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A Comparison of High-Performance Short-Duration and Repeated-Seasonal Grazing Systems

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A COMPARISON OF HIGH-PERFORMANCE SHORT-DURATION AND REPEATED-SEASONAL GRAZING SYSTEMS

by

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

A COMPARISON OF HIGH-PERFORMANCE SHORT-DURATION AND REPEATED-SEASONAL GRAZING SYSTEMS

JERRY DAVID VOLESKY

Six replications of 1-herd 16-subunit High-Performance Short-Duration (HPSDG) and Repeated-Seasonal (RSG) (May-Sep.) grazing system treatments were compared during 1983 and 1984 at the Cottonwood Range and Livestock Research Station located in western South Dakota. Calves and lambs were allotted to the experimental pastures in sets approximately equal on an animal unit basis. Animal numbers were adjusted with put-and-take sets to attain planned forage levels for each cycle of rotation in HPSDG and comparable end of season forage use levels in both treatments. The HPSDG system was operated with four cycles of rotation that had 1, 2, 2 and 3 occupation days and 15, 30, 30 and 45 planned nonuse days during cycles one through four, respectively. Animal performance and production, diet composition and quality, vegetation, standing crop dynamics, forage utilization, soil compaction, and emergence, growth and developmental characteristics of key plant species were studied.

Seasonal average daily gains (ADG) of both RSG calves and lambs were greater during 1983 (0.52 vs. 0.39 kg/d and 72.6 vs. 45.4 g/d), and RSG calf ADG was greater during 1984 (0.68 vs. 0.62 kg/d) ($P<.05$). Attained stocking rates were 24 and 21% higher in HPSDG during 1983 and 1984, respectively, resulting in greater calf and combined (calf + lamb) gain per hectare in the HPSDG treatment during 1984 ($P<.05$). Diet

quality, as estimated from fecal nitrogen, was better for the RSG livestock, (P<.05). Diet composition data show the compatibility of the calf and lamb combination in both grazing systems treatments with calves selecting western wheatgrass (*Agropyron smithii* Rydb.) and annual grasses and lambs selecting shortgrasses (buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths)).

Distinct changes in standing crop and apparent forage use before and after subunit occupation were quantified in HPSDG as well as at selected dates in RSG. In 1984, peak live plus recent-dead standing crop was observed on August 24 in an ungrazed treatment (2080 kg/ha), July 20 in RSG (1358 kg/ha) and immediately before subunit occupation during cycle 4 in HPSDG (1472 kg/ha). Western wheatgrass and shortgrasses accounted for about 80 to 82% of this peak standing crop in all three treatments. End of season use estimates of western wheatgrass were not different between treatments (P>.05), but use of the two shortgrasses was higher in HPSDG (P<.05).

Soil compaction in RSG and HPSDG was similar on the delineated strata subject to the greatest amount of animal traffic. This strata (closest to water; HPSDG center) however, accounted for a substantially larger portion of the total HPSDG pasture than it did in RSG.

Densities, heights, number of leaves and length of first leaves of western wheatgrass tillers were not different in RSG and HPSDG treatments (P>.05).

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1.0 INTRODUCTION

Grazing systems, along with kind and proportion of grazing animals, spatial grazing distribution, season of grazing and stocking rate are the critical variables of grazing management. Furthermore, grazing systems can be defined as the manipulation of: periods of occupation, periods of nonuse, and stocking density within the grazing period and their sequence between years in order to control the timing, frequency and intensity of defoliation of forage species in order to optimize forage production, animal production, and/or other ecosystem values (Lewis, 1982a). In recent years, much attention has been directed towards the use of intensively managed systems referred to as "short-duration", "time-controlled", "controlled" or "rapid-rotation", all operated under similar principles. Of particular interest to ranch managers in these troubled economic times, has been the claim that proper implementation of a short-duration system will, as a rule, result in a two-fold increase in livestock carrying capacity (Savory, 1978). However, quantitative data supporting this claim are relatively scarce.

The basic principles of these intensively managed short-duration systems are European in origin (Voisin, 1959) and many variations have evolved over the years with applications in numerous range ecosystems worldwide. This has contributed to much confusing terminology and questions as

to which system or variation of a system is most suitable for a particular kind of range or grazing management situation.

The widespread implementation of short-duration grazing systems in the United States beginning in the mid-1970's prompted seriously needed experimentation to evaluate various short and long-term aspects of this grazing system. Additionally, experimentation was needed to determine: 1) the optimum length of occupation period; 2) the optimum utilization of the key species at each occupation; 3) the optimum nonuse period; 4) the variation in the above optima by range site, by year, by dates within year and by utilization level; 5) the best way to provide the flexibility which is needed; and 6) the cost effectiveness of the system (Lewis *et al.*, 1982b).

The objectives of this study, conducted at the Cottonwood Range and Livestock Research Station and reported herein, were to evaluate the effect of a High-Performance Short-Duration grazing system compared with a Repeated-Seasonal grazing system on stocking rate; animal performance per animal and per area; diet composition and quality; standing crop dynamics; above-ground net primary production; cumulative effects on emergence, growth and developmental characterics of key forage species; spatial patterns of tiller defoliation; and soil compaction; when managed for similar levels of utilization. The study was designed with several replicates of small size in order to answer basic

questions and to assess the need for further research on a size scale for direct application to ranches.

2.0 REVIEW OF LITERATURE

2.1 Grazing Systems

2.1.1 Historical Perspectives

In the United States, the need for controlling livestock grazing to prevent excessive use of forage plants was first recognized and reported during the late nineteenth and early twentieth centuries. At that time, unrestricted grazing of ranges was common and resulted in rapid deterioration of the range resource. Appropriately, it was at this time that the profession of range management established itself as a science and active investigations designed to control livestock use through management systems were initiated (Stoddart *et al.*, 1975). As early as 1895, Smith (1895) tested deferred and alternate grazing to provide for the improvement of deteriorated range in central Texas. Sampson (1913) reported preliminary results of a system of deferred and rotation grazing based on the growth requirements of vegetation that would naturally reseed overgrazed portions of sheep range. Jardine and Anderson (1919) further discussed this plan of grazing and strongly recommended it where feasible.

During the period 1915 to 1940, studies were initiated in Kansas (Anderson, 1940), North Dakota (Sarvis, 1941), Colorado (Hanson *et al.*, 1931) and Alberta (Clarke *et al.*, 1943) to evaluate various aspects of deferred grazing and rotation grazing plans. In most cases, improvement of the

vegetation was realized when deferred grazing was incorporated with rotation grazing which in turn lended itself to an increase in carrying capacity. However, gains per animal were not increased. Sampson (1951), in introducing a symposium on grazing systems, clarified and defined deferred grazing as a deferment of cropping until after seed maturity; rotational grazing as a systematic shifting of livestock at desirable intervals to different subunits without specific provisions for seed production; and deferred-rotation grazing as a combination of the two where the deferment of a pasture is rotated over the years. As a rule, ranges which have been improved through deferred grazing are maintained in good condition by rotation grazing under proper stocking (Sampson, 1951). Hormay (1970) described a more complex rest-rotation plan which included the systematic resting (year-long nonuse) of management subunits as well as periods of deferment.

There was minimal use of grazing systems on either public or private rangeland before World War II. After World War II however, public land management agencies began requiring the use of specialized grazing systems, many of which were adopted or modified from the previously mentioned researchers.

Worldwide, the recognition of the importance of grazing systems had begun even earlier. The management of the Hema Reserves in the Middle East over 1400 years ago included protection from grazing and mowing of some tracts

and the regulation of the amount and the seasonal distribution of grazing and mowing of others (Drasz, 1978). Voisin (1959) reported documentation of several of the principles of short-duration grazing systems as early as 1777 by James Anderson in Scotland. A variety of grazing system types have been used for many years and have been researched in countries throughout Europe, in Australia, and New Zealand as well as in other locations worldwide. In the Soviet Union, Larin (1962) reported more than 30 experiments comparing what he referred to as "systematic" versus "nonsystematic" grazing schemes throughout all natural regions of the country between 1930 and 1934.

The term grazing system, in it broadest sense, includes the grazing methods associated with nomadic herdsmen who for centuries, have based the movement of their livestock on the quantity of forage available and the quality in relation to the changing seasons. Platou and Tueller (1985) have associated the migratory patterns of native ungulates with the descriptor "natural grazing systems" and emphasized how these have resulted from the coevolution of the plants and native ungulates. They also suggested how comparison and evaluation of these salient plant and animal features resulting from evolution could suggest characteristics which should be retained in a livestock management system to maintain the efficiency inherent in natural grazing systems.

2.1.2 Purpose

Heady (1975) emphasized some of the characteristics and objectives needed in a good grazing system. These characters and objectives (adapted from Heady, 1975) can be outlined as follows:

I. A good grazing system should:
   a) Take into account plant physiology and life history.
   b) Be suited to kinds of plants present.
   c) Be adapted to soil conditions to preclude puddling.
   d) Improve range condition and forage production by favoring desired plants.
   e) Not be detrimental to animal gains.
   f) Be practical to implement in a ranching operation.

II. Objectives sought in a good grazing system are:
   a) Restoration of forage plant vigor.
   b) Allowing plants to produce seed.
   c) Heavier and more uniform utilization.
   d) Increased animal production.

The above outline, for the most part, ideally summarizes the purpose of grazing systems. Lewis (1982b) in a segment of a definition of a grazing system, stresses optimization of forage production, animal production and/or other ecosystem values. He further stressed that grazing systems should be tailored to the requirements of each operation and must be flexible to adapt to unforeseen changes in the growth and nutritional value of the vegetation, to market fluctuations and to various other emergencies in management.

Savory and Parsons (1980) and Savory (1983) essentially elaborated and emphasized the same basic ideas of Heady (1975) as a selling point for what they believed to be

an optimum or ideal grazing system.

The Arizona Interagency Range Committee (1973) (in Kothmann, 1980) listed the objectives of various grazing systems as the distribution of utilization, restoration of vegetation on sacrifice areas, maintenance of forage density and composition, meeting nutritional needs of and avoiding stress on livestock, reduction of supplemental feeding and minimization of labor costs. Lewis (1969) included grazing systems as one of several dependent factors that can be manipulated to induce range ecosystem progression.

2.1.3 General Classification and Terminology

Lewis (1981, 1982a and 1984) defined grazing management as a part of the management of the grazing food web involving the manipulation of: kinds and proportion of grazing animals, spatial grazing distribution, season of grazing, stocking rate, and grazing system. Furthermore, grazing system is defined as a part of grazing management involving the manipulation of: periods of occupation, periods of nonuse, and stocking density within the grazing period and their sequence between years in order to control the timing, frequency and intensity of defoliation of forage species in order to optimize forage production, animal production, and/or other ecosystem values, subject to economic and physical constraints and managerial preferences (Lewis, 1982a,b, 1983a and 1984). Other sources, Range Term Glossary Committee (1974), Lacey and Van Poollen

(1979), Gray *et al.* (1982), Heady (1970), and Kothmann (1980) all somewhat similarly defined grazing system although not as complete in detail as in Lewis' definition. Heady (1970) emphasized that the grazing of seeded pastures, crested wheatgrass for example, is an indispensible part of a rancher's feeding program, but should not be confused with the range grazing systems. Grazing systems as defined by Lewis can be applied to all types of forages that are grazed by animals.

Major confusion exists in the classification and nomenclature of grazing systems as well as the associated and descriptive terminology of those grazing systems. The descriptor short-duration for example, can be associated with rotational systems, but a rotation system is not necessarily of short duration. Standardization is imperative in order to make correct comparisons and interpretations from the immense world-wide collection of literature related to grazing systems (Lewis, 1983a). Kothmann (1980) indicated that many reviewers have summarized literature comparing general groups of systems with no regard to the specific kind of grazing system being considered. In an attempt to clarify some of the associated terminology, Heady (1961 and 1970), Scarnecchia (1985), Scarnecchia and Kothmann (1982), Gray *et al.* (1982), Kothmann (1974 and 1980), Hodgson (1979) and the Range Term Glossary Committee (1974) among others, have published approaches to define and standardize some of

these terms. Heady (1970) stressed the tightening of terminology by using the terms deferred, rest, rotation and continuous to refer only to manipulations of grazing periods.

Information on grazing system classification is much more limited. A general grouping made by Heady (1961) separated continuous and specialized systems. Continuous included both year-long and season-long grazing while specialized included rotation, deferred, rest-rotation and deferred-rotation. Lewis (1969) developed a relatively simple classification key which delineated seven systems. These included continuous, deferred, rotational-deferment, deferred-rotation, rest, rest-rotation and rotational grazing systems. Kothmann (1974) pointed out that several of these terms may not be applicable to any particular grazing system, but generally refer to a category of systems. Lacey and Van Poollen (1979) described a dichotomous key for the classification of grazing systems. Their key, based on a concept from Lewis (1969), identified 14 different grazing systems.

Hodgson (1979) suggested avoidance of single words or short phrases to describe specific and often complex routines of grazing management. Primary delineations made by Hodgson (1979) included continuous stocking (animals kept on an area continuously), set-stocking (constant number of animals for the whole or major part of a grazing season) and rotational grazing (regular sequence of grazing and rest for particular areas of the pasture). Additional management

details that should be included in the description were classes of livestock (separate or mixed), duration of the period of use of an area of land for cutting or grazing and information on the time scale of occupation and nonuse periods within a rotational system.

Lewis (1983b) developed a more descriptive and detailed key that will be used for unification of the subsequent dicussion of grazing systems. The key by Lewis (Table 1) used occupation periods, nonuse periods, grazing animal concentration index and stocking density as the four variables to classify the kinds of grazing systems.

Table 1

Classification of kinds of grazing systems.[1]

1.	Composed of more than one single grazing system	I. COMBINED
1.	Composed of only a single grazing system	2
2.	All subunits (pastures) grazed 2 times or less each year (Long-Duration Systems)	3
2.	All subunits (pastures) grazed 2 times or more each year (Rotation Systems)	12
3.	Subunits (pastures) grazed at the same season each year (Fixed-Season Systems)	4
3.	Subunits (pastures) grazed at different seasons in different years (Variable-Season Systems)	5
4.	Subunits (pastures) grazed for the entire period that grazing is possible each year =>	II. CONTINUOUS
4.	Subunits (pastures) grazed for only part of the grazing season	III. REPEATED-SEASONAL
5.	Nonuse timed to benefit important range plants (Beneficial Nonuse or Deferment)	6
5.	Nonuse not so timed (Abeneficial Nonuse)	11
6.	Beneficial nonuse selected for certain subunits (Selected Beneficial Nonuse)	7
6.	Beneficial nonuse rotated among subunits (Rotated Beneficial Nonuse)	8
7.	Nonuse for an entire year	IV. SELECTED YEARLONG BENEFICIAL NONUSE
7.	Nonuse for only part of a year	V. SELECTED SEASONLONG BENEFICIAL NONUSE
8.	Nonuse for an entire year (Rotated-Rest)	9
8.	Nonuse for part of a year (Rotated-Deferment)	10
9.	Grazing Animal Concentration Index (GACI) 2 or less	VI. DISPERSED ROTATED-REST
9.	GACI more than 2 but less than 6	VII. SEMIDISPERSED ROTATED-REST

(continued)

Table 1 (continued)

10. GACI 2 or less	VIII. DISPERSED ROTATED-DEFERMENT
10. GACI more than 2 but less than 6	IX. SEMIDISPERSED ROTATED-DEFERMENT
11. Grazed when best for grazing	X. SEASONAL-SUITABILITY
11. Grazing not so timed	XI. INTERMITTENT
12. GACI less than 6 (Low-Concentration Rotation)	13
12. GACI 6 or more (High-Concentration Rotation)	14
13. GACI equal to or less than 2	XII. DISPERSED LOW-CONCENTRATION ROTATION
13. GACI more than 2 but less than 6	XIII. SEMIDISPERSED LOW-CONCENTRATION ROTATION
14. Occupation period long enough to allow multiple grazing of a grass shoot in one occupation (Intermediate-Duration)	15
14. Occupation period short enough to prevent multiple grazing of a grass shoot in one occupation (Short-Duration)	17
15. Stocking density high enough to maximize regrowth stimulation and forage use efficiency and to minimize selective grazing (High Utilization Intermediate-Duration)	16
15. Stocking density not so (other kinds of Intermediate-Duration).	
16. Nonuse period long enough for senescence or mortality of regrowth =)	XIV. LONG-NONUSE HIGH-UTILIZATION INTERMEDIATE-DURATION
16. Nonuse period not so (other kinds of Nonuse High-Utilization Intermediate-Duration).	
17. Stocking density high enough to maximize regrowth stimulation and forage use efficiency and to minimize selective grazing (High-Utilization Short-Duration)	18
17. Stocking density not so	19
18. Nonuse period short enough to slow regrowth .	XV. SHORT-NONUSE HIGH-UTILIZATION SHORT-DURATION
18. Nonuse period not so (other kinds of Nonuse High-Utilization Short-Duration).	
19. Stocking density high enough to optimize regrowth stimulation, forage use efficiency and selective grazing (High-Performance Short-Duration)	20
19. Stocking density low enough to minimize regrowth stimulation and forage use efficiency and maximize selective grazing	XVI. LOW-UTILIZATION SHORT-DURATION
20. Nonuse period short enough to slow regrowth .	XVII. SHORT-NONUSE HIGH-PERFORMANCE SHORT-DURATION
20. Nonuse period not this short	21
21. Nonuse period long enough for rapid regrowth =)	XVIII. OPTIMUM-NONUSE HIGH-PERFORMANCE SHORT-DURATION
21. Nonuse period long enough for senescence and mortality of regrowth =)	XIX. LONG-NONUSE HIGH-PERFORMANCE SHORT-DURATION

[1] From Lewis, 1983b.

Several variations and forms of the preceeding key have been made by Lewis (1982a,b, 1983a and 1984), all utilizing the similar basic criteria and concepts.

The key by Lewis (1983b) utilized the terms deferred, rest, rotation, *etc.* in an adjective form to provide a

standard and relatively thorough distinction of that grazing system and appropriately, a reference to manipulations of grazing periods as was emphasized by Heady (1970).

Descriptors referring to some of the anticipated results or goals (high utilization, high performance) are also included with some of the systems. Booysen (1969), Booysen and Tainton (1978) and Acocks (1966) similarly include these in names of systems (High-Production, High-Utilization and Non-Selective Grazing).

Combined systems, as classed by Lewis (1983b) are a combination of two or more kind(s) of simple grazing systems operating on the same area. A grazing system commonly known as the Merrill Four-Pasture System is an example of a combined system that integrates both continuous and rotated-deferment systems. All animals normally carried on four pastures are divided equally among three pastures and grazed 12 months. The fourth pasture is not used for four months (Merrill, 1954).

The need for increased management and flexibility becomes apparent for any of the systems that fall into the intermediate or short-duration category. Needed changes in the nonuse period for example, brought about by the changing season or precipitation, would be required to maintain the integrity and goal of the system. Failure to do so could change the classification of the system to that of a less efficient system and have detrimental results.

In addition to the classification scheme, Lewis (1984) outlined a set of grazing system gradients (Table 2) that are also very valuable in delineating some of the specifics of a grazing system. Grazing animal concentration index (GACI) as outlined in Table 2 is defined as the reciprocal of the grazing fraction, and grazing fraction is the fraction of land (unit or units) in a single grazing system which is being grazed at any one time (Lewis, 1984). Other terms that will be used in this paper relating to management of animal numbers include: grazing pressure, which is the animal demand per unit weight of forage at any instant of time; herbage allowance is the forage available per unit of animal demand (Scarnecchia and Kothmann, 1982); stocking density is the relationship between number of animals and area of land at any instant of time; and stocking rate is the area of land which the operator has allotted to each animal unit for the entire grazable period of the year (Range Term Glossary Committee, 1974); or the reciprocal, the number of animals of a specified class per unit of land (Hodgson, 1979). The latter definition is most useful when considering animal production from a grazing system and the former when considering the supply of forage per animal (Shaw, 1970). The most useful expression of stocking rate is the amount of animal forage demand per unit area (AUM's/ha). This was recommended by Scarnecchia and Kothmann (1982).

Table 2

Grazing system gradients.[1]

A. Grazing Animal Concentration Index (GACI):

- 1) ≥1 and <2 : Dispersed
- 2) ≥2 and <6 : Semidispersed
- 3) ≥6 and <16 : Semiconcentrated
- 2) ≥16 : Concentrated

B. Occupation Periods and Nonuse Periods (interrelated variables).

1. Occupation Periods
   - a) Number of occupations
     - 1) 1 : Unicycle
     - 2) ≥2 : Multicycle
   - b) Duration of occupation (potential for number of times tillers are grazed during rapid growth - interacts with herbage allowance)
     - 1) 1 (≤4 days) : SHORT DURATION
     - 2) 2 (>4 <25 days) : INTERMEDIATE DURATION
     - 3) >5 (≥25 days) : LONG DURATION
   - c) Season of occupation (in relation to plant phenology).
   - d) Seasonal Sequence between years
     - 1) same each year : FIXED-SEASON
     - 2) different seasons : VARIABLE-SEASON

2. Nonuse Periods
   - a) Length
     - 1) None . . . . ZERO-NONUSE
     - 2) Short enough to reduce regrowth rate of grazed tillers . . . . SHORT-NONUSE
     - 3) Long enough for rapid regrowth, but short enough for high nutritional value . . . . OPTIMUM-NONUSE
     - 4) Long enough to replenish food stores, but also for forage maturation and dry matter disappearance . . . . LONG-NONUSE
   - b) Season
     - 1) Dormant . . . . DORMANT-SEASON NONUSE
     - 2) Not planned to benefit major plant taxa . . . . ABENEFICIAL NONUSE
     - 3) Planned to benefit plant taxa . . . . BENEFICIAL-NONUSE
       - 1) All species . . . . YEAR-LONG
       - =) . . . . GROWING-SEASON
       - 2) Species group . . . . specify
       - 3) Species . . . . specify
   - c) Seasonal sequence
     - 1) Same each year . . . . FIXED-SEASON
     - 2) Different seasons in different years . . . . VARIABLE-SEASON

[1] From Lewis, 1984.

