Reprinted from

Forage evaluation:

concepts and techniques

edited by
J. L. Wheeler
R. D. Mochrie

MANIPULATING RANGELAND FORAGE QUALITY WITH THE GRAZING ANIMAL

D.M. Anderson

Abstract

The positive balance that evolved between plants and grazing animals is not maintained under continuous grazing. Optimum production from the plant:grazing-animal system can be realized from only high leaf:stem and green:dead ratios in both the standing crop and animal diets. If we are to realize optimum production, we will need grazing methods in which time of year, frequency, and duration of defoliation can be controlled for individual plants and still permit high animal selectivity. By constructing more paddocks, stocking density can be increased and the extent of defoliation on individual plants can be manipulated. High individual animal production and proper individual plant defoliation can only be obtained under high stocking density if livestock are frequently moved between paddocks. To accomplish this, paddock design must ensure that animal stress and labor requirements are held to a minimum. However, the added flexibility derived from rotating animals among paddocks substantially increases the management required to obtain high animal performance and proper plant usage.

INTRODUCTION

With reduced profitability in the conversion of grain into carcass beef, interest to increase production from U.S. rangelands is being renewed (USDA 1974; Van Dyne et al. 1980). Much of our lifestyle in food habits, clothing and home furnishings is intrinsically linked to livestock. Therefore, forage quality must be addressed from the grazing animal's needs. The object of this paper will be to discuss the necessary components that must be incorporated into a grazing method to optimize diet quality at the plant:grazing-animal interface.

BACKGROUND

In the U.S., the documentation of the chemical composition of grass began before the turn of the century; however, most studies were conducted after 1900 (Renner et al. 1938). Gradually during the late 1940's, the chemical information on standing crop was incorporated into investigations involving grazing livestock. Torell's (1954) classic paper described the practical use of the esophageal fistula to obtain a reliable estimate of dietary chemical and botanical composition. With this approach, investigators were able to document the importance of animal selectivity in diet quality and animal production (Theurer et al. 1976).

Cooperative research has been published on range livestock nutrition techniques (Harris et al. 1967), chemical composition of fistula samples (Lesperance et al. 1974), diet botanical composition (Theurer et al. 1976), and intake and digestibility of range forages (Kartchner and Campbell 1979). The results of these studies have established that digestible protein, digestible energy, phosphorus, and carotene (Vitamin A) are the most limiting components of forage quality for livestock grazing rangelands in the western United States (Cook et al. 1977; Kothmann 1980).

Grasses and wild ungulates had a coevolutionary history that dates back more than 20 million years in which competitive fitness was enhanced by natural rotational grazing due to seasonal rainfall patterns (McNaughton 1979; Van Dyne et al. 1980). As early as 1777, man approached a suitable grazing method that simulated "natural rotation" (Davies 1976). However, in the years since 1870, a significant evolution in grazing has altered the positive balance between the standing crop and the grazing animal. With the introduction of barbed wire in the 1870's, followed by digging of water wells to tap ground water and growing feed to supplement range forage during drought periods, the tendency of man to overgraze rangeland with a consequent loss of productive capacity has been persistent (Youngblood 1922). Most studies have shown that livestock production per animal is the same or lower for management systems in which livestock are rotated to different pastures, compared to continuous grazing (Herbel 1973).

Continuous grazing defined as unrestricted access of livestock to any part of the range throughout the grazing season (Heady 1970) has been accepted as the base upon which all other methods of grazing have been evaluated. The result has been that non-systematic use of the standing crop along with low animal production per acre is accepted as a normal condition. Too often, if a grazing system did not reflect a positive trend in animal weight when compared with continuous grazing, the "method" was abandoned without further evaluation (Acocks 1966). Grazing systems are necessary to vary the length and season of grazing (Anderson 1967). With grazing systems, improved livestock distribution and full uniform use of the standing crop have been proposed as worthy objectives (Booysen 1964; Wambolt 1973) along with improvements in range condition (Rogler 1951). Several studies in which short periods of defoliation were compared to continuous grazing, improved rangeland conditions and increased carrying capacity (Leithead 1974) and improved average daily gain of animals (Frasure et al. 1980) have been reported. The ineffectiveness of most grazing systems can be attributed to the inability of the manager to control the extent of defoliation of individual plants. These failures to control type and amount of defoliation often result in low nutrition for the grazing animal. However, when defoliation of individual plants can be controlled in a grazing system, rest periods can be shortened and the physiological vigor of the standing crop maintained. A high degree of control over standing crop quantity and quality will accomplish equal use of individual plants within a species (Kothmann 1980).

