smeins, F. E., and Merrill, L. B. (1978). Influence of soil, vegetation, and grazing management on infiltration rate and sediment production of Edwards Plateau rangeland. *J. Range Manag. 32*: 33-37.
McIlvain, E. H., and Savage, D. A. (1951). Eight-year comparisons of continuous and rotational grazing on the Southern Plains Experimental Range. *J. Range Manag. 4*: 42-47.
McIlvain, E. H., and Shoop, M. C. (1969). Grazing systems in the southern Great Plains (abstract). *Am. Soc. Range Manag. 22*: 21-22.

McIlvain, E. H., Baker, A. L., Kneebone, W. R., and Gates, D. H. (1955). Nineteen-year summary of range improvement studies at the U.S. Southern Great Plains Field Station, Woodward, Oklahoma. Woodward Prog. Rep. 5506.

McNaughton, S. J. (1979). Grazing as an optimization process. *Am. Naturalist 113*: 691-703.

Merrill, L. B. (1954). A variation of deferred-rotation grazing for use under Southwest range conditions. *J. Range Manag. 7*: 152-154.

Merrill, L. B. (1969). Grazing systems in the Edwards Plateau of Texas (abstract). *Am. Soc. Range Manag. 22*: 22.

Nelson, A. B., Herbel, C. H., and Jackson, H. M. (1970). Chemical composition of forage species grazed by cattle on an arid New Mexico range. New Mexico Agr. Exp. Sta. Bull. 561.

O'Rourke, J. T. (1978). Grazing rate and system trial over 5 years in a medium-height grassland of northern Tanzania. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 563-566.

Owen, D. F., and Wiegert, R. G. (1976). Do consumers maximize plant fitness? *Oikos 27*: 488-492.

Owen, D. F., and Wiegert, R. G. (1981). Mutualism between grasses and grazers: An evolutionary hypothesis. *Oikos 38*: 376-378.

Paige, K. N., and Whitham, T. G. (1987). Overcompensation in response to mammalian herbivory: The advantage of being eaten. *Am. Naturalist 129*: 407-416.

Parsons, S. D. (1984). Introduction to the Charter Estate Grazing Trial. *Zimbabwe Agr. J. 81*: 39-40.

Paulsen, H. A., Jr., and Ares, F. N. (1962). Grazing values and management of black grama and tobosa grasslands and associated shrub ranges of the Southwest. U.S. Department of Agriculture Tech. Bull. 1270.

Pieper, R. D. (1980). Impacts of grazing systems on livestock. In *Grazing Management Systems for Southwest Rangelands. A Symposium*, K. C. McDaniel and C. D. Allison (Eds.). Range Improvement Task Force, New Mexico State University, Las Cruces, pp. 133-151.

Pieper, R. D. (1981). The stocking rate decision. In *Proceedings of the 1981 International Rancher's Roundup*, L. D. White and A. L. Hoermann (Eds.). Texas Agricultural Extension Service, Uvalde, pp. 199-204.

Platou, K. A., and Tueller, P. T. (1985). Evolutionary implications for grazing management systems. *Rangelands 7*: 57-61.

Platts, W. S., and Raleigh, R. F. (1984). Impacts of grazing on wetlands and riparian habitat. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences*, Westview Press, Boulder, Colorado, pp. 1105-1117.

Prasad, N. L. N. S., and Guthery, F. S. (1986). Wildlife use of livestock water under short-duration and continuous grazing. *Wildlife Soc. Bull. 14*: 450-454.

Pratchett, D., and Schirvel, B. (1978). The testing of grazing systems on semiarid rangelands in Botswana. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 567-568.

Ratliff, R. D. (1962). Preferential grazing continues under rest-rotation management. Pacific Southwest Forest and Range Exp. Sta. Res. Note 206.

Ratliff, R. D., and Reppert, J. N. (1968). A summary of cattle weights and gains over a 13-year period of rest-rotation grazing (abstract). *Am. Soc. Range Manag. 21*: 55.

Reardon, P. O., and Merrill, L. B. (1976). Vegetative response under various grazing management systems in the Edwards Plateau of Texas. *J. Range Manag. 29*: 195-198.

Reynolds, H. G. (1954). Meeting drought on southern Arizona rangelands. *J. Range Manag. 7*: 33-40.

Roberts, B. R. (1967). Non-selective grazing—an evaluation. *Farmers Weekly (S. Afr.) July 19*: pp. 40-49; *July 26*: pp. 34-39; *August 2*: pp. 34-37.

Rodriguez, A., and Jameson, D. A. (1988). Rainfall risk in grazing management. *Ecol. Model. 41*: 85-100.

Rogler, G. A. (1951). A twenty-five year comparison of continuous and rotation grazing in the northern plains. *J. Range Manag. 4*: 35-41.

Sandford, S. (1983). *Management of Pastoral Development in the Third World.* John Wiley & Sons, New York.