The terminology associated with the physical description of grazing systems, particularly short and intermediate-duration systems, is often confusing. Subunit will be used to describe the enclosed subdivisions of the entire short-duration system pasture or pasture unit. Paddocks (Voisin, 1959 and 1962), parcels (Leconte, 1982a,b), strips, folds (Holmes *et al.*, 1950), camps (Booysen, 1969), enclosures (Larin, 1962), plots (Jamieson and Hodgson, 1979) or simply pastures (Taylor *et al.*, 1980) have been used to describe subunits or the unit of land grazed or to be grazed at any instant of time. The entire short-duration system unit was referred to as a cell (Savory, 1978 and 1983; Savory and Parsons, 1980; Westmoreland *et al.*, 1981 and Kirby and Bultsma, 1984).

In addition to the classification scheme and outline of gradients associated with grazing systems, Lewis (1984) stressed the awareness of specific details in order to adequately define and describe various grazing systems (Table 3).

Due to the multitude of varying factors within a grazing system, these specifications as well as the descriptive gradients are desirable informational components when defining and especially when evaluating grazing systems because systems of the same major kind may differ greatly in performance due to the specific details.

Several of these grazing system gradients will be used in an abbreviated form in the following discussion of

Table 3

Grazing system specifications.[1]

1) Grazing period (days and dates)
2) Number of subunits
3) Arrangement of subunits (adjacent, unplanned)
4) Number of herds
5) Duration of occupation (constant or variable)
6) Duration of nonuse (constant or variable)
7) Occupations per year
8) Grazing animal concentration index
9) Relative grazing rate by season (constant or variable)
10) Criteria for leaving subunit (date, phenology, use)
11) Criteria for length of nonuse period (date, growth)
12) Grazing pressure per occupation (range of values)
13) Use per occupation
14) Terminal use
15) Subunits added (number and dates)
16) Subunits skipped (number and dates)
17) Subunits mowed (number and dates)
18) Area with seasonal beneficial nonuse (percent area)
19) Area with yearlong nonuse (percent area)
20) Sequence of seasonal beneficial nonuse
21) Sequence of yearlong nonuse

[1] From Lewis, 1984.

grazing systems. The abbreviated form, adapted from Kothmann (1974), consists of a numerical description of the four following factors: number of pastures or management subunits, number of herds, length of occupation per subunit and length of nonuse for any given subunit in the system. An example abbreviated form following a grazing system name might be (6-1:28/140d) which refers to a system with 6 subunits, one herd, 28 days occupation per subunit and 140 days nonuse. Some grazing systems have variable occupation and nonuse periods coinciding with the growth rate of the vegetation and

will have the range (x-x/x-xd) of occupation and nonuse days noted. If sufficient descriptive information was found, confusing grazing system names in the literature were modified to follow the classification of Lewis (1983b) (Table 1) to the point where a family or categorical name could be used.

2.2 Repeated-Seasonal Grazing and Related Grazing Systems

Repeated-Seasonal Grazing (RSG) systems include those which allow continuous animal occupation for only a part of the period during which grazing is feasible each year and that grazing period occurs at the same time each year (Lewis, 1983b). A single undivided pasture is involved allowing livestock access to the entire unit for the duration of the grazing period. RSG systems are closely related to and often have been confused with continuous grazing, but continuous differs in that the animal occupation is for the entire period during which grazing is feasible each year and, depending on the geographical location, this could be from a few months to an entire year. Seasonal-suitability grazing, also closely related, differs in that grazing is planned for early season use of diverse vegetation types when they are most valuable for grazing. Continuous grazing and its related derivations, were some of the earliest and most commonly used types of systems and are still abundant throughout all grazing regions (Gray *et al.*, 1982). The reasons for their popularity have been attributed to their managerial simplicity and relative successfulness in con-

trast to the "specialized systems" (Holechek, 1983). Because of these factors and their compatibility with seasonal changes, RSG systems are the most frequently used and applied in the Northern Great Plains.

In the subsequent discussion, the period of occupation of RSG and continuous systems reviewed will be noted in parenthesis.

2.3 High-Performance Short-Duration Grazing and Related Grazing Systems

The short-duration group of grazing systems has the classification characteristics of having a grazing animal concentration index of six or more and the occupation period short enough to prevent multiple grazing of a grass shoot in one occupation. There are three members of the family of Short-Duration Grazing (SDG) systems delineated by length of nonuse periods (short, optimum and long) (Lewis, 1983b) (Table 1) and three delineated by utilization level (high, optimum and low). A High-Performance Short-Duration grazing system (HPSDG) is one with optimum nonuse periods and optimum utilization levels. It should have a stocking density and grazing pressure high enough to optimize regrowth stimulation, forage use efficiency and selective grazing and a nonuse period long enough to optimize plant vigor and nutritional value.

Other rotation plans, in this sense related to the general principles of short-duration grazing (*ie.* a rela-

tively rapid rotation through subunits) but described by a variety of terminology, have been implemented and used worldwide for some time. Their application on grazing lands in the United States however, did not begin until the mid-1970's. One rotational plan was known first in South Africa as "Non-Selective Grazing" or the "Acocks-Howell plan", in which intensive grazing for two weeks or less was followed by ungrazed periods of six weeks to five months (Acocks, 1966). Later, in Zimbabwe (Rhodesia), a similar plan was labeled "Short-Duration Grazing" (SDG) (Goodloe, 1969), and is the origin of the name used today. Voisin (1959, 1962), Larin (1962), and Semple (1970) all describe such grazing plans implemented in various countries throughout the world, some of which are very similar or identical to the intermediate and short-duration types defined by Lewis (1983b) and others. Voisin (1959, 1962) was one of the first to thoroughly delineate and holistically discuss the aspects of what he termed "rational grazing". "Strip" or "belt" grazing are names commonly used in some of the European countries as well as New Zealand and Australia, again for the most part referring to some form of short-duration grazing. Larin's (1962) report of pasture management practices in the Soviet Union used the name "pasture rotation", defined as a system for the care and utilization of natural and sown pastures, based on a two or many year regime intended to maintain or increase pasture productivity. Larin used the terms "systematic plot-

enclosure" or "plot" grazing systems, but in addition, encouraged the use of other management practices such as mowing, fertilization and irrigation.

2.4 Integrative Discussion of RSG, HPSDG and Related Grazing Systems

2.4.1 Effect on the Grazing Animal

2.4.1.1 Animal Behavior

Animal behavior can be classified into several categories; namely feeding, social, resting and sexual behavior (Arave and Albright, 1981), all of which can be altered or influenced by a grazing system. Grazing behavior can be described as the foraging response elicited from a herbivore by its complex interaction with the surrounding environment (climate, time of day, forage composition, forage quality and quantity, topography) and compared to the other behavioral categories, probably ranks highest in importance in association with a grazing system because it is related to the immediate well-being and performance of the herbivore (Lynch and Hedges, 1979). This foraging response is implemented by the animal's basic senses of taste, smell, sight and touch (Tribe, 1950).

The total effect of a grazing system on animal behavior can come from two different directions: 1) the immediate effect of the system on stock density, herding patterns, movement and associated social interactions, and 2) the more indirect effects on the vegetation, including such things

as herbage yield, plant spacing, plant height or accessibility, herbage digestibility, water content, toxic metabolites, botanical composition and palatability (Allden and Whittaker, 1970). Any of these latter, indirect effects may result from or be related to the grazing process or pattern which is initially influenced by the system. It appears that a complex grazing system - effect - response cycle takes place.

Numerous behavioral characteristics have been monitored in studies comparing related forms of short-duration and repeated-seasonal grazing systems. Some of these characteristics include distance traveled, time spent grazing, resting, ruminating and sleeping, or the spatial distribution of animals within a pasture or subunit.

Travel influences the energy requirements of free grazing cattle. The energy cost of travel may increase the maintenance energy requirements of grazing livestock by 10 to 24% compared to stall-fed animals (Ribeiro *et al.*, 1977; Havstad and Malechek, 1982). Anderson (1977) and Anderson and Kothmann (1980) reported distance traveled by heifers in a year-long continuous to be greater than in a rotation (5-1:28-112d) system. Walker *et al.*, (1985) reported cows in a short-duration grazing (SDG) system (16-1:3-6/45-90d) tended to walk farther, and travel distance was more variable than cows in a year-long continuous system. Walker *et al.*, (1982) found the same results in simulated 14 and 42 subunit SDG systems. In addition, no differences were found in the

amount of time spent sleeping (36 min/d), or loafing.

Hart *et al.*, (1983) reported no differences in percent of time spent grazing (52), traveling (6) and resting (42) between a RSG system (Jun.-Oct.) and a SDG system (8-1: 3-7/21-49d). Walton *et al*, (1981) however, found steers to graze longer in a RSG system than in a rotation system (4-1: 7-10/21-30d). No differences were found in the amount of time spent ruminating. Gammon and Roberts (1980a) and Castle *et al.*, (1975) also reported longer grazing time in continuously grazed pastures.

The conflicting results between authors with regards to the distance traveled by animals in the systems has no clear explanation. Gammon and Roberts (1980a), who also reported cattle tended to travel further in rotational systems, found cattle grazing different areas of a subunit more frequently but for a shorter period of time. They suggested that the additional movement by the rotated cattle may have resulted because of crowding. Reasons for livestock to travel are numerous, with some of the more important being for the selection and prehension of high quality and palatable plants, for the grazing of any type of forage plants, for obtaining water, salt or mineral, to seek social interactions with other livestock and to escape severe environmental conditions.

The indirect effects of grazing system on animal behavior (*ie.* resultant forage status and characters after

the initial animal grazing which was influenced by the grazing system) have also been studied. Jamieson and Hodgson (1979) concluded that the rate of biting and intake per bite are sensitive to variations in forage mass and pasture height, but the ability of the animal to make compensating changes in grazing time may be limited and appears to be dependent in part upon the system. Thus, variations in the short-term rate of forage intake is likely to be a major determinant of daily forage intake. Intake per bite and rate of intake were shown to decline progressively with decreasing pasture height. Furthermore, in this study, the decline in intake per bite and rate of intake were more evident in a strip-grazing system which is conducive to rapidly decreasing plant height in the subunits. Similar results were reported by Hodgson (1981) and in addition, variations in forage density were found to not influence intake per bite and short-term rate of forage intake.

These effects on grazing behavior have implications ultimately on animal performance. Hart (1978) concluded that gain per animal decreased linearly as grazing pressure (animals per unit of forage), increased. Kothmann *et al.* (1971), Launchbaugh *et al.* (1983), as well as numerous others have reported that heavier stocking rates decreased animal performance.

2.4.1.2 Animal Performance and Production

The liveweight gain of the growing, grazing animal is dependent on several factors, with quality and quantity of intake ranking highest in importance. Grazing management systems affect both quality and quantity of intake in the sense that it is the system that dictates how the forage is presented to the grazing animal. Kothmann (1980) and Launchbaugh *et al.* (1978) caution that many grazing systems are overlooking the nutritional and functional needs of the livestock.

Forage quality is dependent on several factors, especially plant species, plant part and season of growth (Heady, 1975). A common principle observed in grazing intensity studies is that weight gain per animal is greater under light than heavy grazing treatments. However, because of the greater stocking rate, production per unit area is greater under the heavily grazed treatment rather than the lightly grazed treatment (Van Dyne *et al.*, 1978; Morley, 1981). The decreased performance with the heavy grazing treatment can be a function of both decreased quantity and quality of intake.

Hart (1978), following a thorough literature review produced a family of curves relating animal gain to stocking rate. In general, gain per animal decreased linearly as animal units per unit of forage, or grazing pressure, increased. However, with very light stocking rates, animal

gains were initially unchanged and then declined. Mott (1960) found a curvilinear relationship. The point at which adding more animals reduced the average performance of all livestock was referred to as the critical stocking rate (Hart, 1978; Reece, 1985).

It is recognized that the greatest individual animal performance is attainable under continuous or repeated-seasonal grazing systems with stocking rate as the major factor determining gain. These systems have become the most commonly used standard to which livestock performance in other systems is compared.

Studies comparing animal performance in repeated-seasonal and short-duration systems (or closely related systems) are fairly numerous (Table 4). A common fault of the vast majority of these grazing system comparison studies has been the use of a fixed-stocking approach in which the number of animals per unit area are uniform during the entire grazing period. Additionally, in the comparative studies, stocking rates were equal in both systems, greater in one than the other, or at some percentage greater or less than the general recommended stocking rate for that area. Mott (1960) emphasized the need to adjust stocking rate to provide equal grazing pressures on all treatments and replications, since failure to do so may bias performance per animal and production per area. Burns *et al.* (1970) described a put-and-take system of stocking where some

Table 4

Literature summary of selected studies evaluating animal performance in SDG, RSG and related systems.

Reference	Location/Vegetation	Livestock	Systems Compared	Results
Bilger *et al.*, 1983	South Dakota native range	ewes	HPSDG (16-1:1-3/15-45d) RSG (May-Sep.)	No difference in ADG.
Sharrow & Krueger, 1979 and Sharrow, 1983b	Oregon ryegrass-subclover	ewes/lambs	Low-Concentration Rotation (5-1:4/16) Continuous	Greater ewe ADG during spring & fall in the rotation system but greater in the continuous system in summer.
Jung *et al.*, 1985	Nebraska smooth bromegrass	heifer calves	SDG (8-1:2-4/14-28d) RSG (May-Aug.)	No difference in ADG.
Heitschmidt *et al.*, 1982c	Texas native range	heifers	SDG (10-1:3-7/27-63d) RSG (Apr.-Oct.)	No difference in ADG.
Anderson, 1977	Texas native range	heifers	Low-Concentration Rotation (5-1:28/112d) Continuous (Mar.-Dec.)	No difference in ADG.
Anderson, 1982	New Mexico native range	yearling heifers	SDG (10-1:4/36d) RSG (May-Oct.)	No difference in ADG.
Pitts & Bryant, 1982	Texas native range	yearling steers	SDG (16-1:2-4/30-60d) Continuous	No difference in ADG one year but less in SDG when SDG stocking rates were doubled.
Hart & Test, 1984	Wyoming native range	yearling steers	SDG (8-1:3-7/21-49d) RSG (Jun.-Oct.)	ADG less in SDG when stocking rates were moderate but no difference when stocking rates were heavy.

(continued)

Table 4 (continued)

Reference	Location/Vegetation	Livestock	Systems Compared	Results
Leconte, 1982a,b	France ryegrass	yearling steers	SDG (12-1:2-4/22-44d) RSG (Apr.-Oct.)	No difference in seasonal ADG's; some variable within cycle differences.
Denny *et al.*, 1977	Zimbabwe native range	steers	SDG (12-1:1-14/11-154) Combined[1]	No difference in ADG except during the early growing season when SDG ADG's were less.
Baker *et al.*, 1982	England ryegrass	cows/calves	SDG (12-1:2-5/22-55d) RSG (May-Oct.)	ADG of cows greater in SDG; gains of calves not different.
Kirby *et al.*, 1982	North Dakota native range	cows/calves	SDG (8-1:5/35d) RSG (Jun.-Oct.)	No difference in ADG's (cows or calves).
Ottosen *et al.*, 1975	Australia tropical grass/legume	dairy cattle	SDG (10-1:1/9d) Continuous	Milk production less in SDG.
Castle & Watson, 1973	England ryegrass	dairy cattle	SDG (28-1:1/27d) Wye College[2]	No difference in ADG, milk yield or milk quality.
Brundage & Peterson, 1952	Minnesota alfalfa/bromegrass	dairy cattle (monozygotic twins)	Rationed[3] RSG (May-Aug.)	No difference in ADG, milk or butterfat production.

[1] Four pastures, three herds; three of four pastures grazed entire year and one pasture is systematically burned and rested one year.

[2] Wye College system features four separate pastures with the animals being offered 1/7 of one pasture each day and there were no back fences.

[3] Daily offering of a very small portion of the total pasture with maximum forage harvested.

variable such as forage use or a predetermined stubble height is used as the determinant for any changes in the number of animals during the grazing period.

Results of the grazing system comparative studies reviewed (Table 4) are variable with no clear-cut advantage or disadvantage visible. Hart and Test (1984) concluded in their study that steer gains were primarily a function of grazing pressure rather than grazing system. This was probably true in many of the other studies also.

Probably a more critical factor in the evaluation of grazing systems is the return in gain per unit area rather than gain per animal (Pieper, 1980). The most accurate assessment of this factor comes from grazing system comparative studies where the put-and-take approach to stocking is used. The trials by Leconte (1982a,b) did include a put-and-take approach with forage utilization as the determinant. Over the four years of the study, the repeated-seasonal system produced 72.2% as much total weight gain per acre as did the short-duration system.

Heitschmidt *et al.* (1982c) reported production per hectare to be approximately doubled with SDG. The stocking rates, however, were fixed for the entire period with SDG at twice that of RSG. Jung *et al.* (1985) found no difference in production per hectare with equal stocking rates one year, but when SDG stocking rates were set at 131% of RSG, produc-

tion per hectare was increased by 24.2%. Kirby *et al.* (1985), reported greater than double production per hectare in western North Dakota with a SDG system (8-1:5/35d) compared to a RSG system (Jun.-Oct.). In this study, SDG stocking rates were 162% of RSG stocking rates and end of season forage use was estimated to be 5% higher in SDG.

In conclusion, it appears that regardless of system, individual animal performance is mainly a function of stocking rate or grazing pressure. The relationships of production per animal, production per area and stocking rate have been reviewed by several authors (Mott, 1960; Beranger and Micol, 1981; among others).

2.4.1.3 Chemical and Botanical Composition of Diets

Several investigators have evaluated the chemical and botanical composition of diets selected by animals in comparative studies of short-duration and repeated-seasonal grazing systems. Studies have shown the negative relationship between stocking rate and individual animal performance in conventional grazing systems. However, SDG proponents state that stocking rates can be increased and still maintain an acceptable animal performance by reducing the length of stay on a subunit, or in other words, move the animals before the quality and quantity of the forage remaining in the subunit becomes low enough to seriously affect animal performance.

Taylor *et al.* (1980), in an evaluation of an intermediate-duration (7-1:21/126d), a short-duration (7-1:7/42d)

and a combined (Merrill 4-pasture, 3-herd) system on Texas range, found botanical composition of the diets in the intermediate-duration system to vary significantly between collection at the beginning and end of each grazing period. Diets from the SDG system were characterized by higher percentages of grasses and less forbs compared to the intermediate-duration system. Crude protein (CP) and *in vitro* organic matter digestibility (IVOMD) were higher in diets from the SDG system. Botanical composition and diet quality were comparable between the combined and SDG system. Anderson and Kothmann (1980) observed a significant linear decrease in the percentage of forbs consumed from day 1 to day 28 in an intermediate-duration system (8-1:28/196d). This was most likely due to a diminishing supply of palatable forbs in the subunit being grazed. Ralphs *et al.* (1986) were able to detect a decline in diet quality (CP and IVOMD) in cattle and sheep diets after only three days occupation in a SDG subunit. These declines were even more pronounced as stocking rates were increased. Humann *et al.* (1985) found no significant differences in CP and IVOMD of sheep diets between a RSG (Jun.-Oct.) and a SDG system (8-1:5/35d). Sheep preferences for forage classes were also similar between grazing systems with forbs preferred and grasses and browse generally avoided. Kothmann *et al.* (1986b) also found no crude protein or IVOMD differences in selected forage in year-long continuous pastures and simulated 14 and 42 subunit SDG systems.

2.4.2 Effect on Vegetational Characteristics

2.4.2.1 Production and Quality

The effect of livestock grazing on rangeland has been most often related to changes in standing crop resulting from changes in species composition (Sims *et al.*, 1978; Sims and Singh, 1978a). The accurate estimation of production, however, has been a problem due to the complicating effects of the grazing process. Exclusion of livestock grazing creates an artificial environment because periodic grazing may alter the growth response of a plant in contrast to a non-grazed plant (McNaughton, 1979).

Heitschmidt *et al.* (1982a), utilizing frequent harvest techniques to estimate aboveground net primary production (ANPP) in a SDG system (10-1:3-7/27-63) and an ungrazed exclosure, reported 96 g/m^2 greater ANPP in the SDG system one year, but 84 g/m^2 less ANPP in the SDG the next year. Comparing a low-concentration rotation system (5-1:4/16d) and a RSG (Apr.-Dec.) system, Sharrow (1983a) reported more available forage in the low-concentration rotation system during the mid and late-spring period but similar forage standing crop during the remainder of the season. Hart and Test (1984) reported no differences in forage production between their SDG (8-1:3-7/21-49d) and RSG (Jun.-Oct.) systems. Dowhower *et al.* (1986), comparing herbage responses in a year-long continuous system and simulated 14 and 42 subunit SDG systems concluded that differences between

treatments were primarily a function of stocking rate and not type of grazing system.