With the increased awareness of the potential that exists at the plant:grazing animal interface, continuous grazing and most traditional grazing systems have been critically reevaluated by range animal nutritionists in the United States. This movement has come about because of the efforts of Voisin (1959), Goodloe (1969), and recently Savory (1978).

COMPONENTS FOR OPTIMUM GRAZING

Stocking Rate

Once the decision to graze livestock has been made, stocking rate becomes the first, and most basic decision (Kothmann 1980). Stocking rate is defined as the total area of land in a system of management that the operator has allotted to each animal-unit year in the system (Kothmann 1974). Allison (1978) found that paddocks with low stocking rates have a high amount of wasted herbage. However, production per animal is generally high (Wolfe 1972). Understocking a continuously grazed pasture and some rotation systems have been deemed essential to reduce grazing pressure during the summer growing season (Wambolt 1973; Martin and Cable 1974; Bishop and Birrell 1975). Even then, the range may deteriorate at such a slow rate that long periods of time will be required to document the deterioration (Gammon 1968).

Flexibility under continuous grazing is limited because once kind and class of animal, pasture size, watering and supplement location are decided upon, only stocking rate can be varied. Especially during drought, this lack of flexibility does not allow animal and standing crop production to remain at an acceptable level. Simply rotating animals between pastures is not sufficient for optimum production. A proper balance between frequency and intensity of defoliation of individual plants is essential to optimize high leaf:stem, and green:-dead ratios within the standing crop with correspondingly high ratios in the animal diets brought about by animal selectivity (Anderson 1977; Allison 1978; Kothmann 1980).

Grazing Pressure

Kothmann (1974) defines grazing pressure as the actual animal:-forage ratio at a specific time. This ratio varies seasonally (Tayler and Deriaz 1963; Hart 1978); animal performance is most sensitive when both green and dead herbage are simultaneously available (Kothmann 1980). Therefore, if we assume that availability is not limiting the dry matter intake, grazing pressure has little effect on nutrient intake during seasons when almost all of the available forage is either green or dormant.

By increasing grazing pressure, Duvall (1970) showed that grazing of new herbage can be maximized and old herbage held to a minimum. However, grazing periods must be kept short during early growth of grass when the grass is most susceptible to damage (Jefferies 1970).

Stocking Pressure

Stocking rate, stocking density and duration of grazing within and between cycles in a rotation system, all influence stocking pressure (Kothmann 1980). Stocking pressure has been defined as the weight of forage that the operator has allowed per animal-unit for a grazing period expressed as weight of forage per animal unit (Kothmann 1974). Allison (1978) showed that intake could be reduced significantly if low stocking pressure values (less available forage) were coupled with long periods of grazing within a cycle, especially as phenological state of the vegetation approached maturity. Earlier Kothmann et al. (1975) indicated that low stocking pressure values maintained for too long may depress livestock production.

Stocking Density

Kothmann (1974) defines stocking density as the relationship between number of animals and area of land at any instant of time expressed as animal-units per acre or acres per animal unit. Stocking density is a function of both stocking rate and number of pastures. Under continuous grazing, stocking rate is often low. Stocking density also is low because of an inadequate number of paddocks.

Grazing distribution is a problem under continuous grazing and may cause unequal use of individual plants even in the same species (Arnold and Dudzinski 1978; Kothmann 1980). Kothmann further states that the low efficiency of forage use on most ranges can be attributed to the fact that a high proportion of tillers are not defoliated or are defoliated infrequently throughout a grazing season whereas other tillers are overused.

If we are to achieve more uniform use of the standing crop, either stocking rate or stocking density, or both, have to be increased. Under semiarid range conditions, an increased stocking rate is normally inappropriate; therefore, the alternative is to build additional paddocks in order to increase stocking density, particularly if the availability of grass is limited with respect to number of livestock grazing. Grass will be used more efficiently with a rapid rotation of livestock through several pastures with high stocking densities than with continuous grazing (McMeekan 1960).