Savory, A. (1979). Range management principles underlying short duration grazing. In *Beef Cattle Science Handbook*, Vol. 16, M. E. Ensminger (Ed.). Agriservices Foundation, Clovis, California, pp. 375-399.

Seligman, N. G., and Gutman, M. (1978). Cattle and vegetation responses to management of Mediterranean rangeland in Israel. In *Proceedings, First International Rangeland Congress*, D. N. Hyder (Ed.). Society for Range Management, Denver, Colorado, pp. 616-618.

Shiflet, T. N., and Heady, H. F. (1971). Specialized grazing systems: Their place in range management. Soil Conservation Service TP-152.

Skovlin, J. M. (1984). Impacts of grazing on wetlands and riparian habitat: A review of our knowledge. In *Developing Strategies for Rangeland Management; National Research Council, National Academy of Sciences.* Westview Press, Boulder, Colorado, pp. 1001-1103.

Skovlin, J. (1987). Southern Africa's experience with intensive short duration grazing. *Rangelands 9*: 162-167.

Skovlin, J. M., and Harris, R. W. (1970). Management of conifer resources for cattle, deer and elk. *Proc. Int. Grassl. Cong. 11*: 75-78.

Smith, D. R., Fisser, H. G., Jefferies, N., and Stratton, P. O. (1967). Rotation grazing on Wyoming's Big Horn Mountains. Wyoming Agr. Exp. Sta. Res. J. 13.

Smith, E. F., and Owensby, C. E. (1978). Intensive-early stocking of Kansas Flint Hills range. *J. Range Manag. 31*: 14-17.

Smith, E. F., Anderson, K. L., Owensby, C. E., and Hall, M. C. (1967). Different methods of managing bluestem pasture. In 54th Annual Livestock Feeders Day, Kansas Agr. Exp. Sta. Bull. 507, pp. 34-38.

Smith, M. A., and Rodgers, J. D. (1988). Grazing management to maintain or enhance wildlife habitat. In *Guidelines for Increasing Wildlife on Farms and Ranches*, F. R. Henderson (Ed.). Kansas Cooperative Extension Service S-25, pp. 9B-14B.

Smoliak, S., Dormaar, J. F., and Johnston, A. (1972). Long-term grazing effects on *Stipa-Bouteloua* prairie soils. *J. Range Manag. 25*: 246-250.

Society for Range Management (1974). *A Glossary of Terms Used in Range Management*, 2nd ed. Range Term Glossary Committee, Society for Range Management, Denver, Colorado.

Stephenson, G. R., and Rychert, R. C. (1982). Bottom sediment: A reservoir of *Escherichia coli* in rangeland streams. *J. Range Manag. 35*: 119-123.

Stephenson, G. R., and Street, L. V. (1978). Bacterial variations in streams from a southwest Idaho rangeland watershed. *J. Environ. Qual. 7*: 150-157.

Stubblefield, T. M. (1956). Greater returns from cow-yearling operations on Southwest ranges. *J. Range Manag. 9*: 8-10.

Thurow, T. L., Blackburn, W. H., and Taylor, C. A., Jr. (1988). Infiltration and interrill erosion responses to selected livestock grazing strategies, Edwards Plateau, Texas. *J. Range Manag. 41*: 296-302.

Tiedemann, A. R., Higgins, D. A., Quigby, T. M., Sanderson, H. R., and Marx, D. B. (1987). Responses of fecal coliform in streamwater to four grazing strategies. *J. Range Manag. 40*: 322-329.

Torell, L. A., and Hart, R. H. (1988). Economic consideration for efficient stocking rates on rangeland. In *Fort Keogh Research Symposium*, R. S. White and R. E. Short (Eds.). Montana Agr. Exp. Sta., pp. 71-76.

Valentine, K. A. (1967). Seasonal suitability, a grazing system for ranges of diverse vegetation types and condition classes. *J. Range Manag. 20*: 395-397.

Van Haveren, B. P. (1983). Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. *J. Range Manag. 36*: 586-588.

Van Poollen, W. H., and Lacey, J. R. (1979). Herbage response to grazing systems and stocking intensities. *J. Range Manag. 32*: 250-253.

Wood, M. K., and Blackburn, W. H. (1981a). Grazing systems: Their influence on infiltration rates in the Rolling Plains of Texas. *J. Range Manag. 34*: 331-335.

Wood, M. K., and Blackburn, W. H. (1981b). Sediment production as influenced by livestock grazing in the Texas Rolling Plains. *J. Range Manag. 34*: 228-231.

Worthington, D. K. (1984). The Charter Estate Grazing Trial—animal production and management. *Zimbabwe Agri. J. 81*: 41-48.

Wylie, B., and Pieper, R. D. (1990). Influence of watering frequency and grazing system on heifer weight gains in central Nigeria. *World Anim. Rev.*, in press.

Wylie, B., Senock, R., Snyder, L., Roettgen, B., and Porter, B. (1985). *Grazing and Animal-Plant Relationships in Pastoral Development in Central Niger.* U.S. Agency for International Development, Niamey, Niger, pp. 163-224.