Interpretations from controlled greenhouse studies have also been used to predict vegetation response to grazing. Many of the studies attempted to simulate grazing patterns and frequencies of different systems. Moderate clipping has been shown to stimulate the greatest growth rate of western wheatgrass (*Agropyron smithii* Rydb.) followed by a heavy and light clipping treatment, respectively (Bokhari and Singh, 1974). In addition, shoots of clipped plants continued to grow throughout the 80-day experiment, whereas, the unclipped control plants ceased to show any positive dry matter accumulation after 50 days. Similarly, McNaughton *et al.* (1983), studying an African warm-season sedge, and Cable (1982), working with Arizona cottontop (*Trichachne californica* (Benth.) Chase), both observed growth to be stimulated by defoliation. Net photosynthesis in western wheatgrass (Painter and Detling, 1981) as well as blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths) (Detling *et al.*, 1979) has been shown to increase following clipping. Clipping without removal of shoot apices usually depresses tillering while tiller production is usually enhanced when the clipping does remove the shoot apices (Youngner *et al.*, 1976).

In a field clipping study, Holderman and Goetz (1981) reported intensive defoliation (2.54 cm stubble height) to

increase yields on several western North Dakota mixed prairie species, but to decrease it on others. Schmidt *et al.* (1985), clipping western wheatgrass at three heights to achieve 15, 30 and 45% removal at varying rest intervals, found biomass production and regrowth were greatest at the two lower levels of removal with about 30 days of rest. The effects of defoliation on carbohydrate reserves have also been well documented (Menke and Trlica, 1981, 1983).

The generalized conclusions of Heitschmidt *et al.* (1982a) were that grazing will reduce the immediate biomass of all categories of standing crop and litter. This reduction in standing crop will accelerate vegetative growth and increase ANPP under certain environmental conditions, particularly under moist growing conditions. Consequently, with the greater temporal and spatial control of grazing inherent in a short-duration system, it may be possible to attain greater ANPP with this system than with a repeated-seasonal or continuous grazing system. However, a critical factor is to use the optimum level of grazing intensity, which will vary considerably within and between years. This necessitates a great deal of management flexibility with regards to such factors as stocking density and/or rate of livestock movement within a short-duration system (Heitschnidt *et al.*, 1982a).

The issue of forage quality resultant from different grazing system treatments has had some study. Heitschmidt

et al. (1982b) hypothesized that a significant increase in forage quality may at least in part account for the dramatic increase in livestock carrying capacity following implementation of the SDG system proposed by Savory (1978). Heitschmidt *et al.* (1982b) observed a greater percentage crude protein (CP) in forage from a SDG system (10-1:3-7/27-63) than in an ungrazed control. However, Jung *et al.* (1985) reported no difference in the crude protein content of the forage when stocking rates were equal in a RSG (May-Aug.) and a SDG (8-1:2-4/14-28d) system. However, when SDG stocking rates were increased to 131% of that of RSG, CP was significantly higher in SDG. They hypothesized that due to the higher grazing intensity in each subunit of the SDG system during the time they were actually grazed, the forage quality would be higher in that system than in RSG because a larger percentage of the plants should have been grazed and, therefore, retarded in maturity. No explanation was given though, as to why average daily gains (ADG) of the heifers in this same trial were not different even though the CP concentration of the forage in the SDG system was found to be higher. Data from Heitschmidt *et al.* (1982b) also suggests that percent CP of forage is primarily a function of the physiological age of the plant tissue, and thus any management practice reducing rate of leaf senescence or stimulating growth should increase average forage quality.

2.4.2.2 Botanical Composition

Two important variables responsible for changes in the botanical composition of rangelands are precipitation and grazing intensity. A classic example of the effects of grazing intensity on native mixed prairie is provided by Lewis *et al.* (1956). Utilization averaging 69% over nine years caused a marked decrease in the amount of western wheatgrass, the dominant midgrass species, and an equally dramatic increase of buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama, warm-season shortgrass species. The range condition percentage decreased from 60 to approximately 30. In contrast, the light grazing intensity (approximately 28% utilization) resulted in a slight increase in western wheatgrass and subsequently, an improvement in range condition.

Additionally, in many types of grazing systems, selective grazing of palatable and highly preferred plant species by livestock may result in detrimental changes in botanical composition of the range. The effects with heavier stocking may be even more pronounced. In South Africa, this was a recognized problem blamed on continuous grazing, and the approach called "Non-Selective Grazing" was recommended by many land managers (Booysen, 1969; Booysen and Tainton, 1978). The Non-Selective Grazing approach essentially involved the use of many of the principles of SDG.

Beneficial changes in botanical composition induced by a properly managed short-duration system have been claimed possible by Savory (1978, 1983) and Savory and Parsons (1980). Denny *et al.* (1977) reported neither of the grazing systems tested (SDG (12-1:1-14/11-154d) or combined) provided a means of bringing favorable changes in botanical composition. However, a severe drought during two of the five years of the study complicated matters.

After four years of a SDG (12-1:2-4/22-44d) and RSG (Apr.-Oct.) comparison, Leconte (1982a) found less forbs and more annual grasses in RSG pastures but a greater percentage of bare soil in the SDG pastures. Kothmann *et al.* (1986a), using a simulated SDG system at four stocking rates over a five year period, concluded a shift in species composition to be occurring with little bluestem (*Andropogon scoparius* Michx.) decreasing and a more grazing resistant species, brownseed paspalum (*Paspalum plicatulum* Michx.), to be increasing.

2.4.2.3 Patterns of Defoliation

Gammon and Roberts (1980a,b) noted that experiments comparing different SDG grazing systems have generally shown either little or no difference in animal production or vegetation response between systems with different numbers of subunits, or have shown lower production from the systems with more subunits. In many cases there has been no clear explanation for these results, and it is likely that a

knowledge of the patterns of defoliation that occurred would elucidate them.

Gammon and Roberts (1978a), studying native vegetation in Zimbabwe (Rhodesia), found that from five to 15% of the grass tillers were grazed during any given four-week period on pastures continuously grazed at the moderate recommended stocking rate. They noted an interaction between severity and frequency of defoliation. Plants grazed most frequently were also grazed most intensively (Gammon and Roberts, 1978b). In addition, tillers grazed lightly, or not at all early in the season were less likely to be grazed later in the season or at high intensities. Heights of grazing under the continuous and short-duration (6-1:6-12/ 30-60d) system were similar for most species for most periods. Differences in frequencies of defoliation between continuous and short-duration were small when considered over all species and the overall frequency or percentage of individual tillers that contribute little or none to the "grazed" forage is substantial. Kothmann (1980) considered it essential that utilization patterns be changed to bring these tillers into "production". Gammon and Roberts (1978c) concluded that large increases in herbage yields, carrying capacity and animal production could not be expected with this particular short-duration system, by comparison with the continuous system, due to differences in the pattern of defoliation. Briske and Stuth (1982) similarly reported that a large

percentage of the leaves and tillers within a pasture remain ungrazed or were only lightly grazed even at relatively high stocking densities.

2.4.3 Effect on Soil Characteristics

Several investigations have been conducted to evaluate the effects of the livestock on soil characteristics as influenced by repeated-seasonal and short-duration systems. Characteristics usually studied include water infiltration rates, bulk density and sediment production. Variables influencing infiltration rates include aggregate stability, organic matter content, bulk density, initial soil moisture content, mulch, standing crop, ground cover, perennial grass cover and total grass cover (Wood and Blackburn, 1981b).

Wood and Blackburn (1981b) found infiltration rates to be approximately equal in an intermediate-duration (8-1:17/119d) and a heavily stocked yearlong continuous system. McCalla *et al.* (1984a) reported infiltration rates to also be similar in a SDG (14-1:4/42d) and a heavily stocked continuous system, but significantly faster in a lightly stocked continuous pasture. Weitz and Wood (1986) reported similar results when comparing lightly and heavily stocked continuous and a SDG system. Evaluating bulk density under different grazing intensities, Van Havern (1983) concluded higher grazing intensites increased bulk densities of fine-textured soils but had less impact on coarser-textured soils.

Sediment production also has been reported to be influenced by grazing system (McCalla *et al.*, 1984b; Wood and Blackburn, 1981a; Gamougoun *et al.*, 1984). In all cases, an increased stocking rate, grazing intensity or stocking density resulted in greater sediment production. Pluhar *et al.* (1984) specifically reported decreased infiltration rates and corresponding increases in runoff and sediment production in a simulated 14 subunit SDG system compared to a continuous system.

2.4.4 Other Considerations

2.4.4.1 Wildlife

One area of potential impact of intensive grazing systems is on the nesting characteristics, nesting success, population density and movement of upland gamebirds and ground-nesting non-gamebirds as well as waterfowl. Westmoreland *et al.* (1981) expressed concern that high stocking densities of livestock under short-duration grazing could increase nesting losses due to trampling. Conversely though, a smaller percentage (1 of n subunits) of the short-duration system is subject to trampling at any one time.

Koerth *et al.* (1983) found no difference in the number of simulated nests trampled between a continuous system stocked at 8.0 ha/steer and a SDG system (16-1:3/45d) stocked at 5.3 ha/steer. Stocking rate in an individual subunit during its occupation was 0.83 ha/steer. Similarly,

Bareiss *et al.* (1986) reported no differences in coverage, density and dispersion of suitable nest sites or in loss rates of artificial bobwhite and wild turkey nests in equally stocked continuous and SDG (10-1:3-6/27-54d) systems. Grosz and Kirby (1986) reported no increase in simulated nest loss even as stocking rate increased from 1.0 to 2.5 times the recommended rate in their short-duration system (8-1:5/35d). Sparse vegetation losses were approximately twice that of heavy vegetation. Trampling is only one of several factors involved in the grazing by ground-nest interaction. Possibly much more important are the resultant vegetation characteristics that attract or distract birds to or from a potential nesting site as well as the predators of that nest (Bowman and Harris, 1980).

Big game animals are another wildlife category potentially affected by grazing systems. Cohen and Bryant (1985) reported a significantly greater distance traveled by white-tail deer *(Odocoileus virginianus)* during the summer months in a SDG system than in a continuous system. Pronghorns *(Antilocarpa americana)* can be affected by "sheep-tight" pastures and will avoid if possible, heavily grazed livestock pastures. On the other hand, unused or deferred pastures, and hence possibly subunits during their nonuse periods, tend to attract big game animals (Klebenow, 1980).

A complete understanding of the grazing systems and wildlife interaction is still lacking. Important

considerations though, are the availability and quality of food, the adequacy of cover, and the interspersion of these two habitat features (Klebenow, 1980), as well as possible social wildlife-livestock interactions.

2.4.4.2 Ranch Economics

The bottom line for many ranchers on whether to implement a different grazing system on their ranch or not, is the economic return they expect to receive. A common deficiency however, in many range experiments and ranch adoptions of grazing systems has been the lack of in-progress and follow-up economic analyses of the results (Gray and Fowler, 1980).

Theoretically, if the carrying capacity and resultant production per unit area of land could be increased with a newly implemented grazing system to the point of exceeding the input costs (fencing, water development, technical expertise, *etc.*), then that system would be of benefit to a rancher.

Allan Savory, developer and proponent of a land management plan called Holistic Resource Management (HRM), includes a form of SDG as being essential in the plan. The SDG system however, must include a time factor as well as two other factors, number of animals and land area. One of the greatest advantages claimed with a SDG system, managed under his auspices, is a greater economic return to the rancher (Savory, 1978, 1983; Savory and Parsons, 1980; Walter, 1984).

Thorough published studies comparing economic returns between SDG and RSG systems are however, relatively few in number. Conner *et al.* (1986) did report a return of $18.77 per hectare in a 14-subunit SDG system (3.6 ha/AU) compared to $24.03/ha in a moderately (5.9 ha/AU) grazed continuous system and $22.75 in a heavily (5.1 ha/AU) grazed continuous system.

Whitson (1982) correlated management intensity with economic risk and concluded that a short-duration system, requiring a much greater intensity of management, increased the chances of economic failure. The long-term economic results of a grazing system would be another important consideration that, especially in the case of short-duration systems, have not been thoroughly evaluated.

2.5 Summary and Conclusions

The literature pertaining to the many different types of grazing systems is immense. In the past decade, very great attention has been directed towards the use of the many variations of short-duration grazing. This has created the need for research and testing of those systems.

A preliminary step in this discussion of grazing systems has been an attempt to clarify and standardize some of the classifications and terminology associated with the different systems. A classification scheme, grazing system gradients and specifications developed by Lewis (1983b, 1984) were presented (Tables 1, 2 and 3).

Many of the the studies involving short-duration systems have compared them against various repeated-seasonal or continuous systems. Major characteristics compared include: animal behavior, performance and production; chemical and botanical composition of animal diet; forage production and quality; botanical composition of the vegetation; defoliation patterns; soil; and in some cases wildlife and ranch economic aspects.

The effect of a particular grazing system on any of these characteristics is complicated by the variations within and between grassland ecosystems, variations between years, season of the year, weather, slight variations of the systems and experimental approach and management of the system. In short, this has caused variable and conflicting results with few concrete conclusions with respect to the different parameters studied in the grazing system comparisons. Several previously known principles and relationships, such as that of production per animal, animal production per unit area of land and stocking rate or grazing intensity; or stocking density and some of the soil characteristics have been reconfirmed.

From the literature reviewed, it appears that one positive aspect of SDG systems is a possible increase in animal production per unit area of land. It was suggested that the reasons for this are an increase in forage production, improved spatial distribution of grazing and in some

cases, an increase in forage quality.

The introduction and use of short-duration grazing systems in the United States has been beneficial in that it has forced range scientists into taking a closer look at the different aspects of grazing management which is the most critical tool in range management. In addition, it has done much to stimulate rancher interest and awareness of many of the principles of range management.

There still is a need for further study and long-term testing of all types of grazing systems, particularly SDG systems. The long-term testing will provide data for a variety of years and for the detection of possible cumulative effects that a grazing system has on the grassland ecosystem. With specific regard to SDG systems, definitive answers are still needed for such questions as: what is the optimum number of subunits; what are the influences of periodic utilization and complete protection on the vigor and survival of undesirable species; what is the influence of degree of utilization of the desirable plants on their vigor and growth rates (Booysen, 1969); what is the optimum length of periods of occupation and nonuse and how they vary by site, season and year; and what is the optimum degree of use and amount of residue following each occupation (Lewis, 1982b)?

3.0 DESCRIPTION OF THE EXPERIMENTAL AREA

3.1 Cottonwood Range and Livestock Research Station

3.1.1 General Location

The studies reported herein were conducted at the Cottonwood Range and Livestock Research Station located on the Northern Great Plains in west-central South Dakota. The station is 19 km west of Philip and 120 km east of Rapid City, South Dakota at latitude 43 degrees 57 minutes N and longitude 101 degrees 52 minutes W. The station encompasses all land in sections 16 and 21 and portions of sections 20, 22 and 28 of Township 1 South and Range 19 East.

3.1.2 Soils, Geology and Topography

The Cottonwood station lies within the Pierre Hills of the Missouri Plateau physiographic region at a mean elevation of 744 m (2241 ft). Ancient stream erosion has shaped the landscape into rather gentle, long sloping hills with a total relief of approximately 60 m (197 ft). Higher hills that are flat-topped have been protected from erosion by cappings of more resistant strata of sandier limestone or sandstone (White, 1965).

The stratigraphy of the bedrock is not completely known and understood. The lowest strata exposed is a member of the Pierre formation. Parent materials of the soils were predominantly from the Pierre formation (shales) as well as the Foxhills and Chadron formations. The latter two formations have all been removed except from the higher ridges.

Sandier materials ranging in texture from fine sandy loams to clay loams have been deposited on some of the slopes and ridge tops. Variations in relief and drainage have led to catena development.

Westin and Malo (1978) delineate the area as a warm, very dry plain with the Pierre-Kyle soil association encompassing the area. Kyle clay is the dominant soil series. Modern nomenclature for the Kyle soil series (U.S. Soil Survey Staff, 1975; Westin and Malo, 1978) is as follows:

Order: *Aridisol*
Suborder: *Orthid*
Great Group: *Camborthid*
Subgroup: *Ustertic*
Family: *Very-fine, montmorillonitic, mesic*

Other soil series common on the Research Station include the Nunn (loam), Pierre (clay) and the Pierre-Samsil (clays) (U.S.D.A.-S.C.S., 1987).

3.1.3 Vegetation

The Cottonwood Range and Livestock Research Station lies in the northern part of the Mixed Prairie Association (Clements, 1920), the Mixed Grass region (Shantz and Zon, 1924) or the Wheatgrass-Needlegrass Association (Kuchler, 1964) in the Rolling Pierre Shale Plains Land Resource Area (Westin and Malo, 1978). Short and medium height (mid-grasses) are co-dominant. In addition, all three major photosynthetic pathways, namely C_3 (Benson-Calvin), C_4 (Hatch-Slack) and CAM (Crassulacean Acid Metabolism) are

represented among the species of plants (Sims *et al.*, 1978). C_3 and C_4 pathways correlate with the concept of cool and warm season plants, respectively, and knowledge of the photosynthetic pathways is a valuable tool in understanding patterning of range vegetation along environmental gradients (Waller and Lewis, 1979).

A composite inventory adapted from Lewis *et al.* (1956) listing the major species of grasses, forbs and shrubs observed at the research station as well as the common and scientific names and authority of the species mentioned in this paper is presented in Appendix Table 1. Common names follow Beetle (1970) and scientific names and authorities follow Great Plains Flora Association (1986).

Western wheatgrass (a midgrass) is the dominant cool season (C_3) species and buffalograss and blue grama are dominant warm season (C_4) species of this region. The latter two species will often be collectively referred to as the shortgrass component in subsequent discussion. Green needlegrass is another midgrass of minor importance in terms of forage production. Needleleaf sedge is the most abundant sedge. Japanese brome, a partially naturalized species, is the most common annual grass in some years, while six-weeks fescue is occasionally abundant. Numerous species of forbs can also be observed, but their collective contribution to the total forage production is nominal.

During the Grassland Biome Study (1970 - 1972), cool

season grasses were found to contribute approximately 78% of the peak standing crop on areas in high range condition and warm season grasses accounting for 19%. On areas in low range condition, cool season grasses contributed approximately 18% and warm season grasses approximately 74% of the peak standing crop (Sims *et al.*, 1978a).

Western wheatgrass, buffalograss and blue grama make up more than 75% of the total annual forage production. Net annual above-ground primary production (ANPP) can be quite variable between years with precipitation as the major determining factor. In a permanent exclosure in high range condition, Sims and Singh (1978b), using data from Lewis *et al.* (1971) and Dodd *et al.* (1974), reported ANPP of approximately 2120 (2379), 2550 (2862) and 2790 kg/ha (3131 lb/a) for 1970, 1971 and 1972 respectively. ANPP for those same three years in a temporary exclosure in low range condition was 1600 (1796), 2050 (2301) and 1770 kg/ha (1986 lb/a).

3.2 Experimental Pastures

3.2.1 Physical Description

The grazing systems experiment encompassed 39.4 ha (97.2 a) in the southwest quarter of section 22 (T 1 S, R 19 E) which is located in the southeast corner of the research station. The six replications of Repeated-Seasonal Grazing (RSG) were 4.4 ha (10.8 a) each and the six High-Performance Short-Duration (HPSDG) replications were 2.2 ha (5.4 a) each. Two holding pastures (HP) were also located

within the cluster of experimental pastures (Figure 1). Pastures were fenced in 1980.

The HPSDG pastures were divided into 16 subunits encompassing 0.14 ha (0.35 a) each. Subunit numbering was as shown in Figure 1. High-tensile three-wire electric fence was used for all subunit divisions as well as many perimeter divisions. Woven wire along with standard barbed wire was used for the remaining fences.

HPSDG centers were 2.4 m X 2.4 m (8 ft X 8 ft) in size and contained water and mineral. A small stock dam located in the central holding pasture was the primary source of water for the experimental animals. Access roads or trails were available to all pastures.

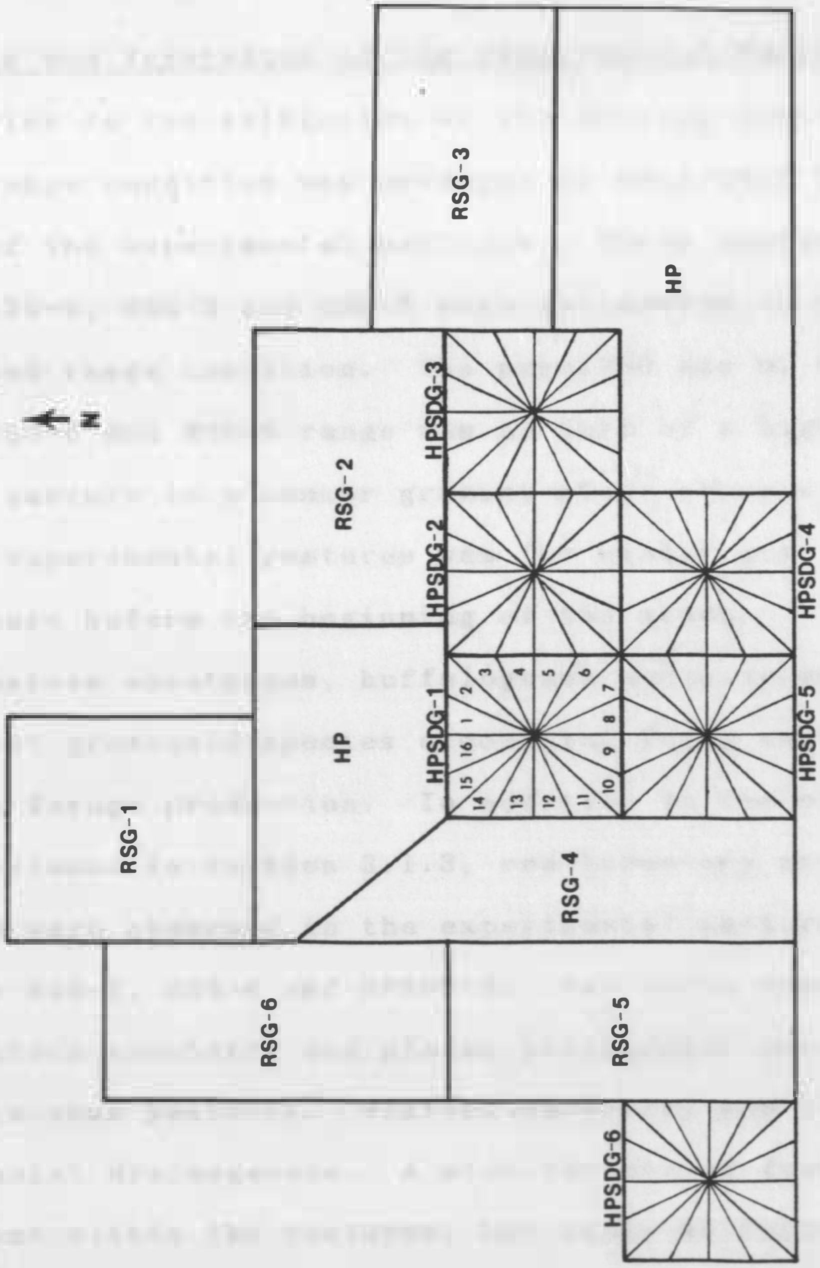

Figure 1: Arrangement of the grazing systems experimental pastures. RSG: Repeated-Seasonal Grazing, HPSDG: High-Performance Short-Duration and HP: Holding Pasture.