Paddocks

Rapid rotation of livestock requires adequate handling facilities and paddock design that will not induce stress to the livestock. Savory (1979) has proposed a "cell" pasture design in which wedge-shaped paddocks converge to a center, like the spokes of a wheel converge on the hub. To ensure movement of the herd between any two or more paddocks, he proposed that all paddocks open into the "hub" area.

Water and handling facilities are located within the "hub". Regardless of which paddock is being grazed or how frequently the animals are rotated the water source serves as a common location. This common location should prevent stress because the animals do not need to be completely reoriented after each move. The area around the water must be kept small in order to discourage grazing, resting, or bedding in the "hub" area. These three factors are all responsible for creating sacrifice areas around water sources in pastures grazed under continuous management. According to Savory (1979), no sacrifice areas develop with the wedge-shaped paddocks that radiate out from a common center. Arnold and Dudzinski (1978) show that if crowding is too great, a depression in animal production may result. However, paddock size does not effect weight gain in cattle (Southcott et al. 1968).

THE PLANT:GRAZING-ANIMAL INTERFACE

Monocots grow from intercalary meristems that are more protected from grazing than are the terminal meristems of dicots (Dahl and Hyder 1977). Thus, most grass grows from an intercalary meristem located at the plant base (Hyder 1972). Provided the environmental factors required for growth are not limiting, growth becomes a function of the amount of photosynthetically active tissue (Donald and Black 1958). The plants are defoliated progressively downward and inward from the top and sides (Voisin 1959). The key then to proper grazing is to synchronize the processes of defoliation and growth.

The average digestible protein, digestible energy, phosphorus and carotene content of the standing crop varies between grasses, forbs and shrubs and also during phenological development (Cook et al. 1977). High crude protein is closely associated with growth and high forage nutritive value (Dietz et al. 1958; Sell et al. 1959). Forage quality is lowered as plant tissue ages and leaf:stem and green:dead ratios are reduced (Beaty et al. 1978). These changing morphologies result primarily from changes in temperature and photoperiod (Blaser et al. 1977). Likewise, forage digestibility (Moore and Mott 1973), protein (Pieper et al. 1978) and most minerals (Nelson et al. 1970) decrease as the growing season progresses. Immature forage is nutritionally important to animal diet quality because early growth corresponds to the lowest grass stem content; i.e., highest leaf:stem ratio (Brougham 1957). Nutrient requirements of the grazing animal also vary throughout the year. Mature forage is generally adequate to meet maintenance requirements whereas green plant material, particularly leaves, is necessary for animal production (Kothmann 1980).

FORAGE QUALITY AND GRAZING

Forage quality and quantity must be balanced because maximizing either component alone will render the other component unacceptable for sustained livestock production. The genetic propensity of plants to mature and forage quality to decline is well known. However, forage quality on a particular date may vary from year to year because of differences in weather pattern, particularly moisture. Results in a limited number of studies show that leaf quality decreases at a slower rate than that of stem quality (Cook and Harris 1950; Terry and Tilley 1964; Nelson *et al*. 1970; Kothmann and Kallah 1978). Thus, if photosynthetically mature leaves are removed before death from old age (Sampaio *et al*. 1976) or death hastened by shading, moisture and temperature stresses (Beaty *et al*. 1980), the prospects for maintaining good livestock performance are usually favorable because a substantial quantity of the forage that would normally be lost can be put into production (Duvall 1970). Excessive mature forage may hamper the efforts of animals to obtain green forage (Blaser *et al*. 1977; Kothmann 1980). A substantial part of mature forage may become litter; and if that litter is allowed to accumulate, spring growth may be slowed because of the cool soil temperatures (Kucera and Ehrenreich 1962).

Davies (1976) stated that if foraging is timed so the plant is defoliated towards the period of maximum growth, maximum yield, and acceptable quality can be realized. Less palatable species had a higher percentage of tillers defoliated when defoliation intervals were $\leq$ 14 days (Gammon and Roberts 1978). Kothmann (1980) interpreted an increase in the use of less palatable species to mean that increased palatability of forage is highly related to maturity. With proper timing of defoliation, a higher proportion of tillers of all plant species will be used and will contribute to increasing the carrying capacity of most rangelands.