3.2.2 Soils and Vegetation of the Experimental Pastures

Prior to the initiation of the Grazing Systems study in 1980, range condition was assessed as excellent for the majority of the experimental pastures. Three pastures, namely HPSDG-6, RSG-5 and RSG-6 were delineated in an area of high good range condition. The pre-1980 use of the HPSDG-6, RSG-5 and RSG-6 range was as part of a high range condition pasture in a summer grazing study whereas use of the other experimental pastures was for winter grazing for several years before the beginning of the study.

Western wheatgrass, buffalograss and blue grama were the dominant graminoid species accounting for a vast majority of the forage production. In addition to the other species reviewed in Section 3.1.3, red three-awn and needle-and-thread were observed in the experimental pastures, especially RSG-3, RSG-4 and HPSDG-5. Two shrub species, namely western snowberry and plains pricklypear were also observed in some pastures. Western snowberry was limited to the more moist drainageways. A wide variety of forb species were present within the pastures, but again as typical for all range in this area, they accounted for a relatively small portion of the total forage production. Nonetheless, some of the more common species present included scarlet globemallow, American vetch, Nuttall's violet, Lousisiana sagewort, common starlily and wild parsley.

Topographical and associated soil differences lead to some distinct vegetational differences. A ridge extending through portions of HPSDG-5, HPSDG-1, RSG-4, RSG-5 and RSG-6 featured shallow and thin upland range sites supporting primarily shortgrasses and sedges with only scattered pockets of western wheatgrass. Small areas of thin-surfaced natric soils (natrustolls) were in many of the pastures. Natric soils were generally termed solodized solonetz soils under the older classification systems. These soils support mostly buffalograss along with some blue grama and needleleaf sedge.

Kyle and Pierre (clays) were the two major soil series of the experimental pastures. The Nunn series (loam) was also present in portions of RSG-3, RSG-4 and HPSDG-5 and the Pierre-Samsil series in a relatively small portion of RSG-4, 5 and 6. The latter series is characteristic of upland ridges (U.S.D.A.-S.C.S., 1987).

Of the 39.4 ha (97.2 a) utilized by the experimental pastures, approximately 72% of that area was classed as clayey, 20% silty, 5% shallow, 2% thin upland and 1% as a claypan range site. The claypan range sites were usually complexed with silty or clayey range sites. Percent of each range site by replicate pasture is given in Table 5. The United States Department of Agriculture-Soil Conservation Service technical guide for west-central South Dakota (U.S.D.A.-S.C.S., 1979) considers the silty range site to be

slightly more productive than the clayey range site followed by the thin upland, shallow and claypan range sites in descending order of productivity (Table 5).

Table 5

Percentage of each range site and relative productivity of each of the six RSG and HPSDG replicate pastures.

	Range Site or Complex									
Pasture	Clayey	Silty	Shallow	Thin upland	80% Cy 20% Cp	60% Cp 40% Si	60% Si 40% Cp	70% Cy 30% Si	Relative Replicate Productivity[1]	Relative to the Mean of all Pastures Percent
RSG-1	85	1	1	--	13	--	--	--	2281	99
RSG-2	87	3	--	--	--	10	--	--	2280	99
RSG-3	8	77	--	3	--	4	8	--	2444	106
RSG-4	66	20	11	3	--	--	--	--	2283	99
RSG-5	84	6	10	--	--	--	--	--	2267	98
RSG-6	84	2	14	--	--	--	--	--	2240	97
HPSDG-1	85	--	--	15	--	--	--	--	2248	97
HPSDG-2	100	--	--	--	--	--	--	--	2298	99
HPSDG-3	83	3	--	--	--	--	14	--	2292	99
HPSDG-4	41	45	--	--	--	--	--	14	2408	104
HPSDG-5	26	59	--	15	--	--	--	--	2380	103
HPSDG-6	95	5	--	--	--	--	--	--	2309	100
Production[2]	2298	2522	1850	1962	2186	2051	2208	2365		

[1] (Air dry kg/ha). Calculated from the percent of each site or complex of sites in the pasture times average production of that site or complex.

[2] Air dry kg/ha average for each site or complex of sites in excellent condition. From U.S.D.A.-S.C.S., 1979.

3.3 Climate

3.3.1 Precipitation

The average annual precipitation at the headquarters during the 75-year period, 1910 through 1984, has been 396.5 mm (15.61 in). The median precipitation (that is the value where half the years have more and half the years have less precipitation) for this period is 385.6 mm (15.18 in). Median annual, seasonal and monthly precipitation amounts for the 75-year period are less than the mean due to climatic phenomena where extremes of greater amounts are more common than extremes of lesser amounts.

Approximately 78% of the precipitation falls during the six month growing season of April through September. The mean and median growing season precipitation for the 75-year period is 310.9 mm (12.24 in) and 303.8 mm (11.96 in) respectively. Sims and Singh (1978a) concluded the current growing season precipitation to be the most important single factor as it will account for approximately 70% of the variability in the total shoot standing crop in Great Plains grasslands.

The main source of rainfall during the growing season is thundershowers which produce a wide range of amounts and intensities. May, June and July are normally the wettest months of the year, and November through February normally receive the least precipitation (U.S.

Weather Bureau, 1967). Mean and median warm season (June, July and August) precipitation is 165.4 mm (6.51 in) and 161.5 mm (6.36 in) respectively.

Total annual precipitation during 1983 was 96% of the 75-year mean (Table 6). Total growing season and warm season precipitation was somewhat below the mean but a greater cool season precipitation (previous September-May) probably enhanced soil water reserves. July and August precipitation was 66 and 55% of the mean respectively. This, coupled with the warm temperatures normally received during this period, resulted in reduced shortgrass growth with early initiation of dormancy.

Total annual precipitation during 1984 (Table 7) was 105% of the mean. The growing season and warm season pre-cipitation was moderately above the mean, primarily due to an exceptionally wet June in which 116.9 mm (6.57 in) fell. July and August precipitation was again substantially below the mean.

September precipitation was 27 and 40% of the mean for 1983 and 1984 respectively. This hampered initiation of fall growth of cool season species; particularly western wheatgrass and Japanese brome which occurs if climatic variables are favorable.

Precipitation data are also presented for the first six months of 1985 (Table 8).

TABLE 6

Monthly precipitation at the Cottonwood Range and Livestock Research Station, 1983.[1]

Month	Precipitation mm	(inches)	Percent of 75-year mean
January	3.0	(0.12)	30
February	0.8	(0.03)	8
March	30.5	(1.20)	150
April	27.4	(1.08)	58
May	105.7	(4.16)	146
June	56.4	(2.22)	74
July	33.0	(1.30)	66
August	21.6	(0.85)	55
September	7.6	(0.30)	27
October	46.0	(1.81)	181
November	37.1	(1.46)	339
December	12.2	(0.48)	133
Total, annual	381.3	(15.01)	96
Total, growing season (Apr.-Sep.)	251.7	(9.91)	81
Total, warm season (June, July, Aug.)	111.0	(4.37)	67
Total, cool season (previous Sep.-May)	317.0	(12.48)	137
Total, vegetative year (previous Sep.-Aug.)	428.0	(16.85)	108
Total, grazing season (May 29 - Oct. 3)	130.6	(5.14)	-

[1] U.S. Weather Bureau, 1983.

TABLE 7

Monthly precipitation at the Cottonwood Range and Livestock Research Station, 1984.[1]

Month	Precipitation mm	(inches)	Percent of 75-year mean
January	0.5	(0.02)	5
February	3.3	(0.13)	35
March	10.7	(0.42)	53
April	56.9	(2.24)	124
May	80.0	(3.15)	111
June	166.9	(6.57)	220
July	34.5	(1.36)	69
August	25.9	(1.02)	66
September	11.2	(0.44)	40
October	1.3	(0.05)	5
November	15.7	(0.62)	144
December	9.6	(0.38)	106
Total, annual	416.6	(16.40)	105
Total, growing season (Apr.-Sep.)	375.4	(14.78)	121
Total, warm season (June, July, Aug.)	227.3	(8.95)	137
Total, cool season (previous Sep.-May)	254.2	(10.01)	110
Total, vegetative year (previous Sep.-Aug.)	481.6	(18.96)	121
Total, grazing season (May 15 - Sep. 23)	282.4	(11.12)	-

[1] U.S. Weather Bureau, 1984.

TABLE 8

Monthly precipitation at the Cottonwood Range and Livestock Research Station, January through June, 1985.[1]

Month	Precipitation mm	(inches)	Percent of 75-year mean
January	15.0	(0.59)	147
February	0.3	(0.01)	3
March	31.0	(1.22)	154
April	20.1	(0.79)	44
May	18.3	(0.72)	25
June	49.5	(1.95)	65
Total, cool season (previous Sep.-May)	122.4	(4.82)	53

[1] U.S. Weather Bureau, 1985.

All of the aforementioned precipitation data were collected at the U.S. Weather Bureau benchmark facilities located at the research station headquarters, approximately 2.8 km (1.75 mi) northwest of the experimental pastures of this study. Several months of precipitation data were collected from a rain gauge located in the permanent exclosure used in the Grassland Biome Study nearly adjacent to the grazing systems experimental pastures. These records are compared with headquarters records (Table 9).

Hanson *et al.* (1978) in a watershed investigation conducted approximately 0.4 km (0.25 mi) west of the current grazing systems experimental pastures reported mean annual precipitation to be 54.9 mm (2.16 in) less at the watersheds than at the headquarters (10-year period, 1963-1972). The watershed pasture precipitation could be predicted from

TABLE 9

Comparison of the permanent exclosure and headquarters precipitation records, 1983 and 1984.

- 1983 -

Month	Exclosure mm	(inches)	Headquarters mm	(inches)
July	34.5	(1.36)	33.0	(1.30)
August	8.1	(0.32)	21.6	(0.85)
September	6.4	(0.25)	7.6	(0.30)
Total	51.5	(2.03)	62.2	(2.45)

- 1984 -

Month	Exclosure mm	(inches)	Headquarters mm	(inches)
May	63.5	(2.50)	80.0	(3.15)
June	150.1	(5.91)	166.9	(6.57)
July	35.6	(1.40)	34.5	(1.36)
August	23.1	(0.91)	25.9	(1.02)
Total	272.3	(10.72)	307.3	(12.10)

from headquarters precipitation by the following equation:

$$\hat{Y} = 0.044 + 0.816X$$

where $\hat{Y}$ is the monthly precipitation at the watersheds and X is the monthly precipitation at the headquarters. This equation accounted for 92.7% of the variation in monthly amounts of precipitation on the watersheds over the 10-year study period.

Of the seven months of comparative data available from 1983 and 1984 (Table 9), the headquarters had five months with substantially more precipitation and the perma-

nent exclosure had two months with slightly more precipitation. The totals of the months reported subsequently had the headquarters receiving more precipitation. This coincides with Hanson *et al.* (1978) results finding the headquarter's gauges to record more precipitation than the pasture gauges. One possible explanation of the higher precipitation at the headquarters is that the gauge is located south and east of a shelterbelt with several single trees to the south whereas the pasture gauges were unprotected. A complete review of station precipitation records revealed the period from 1946 (three years after establishment of the shelterbelts) through 1984 to average 29.7 mm (1.17 in) of precipitation more annually than the period 1910 through 1945 even with three extremely dry years during the 1930's deleted from the calculation.

Another possible reason for the pasture and headquarters precipitation difference could be the influence of Cottonwood Creek and its associated topography. The creek passes just to the south of the headquarters. It could be hypothesized that thunderstorms "follow" the creek.

3.3.2 Temperature

The mean annual temperature during the 75-year period 1910 through 1984 has been 8.2° Celsius (46.8°F) (U.S. Weather Bureau, 1967-1984). Temperatures are highly variable and wide differences occur in day and night, monthly and annual temperatures. The frost-free season is generally

from mid-May until near the end of September or approximately 136 days (U.S. Weather Bureau, 1967). Mean growing and warm season temperatures for the 75-year period are 17.4°C (63.3°F) and 24.2°C (75.5°F) respectively.

Growing season temperatures in 1983 were 100% of the 75-year mean (Table 10). Warm season temperatures were 103% of the mean primarily due to an exceptionally warm August which had 10 days with daytime highs of 37.5°C (100°F) or higher and 22 days with daytime highs of 35°C (95°F) or higher.

Growing season and warm season temperatures in 1984 were 99 and 100% of the mean, respectively (Table 11). August temperatures were again above the mean (105%).

Temperature data for the first six months of 1985 are shown in Table 12.

TABLE 10

Mean monthly temperatures at the Cottonwood Range and Livestock Research Station, 1983.[1]

Month	Temperature degrees C	(°F)	Percent of 75-year mean
January	-1.8	(28.8)	154
February	0.1	(32.2)	138
March	1.7	(35.1)	107
April	4.3	(39.8)	86
May	10.6	(51.1)	90
June	18.1	(64.6)	96
July	24.6	(76.3)	102
August	26.5	(79.7)	109
September	16.6	(61.9)	100
October	8.7	(47.7)	96
November	1.0	(33.8)	99
December	-15.5	(4.1)	18
Mean, annual	7.9	(46.3)	99
Mean, growing season (Apr.-Sep.)	16.8	(62.2)	100
Mean, warm season (June, July, Aug.)	23.1	(73.5)	103
Mean, cool season (previous Sep.-May)	3.8	(38.8)	101
Mean, vegetative year (previous Sep.-Aug.)	8.6	(47.5)	101

[1] U.S. Weather Bureau, 1983.

TABLE 11

Mean monthly temperatures at the Cottonwood Range and Livestock Research Station, 1984.[1]

Month	Temperature degrees C	(°F)	Percent of 75-year mean
January	-4.5	(23.9)	128
February	0.7	(33.2)	142
March	0.0	(32.0)	97
April	6.5	(43.7)	94
May	11.9	(53.4)	94
June	18.5	(65.3)	97
July	23.3	(73.9)	99
August	24.6	(76.2)	105
September	14.2	(57.6)	93
October	7.7	(45.9)	92
November	1.8	(35.2)	103
December	-8.4	(16.9)	71
Mean, annual	8.0	(46.4)	99
Mean, growing season (Apr.-Sep.)	16.5	(61.7)	99
Mean, warm season (June, July, Aug.)	22.1	(71.8)	100
Mean, cool season (previous Sep.-May)	2.8	(37.1)	96
Mean, vegetative year (previous Sep.-Aug.)	7.6	(45.6)	97

[1] U.S. Weather Bureau, 1984.

TABLE 12

Mean monthly temperatures at the Cottonwood Range and Livestock Research Station, January through June, 1985.[1]

Month	Temperature degrees C	(°F)	Percent of 75-year mean
January	-8.1	(17.4)	93
February	-7.1	(19.3)	83
March	0.9	(33.7)	102
April	10.0	(50.0)	107
May	16.6	(61.8)	109
June	16.7	(62.0)	92
Mean, cool season (previous Sep.-May)	2.0	(35.6)	92

[1] U.S. Weather Bureau, 1985.

3.3.3 Evaporation

Wind velocity at the station averages 13 to 18 km/hr (8-11 mph), and high winds are possible any time during the year (U.S. Weather Bureau, 1967). The combined effect of high temperature, frequent wind and low humidity produce a mean evaporation from a free water surface of over 285 mm (11.25 in) per month during July and August.

Monthly evaporation data for 1983 and 1984 as well as the 31-year means (1954 through 1984) are shown in Table 13. Evaporation during June of 1983 and 1984 was somewhat less than the 31-year mean. This correlates with June temperatures that were slightly cooler than the mean for these two years. Conversely, higher August temperatures during 1983 and 1984 were reflected in evaporation readings that were somewhat higher than the mean. Total warm season

evaporation was only 7 mm (0.27 in) above and 12 mm (0.47 in) below the mean for 1983 and 1984 respectively.

TABLE 13

Total evaporation at the Cottonwood Range and Livestock Research Station, April through October, 1983[1] and 1984.[2]

Month	1983 Evaporation mm	(inches)	1984 Evaporation mm	(inches)	1954-1984 Mean mm	(inches)
April	M	M	M	M	150.1	(5.91)
May	M	M	M	M	197.6	(7.78)
June	196.1	(7.72)	202.2	(7.96)	224.8	(8.85)
July	299.0	(11.77)	269.5	(10.61)	290.6	(11.44)
August	291.6	(11.48)	295.7	(11.64)	264.2	(10.40)
September	240.0	(9.45)	196.7	(7.75)	207.0	(8.15)
October	89.9	(3.54)	M	M	134.9	(5.31)
Total, April-October	M	M	M	M	1469.1	(57.84)
Total, warm season (June-Aug.)	786.7	(30.97)	767.4	(30.21)	779.5	(30.69)

[1] U.S. Weather Bureau, 1983.
[2] U.S. Weather Bureau, 1984.
[M] Missing data

4.0 EXPERIMENTAL PROCEDURES

4.1 Experimental Design

The overall experimental design of the study was a randomized complete block with two treatments and six replications. The two treatments were the two different grazing systems, High-Performance Short-Duration Grazing (HPSDG) and Repeated-Seasonal Grazing (RSG). Physical description and pasture arrangement were given in Section 3.2.1 and Figure 1 (p. 49, 50 and 51).

The 1983 and 1984 grazing seasons were the third and fourth consecutive years of this RSG and HPSDG comparative study. The overall experimental design during the 1981 and 1982 seasons was the same with yearling ewes being used as the experimental animals (Bilger *et al.*, 1983) whereas lambs and calves in combination were used during 1983 and 1984.

4.2 Grazing Guidelines and Schedules

The length of the grazing season during 1983 and 1984 was 120 and 121 days, respectively. The HPSDG system was conducted with four cycles of rotation around the 16 individual subunits. The first cycle had one day of livestock occupation per subunit and then correspondingly 15 days of nonuse. Cycles 2 and 3 had two days of occupation per subunit and 30 days nonuse. The fourth cycle was planned to have three days of occupation and since this was the last cycle of the season, the nonuse period for any subunit was the number of days from its occupation to the next

date it was occupied the following year. Variability in the number of nonuse days for individual subunits occurs when there is a change from the one day occupation to the two day occupation (cycles 1 and 2) and from the two day occupation to the three day occupation (cycles 3 and 4) because the additional day of occupation in each subunit delays by one day, the start of occupation for following subunits.

The lengths of these occupation periods for each of the cycles were planned in an attempt to have them short enough so that regrowth following grazing would not be grazed in the same cycle. Nonuse periods were planned to be long enough for recovery from grazing before the beginning of the next cycle. Voisin (1962) additionally emphasized the need for shorter periods of occupation during the time of rapid vegetation growth (early summer) and conversely, longer occupation periods during periods of slow vegetation growth (late summer) or dry seasons. This timing factor lends itself to the needed flexibility in HPSDG systems.

Expected use levels were approximately 10, 20 and 30 percent for a 1, 2 and 3 day occupation period respectively. Use in excess of 30 percent for any period was not allowed. Numbers of sets of animals were adjusted to secure end of season use levels of approximately 40 to 50 percent in both HPSDG and RSG. The key use species observed for these levels of use were western wheatgrass, buffalograss and blue grama. These planned use levels were the major criteria for

any adjustments in animal numbers during the course of the grazing season.

Grazing commenced in subunit 9 and rotation through the subunits proceeded clockwise in both 1983 and 1984. Animals were moved at approximately 1300 hr each scheduled moving day. In 1981, grazing began in subunit 1 and proceeded clockwise and in 1982, it began in subunit 16 and proceeded counter-clockwise (Bilger, personal communication).

Table 14 presents the starting dates for each of the four cycles during the two years.

Table 14

Starting dates of each of the four HPSDG cycles during 1983 and 1984.

Year	Cycle 1	Cycle 2	Cycle 3	Cycle 4
1983	May 29	Jun. 15	Jul. 18	Aug. 20
1984	May 15	Jun. 1	Jul. 4	Aug. 6

Livestock occupation in the RSG treatment began and terminated at the same dates as did HPSDG. Termination dates were September 29 and September 16 for 1983 and 1984 respectively. The total length of HPSDG cycle 4 during 1983 was 40 days rather than the planned 48 days (16 subunits at 3 days) because occupation was reduced to two days for half of the subunits when available forage was becoming low and allowing the animals to remain for the scheduled three days would have caused forage use to exceed the planned level. This was also

done in 1984 and resulted in a cycle 4 length of 41 days.

4.3 Experimental Livestock

A combination of lambs and calves were used as the experimental animals. One-half Suffolk, 3/8 Rambouillet and 1/8 Columbia lambs (ewes and wethers) with an average initial weight of 28.6 kg (63 lb) were used in 1983. In 1984, the lambs were of similar breeding and had average initial weights of 27.2 kg (60 lb). The 1983 group of calves were crossbred heifers, predominantly Limousin X Hereford or Limousin X Angus with an average initial weight of 165.1 kg (364 lb). The 1984 calves were of straight Hereford background with an average initial weight of 165.6 kg (365 lb).

All animals originated from area producers, arrived at the Research Station approximately four weeks before the grazing season began and were maintained in drylot until then. The receiving diet during this period was a native hay, dehydrated alfalfa pellet and corn-oats creep ration mix. In order to adapt the animals to grazing roughages, the creep ration portion of the diet was gradually phased out and hay and alfalfa pellets proportionally increased until the start of grazing. All calves were given vitamin A and E as well as worming injections. Lambs were also wormed as well and vaccinated for enterotoxemia. Tramisol (riperol levamisol hydrochloride) was used as the vermifuge.

Once the trials began, iodized salt blocks were provided to HPSDG animals in the pasture centers. RSG salt

blocks were placed in the pastures at the opposite end of the water source to encourage better livestock distribution. Salt blocks were replaced with 10% phosphorus (as well as varying amounts of other minerals and vitamins) blocks about July 1 of each year.

4.4 Measures of Response

4.4.1 Animal Measures

4.4.1.1 Stocking Rates

The livestock were grazed in sets with one set consisting of three lambs and one calf. This lamb to calf ratio was used because it approximates one-half lamb and one-half calf on an animal unit (AU) basis. Three-28 kg lambs for example, total 0.33 AU while one 165 kg calf equals 0.39 AU. Animal unit values for the calves were derived from the reference base $W^{0.54}$ and the linear equation $\hat{Y} = 0.297(X^{0.54})$ where $\hat{Y}$ is the dry matter intake and X is the body weight in kg. The estimated dry matter intake is then divided by 12.0 (standard dry matter intake weight for one AU) to give the AU value. The reference base $W^{0.54}$ was developed by Colburn and Evans (1968) and preferred over $W^{0.75}$ when its applications are for younger growing animals on roughage diets. Lamb AU values were derived from National Research Council dry matter intake requirements (N.R.C., 1975).

The trial was begun each year with two sets of animals in each replicate of each treatment. The HPSDG stocking density however, was twice that of RSG because HPSDG pastures

(2.2 ha) were one-half the size of RSG pastures (4.4 ha). Extra sets of animals were available to place in either treatment if visible forage use levels were less than planned. Conversely, sets of animals were removed if forage use began to exceed planned levels. Thus, the stocking rate resulting in a given use level was a dependent factor, a measure of the effect of the grazing system.

4.4.1.2 Weight Gains

All livestock weights were measured at the start of the first and at the end of each of the four HPSDG cycles. Livestock were gathered during the late afternoon, penned without food or water for an overnight shrink and weighed the following morning. All calves were herded approximately 1 km (0.62 mi) to the weigh scale facilities. HPSDG lambs were penned in the pasture centers and RSG lambs were held in pens adjacent to their respective replicate pastures. Lambs were weighed with a hand-held scale. All weights were recorded to the nearest pound.

Gain per hectare (kg) was calculated as total gain of record animals divided by area of pasture in hectares times total AUMs of grazing furnished divided by AUMs grazing furnished to record animals.

4.4.1.3 Wool Growth

The initial step for wool growth determination was the application of black wool paint just above the rump on all lambs on the first day of grazing. The spot of paint was

worked in and rubbed to skin level. At each subsequent weigh-day, a ruler was used to measure to the nearest millimeter, the length of new wool growth from skin level to the painted wool. Similar procedures of this sort are described by Langlands and Wheeler (1968).

4.4.1.4 Diet Composition, Quality and Quantity

4.4.1.4.1 Fecal Indices of Composition

Fecal samples were collected from each animal on May 23, June 17, July 20 and August 20, 1984. These dates correspond to the approximate midpoints of each of the four HPSDG cycles. The samples were placed in plastic bags and frozen immediately after collection. The individual animal fecal samples were later dried in a forced-air oven for 48 hours at 60°C and then ground through a one millimeter screen (20 mesh) in a Wiley mill.

The individual animal fecal samples were then composited in 96 treatment X replication X date X livestock class samples. Microhistological analyses to estimate botanical composition of the fecal samples were performed by the Composition Analysis Laboratory at Colorado State University. Twenty fields per slide were examined. The microhistological analyses of fecal samples as described by Hansen *et al.* (1985) briefly involves a wash with bleach to remove pigments; a wash and screening with hot water to remove solubles and extremely small nondiagnostic particles and transfer and fixing of material to the microscope slide. Additional

stains, bleaching or mounting mediums may be used. The main cellular characteristics used as clues for identification of plant fragments include cuticles, stomates, cell walls, asperites, glands, trichomes, silica cells, druses, crystals, and starch grains as well as cellular configurations, size and other morphological characteristics (Hansen *et al.*, 1985).

An additional 12 hand-compounded herbage samples (two replications of six) of known botanical composition were also microhistologically analyzed for the purpose of technique calibration. These herbage samples were also dried and ground in the same manner as the fecal samples. The six-gram hand-compounded calibration samples had varying percentages of each of the species group constituents (Table 15).

Table 15

Percentage composition of six hand-compounded herbage samples used for calibration of fecal sample indices of composition.

	Sample					
Species Group	1	2	3	4	5	6
Western wheatgrass	12	24	36	48	60	72
Shortgrasses[1]	72	60	48	36	24	12
Forbs[2]	4	6	0	2	8	10
Annual grasses[3]	6	4	10	8	2	0
Other grasses[4]	3	4	1	2	5	6
Sedges	3	2	5	4	1	0

[1] Shortgrass component was 50% blue grama and 50% buffalograss.
[2] Forb component included several species nonproportionally grouped.
[3] Annual grass component was 50% Japanese brome and 50% sixweeks fescue.
[4] Other grasses included several perennial species nonproportionally grouped.

The microhistologically determined relative densities of hand-compounded herbage samples were regressed against the actual percentages of each component and the resultant equations were used to calibrate the fecal sample's relative densities to calibrated indices of percent composition.

4.4.1.4.2 Fecal Nitrogen

Duplicated Kjeldahl nitrogen determinations were run on another set of the composited 96 fecal samples. Procedures followed Association of Official Agricultural Chemists guidelines (A.O.A.C., 1980). In addition, an aliquot of each sample was placed in a muffle furnace and burned at 550°C for two hours for ash determination and the expression of nitrogen or crude protein on an organic matter basis. Representative forage samples collected at the four dates of fecal sample collection were also analyzed for nitrogen content.

4.4.1.4.3 Water Intake

A relatively simple method of estimating forage intake by grazing animals has been the water intake method. Water intake has been shown to be quantitatively related to forage intake in ruminants (Phillips, 1960; Johnson *et al.*, 1966). The method requires measurement of mean air temperature, water or dry matter content of the forage and water drunk (Hyder *et al.*, 1966). These data are usually equated with water intake rates in volume of water consumed per weight of food dry matter eaten at various temperatures to arrive at an estimate of forage intake. Winchester and

Morris (1956) have published these rates for English breeds of cattle for a wide range of air temperatures. Forbes (1968) and Hyder *et al.* (1968) further discuss sampling procedures and relationships of forage intake to water intake.

In this study, water was provided to the grazing animals in each of the replications via two-208 liter (55 gal) barrels fitted with float-type hog waterers. Barrels were located in HPSDG centers and in the corners of RSG replicate pastures opposite the salt and mineral blocks. The covered barrels were refilled approximately every three to seven days depending on demand. Before each refilling, centimeters of disappearance was measured. Centimeters of disappearance was converted to liters of consumption by multiplying by 2.366.

4.4.2 Vegetation Measures

4.4.2.1 Emergence, Growth and Developmental Characteristics

Emergence, growth and developmental characteristics of western wheatgrass, buffalograss and blue grama were studied during the spring and early summer of 1984 and 1985. The intent of this substudy was to evaluate the cumulative effects of the grazing treatments on the aforementioned characteristics of the three species.

Previous years grazing intensity has been shown to influence the elongation rate of shoots and leaves of grasses. Short and Woolfolk (1956) for example, reported the

mean maximum height of western wheatgrass plants to be almost 20% greater in areas in good range condition than in areas in poor range condition. Reed and Peterson (1961), also studying western wheatgrass, found fewer leaves per tiller in heavily grazed pastures than in lightly grazed pastures. Johnson (1956) found the average leaf length of blue grama to consistently increase as grazing intensity decreased. With respect to tiller densities, Tallowin (1981) concluded different grazing management systems will cause marked differences in density in perennial ryegrass swards.

In this study, a total of 80 permanently located 10 cm X 100 cm (0.1 m^2) plots were established on areas as outlined in Table 16. All upland areas were on clayey range sites with an 8% slope whereas the drainageway areas were on silty range sites with a 3% slope.

The procedure for the emergence sampling involved a density determination by counting all newly emerged tillers found within the 0.1 m^2 area of the plot frame. Each of these tillers were marked at the base with paint of a selected color. The first five tillers (record tillers) to occur within the plot frame were also marked at the tip of the first leaf with distinct individual colors. The length of each of the first leaves, the total number of leaves and the area in which the first five tillers occurred was recorded.

During subsequent sampling dates (measurement sequences), the procedure was repeated with new sets of tillers.

In addition, length of first leaf and total number of leaves were recorded for the initial or previous set of tillers. To avoid confusion, each tiller set had distinct base colors.

Table 16

Study areas and respective number of plots utilized in the emergence substudy.

Upland Study Areas	Plots
Repeated-Seasonal grazed lightly[1]	10
Repeated-Seasonal grazed heavily[2]	10
Repeated-Seasonal shortgrass areas[3]	5
High-Performance Short-Duration grazed early[4]	10
High-Performance Short-Duration grazed late[5]	10
High-Performance Short-Duration shortgrass areas[3]	5
Repeated-Seasonal grazed moderately[6]	10
Permanent exclosure	10
Drainageway Study Areas[7]	
Repeated-Seasonal drainageway	5
High-Performance Short-Duration drainageway	5

[1] Grazed lightly refers to an area receiving light use the previous four years.
[2] Grazed heavily refers to an area receiving heavy use the previous four years.
[3] RSG and HPSDG shortgrass areas refer to sites dominated primarily by buffalograss and blue grama.
[4] HPSDG grazed early refers to a subunit grazed early in the initial cycle of rotation.
[5] HPSDG grazed late refers to a subunit grazed late in the fourth cycle of rotation.
[6] RSG grazed moderately refers to an area grazed by steers from June through August as part of a Range Condition Study
[7] Drainageway areas were established in 1985.

Final tiller heights were assessed on the last sampling date for all sets of record tillers.

The procedure was similar in 1984 and 1985 except the total number of newly emerged tillers found in the entire 0.1 m² plot area were not counted in 1984. In some cases during 1985, particularly when sampling buffalograss and blue grama which had very large numbers of newly emerged tillers, a 0.05 m² area was used.

Sampling of western wheatgrass began each year around the first of April. It was at this time when new western wheatgrass tiller emergence began. Sampling of buffalograss and blue grama began in late May during 1984. Subsequent follow-up sampling of each set of tillers was conducted at approximately two to three week intervals.

4.4.2.2 Standing Crop and Above-ground Net Primary Production

Standing crop was estimated using 0.25 m² circular plot frames during mid-July and at the end of the grazing season during 1983. In 1984, standing crop was estimated every fourth subunit coinciding with animal movement in each HPSDG cycle and standing crop estimates in RSG were made at the time HPSDG was in mid-cycle as well as at the end of the grazing season.

A double-sampling technique (Wilms *et al.*, 1944; Cook and Stubbendieck, 1986) was used in which a larger number of

weight-estimated plots were calibrated with plots that were estimated, clipped to ground level and bagged. The dry weight (g) of each species for each category (live, recent-dead and old-dead) was estimated. All clipped samples were dried for 24 hr at 55°C and later separated by species and category in the laboratory. Two species, buffalograss and blue grama, were not separated and were collectively described as the shortgrass component. In addition, a Tektronix J-16 biometer was used to distinguish the live and old-dead portions of this shortgrass component. The instrument had been modified to accept two uncorrected probes filtered at 675 ±25 and 800 ±25 nm (Waller *et al.*, 1981). Biometer calibration involved the use of 11 samples with known proportions of live and old-dead plant material. The 11 calibration samples had from zero to 100% live material combined with 100 to zero percent old-dead material at 10% increments. Biometer readings were taken at 675 and 800 nm wavelengths with both black and white panel backgrounds as well as blanks with both panel backgrounds. Stepwise multiple regression analyses were used for the selection of the best model that would predict the percentage of live and old-dead material in the unknown shortgrass samples.

During the 1983 season, six permanently located plots in subunits 7 and 10 of each HPSDG replication were estimated during the sampling periods. An additional two calibration plots (estimated and clipped) per replication were used.

Twelve randomly located permanent plots were estimated in each RSG replication and three calibration plots per replication were harvested.

In 1984, five permanently located plots in subunits 2, 6, 10 and 14 of each HPSDG replication (20 plots total/ replication) were estimated. Estimation was done before livestock entered and again after they left the designated subunits. Five calibration plots per replication were also clipped, many of which were within the subunits while others were clipped in holding areas to avoid excessive clipped spots within the subunits. Twenty-five randomly located permanent plots were estimated in each RSG replication and five calibration plots per replication were harvested. A group of plots located in ungrazed areas (holding areas) were also sampled each of the two years. For training purposes, test plots were estimated and immediately clipped, dried, sorted and weighed before each grazing season as well as periodically during the season.

Above-ground net primary production (ANPP) was estimated by the summation of the peak live + recent-dead (yield) weights of the individual species (Singh *et al.*, 1975; Lauenroth *et al.*, 1987).

<u>4.4.2.3 Forage Utilization</u>

<u>4.4.2.3.1 Seasonal Utilization Dynamics</u>

Two different forage utilzation estimation procedures were used during the 1983 grazing season. A grazed-class

technique (Schmutz *et al.*, 1963) was used, in which 100 plants each of the three key use species (western wheatgrass, buffalograss and blue grama) per replication were observed via a paced transect and assigned to one of six use classes. The six use classes were 0, 10, 30, 50, 70 or 90% removed by weight. Mounted specimens of each of the different classes were used as a field reference. This procedure was used during an early and mid-season sampling period. Due to questionable results with this procedure, the end-of-season use sampling was conducted by randomly locating fifty-0.062 m^2 (25 cm X 25 cm) plots per treatment-replication and collectively estimating the use of all the western wheatgrass and shortgrasses within the plot. Three strata (midgrass, shortgrass or mixed) were delineated for each plot area.

In 1984, forage utilization was estimated in conjunction with the standing crop estimations. Timing and number of use estimates follow that of the standing crop estimates outlined in the previous section. The estimations were made on the total live plus recent-dead standing crop of western wheatgrass and the shortgrasses. Additional use calibration plots were included where varying amounts of vegetation were removed (simulating grazing) and collected by one person followed by an estimation of use by another person and then clipping of the plot to ground level. Collected "use" and residue-portions were later species separated and weighed. The estimated use-portion was then

regressed against the actual use-portion and prediction equations developed.

4.4.2.3.2 Spatial Patterns

Spatial patterns of forage utilization were assessed each year at the completion of the grazing season. The procedure involved the development of utilization maps on overlays on 1:3000 color infrared photographs (20.3 cm X 25.4 cm or 8 in X 10 in prints). Soils, topographical anomalies and major livestock concentration areas were delineated in each of the HPSDG and RSG replicated pastures. Use and residue estimations from 0.25 m^2 plots within each of these areas aided in the determination of the actual boundaries as well as use and residue levels within each of the mapped units.

4.4.2.4 Growth Characteristics Comparison

This 1984 substudy was undertaken on July 18 and 19 to evaluate selected growth characteristics of western wheatgrass within three treatments. Five area comparisons were made in which a total of 805 plants were selected from adjacent locations in HPSDG, RSG and ungrazed pastures. In RSG and HPSDG, 35 ungrazed and 35 grazed plants were randomly selected from 10 different areas via a wandering pace-transect in which after every second pace, the plant nearest one's shoe tip was collected. Thirty-five ungrazed tillers in each of three ungrazed areas were also collected. The 13 areas corresponded with the five comparisons in which the areas were adjacent (separated only by a fenceline) to

each other (Table 17). Two of the comparisons (5 locations) were on silty range sites and three (8 locations) were on clayey range sites.

Table 17

Location and range site of the 13 western wheatgrass collection areas for each of the five comparisons.[1]

Comparison	Location			Range Site
1	RSG-4	HPSDG-5	--	clayey
2	RSG-4	HPSDG-1	central holding area	clayey
3	RSG-3	HPSDG-3	southeast holding area	silty
4	RSG-4	HPSDG-5	--	silty
5	RSG-5	HPSDG-6	permanent exclosure	clayey

[1] Thirty-five grazed and ungrazed plants collected per location in each treatment.

All collected plants were later dried (55°C for 24 hr), weighed, total height measured, number of leaves determined and the length of each leaf measured. Of the plants that were grazed, an assessment of the number of leaves that were grazed was also taken.

4.4.2.5 Dry Matter Content

During 1983, 10 randomly collected forage samples of about 40 g in weight were used for determination of forage dry matter content. The samples were collected approximately every 15 days, weighed immediately after collection, dried for 24 hr at 55°C and then reweighed. Sample collection began on May 31 and ended on September 26.

In 1984, samples were collected in a manner attempting to simulate the diet as it would be selected by a grazing

animal. These samples were collected from each treatment-replication (12 total) at one week intervals from May 18 through September 14. Dry matter content was determined the same as it was in 1983. Samples were collected from each replicate pasture of each treatment.

4.4.3 Soils

4.4.3.1 Soil Compaction

An index of soil compaction was obtained from the depth of penetration of a tapered rod dropped from a standard height. This technique has been quite useful when assessing relative compaction, however, soil moisture and stoniness can alter penetrometer readings (Cook and Stubbendieck, 1986).

In 1983, soil penetrometer readings were taken June 7 through June 10 and October 15 through October 18. Readings in HPSDG pastures were taken within three assigned strata. The three strata were based on distance from the HPSDG pasture center which contained water, mineral and the gates to facilitate livestock movement from one subunit to the next. Strata 1 was the one-third of the subunit closest to the center; strata 2 was the middle third and strata 3 was the one-third of the subunit furthest from the center. Twenty-five penetrometer readings were taken per strata per replication.

Penetrometer readings in RSG pastures were also taken within three defined strata, and in this case, strata were

delineated based on distance from the RSG water barrel locations. In addition, 200 RSG penetrometer readings were taken at the end of the grazing season (October) in two strata delineated as having either high (>40%) or low (<10%) forage use.

In 1984, penetrometer readings were taken during mid August as well as just after the end of the grazing season (early October). Readings were again from the same 1983 defined strata in both RSG and HPSDG. Sampling during both years was conducted on clayey, silty and claypan range sites.

Analysis of variance procedures were used to test differences between the defined strata, soils and treatments.

4.4.3.2 Penetrometer Indices and Soil Bulk Density

In a related 1983 substudy, an attempt was made to define the relationship between soil bulk density and the penetrometer indices. Eighty-four penetrometer readings were taken and accompanying each, a four centimeter (diameter) core of soil was excavated to to the depth of penetration. Loose sand poured from a graduated cylinder was used to estimate the volume of the excavated soil. The excavated soil samples were later dried and weighed and bulk density of each determined by division of the dry weight by the volume.

In 1984, the relationship between bulk density and the penetrometer indices was again evaluated. In this sub-study, a 365 cc core (5.1 cm diameter x 15.2 cm length (2 in x 6 in)) was extracted in the same area that the penetrometer

reading was taken. The 32 soil core samples were later dried and bulk density determined as was done in 1983.

Regression analyses were used to assess the relationship between soil bulk density and the penetrometer indices.

4.4.3.3 Soil Water

During the 1984 grazing season, soil water in a 2.54 X 15.2 cm (1 X 6 in) core was determined by the gravimetric method which involves weighing the sample before and after oven drying (24 hr at 105°C) (Cook and Stubbendieck, 1986). Cores were collected every 10 days from May 27 through August 26.

Additional soil water data collected with a neutron probe in another study at the Research Station were available for both 1983 and 1984.

4.5 Statistical Analyses

Statistical analyses of the various data sets were aided by the appropriate Statistical Analysis System (SAS) (Release 5.15) procedures for a mainframe computer (SAS Institute Inc., 1985). Testing was at the 0.05, 0.01 and 0.001 significance levels.

In addition to the standard analysis of variance (ANOVA) or regression procedures, several (where appropriate) data sets were subjected to repeated measures (within-subjects) analysis procedures. Measurements on the same experimental units over dates (time) were taken on the livestock (weight gains and wool growth) as well as on the

nitrogen and botanical composition of the diet estimated from fecal samples.