Defoliation increases the number of shoots (Peterson 1962) and stimulates tiller development and thus enhances leaf growth over stem production (Hodgson 1966; Laude *et al*. 1968). Hodgson and Ollerenshaw

(1969) found that tillers once grazed were the identical tillers grazed again later, rather than those tillers not grazed initially. Gammon and Roberts (1978) concluded that plants grazed most frequently were also grazed most intensively. Proper periods of rest are therefore essential to maintain the standing crop. Dickson et al. (1940) have predicted that higher quality forage may persist later into the growing season if the plants are frequently defoliated.

Rest periods can be short during rapid growth but should be increased as growth slows (Larin 1962; Voisin 1959). Defoliation stimulates regrowth (Blaser et al. 1960) but reduces root growth in most species (Ryle and Powell 1975; McNaughton 1979). Troughton (1957) attributes reduced root growth to a reduction in the amount of photosynthetically active tissue. However, with proper defoliation, a higher proportion of vegetative shoots should be produced and thus provide for a longer period of growth during the season. However, if the plant is defoliated too frequently, the period of time is not long enough to allow for replenishment of root reserves through photosynthesis (Sullivan and Sprague 1943).

Youngner (1972) showed that frequency of defoliation and height of herbaceous vegetation complement each other; reduced severity of one will offset an increased severity of the other in affecting the root system. Animals appear to select against extremes in height; medium-height plants are most often defoliated (Gammon 1976). Voisin (1959) and Hafez and Bouissou (1975) reported that grass harvest is maximum at an average height of 15 cm (6 in). Therefore, if the height heterogeneity within a species can be reduced, more uniform grazing may be possible.

If forage is too short, the nutrient intake will be reduced because plant height appears to influence intake to a greater extent than the amount of biomass present (Allden and Whittaker 1970; Gibbs and Treacher 1976). Diet quality components of crude protein and digestible energy decrease as grazing time within a paddock increases as a result of restriction in selective grazing by the animals (Anderson 1977).

PROJECTIONS

Especially under semiarid conditions where continuously grazed pastures are quite large and stocking rate must be moderate to low, increasing stocking density by increasing the number of paddocks will allow animals to be rotated into areas where short-lived ephemerals exist. The sequence in which paddocks are being grazed may be broken to use this herbage at its peak quality which otherwise might be lost if the area was being grazed under continous management or if pasture design did not permit movement of livestock. With additional research on high-density, rapid rotation of livestock, economically exciting possibilities exist for the ranching profession.

Fertile research opportunities exist in several areas of rapid rotational grazing. If animal travel is consistently less in small paddocks than in large pastures stocked similarly and grazed continuously, nutritional requirements of livestock will need to be adjusted to meet the management method (Anderson and Kothmann 1980). We do not know whether prolonged high stocking density and frequent movement produces stress in animals, especially during time of parturition (Kothmann 1980). Possibly, uniform herbage use may actually be reduced in areas subjected to prolonged high stocking density. Studies have shown feces deposits to cause cattle to reject not only the contaminated herbage but herbage in an area six times the size of the deposit (Brockington 1972).

SUMMARY

Up until "civilized" man dug wells, fenced in ruminants, and began to grow supplemental feeds, plants and animals were in synergistic balance. Range animal nutrition studies began in the U.S. during the 1940's with specialized techniques developed for grazing studies. Digestible protein, digestible energy, phosphorus and carotene (Vitamin A) are the most limiting forage quality components to range livestock production. With man's intervention, too often serious nutrient deficiencies have resulted in grazing animals, which is ironic because plants and grazing evolved simultaneously.

Stocking rate is the first, most basic decision to be made in grazing livestock. Even with proper stocking, under continuous grazing an excessive amount of herbage is not consumed. By manipulating grazing pressure and stocking pressure, green leaf tissue can be

optimized in the animal's diet and animal intake will benefit.