Repeated measures analysis of variance takes into account the correlation of each of the measurements taken on the same experimental units (SAS Institute Inc., 1985). Split-plot designs often lend themselves to repeated measures analysis. Allen (1982) describes this popular method as a "split-plot-in-time". A simple example evaluating growth curves is given where weight gains are measured for consecutive periods on experimental animals receiving one of four diets. Diets become the whole-plot factor and time period the split-plot factor. Split-plot-in-time and -space are also discussed by Steel and Torrie (1980). Repeated measures analysis can also be used for complete block designs as well as incomplete block designs (*eg*. split-plot) (Gill, 1978).

Latour and Miniard (1983) caution that many times the conventional univariate approach to repeated measures analysis is violating the critical assumption that treatment-difference variances are equal (heterogeneity assumption). Cole and Grizzle (1966) and Latour and Miniard (1983) suggest the use of the tools of multivariate analysis of variance (MANOVA) to overcome this problem. SAS procedures (SAS Institute Inc., 1985) provide this alternative and the appropriate multivariate options were used and results presented for these analyses. Univariate test results are also presented and discussed when these tests were more powerful.

5.0 JOURNAL ARTICLE I:

A Comparison of High-Performance Short-Duration and Repeated-Seasonal Grazing Systems: Effect on Performance of Calves and Lambs and on Indices of Diet

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Key words: grazing management, short-duration grazing , common use grazing, diet similarity, diet selection

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Common names of plants follow Beetle, 1970 and scientific names follow Great Plains Flora Association, 1986.
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5.1 Abstract

Performance, production and botanical composition of the diets of calves and lambs grazing in combination were contrasted between a Repeated-Seasonal (RSG) (May-Sep.) and a 16-subunit, 1-herd High-Performance Short-Duration Grazing (HPSDG) system during 1983 and 1984. Animal numbers were adjusted with put-and-take sets of livestock to attain planned forage use levels for each cycle in HPSDG and comparable end-of-season levels in both treatments. Seasonal average daily gains (ADG) of RSG calves were greater in both 1983 and 1984 (0.52, 0.68 vs. 0.39, 0.62 kg/day, respectively, for RSG and HPSDG) ($P<.05$). RSG lamb ADG's were greater in 1983 (72.6 vs. 45.4 g/day, respectively, for RSG and HPSDG) ($P<.05$). Attained stocking rates were 24 and 21% higher in HPSDG during 1983 and 1984, respectively, resulting in greater calf and combined (calf + lamb) production/hectare in the HPSDG treatment during 1984 ($P<.05$). Diet quality, as estimated from fecal nitrogen (N), was better for the RSG livestock especially during the first two grazing periods ($P<.05$). Diet composition data show compatibility of the lamb and calf mix in both grazing system treatments.

5.2 Introduction

Grazing systems are an essential, integral part of grazing management. The simplest and most common grazing system is one in which the animals graze the same area at the same season each year (repeated-seasonal grazing). If the grazing period is for the entire period that grazing is feasible, this is continuous grazing (Lewis 1983). In recent years, much attention has been directed towards the use of intensively managed systems referred to as "short-duration", "time-controlled", "controlled" or "rapid rotation", all operated under similar principles. Of particular interest to ranchers in these troubled economic times, has been the claim that proper implementation of a short-duration system will, as a rule, result in a two-fold or greater increase in livestock carrying capacity (Savory 1978). However, quantitative data supporting this claim are relatively scarce.

Several researchers have evaluated animal performance and production in short-duration grazing (SDG) systems. However, variations in the system (size and number of subunits or paddocks), management of the system (stocking rates, occupation and nonuse periods), geographical location, vegetation type or year to year variations in precipitation are complicating factors that often prevent a clear understanding of what a particular system will do.

Jung *et al.* (1985) found no differences in average

daily gains (ADG) of yearling heifers grazing smooth brome grass (*Bromus inermis* Leyss.) in either a repeated-seasonal grazing (RSG) (May-Aug.) or a SDG system (8 subunits-1 herd: 2-4d occupation/14-28d nonuse). On native range in the Rolling Red Plains of Texas, Heitschmidt *et al.* (1982b) reported no differences in weight gains of growing heifers in RSG (Apr.-Oct.) and SDG (10-1:3-7/35-42d) systems. On native Texas range (High Plains) in poor condition, Pitts and Bryant (1982) found no difference in ADG of yearling steers in a SDG (16-1:2-4/30-60d) and a continuous system. However, when stocking rates were doubled in the SDG system, gains were significantly less on that system. On native mixed-grass range in southeastern Wyoming, Hart and Test (1984) reported ADG of yearling steers in a moderately stocked SDG system (8-1:3-7/21-49d) to be significantly less than in a moderately stocked RSG (Jun.-Oct.) system. There were no differences when both systems had a heavy stocking rate. Baker *et al.* (1982) (ryegrass pastures, England) found ADG of beef cows to be significantly greater in the SDG system (12-1:2-5/22-55d) than in a RSG (May-Oct.) system.

Animal gain per hectare was approximately doubled with the SDG system reported by Heitschmidt *et al.* (1982b). Stocking rates however, were fixed at 2X those in RSG. With SDG stocking rates at 131% of RSG, Jung *et al.* (1985) reported gain/ha to be increased by 24%. Kirby *et al.* (1985) reported greater than 2X gain/ha with a SDG system

(8-1:5/35d) than in a RSG system (Jun.-Oct.). In this study, SDG stocking rates were 162% of RSG.

Each of these grazing system comparisons (cited above) used fixed stocking rates where the number of animals per unit area was constant during the entire grazing period. Animal numbers per unit area were either: 1) equal in both systems, 2) greater in one than the other, or 3) some percentage greater or less than the general recommended stocking rate for that area. Consequently, animal performance and production were a function of stocking rate rather than grazing system. In studies by Hart *et al.* (1986), about two-thirds of the variation in ADG could be accounted for by stocking rate. Mott (1960) emphasized the need to adjust stocking rates to provide equal grazing pressure on all treatments and replications, since failure to do so may bias performance per animal and per area. A put-and-take approach (Burns *et al.* 1970) was utilized by Leconte (1982a,b) with forage utilization used as the determinant. The results of his studies revealed that RSG (Apr.-Oct.) produced 72% (4-year average) as much production per area as a SDG system (12-1:2-4/22-44d).

The objectives of this study were to evaluate performance per animal and per area in High-Performance Short-Duration (HPSDG) and Repeated-Seasonal (RSG) grazing systems. A HPSDG system is one in which occupation periods, nonuse periods and utilization levels are planned with flexibility

to provide high performance per animal and per area. A put-and-take approach was used to attain planned forage use levels. Additionally, diet composition and fecal nitrogen were studied.

5.3 Study Area and Methods

These studies were conducted during 1983 and 1984 at the Cottonwood Range and Livestock Research Station located in west-central South Dakota (43°57'N, 101°52'W). The experimental area lies in the Mixed Prairie region of the Northern Great Plains where short and medium height grasses are co-dominant. Western wheatgrass (*Agropyron smithii* Rydb.), buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths.) comprise over 75% of the total annual forage production in high range condition (Lewis *et al.* 1956). Soils on the Research Station are primarily Usteric Camborthids classified as a clayey range site (USDA-SCS 1979). Kyle, Pierre and Nunn were the major soil series of the experimental pastures (USDA-SCS 1987).

Precipitation at the Research Station averaged 396 mm from 1910-1984 with approximately 78% falling during the April through September growing season. Annual precipitation was 381 and 416 mm during 1983 and 1984, respectively. During 1983, precipitation was 81 and 67% of the long-term mean for the growing and warm (Jun.-Aug.) seasons, respectively. Cool season precipitation (previous Sep.-May)

however, was 137% of the mean. During 1984, precipitation was 121 and 137% of the long-term mean for the growing and warm seasons and the cool season precipitation was 110% of the mean.

The experimental design of the study was a randomized complete block with two treatments and six replications. The two treatments were the two different grazing systems, High-Performance Short-Duration Grazing (HPSDG) and Repeated-Seasonal Grazing (RSG) as classified by Lewis (1983). HPSDG pastures were 2.2 ha in size and divided into 16 subunits (paddocks) arranged in a wagon wheel configuration. RSG pastures (4.4 ha) were not subdivided, allowing livestock access to the entire unit for the duration of the grazing period. The HPSDG system was conducted with four cycles of rotation and subunit occupation periods of 1, 2, 2 and 3 days with corresponding nonuse periods of 15, 30, 30 and 45 days for cycles 1 through 4 respectively. The progressive increase in length of occupation and nonuse periods corresponds to the declining vegetation growth rate as was suggested by Voisin (1962). The grazing seasons ran approximately May through September during the two years of the study.

Lambs (ewes and wethers) and heifer calves were used as the experimental animals. Average initial weights of the lambs were 28.6 and 27.2 kg in 1983 and 1984 respectively. Average initial weights of the calves were 165.1 and 165.6 kg for the two years.

The lambs and calves were grouped in sets with one set consisting of one calf and three lambs. At the start of the grazing season, a combination of two calves and six lambs (2 sets) were randomly allotted to each replicate pasture of each treatment. HPSDG's initial stocking density (0.64 AU/ha) was 2X that of the doubly large RSG pastures. An end of season forage use goal of 40 to 50% on any of three key use species (western wheatgrass, buffalograss or bluegrama) was a primary criterion for adjustments of numbers of sets of animals in both RSG and HPSDG. Additionally in HPSDG, planned use levels of approximately 10, 20 and 30% for a one, two and three day occupation were used as criteria for animal number adjustment. The adjustments were made with put-and-take sets of animals.

All livestock weights were measured at the start of the first and at the end of each of the four HPSDG cycles. Livestock were gathered during the late afternoon, penned without feed or water for an overnight shrink and weighed the following morning.

An index to the botanical composition of diet of the lambs and calves was provided during 1984 by the microhistological examination of fecal material. Fecal samples were collected from each animal on May 23, June 17, July 20 and August 24 (HPSDG cycle midpoints). Fecal samples were later dried (48 hr at 60°C) and then ground through a one mm screen (20 mesh). Individual calf and lamb samples were then

composited into treatment x replication x date samples. Microhistological analyses were performed by the Composition Analysis Laboratory at Colorado State University. Percent relative density of discerned fragments for a species was calculated. The relationship between percent relative density and dry weight for most plant species is highly correlated (Sparks and Malechek 1968). Similarity indices (Oosting 1956) and selection (preference) indices (Van Dyne *et al.* 1978) were also calculated using PRD as an index of the botanical composition of the diets.

Duplicated Kjeldahl nitrogen (N) determinations were run on another set of the composited fecal samples. Procedures followed standard guidelines (AOAC 1980). In addition, an aliquot of each sample was burned in a muffle furnace (2 hr at 550°C) for ash determination and the expression of N on an organic matter basis.

Statistical analyses of the various data sets were conducted by using the appropriate Statistical Analysis System (SAS) procedures for a mainframe computer (SAS Institute Inc. 1985). Testing was at the 0.05, 0.01 and 0.001 significance levels. Production per area (gain in kg/ha) were subjected to usual analysis of variance procedures. All other data sets were evaluated with repeated measures analysis of variance which takes into account the correlation of each of the measurements taken on the same experimental units (SAS Institute Inc. 1985). Additionally,

a multivariate approach (Latour and Miniard 1983; Cole and Grizzle 1966) was used, as many times, the conventional univariate approach violates the critical heterogeneity assumption. Sampling or weigh dates were used as the repeated time factors. Model components were treatments, replications, dates (periods) and all associated first order interactions. Where needed, protected LSD's were used for mean separation (Steel and Torrie 1980). Years were analyzed separately due to differences in livestock breeds and trial starting dates.

5.4 Results and Discussion

Livestock Performance and Production

The statistical analyses of average daily gain (ADG) of calves revealed significant treatment and period effects during both years. RSG calf ADG was greater both years ($P<.05$) (Table 1). The greatest difference between treatments occurred during periods (cycles) 1 and 2.

ADG during periods 2 and 3 (Jun. 15 - Aug. 20 during 1983 and Jun. 1 - Aug. 6 during 1984) was significantly greater than periods 1 and 4 during both years ($P<.05$) (Table 1). With the exception of the lower period 1 ADG, this parallels vegetative growth dynamics in the area. These early-weaned livestock were maintained in drylot prior to the start of the trial and the grazing adaptation stress could account for the lower ADG during period 1.

Analysis of lamb ADG revealed a significant treatment x period interaction in both years in addition to significant

treatment and period in effects in 1983 and a period effect in 1984 (Table 2). RSG lamb ADG was greater during periods 1 and 4 in 1983 and period 2 in 1984 ($P<.05$).

Season ADG was greater for the RSG lambs in 1983 ($P<.001$), but there were no differences in 1984. Similar to the calves, lamb ADG was highest during period 2 in 1983 and during periods 2 and 3 during 1984 ($P<.01$) (Table 2).

Stocking rates which resulted from the put-and-take approach to attain the desired forage use levels were 21 and 24% greater in HPSDG than in RSG for 1983 and 1984 respectively (Table 3). Attained stocking rates for both treatments were somewhat higher in 1983 than in 1984. Forage growing conditions for the most part, were favorable and comparable both years, but critical May precipitation was 25.7 mm greater and cool season precipitation (previous Sep.-May) was 62.8 mm greater in 1983 than in 1984. This may partially account for the increased stocking rates that were attained.

Statistical analyses of livestock production (gain/ha) data revealed significant treatment differences during 1984 (Figure 1). The 1984 HPSDG calf (47.8 kg/ha) and the combined (calf + lamb) gain (63.6 kg/ha) was greater than the RSG calf gain (41.9 kg/ha) and combined gain (59.0 kg/ha) ($P<.05$). In essence, the lower ADG of HPSDG was offset by the greater stocking rates that were attained to give the greater gain/ha. Similarly, across treatments, gain/ha was somewhat higher in 1984 than in 1983 even though stocking

rates were less because the 1984 ADG was substantially better.

Botanical Composition of Diet

A total of 20 different species or genera (8 perennial grasses, 2 annual grasses, 11 forbs and 1 sedge) were identified in the fecal samples from the lambs and calves in the RSG and HPSDG grazing systems. The species or genera were delineated into the following six categories for analysis and discussion: 1) annual grasses (Japanese bromegrass (*Bromus japonicus* Thunb. ex Murr.) and six-weeks fescue (*Festuca octoflora* Walt.); 2) western wheatgrass; 3) shortgrasses (buffalograss and blue grama); 4) forbs; 5) sedges and 6) other grasses.

The percent relative density in the fecal samples was used as an index of animal diets. For the dates sampled, RSG lamb and calf diets contained a greater variety of forb species (11 vs. 3 in HPSDG) as might be expected with the greater opportunity for selection in RSG. Additionally, the relatively small area of an HPSDG subunit would contain a limited supply of forbs which could be diminished rapidly in an occupation period and depending on new growth, the supply could be limited during later cycles. HPSDG calf samples did not contain any forbs on the last three periods (cycles 2, 3 and 4). Annual grasses and western wheatgrass were major components of calf diets and shortgrasses were the major component in lamb diets in both treatments (Figures 2 and 3).

The statistical analyses of percent relative density

for each of the six categories revealed significant treatment and date effects for both the calves and lambs (P<.05). There were no significant interactions. RSG calf samples contained a greater percentage of western wheatgrass (32.0 vs. 19.2) and forbs (1.3 vs. 0.3) and less annual grasses (49.6 vs. 64.9) than HPSDG samples (P<.05). RSG lamb samples also contained a greater percentage of forbs (5.6 vs. 1.8) as well as less sedges (11.5 vs. 16.7) than HPSDG samples (P<.05) (Figures 2 and 3).

Important date effects for both the calves and lambs included a greater percentage of western wheatgrass on May 23 and Aug. 24 than on the middle two dates and percentage of shortgrasses was least on May 23 compared to the other three dates (P<.05). For the calves, percentage of annual grasses was greater on Jun. 17 and Jul. 20 than on the first and last dates (P<.05). For the lambs, percentage of annual grasses was greater on May 23 than on the other three dates and percentages of sedges and forbs were greater on the first two dates than on the last two (P<.05).

Selection indices were calculated for each of the six species groups as the ratio of the percentage of a species in the diet to the percentage of the species in the live plus recent-dead herbage residue (Table 4). Calves in both treatments showed an unexpected high degree of selection for the annual grasses. Selection for annual grasses by yearling steers was also reported in an earlier study at the Research

Station (Rodgers 1972). Calf selection indices in both treatments were also relatively high for the "other grasses" group and least for the shortgrasss and forbs groups. Lambs in both treatments showed selection for the shortgrasses, annual and other grasses groups and a strong avoidance of western wheatgrass (Table 4).

Kulcyznski's similarity indices (Oosting 1956) were calculated to estimate the amount of dietary overlap between the calves and lambs within the grazing system treatments (Table 4). For all species groups, these similarity index means were never excessively high. Similarity indices for the annual and other grasses groups were among the highest as those two groups were selected by both calves and lambs.

Similarity indices were generally the highest for all species groups in both treatments on the May 23 sampling date as would be expected since the warm-season species had not yet begun rapid growth and consequently, the least amount of live forage was available at that time.

Probably the most important similarity and selection indices to consider are those for the two dominant groups, western wheatgrass and shortgrasses. Here the compatibility of the combination of calves and lambs (especially in RSG) can be seen with the relatively low similarity indices and the lambs expressing strong avoidance of western wheatgrass and selection for the shortgrasses (Table 4).

There is a need for long-term testing of short-duration systems to provide data for a variety of years and to detect possible cummulative effects of the system on grassland ecosystems. The number of subunits, length of periods of occupation and nonuse and their variation by site, season and year, as well as the degree of use and amount of residue following each occupation are among the most important variables that should be optimized.

The grazing of a combination of cattle and sheep appears to have excellent potential for improving livestock production for the kind of range used in these trials. Unplanned comparisons suggest the hypothesis that mixing kinds of livestock in RSG may permit stocking rate increases as large as those due to HPSDG.

exception of period 1, declines in fecal N were consistent with declines in ADG. Livestock ADG's were the lowest during period 1 but fecal N was highest on May 23 (period 1 mid-point). Compensatory growth may have been exhibited after this initial 16 day period.

5.5 Conclusions

Data from these trials suggest that properly and intensively managed HPSDG systems may allow an increase in stocking rate and result in a slight increase in livestock production per area, however, individual animal performance may be somewhat reduced. Improved spatial distribution and harvesting efficiency by grazing livestock have been suggested as reasons for an increase in stocking rate with similar levels of sue. Additionally, Heitschmidt *et al.* (1982a) reported short-duration grazing may enhance forage growth and production on a short-term basis if growing conditions are favorable. The plant-animal-climate association within a HPSDG system lends itself to a need for very intensive management and flexibilty of the system. Dry conditions from mid-July through September which are fairly typical for this area were experienced both years of the study. In this case, management must first be observant of forage use and residue levels and then be flexible by being able to provide supplemental feed, reducing animal numbers or having reserve pastures in order to prevent serious overuse.

Fecal Nitrogen

Analysis of percent fecal N revealed a significant treatment x date interaction in addition to significant treatment and date effects (Table 5). The RSG calf and lamb samples had a greater percentage fecal N on the May 23 and June 17 sampling dates and the RSG treatment mean was higher than HPSDG ($P<.05$) (Table 5).

Wofford *et al.* (1985) observed a high correlation ($r=.83$) between percent diet N and percent fecal N. Similar results were also reported by Clarke *et al.* (1966) and Fels *et al.* (1959). This relationship has the greater validity with low and moderate N forage diets than with high N diets due to a greater degree of confounding with endogenous metabolic N in high N diets. It can be suggested then, that one reason for the greater ADG of livestock in RSG was their opportunity for greater selection of species and plant parts, resulting in a diet higher in N. Fels *et al.* (1959) presents evidence that grazing sheep will select for nitrogen content in the forage.

Fecal N decreased over the season for both calves and lambs corresponding to the increase in forage maturity ($P<.05$) (Table 5). Forage samples collected on the same four dates contained 2.41, 1.78, 1.34 and 0.98% N (organic matter basis) (15.1, 11.2, 8.4 and 6.1% crude protein) on May 23, June 17, July 20 and August 24, respectively. With the

Table 1. Average daily gain (kg) of calves in Repeated-Seasonal (RSG) and High-Performance Short-Duration (HPSDG) grazing systems at the Cottonwood Range and Livestock Research Station, 1983 and 1984.

	1983			1984		
Period[1]	RSG	HPSDG	Period Means[2] ±SE	RSG	HPSDG	Period Means[2] ±SE
1	0.27	0.15	0.21[a] ±0.09	0.58	0.48	0.53[a] ±0.05
2	0.98	0.68	0.83[b] ±0.06	1.00	0.76	0.88[b] ±0.04
3	0.58	0.50	0.54[c] ±0.04	0.78	0.79	0.78[b] ±0.06
4	0.25	0.22	0.24[a] ±0.05	0.39	0.43	0.41[a] ±0.03
Season Means[3] ±SE	0.52[A] ±0.04	0.39[B] ±0.04		0.68[A] ±0.03	0.62[B] ±0.02	

[1] Periods correspond to the four HPSDG cycles of rotation.

[2] Within years, period means with unlike superscripts differ ($P<.01$ in 1983 and $P<.05$ in 1984).

[3] Within years, season treatment means with unlike superscripts differ ($P<.05$).

Table 2. Average daily gain (g) of lambs in Repeated-Seasonal (RSG) and High-Performance Short-Duration (HPSDG) grazing systems at the Cottonwood Range and Livestock Research Station, 1983 and 1984.

	1983				1984			
Period[1]	RSG	HPSDG	Period Means[2]	±SE	RSG	HPSDG	Period Means[2]	±SE
1	47.8[a]	-37.8[b]	5.0[A]	±11.3	-9.4[a]	-12.4[a]	-10.9[A]	±10.6
2	157.5[a]	157.5[a]	157.5[B]	±6.5	196.1[a]	133.8[b]	164.9[B]	±6.1
3	66.4[a]	55.9[a]	61.2[C]	±7.5	135.4[a]	144.4[a]	139.9[B]	±8.4
4	23.2[a]	6.8[b]	15.0[A]	±6.3	19.5[a]	18.4[a]	18.9[A]	±7.0
Season Means[3]	72.6[A]	45.4[B]			86.2[A]	72.6[A]		
±SE	±3.8	±5.3			±5.1	±5.7		

[1] Periods correspond to the four HPSDG cycles of rotation.
[2] Within years, period means with unlike superscripts differ (P<.01).
[3] Within years, season treatment means with unlike superscripts differ (P<.001).
[ab] Within years and periods, treatment means with unlike superscripts differ (P<.05).

Table 3. Sets of livestock, periodic (cyclic) and cumulative stocking rates (AUMs/ha) in HPSDG and RSG systems, 1983 and 1984.[1]

1983

		HPSDG			RSG		
Period	Cycle	Sets	Stocking Rate	Cumulative Stocking Rate	Sets	Stocking Rate	Cumulative Stocking Rate
5/29-6/14	1	2	0.361	0.361	2	0.180	0.180
6/15-7/17	2	2	0.706	1.067	2	0.353	0.533
7/18-8/19	3	3/2[A]	0.933	2.000	3	0.578	1.111
8/20-9/29	4	1	0.452	2.452	3	0.923	2.034

1984

		HPSDG			RSG		
Period	Cycle	Sets	Stocking Rate	Cumulative Stocking Rate	Sets	Stocking Rate	Cumulative Stocking Rate
5/15-5/31	1	2	0.361	0.361	2	0.180	0.180
6/1-7/3	2	2	0.699	1.060	2	0.350	0.530
7/4-8/5	3	1	0.408	1.468	3	0.605	1.135
8/6-9/16	4	1	0.526	1.994	3/1[B]	0.472	1.607

[1] One set = 1 calf and 3 lambs.

[A] Three sets started cycle 3 in HPSDG, but 1 set was removed after 16 days (8 subunits).

[B] Two sets in RSG were removed after 16 days into this period.

Table 4. Preference and similarity indices (PI and SI) of "diets" of calves and lambs in RSG and HPSDG systems at four sampling dates.[1,2]

Species (Group)	May 23			June 17			July 20			August 24		
	PI			PI			PI			PI		
	Calf	Lamb	SI	Calf	Lamb	SI	Calf	Lamb	SI	Calf	Lamb	SI
RSG												
Western Wheatgrass	1.0	0.3	44.4	0.5	0.1	32.9	0.5	0.1	19.3	0.6	0.1	35.7
Shortgrasses	0.1	0.8	23.0	0.3	1.6	32.6	0.4	2.2	29.7	0.3	1.8	27.1
Annual Grasses	2.9	2.8	97.7	5.0	1.6	48.5	6.5	0.7	20.3	8.5	0.5	11.3
Forbs	0.3	1.4	39.5	0.2	0.8	45.5	0.1	0.6	18.7	NP	0.2	–
Sedges	2.7	3.4	88.6	0.7	2.8	41.4	0.1	3.5	5.1	0.3	3.2	15.7
Other Grasses	2.7	6.2	60.2	3.8	4.0	97.1	4.5	4.2	96.1	5.1	17.9	44.4
HPSDG												
Western Wheatgrass	0.7	0.2	51.3	0.4	0.1	51.1	0.3	0.1	13.1	0.5	0.1	41.3
Shortgrasses	0.1	0.8	17.6	0.3	1.1	43.8	0.3	1.9	26.4	0.4	2.0	36.2
Annual Grasses	2.7	1.2	62.1	3.8	1.0	41.1	4.0	1.4	51.0	4.4	0.8	31.6
Forbs	0.1	0.3	66.7	NP	0.3	–	NP	0.3	–	NP	0.4	–
Sedges	1.5	4.6	50.2	NP	4.2	–	0.1	1.8	7.4	0.3	1.4	36.4
Other Grasses	3.0	10.1	46.6	6.2	27.3	36.9	8.7	5.4	76.7	5.0	24.1	34.5

[1] Perference index (PI) equals percent in diet (percent relative density in fecal sample) divided by percent in live + recent-dead standing crop.

[2] Similarity index (SI), calves vs. lambs; 2W/(a+b) x 100 where W is the lesser percentage of the species group in the two diets being compared and a+b is the sum of the percentages of the species group in the two diets.

[NP] Species group not present in diet (fecal sample).

Table 5. Percent nitrogen (organic matter basis) of fecal samples of lambs and calves in RSG and HPSDG systems, 1984.

CALVES

Treatment	Date 5/23	6/17	7/20	8/24	Treatment Means[1]	±SE
RSG	3.42[a]	2.91[a]	2.31[a]	1.95[a]	2.65[A]	±0.12
HPSDG	3.03[b]	2.63[b]	2.27[a]	1.90[a]	2.46[B]	±0.09
Date Means[2]	3.23[A]	2.77[B]	2.29[C]	1.93[D]		
±SE	±0.08	±0.06	±0.04	±0.03		

LAMBS

Treatment	Date 5/23	6/17	7/20	8/24	Treatment Means[1]	±SE
RSG	3.90[a]	2.97[a]	2.40[a]	1.97[a]	2.81[A]	±0.10
HPSDG	3.34[b]	2.66[b]	2.37[a]	2.11[a]	2.62[B]	±0.07
Date Means[2]	3.62[A]	2.82[B]	2.39[C]	2.04[D]		
±SE	±0.11	±0.07	±0.04	±0.04		

[1] Within livestock class, treatment means with unlike superscripts differ (P<.05).
[2] Within livestock class, date means with unlike superscripts differ (P<.01).
[ab] Within livestock class and date, treatment means with unlike superscripts differ (P<.05).

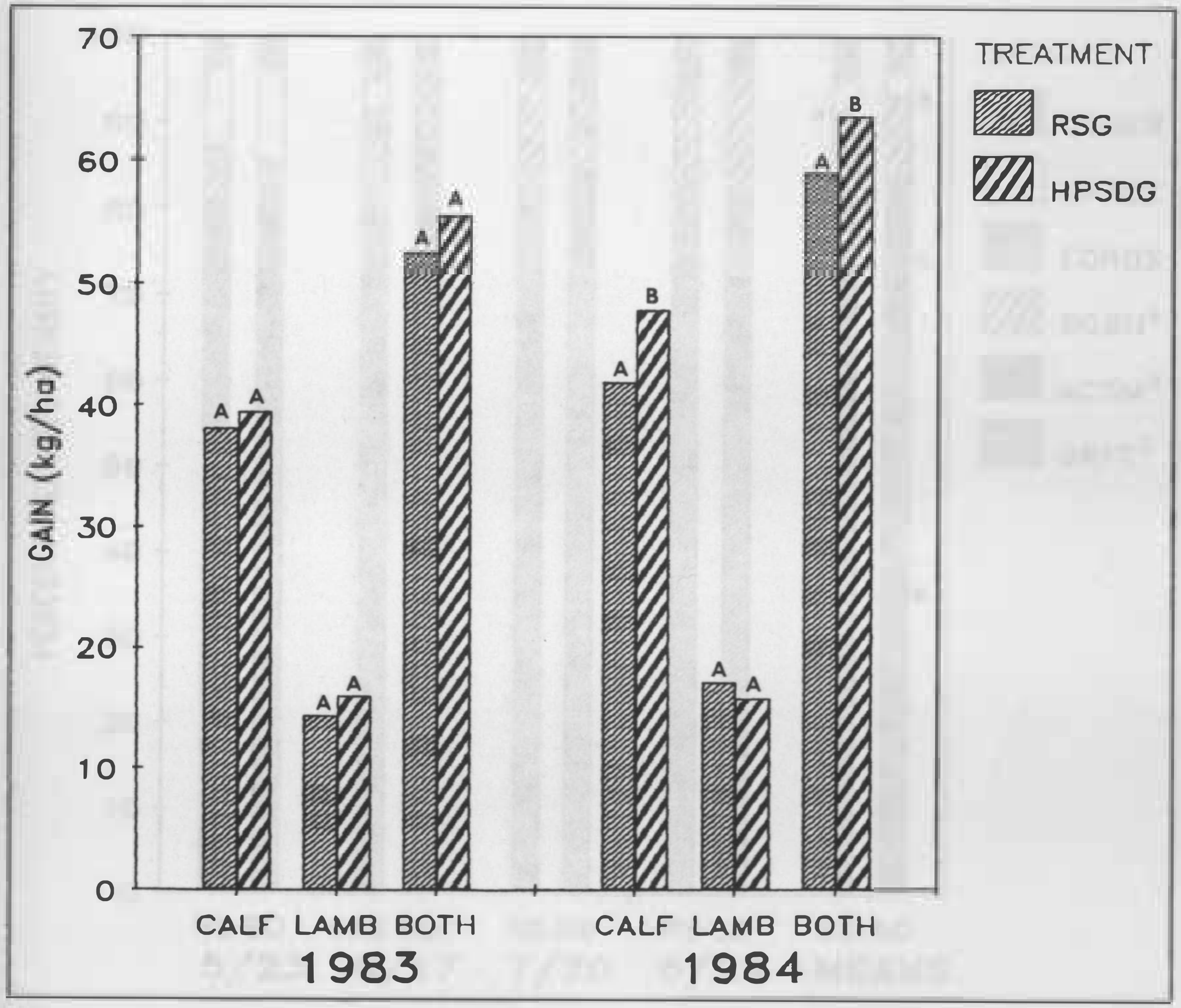

Figure 1. Calculated gain (kg/ha) of calves and lambs in RSG and HPSDG systems, 1983 and 1984.

AB Within years for the calf, lamb and both (combined) comparisons, means with unlike letters differ (P<.05).

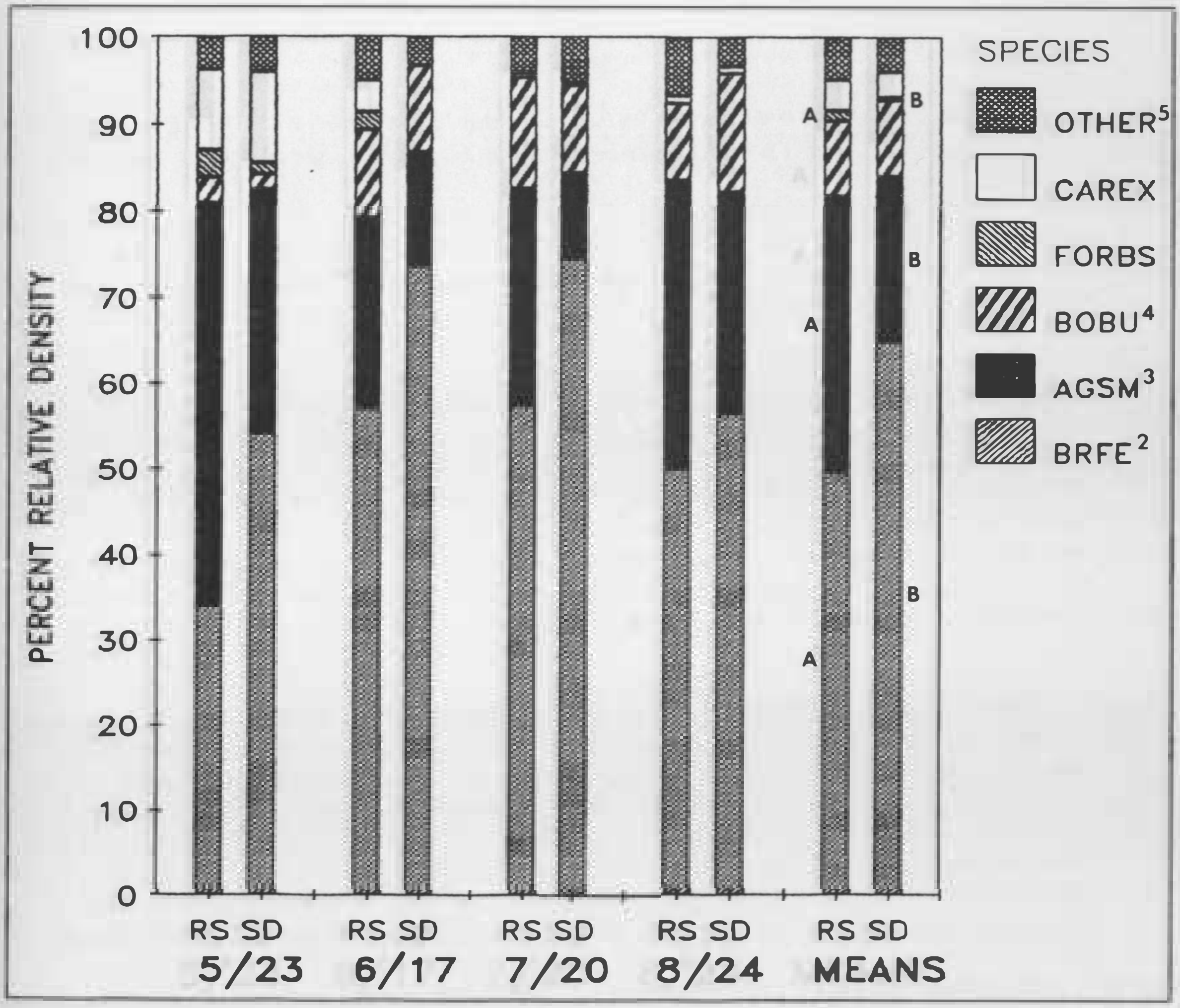

Figure 2. Percent relative density of species observed in microhistologically examined fecal samples of calves in RSG and HPSDG systems at four dates, 1984.[1]

RS = RSG, SD = HPSDG

[A B] For each species group, means with unlike letters differ (P<.05).

[1] Dates correspond to the midpoints of the four HPSDG cycles.

[2] Japanese brome and six-weeks fescue.

[3] Western wheatgrass.

[4] Blue grama and buffalograss.

[5] Other perennial grasses.

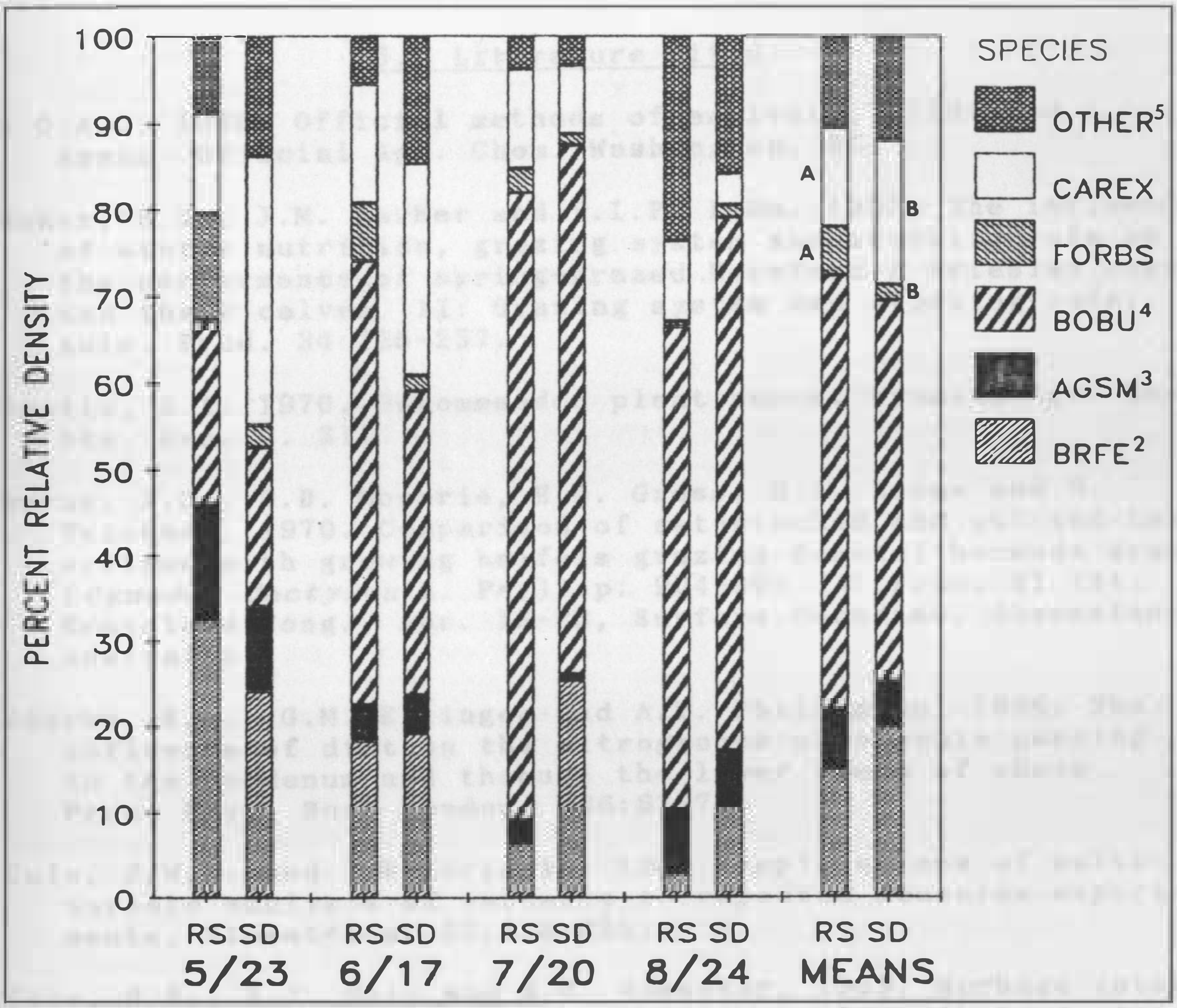

Figure 3. Percent relative density of species observed in microhistologically examined fecal samples of lambs in RSG and HPSDG systems at four dates, 1984.[1]

RS = RSG, SD = HPSDG

[AB] For each species group, means with unlike letters differ (P<.05).

[1] Dates correspond to the midpoints of the four HPSDG cycles.

[2] Japanese brome and six-weeks fescue.

[3] Western wheatgrass.

[4] Blue grama and buffalograss.

[5] Other perennial grasses.

5.6 Literature Cited

A.O.A.C. 1980. Official methods of analysis. (13th ed.) Assoc. Official Agr. Chem. Washington, DC.

Baker, R.D., J.M. Barker and Y.L.P. LeDu. 1982. The influence of winter nutrition, grazing system and stocking rate on the performance of spring-grazed Hereford X Friesian cows and their calves. II: Grazing system and stocking rate. Anim. Prod. 34:225-237.

Beetle, A.A. 1970. Recommended plant names. Wyoming Agr. Exp. Sta. Res. J. 31.

Burns, J.C., R.D. Mochrie, H.D. Gross, H.L. Lucas and R. Teichman. 1970. Comparison of set-stocked and put-and-take systems with growing heifers grazing Coastal bermuda grass (*Cynodon dactylon* L. Per). p. 904-909 *IN*: Proc. XI Int. Grassland Cong., Apr. 13-23, Surfers Paradise, Queensland, Australia.

Clarke, E.M., G.M. Ellinger and A.T. Phillipson. 1966. The influence of diet on the nitrogenous components passing to the duodenum and through the lower ileum of sheep. Proc. Royal Soc. London. 166:63-78.

Cole, J.W.L. and J.E. Grizzle. 1966. Applications of multivariate analysis of variance to repeated measures experiments. Biometrics. 22:810-828.

Fels, H.E., R.J. Moir and R.C. Rossiter. 1959. Herbage intake of grazing sheep in southwestern Australia. Aust. J. Agr. Res. 10:237-247.

Great Plains Flora Association. 1986. Flora of the Great Plains. T.M. Barkley (ed.), Univ. of Kansas Press. Lawrence.

Hart, R.H. and P.S. Test. 1984. Short-duration rotation grazing: theory vs. practice. Proc. II Int. Rangeland Cong. May 13-18, Adelaide, Australia. (in press).

Hart, R.H., G.E. Schuman, M.J. Samuel and M.A. Smith. 1986. Time-controlled grazing research in Wyoming. *IN*: Proc. Short Duration Grazing and Issues in Grazing Management Workshop. Jan. 21-23, Kennewick, WA. (in press).

Heitschmidt, R.K., D.L. Price, R.A. Gorden and J.R. Frasure. 1982a. Short-duration grazing at the Texas Experimental Ranch: Effects on above-ground net primary production and seasonal growth dynamics. J. Range Manage. 35:372-374.

Heitschmidt, R.K., J.R. Frasure, D.L. Price and L.R. Rittenhouse. 1982b. Short duration grazing at the Texas Experimental Ranch: Weight gains of heifers. J. Range Manage. 35:375-379.

Jung, H.G., R.W. Rice and L.J. Koong. 1985. Comparison of heifer weight gains and forage quality for continuous and short-duration grazing systems. J. Range Manage. 38:144-148.

Kirby, D.R., D. Landblom and T. Conlon. 1985. Livestock performance on short duration and repeated season-long grazing treatments in western North Dakota. Proc.: 38th Annual Meeting, Society for Range Management, Feb. 11-15, 1985. Salt Lake City, UT. Abst. 328.

Latour, S.A. and P.W. Miniard. 1983. The misuse of repeated measures analysis in marketing research. J. Marketing Res. 20:45-57.