Meeting the nutritional requirements of the grazing animal while maximizing photosynthetically active tissue through the processes of defoliation and rest must be the goal of grazing management. With continuous grazing, green leaf material cannot be optimized on an individual plant basis. However, with additional paddocks, stocking density can be effectively increased and the time of year and the frequency and duration of defoliation on individual plants can be managed. Herein lies the benefit to be derived from a rapid rotation method of managing the grazing animal.

Defoliation must stimulate new and enhance existing photosynthetically active tissue. Rest must be scheduled so carbohydrate reserves can be replenished, yet must be short enough to minimize excessive amounts of physiologically mature herbage. Individual plants must be used uniformly throughout a paddock to minimize the range in phenological stage of development within a plant species.

High stock density coupled with paddocks designed for efficient movement of livestock is essential. Wedge-shaped paddocks converging into a central "hub", provide flexibility in animal movement without excessive labor requirements or handling stress to the animals.

The added flexibility derived from rotating animals among paddocks substantially increase the management required to obtain optimum animal performance and plant usage.

The rate at which animals are rotated through the paddocks must be synchronized with the phenological state of plant development. During rapid growth of the standing crop, livestock must be rotated rapidly throughout the paddocks to ensure high animal selectivity and reduce defoliation intensity so the standing crop is not damaged. However, during dormancy, grazing periods within a paddock may increase.

Rangelands are subject to droughts of various longevities and intensities. Therefore, research on both the standing crop and the grazing animal must be conducted under rangeland conditions before long term effects of the rapid rotation grazing method can be accurately assessed. This is particularly important because the majority of research on rapid rotation grazing has not been conducted under arid or semiarid environmental conditions. Application of the principles of rapid rotation grazing can then be safely applied when economic conditions are favorable.

REFERENCES

Acocks, J.P.H. (1966). Non-selective grazing as a means of veld reclamation, *Proc. Grassland S. Afr.* 1, 33-39.

Allden, W.G., and I.A. McD. Whittaker. (1970). The determinants of herbage intake by grazing sheep: The interrelationship of factors influencing herbage intake and availability. *Aust. J. Agr. Res.* 21, 755-766.

Allison, C.D. (1978). Forage intake of cattle as affected by stocking pressure. Ph.D. Dissertation. Texas A&M Univ.

Anderson, D.M. (1977). Standing crop, diets, travel, and weight changes under short-duration and continuous grazing. Ph.D. Dissertation. Texas A&M Univ.

Anderson, D.M., and M.M. Kothmann. (1980). Relationship of distance traveled with diet and weather for Hereford heifers. *J. Range Manage.* 33, 217-220.

Anderson, E.W. (1967). Rotation of deferred grazing. *J. Range Manage.* 20, 5-7.

Arnold, G.W., and M.L. Dudzinski. (1978). Ethology of Free-Ranging Domestic Animals. Elsevier Scientific Publishing Co., New York.

Beaty, E.R., J.W. Dobson, and A.E. Smith (1978). Tall fescue tiller weights, green forage present and forage IVDMD. *Agron. J.* 70, 223-226.

Beaty, E.R., and J.L. Engel. (1980). Forage quality measurements and forage research - A review, critique and interpretation. *J. Range Manage.* 33, 49-54.

Bishop, A.H., and H.A. Birrell. (1975). Effect of stocking rate, fodder conservation, and grazing management on the performance of wether sheep in Southwest Victoria. I. Wool Production. *Aust. J. Exp. Agr. and Anim. Husb.* 15, 173-182.

Blaser, R.E., R.C. Hammes, Jr., H.T. Bryant, W.A. Hardison, J.P. Fontenot, and R.W. Engel. (1960). The effect of selective grazing on animal output. Proc. Inter. Grassland Congr., Hurley. Berkshire, VIII, pp. 601-605.

Blaser, R.E., and W.C. Stringer, E.B. Rayburn, J.P. Fontenot, R.C. Hammes, Jr., and H.T. Bryant. (1977). Increasing digestibility and intake through management of grazing systems, pp. 301-345. In 'Forage Fed Beef: production and marketing alternatives in the south'. (Ed. J.A. Stuedemann, D.L. Huffman, J.C. Purcell and O.L. Walker) Southern Coop. Ser. Bull. 220.

Booysen, P. DeV. (1964). A grassveld management system for every farm. *Farming S. Afr.* 40, 64-66.

Brockington, N.R. (1972). A mathematical model of pasture contamination by grazing cattle and the effects on herbage intake. *J. Agr. Sci. Camb.* 79, 249-257.

Brougham, R.W. (1957). Some factors that influence the rate of growth of pasture. 19th Conf. N. Z. Grassland Assoc. pp. 109-116.

Cook, C.W., and L.E. Harris. (1950). The nutritive content of the grazing sheep's diet on summer and winter ranges of Utah. Utah Agr. Exp. Sta. Bull. 342.

Cook, C.W., R.D. Child, and L.L. Larson. (1977). Digestible protein in range forage as an index to nutrient content and animal response. A systems approach to range livestock production. Colo. State Univ., Range Sci. Dept., Sci. Ser. 29.

Dahl, B.E., and D.N. Hyder. (1977). Developmental morphology and management implications, pp. 257-290. In 'Rangeland Plant Physiology'. (Ed. R.E. Sosebee) Society for Range Management, Denver, CO.

Davies, T.H. (1976). The evolution of modern dairy cow grazing systems. *ADAS Q. Rev.* 22, 275-282.

Dickson, R.E., B.C. Langley, and C.E. Fisher. (1940). Water and soil conservation experiments of Spur, Texas. Tex. Agr. Exp. Sta. Bull. 587.

Dietz, D.R. (1971). Nutritive value of shrubs, pp. 289-302. In 'Wildland Shrubs - Their Biology and Utilization'. (Ed. C. McKell, J.P. Blaisdell and J.R. Goodin) U.S. Dep. Agr. For. Serv. Gen. Tech. Rep. INT-1, Intermountain For. and Range Exp. Sta. Ogden, UT.

Dietz, D.R., R.H. Udall, H.R. Shepherd, and L.E. Yeager. (1958). Seasonal progression in chemical content of five key browse species in Colorado. Soc. Amer. For. Proc. 1958, 117-122.

Donald, C.M., and J.N. Black. (1958). The significance of leaf area in pasture growth. *Herb. Abstr.* 28, 1-6.

Duvall, V.L. (1970). Maniplation of forage quality: Objectives procedures and economic considerations, pp. 19-24. In 'Range and Wildlife Habitat Evaluation A Research Symposium'. U.S. Dep. Agr. For. Serv. Misc. Pub. 1147.

Frasure, J.R., R.K. Heitschmidt, and D. Price. (1980). Performance of growing heifers on a 1-herd, 10-pasture rapid rotation system as contrasted to a continuous system - Texas Experimental Ranch, 1978-79. 33rd Ann. Mtg., Society for Range Management, pp. 37.

Gammon, D.M. (1968). Patterns of defoliation during continuous and rotational grazing of rangeland by cattle, pp. 603-605. In 'Proceedings 1st International Rangeland Congress. (Ed. D.N. Hyder) Society for Range Management, Denver, CO.

Gammon, D.M. (1976). Studies of the patterns of defoliation herbage characteristics and grazing behavior during continuous and rotational grazing of the Matopos sandveld of Rhodesia. PhD. Dissertation. Univ. of the Orange Free State.

Gammon, D.M., and B.R. Roberts. (1978). Patterns of defoliation during continuous and rotational grazing of the Matopos sandveld of Rhodesia. 2. Severity of defoliation. *Rhod. J. of Agr. Res.* 16, 133-246.

Gibbs, M.J., and T.T. Treacher. (1976). The effect of herbage allowance on herbage intake and performance of lambs grazing perennial ryegrass and red clover swards. *J. Agr. Sci., Camb.* 86, 355-365.

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

Hafez, E.S.E., and M.F. Bouissou. (1975). The behavior of cattle, pp. 203-245. In 'The Behavior of Domestic Animals'. The Williams and Wilkins Co., Baltimore, MD.

Harris, L.E., C.J. Kercher, G.P. Lofgreen, R.J. Raleigh, and V.R. Bohman. (1967). Techniques of research in range livestock nutrition. Utah Agr. Exp. Sta. Bull. 471.

Hart, R.H. (1978). Stocking rate theory and its application to grazing on rangeland, pp. 547-550. In 'Proceedings 1st International Rangeland Congress. (Ed. D.N. Hyder) Society for Range Management, Denver, CO.

Heady, H.F. (1970). Grazing systems: terms and definitions. *J. Range Manage.* 23, 59-61,

Herbel, C.H. (1973). Grazing systems on native range, pp. K-1 to K-29. In 'Great Plains Beef Symposium, May 29, 30, and 31'. (Ed. F.H. Baker) Great Plains Ag. Council Pub. 63. Univ. of Neb. Ctr. for Cont. Ed., Lincoln, NE.

Hodgson, J. (1966). The frequency of defoliation of individual tillers in a set-stocked sward. *J. Br. Grassland. Soc.* 21, 258-263.

Hodgson, J., and J.H. Ollerenshaw. (1969). The frequency and severity of defoliation of individual tillers in set-stocked swards. *J. Br. Grassland Soc.* 24, 226-234.

Hyder, D.N. (1972). Defoliation in relation to vegetative growth, pp. 304-317. In 'The Biology and Utilization of Grasses'. (Ed. V.B. Youngner) Academic Press, New York.

Jefferies, N.W. (1970). Planned grazing for Montana ranges. *J. Range Manage.* 23, 373-376.

Kartchner, R.J., and C.M. Campbell. (1979). Intake and digestibility of range forage consumed by livestock. Mont. State Univ. Bull. 718.

Kothmann, M.M. (1974). A glossary of terms used in range management. 2nd ed. Society for Range Management, Denver, CO.

Kothmann, M.M. (1980). Integrating livestock needs to the grazing system, pp. 65-83. In 'Proceedings, Grazing Management Systems for Southwest Rangelands Symposium. April 1-2, 1980. Albuquerque, NM'. (Ed. K.C. McDaniel and C.D. Allison) New Mexico State University, Las Cruces, NM.

Kothmann, M.M. and M.S. Kallah. (1978). Phenology, carbohydrate reserves and nutrient content of health aster. *The Southwestern Nat.* 23, 347-362.

Kothmann, M.M., and W.S. Rawlins, and J. Bluntzer. (1975). Vegetation and livestock responses to grazing management on the Texas Experimental Ranch. Texas Agr. Exp. Sta. PR-3310.

Kucera, C.L., and J.H. Ehrenreich. (1962). Some effects of annual burning on central Missouri prairie. *Ecology*. 43, 334-336.

Larin, I.V. (1962). Pasture economy and meadow cultivation. (Trans. from Russian). U.S. Dept. Comm., Office Tech. Serv. No. 61-31195, Washington, D.C.

Laude, G.M., A.H. Murphy, and R.E. Fox. (1968). Tillering at the reproductive stage in Hardinggrass. *J. Range Manage.* 21, 148-151.

Leithead, H.L. (1974). High intensity-low frequency grazing systems increase livestock production. Proc. Inter. Grassland Congr., Moscow, XII, pp. 355-361.

Lesperance, A.L., D.C. Clanton, A.B. Nelson, and C.B. Theurer. (1974). Factors affecting the apparent chemical composition of fistula samples. Univ. of Nevada, Reno., Agr. Exp. Sta., West. Reg. Coord. Comm. No. 8, Bull. T18.

Martin, S.C., and D. R. Cable. (1974). Managing semidesert grass-shrub ranges--Vegetation responses to precipitation, grazing, soil texture, and mesquite control. U.S. Dept. Agr. Forest Serv. Bull. 1480.

McMeekan, C. P. (1960). Grazing management. Proc. Inter. Grassland Congr., Reading, VIII, pp. 21-26.

McNaughton, S.J. (1979). Grazing as an optimization process: Grass-ungulate relationships in the Serengeti. *Am. Nat.* 113, 691-703.

Moore, J.E., and G.O. Mott. (1973). Structural inhibitors of quality in tropical grasses, pp. 53-98. In 'Anti-Quality Components of Forage'. Crop Science Society of America, Madison, WI.

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

Peterson, R.A. (1962). Factors affecting resistance to heavy grazing in needle and thread grass. *J. Range Manage.* 15, 183-189.

Pieper, R.D., A.B. Nelson, G.S. Smith, E.E. Parker, E.J.A. Roggino, and C.F. Hatch. (1978). Chemical composition and digestibility of important range grass species in South-Central New Mexico. N. Mex. Agr. Exp. Sta., Bull. 662.

Renner, F.G., E.C. Crafts, T.C. Hartman, and L. Ellison. (1938). A selected bibliography on mananagement of western ranges, livestock, and wildlife. U.S. Dept. Agr. Misc. Pub. 281.

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

Ryle, G.J.A., and C.E. Powell. (1975). Defoliation and regrowth in the graminaceous plant, the role of current assimilate. *Ann. Bot.* 39, 297-331.

Sampaio, E.V.S.B., E.R. Beaty, and D.A. Ashley. (1976). Bahiagrass regrowth and physiological aging. *J. Range Manage.* 29, 316-319.

Savory, A. (1978). A holistic approach to ranch management using short duration grazing, pp. 555-557. In 'Proceedings 1st International Rangeland Congress'. (Ed. D.N. Hyder) Society for Range Management, Denver, CO.

Savory, A. (1979). Ranch fencing designs for short duration grazing, pp. 380-383. In 'Beef Cattle Science Handbook'. (Ed. M.E. Engsminger) Vol. 16. Agri Services Foundation, Clovis, CA.

Sell, O.E., J.T. Reid, P.O. Woolfolk, and R.E. Williams. (1959). Intersociety forage evaluation symposium. *Agron. J.* 51, 212-245.

Southcott, W.H., M.K. Hill, B.R. Watkin, and J.L. Wheeler. (1968). Effect of paddock size, stocking rate, on the anthelmintics, and trace elements on the weight gain of young cattle. *Proc. Aust. Soc. Anim. Prod.* 7, 118-122.

Sullivan, J.T., and V.G. Sprague. (1943). Composition of the roots and stubble of perennial ryegrass following partial defoliation. *Plant Physiol.* 18, 656-670.

Tayler, J.C., and R.E. Deriaz. (1963). The use of rumen-fistulated steers in the direct determination of nutritive value of ingested herbage in grazing experiments. *J. Br. Grassland Soc.* 18, 29-38.

Terry, R.A., and J.M.A. Tilley. (1964). The digestibility of the leaves and stems of perennial ryegrass, cocksfoot, timothy, fall fescue, lucerne and sainfoin, as measured by an *in vitro* procedure. *J. Br. Grassland Soc.* 19, 363-372.

Theurer, C.B., A.L. Lesperance, and J.D. Wallace. (1976). Botanical composition of the diet of livestock grazing native ranges. Agr. Exp. Sta., West. Reg. Coord. Comm. No. 8, Tech. Bull. 233.

Torell, D.T. (1954). An esophageal fistula for animal nutrition studies. *J. Anim. Sci.* 13, 878-884.

Troughton, A. (1957). The underground organs of herbage grasses. Commonwealth Bureau of Pastures and Field Crops, Hurley, Berkshire, Bull. 44.

USDA. (1974). Opportunities to increase red meat production from ranges of the USA (non-research phase I). U.S. Dept. Agr., Inter-Agency Work Group on Range Production.

Van Dyne, G.M., N.R. Brockington, Z. Szocs, J. Duek, and C.A. Ribic. (1980). Large herbivore subsystems, pp. 270-537. In 'Grasslands, Systems Analysis and Man'. (Ed. A.J. Breymer and G.M. Van Dyne) Cambridge University Press, Cambridge, England.

Voisin, A. (1959). Grass productivity. Philosophical Library, Inc., New York.

Wambolt, C.L. (1973). Range grazing systems. Coop. Ext. Serv., Mont. State Univ. Bull. 340.

Wolfe, E.C. (1972). Pasture management and its effects on the botanical composition and productivity of pasture, pp. 199-220. In 'Intensive Pasture Production'. (Ed. A. Lazenby and F.G. Swain) Angus and Robertson Pty. Ltd., Sydney.

Youngblood, B. (1922). An economic study of a typical ranching area on the Edwards Plateau of Texas. Texas Agr. Exp. Sta. Bull. 297.

Youngner, V.B. (1972). Physiology of defoliation and regrowth, pp. 292-303. In 'The Biology and Utilization of Grasses'. (Ed. V.B. Youngner and C.M. McKell) Academic Press, New York.