Leconte, D. 1982a. Comparison of intensive continuous and intensive rotational grazing systems for beef production. Trials conducted in 1978-1979-1980-1981. (In French). Centre de Recherches Zootechniques et Veterinairies de Theix. Bull. No.15. p. 51-55.

Leconte, D. 1982b. Comparison of intensive continuous and intensive rotational grazing systems for beef production. (In French). Fourrages. No. 89. p. 37-48.

Lewis, J.K. 1983. Kinds of grazing systems and their use in the Northern Great Plains. Proc:. Cottonwood Range and Livestock Research Station Research Day. Oct. 5, 1983. Philip, SD. CO 83-5.

Lewis, J.K., G.M. Van Dyne, L.R. Albee and F.W. Whetzal. 1956. Intensity of grazing: Its effect on livestock and forage production. S. Dak. Agr. Exp. Sta. Bull. 459.

Mott, G.O. 1960. Grazing pressure and the measurement of pasture production. p. 606-611. *IN*: Proc. VIII Int. Grassland Cong. July 11-21, Univ. of Reading, England.

Oosting, H.J. 1956. The study of plant communities. W.H. Freeman and Co., San Francisco.

Pitts, J.S. and F.C. Bryant. 1982. Steer and vegetation response to short duration and continuous, yearlong grazing on the southern High Plains of Texas. p. 201-202. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

Rodgers, D.W. 1972. The effect of range condition and season of grazing on the amount and quality of the diet selected by grazing steers. M.S. Thesis. S. Dak. State Univ., Brookings.

SAS Institute Inc., 1985. SAS user's guide: statistics. (version 5 ed.), SAS Institute Inc. Cary, NC.

Savory, A. 1978. A holistic approach to range management using short duration grazing. p. 555-557. *IN*: D.N. Hyder (ed.) Proc. First Int. Rangeland Cong. Society for Range Management, Denver, CO.

Sparks, D.R. and J.C. Malechek. 1968. Estimating percentage dry weight in diets using a microscope technique. J. Range Manage. 21:264-265.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. (2nd ed.). McGraw-Hill Book Co., New York.

U.S.D.A.-S.C.S. Staff. 1979. South Dakota technical guide (west-central). Section II-D-I. U.S. Dept. Agr. Soil Conser. Service.

U.S.D.A.-S.C.S. Staff. 1987. Soil survey of Jackson County, South Dakota. U.S. Dept. Agr. Soil Conser. Service. (in press).

Van Dyne, G.M., N.R. Brockington, Z. Szocs, J. Duek and C.A. Ribic. 1978. Large herbivore subsystem. p. 269-537. *IN*: A.I. Breymeyer and G.M. Van Dyne (eds.) Grasslands, systems analysis and man. Int. Biol. Prog. 19. Cambridge University Press. Cambridge, England.

Voisin, A. 1962. Rational grazing. Crosby Lockwood and Son Ltd. London, England.

Wofford, H., J.L. Holechek, M.L. Galyean, J.D. Wallace and M. Cardenas. 1985. Evaluation of fecal indices to predict cattle diet quality. J. Range Manage. 38:450-454.

6.0 JOURNAL ARTICLE II:

A Comparison of High-Performance Short-Duration and Repeated-Seasonal Grazing Systems: Effect on Standing Crop Dynamics, Forage Utilization and Production

J.D. Volesky, J.K. Lewis and C.H. Butterfield

Key words: common use grazing, grazing management, short-duration grazing, above-ground net primary production

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Common names of plants follow Beetle, 1970 and scientific names follow Great Plains Flora Association, 1986.
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6.1 Abstract

Standing crop dynamics and forage use were quantified in 16-subunit, 1-herd High-Performance Short-Duration (HPSDG) and Repeated-Seasonal (May-Sep.) grazing treatments. Standing crop dynamics were also quantified in an ungrazed treatment and estimations of above-ground net primary production (ANPP) made in HPSDG and the ungrazed treatment. A mix of lambs and calves occupied the two grazing treatments with proportional sets added or removed to attain planned forage use levels during each cycle of HPSDG and comparable end of season use levels in both treatments. In 1984, peak live (L) + recent-dead (RD) standing crop was observed on August 24 in the ungrazed treatment, July 20 in RSG and immediately before subunit occupation during cycle 4 in HPSDG. Western wheatgrass, buffalograss and blue grama accounted for about 80 to 82% of this peak standing crop in all three treatments. End of season estimated use of western wheatgrass was not different in RSG and HPSDG ($P>.05$), but use of the two shortgrass species was higher in HPSDG ($P<.05$). ANPP was estimated at 1940 and 2144 kg/ha in HPSDG and the ungrazed treatment, respectively.

6.2 Introduction

It has been hypothesized that above-ground net primary production (ANPP) will increase at optimal levels of herbivory (McNaughton 1979) and that an increase in ANPP may be a major factor whereby an increase in livestock carrying capacity may be realized following implementation of properly designed and managed short-duration grazing (SDG) systems (Heitschmidt *et al.* 1982). Van Poollen and Lacey (1979) concluded that both grazing system and stocking intensity will influence herbage production, but stocking intensity has the greater effect of the two variables. Both *in situ* and greenhouse studies have shown defoliation to increase above-ground production of selected species (Aldous 1930; Bokhari and Singh 1974; McNaughton *et al.* 1983).

Precise quantification of the effects of grazing on the dynamics of ANPP in year-long and season-long continuous systems is difficult. Cages or exclosures must be used to prevent livestock consumption of forage, but the exclusion of grazing creates an artificial environment because periodic grazing may alter the growth response of plants in contrast to nongrazed plants (McNaughton 1979). This problem may in part be alleviated in SDG systems if the period of grazing is short (Heitschmidt *et al.* 1982).

Hart and Test (1984) reported no difference in forage production between a SDG (8 subunits-1 herd:3-7d occupation/

21-49d nonuse and a repeated-seasonal (Jun.-Oct.) grazing system. Production was estimated by clipping and weighing forage inside and outside cages. Heitschmidt *et al.* (1982) used frequent harvest techniques to characterize standing crop and above-ground net primary production (ANPP) in a SDG (10-1:3-7/35-42d) and an ungrazed treatment. ANPP was reported to be greater in SDG than the ungrazed treatment one year but less the next, leading to the conclusion that SDG may enhance growth on a short-term basis if growing conditions are favorable. However, another critical observation was that a large portion of the total standing crop that disappeared within the SDG treatment during each grazing event was transferred to the litter fraction rather than being consumed by the livestock.

The successful operation of short-duration grazing systems requires intensive and flexible management. To aid some of the management decisions, answers are needed for such critical questions as: what is the optimum degree of use and residue following each occupation and how does it vary by season and year; and what are the optimum lengths of each occupation and nonuse period and how do they vary by season, year and degree of use (Lewis *et al.* 1982)?

The objectives of this study were to characterize standing crop dynamics and temporal patterns of forage utilization in High-Performance Short-Duration Grazing (HPSDG), and Repeated-Seasonal Grazing (RSG) treatments. ANPP was

also quantified in HPSDG and an ungrazed treatment. A HPSDG system is one in which occupation periods, nonuse periods and utilization levels are planned with flexibility to provide high performance per animal and per area.

6.3 Study Area and Methods

These data were collected during 1983 and 1984 at the Cottonwood Range and Livestock Research Station (43°57' N, 101°52'W; west-central South Dakota) as part of a comparative study of Repeated-Seasonal Grazing (RSG) and High-Performance Short-Duration Grazing (HPSDG) systems (Volesky *et al.* 1986). Precipitation at the Research Station averaged 396 mm from 1910-1984 with approximately 78% falling during the April through September growing season. Monthly precipitation data for 1983 and 1984 with long-term means and medians are given in Figure 1 and the total and important seasonal precipitation data in Figure 2. Mean daily maximum temperatures range from 0.3°C in January to 32.7°C in July. Mean daily minimum temperatures range from -14.6 to 14.8°C in January and July, respectively. The frost-free season is about 136 days extending from mid-May through September (US Weather Bureau 1967).

Study plots were located in an ungrazed area and in each of six replicate pastures of RSG and HPSDG treatments stocked with a combination of calves and lambs. Initial stocking densities were 0.64 and 0.32 AU/ha in HPSDG and RSG, respectively. However, animal numbers were adjusted during

the course of the grazing season to attain planned forage use levels during each cycle of rotation and to attain comparable end of season forage use levels in both treatments. The attained end of season stocking rates were 24 and 21% higher in HPSDG during 1983 and 1984, respectively (Volesky *et al.* 1986). HPSDG pastures were 2.2 ha in size and divided into 16 subunits (paddocks) arranged in a wagon-wheel configuration. RSG pastures (4.4 ha) were not subdivided allowing livestock access to the entire unit for the duration of the grazing period. The HPSDG system was conducted with four cycles of rotation and subunit occupation periods of 1, 2, 2 and 3 days with corresponding nonuse periods of 15, 30, 30 and 45 days for cycles 1 through 4, respectively (Volesky *et al.* 1986).

The vegetation of the experimental pastures was mixed prairie with short and medium height grasses as co-dominants. The midgrass, western wheatgrass (*Agropyron smithii* Rydb.), and the shortgrasses, buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths.) were the co-dominants. Lesser abundant perennial grasses included green needlegrass (*Stipa viridula* Trin.), needle-and-thread (*Stipa comata* Trin. and Rupr.) and red threeawn (*Aristida purpurea* var. *robusta* (Merril) A. & N. Holmgren). Japanese brome (*Bromus japonicus* (Thunb.) ex Murr.) and six-weeks fescue (*Festuca octoflora* Walt.) were the most common annual grasses. Needleleaf sedge (*Carex*

eleocharis Bailey) and threadleaf sedge (*Carex filifolia* Nutt.), as well as numerous forb species were also present, but accounted for a relatively small percentage of the total biomass production.

Clayey and silty range sites comprised approximately 72 and 19% of the total area of the six replicates under the HPSDG treatment and 69 and 18% of the total area of the replicate pastures under the RSG treatment. Shallow, thin-upland, claypan and complexed range sites occupied the remaining area of both treatments. Kyle and Pierre (clays) and Nunn (loam) were the major soil series of the experimental pastures (USDA-SCS 1987).

A double-sampling sampling procedure (Cook and Stubbendieck 1986) was used for the dry-weight estimation of live, recent-dead and old-dead standing crop by species. Numbers of plots, frequency and approach of sampling was different between 1983 and 1984. In 1983, standing crop was estimated in early July and at the end of the grazing period (late September). Permanent plots in HPSDG, RSG and the ungrazed treatment were sampled at those dates and no before and after subunit occupation estimations were made in HPSDG.

In 1984, a more intensive sampling approach was used and as a result, this paper will focus on the 1984 data. Five 0.25 m² circular plot locations were permanently identified in the second, sixth, tenth and fourteenth subunit of each HPSDG replication (20 plots/replication). In RSG, a

total of 25 plot locations/replication were randomly selected and marked. In the unreplicated, ungrazed treatment, 15 plot locations were similarly selected.

Approximately one calibration plot (ocularly estimated and clipped) was sampled for every seven permanent plots were estimated but not clipped. Vegetation was clipped to ground level and stored in paper sacks. All clipped samples were dried for 24 hr at 60°C and later separated by species and category and weighed. These calibration plots were clipped from randomly selected locations in all three treatments.

In HPSDG, standing crop estimations were made in each cycle immediately before the livestock entered and immediately after they left the four designated subunits. In RSG and the ungrazed treatment, estimations were made at the approximate midpoints (May 23, June 17, July 20 and August 24) of the four HPSDG cycles and at the end of the grazing period (September 16). Forage use estimates were made in conjunction with the standing crop estimates. Use calibration plots were also included where varying amounts of vegetation were removed (simulating grazing) and collected by one person followed by an estimation of use by another person and then clipping of the plot to ground level. Collected "use" and residue portions were later species separated and weighed.

Regression analyses were used to quantify the relationship of the clipped weight (dependent variable) to the

ocularly estimated weight (independent variable) for each of the species and categories. Resultant equations were then used to predict all estimated weights as clipped weights. Similarly, regression analyses were used to quantify the relationship of the estimated and actual "use" portions. Predicted forage use estimates were subjected to the usual analysis of variance. Testing was at the 0.05 and 0.01 significance levels. Where needed, protected LSDs were used for separation of means (Steel and Torrie 1980). ANPP in the ungrazed treatment was estimated by two different methods reviewed by Singh *et al.* (1975) and an additional method used in HPSDG is discussed. Standing crop and ANPP data were not subjected to statistical analyses as an objective of the study was to characterize the standing crop dynamics and due to the nature of the two grazing treatments, timing of sampling was different.

6.4 Results and Discussion

1983

Live (L) plus recent-dead (RD) standing crop was very similar in RSG and HPSDG at the first sampling period (early July) averaging 1278 kg/ha (Figure 3). The ungrazed treatment had not received any grazing in the past four years and as a result, the amount of old-dead (OD) in that treatment was substantially more than that found in either RSG or HPSDG. Western wheatgrass accounted for 43, 47 and 57% and the warm season shortgrasses (buffalograss and blue grama) 36,

33 and 30% of the total period 1 L and L + RD standing crop in the RSG, HPSDG and ungrazed treatments respectively. HPSDG had the largest percentage of annual grasses (7) followed by RSG (3) and the ungrazed treatment (2). Forbs, sedges and other perennial grasses constituted the remaining standing crop with similar amounts in each of the three treatments.

End-of-season standing crop was categorized as either RD or OD. September growth of cool season species typically occurs on these ranges but very dry August and September conditions prevented regrowth during 1983 (Figure 3). The amount of OD residue at the end of the season was similar in both the RSG and HPSDG treatments. RD standing crop was however, 148 kg/ha less in HPSDG than in RSG possibly indicating slightly heavier forage use in HPSDG. Occular estimates of end-of-season use of midgrasses were not significantly different (P>.05), but use of shortgrasses was greater in HPSDG in all three of the delineated strata (P<.05) (Table 1). Both midgrass and shortgrass use was affected by strata. Shortgrass use was the least in the mid strata (dominated by midgrasses) and greatest in the short strata (dominated by shortgrasses) (P<.05). Shortgrasses in the mid strata were probably shielded by the midgrasses limiting livestock access. Lambs were also observed to often concentrate on the shortgrass areas.

1984

The maximum L + RD standing crop in the ungrazed treatment was 2080 kg/ha occurring on the August 24 sampling date (Figure 4). Maximum in RSG was 1358 kg/ha (July 20) and maximum in HPSDG was 1472 kg/ha occuring immediately before cycle 4 occupation (Figures 5 and 6). The HPSDG estimate is the average of the standing crop immediately before occupation in the second, sixth, tenth and fourteenth subunits with sampling dates ranging from July 6 (subunit 2) to July 30 (subunit 14). Of the maximum ungrazed treatment standing crop, western wheatgrass accounted for 52% followed by shortgrasses (30%), annual grasses (7%), forbs (5%) and sedges and other perennial grasses accounting for the rest. Western wheatgrass also accounted for 49% of the maximum RSG standing crop followed by shortgrasses (33%), annual grasses (9%) and forbs (5%). In HPSDG, the maximum was made up of 50% western wheatgrass, 30% shortgrasses, 13% annual grasses and 4% forbs. Sedges and other perennial grasses accounted for about 3 to 4% of the remaining standing crop in both RSG and HPSDG.

At the time of the first sampling (May), there was over 100 kg/ha more old-dead residue in RSG compared to HPSDG. This is similar to the difference in the total standing crop left in the two treatments at the end of the 1983 season. At the end of the 1984 season however, OD residue was nearly identical in both treatments. Of the OD residue that was

present in May, 42, 43 and 47% of it had disappeared by the end of the grazing season in HPSDG, the ungrazed treatment and RSG respectively (Figures 4, 5 and 6). The litter fraction was not estimated and therefore, any quantitative estimations of the fate (consumed, trampled, *etc.*) of the OD residue could not be made. Interestingly enough, more OD residue disappeared during the periods of nonuse in HPSDG than during periods of occupation. The greatest nonuse period decline was 8.0 kg/ha/d occurring between cycles 1 and 2 compared to a maximum decline of 5 kg/ha/d during occupation in cycle 4. Immediately after a subunit occupation however, visible grazed and ungrazed subunit contrasts were present and these included many old-dead stems that were disturbed and uprighted by animal movement. This could have resulted in the overestimation of the OD component after subunit occupation.

End-of-season RD standing crop was 1648 and 1171 kg/ha in the ungrazed and RSG treatments respectively. In these two treatments, none was categorized as live (Figures 4 and 5). HPSDG end-of-season L + RD standing crop, estimated immediately after occupation in the selected subunits during the fourth (final) cycle was 1222 kg/ha (Figure 6). The live component observed in the HPSDG residue after cycle 4 occupation was primarily from the subunits (2 and 6) that were grazed early in this last cycle. Visual observations made in HPSDG on September 20, revealed no live material to be

present just as there was none observed in RSG and the ungrazed treatment on that same date. Dry conditions in August and September combined with above normal temperatures in August hastened the maturity of the warm season shortgrasses and prevented regrowth of cool season species in September (Figure 1).

Forage utilization in the RSG replicate pastures was estimated in conjunction with the standing crop estimates made at the midpoints of the four HPSDG cycles and at the end of the grazing season. The apparent cumulative percent use of western wheatgrass, shortgrasses and all species combined and the total L + RD standing crop is plotted against the cumulative grazing days in Figure 7. Estimated end-of-season use was 38.6, 36.5 and 30.4% for the western wheatgrass, total and shortgrasses categories, respectively. Apparent use remained quite low through day 64 (HPSDG cycle 3 midpoint) as use was difficult to detect or was masked by rapidly growing vegetation and by regowth of vegetation that had been previously grazed. Use sharply increased during the last half of the season corresponding to the declining growth rates of the maturing vegetation (Figure 7). A third set of livestock (1 calf and 3 lambs) was added on day 48 but two sets were removed on day 96 as to prevent an excessive terminal forage use level.

Estimated end-of-season forage use in HPSDG was 40.2, 38.3 and 35.8% for the western wheatgrass, total and short-

grass categories, respectively. The HPSDG shortgrass use estimate (35.8%) was greater than the RSG shortgrass use estimate (30.4%) ($P<.05$). This greater use of shortgrasses was also observed in 1983 and suggests a greater efficiency of harvest of the total complement of vegetation offered and in part, could explain why stocking rates were able to be maintained at a higher level in HPSDG was higher (Volesky *et al.* 1986). Two sets of livestock were used through cycles 1 and 2 but this was reduced to one set for cycles 3 and 4.

The apparent cumulative percent use of these three categories and total L + RD standing crop dynamics are presented in Figure 8 and Table 2. The dramatic flucuations in the before and after apparent cumulative percent use of all three forage categories are a result of growth and regrowth that occurred during the nonuse periods. Total cycle 1 use was estimated at about 13% but recovery during its nonuse period (16 d) resulted in a before cycle 2 occupation estimate of 0%. This occurred to a lesser extent between cycles 2 and 3 and to the least extent between cycles 3 and 4 at which time many species were mature. There was however, a slight increase in standing crop between cycles 3 and 4 (Figure 8 and Table 2).

Differences in regrowth and recovery between early and late grazed subunits were observed. At the start of cycle 3 (July 4) recovery of vegetation in the immediate subunits about to be grazed appeared quite favorable. These

first few subunits had last been grazed starting June 1 (plus 2 days/advancing subunit). The last few subunits to be grazed during the cycle (previously grazed about June 20 plus 2 days/advancing subunit) did not however, have recovery equal to that of the earlier grazed subunits. This was due to progressively drier conditions starting in late June and the maturation and senescence of western wheatgrass. This was also observed in 1983 and could be considered to be a common management problem in all short-duration systems that are operated in areas or during periods that have substantial changes in vegetative growth rates.

The amount of L + RD standing crop disappearance was least during occupation in cycle 1 and greatest in cycle 4. Estimates of individual cycle use were comparable with the percent of standing crop disappearance with the exception of western wheatgrass during cycles 1 and 2 (Table 2). Though use of annual grasses was not specifically estimated but rather included in the total, there was a 32 kg/ha disappearance of them during cycle 1 which was greater than the cycle 1 disappearance of western wheatgrasses and shortgrasses combined. This suggests substantial use of the annual grasses, particularly early in the season and corresponds with the large amounts found in the animal diets (Volesky *et al.* 1986).

ANPP in the ungrazed treatment, as calculated by the summation of the peak L + RD standing crops of five species

groups and one individual species was 2144 kg/ha. This value was only 3% higher than the peak L + RD standing crop. The individual species, western wheatgrass accounted for 52% of the ANPP followed by shortgrasses (29%), annual grasses (9%), forbs (5%), sedges (4%) and other perennial grasses (1%). This percentage breakdown by species or species group was also very similar to that of the peak L + RD standing crop. ANPP calculated by the summation of only peak L standing crop was 21% less than using peak L + RD. This is consistent with other studies (Singh *et al.* 1975; Lauenroth *et al.* 1987) comparing these two methods.

As exclosures or cages were not used in the two grazing system treatments because of their limited size, ANPP could not be estimated in RSG. In HPSDG however, standing crop was estimated immediately before and after occupation in the selected subunits and because occupation length was relatively short (1 to 3d), the summation of the positive changes in standing crop incurred during the nonuse periods could be considered a valid estimate of ANPP. This value would also be equal to the summation of the cyclic L + RD disappearance plus the after cycle 4 (end of season) L + RD standing crop assuming there were no declines during the nonuse periods (Table 2). ANPP in HPSDG as estimated with this method using the total L + RD standing crop was 1848 kg/ha (Table 2). Because standing crop of annual grasses, forbs and sedges declined during the nonuse period between cycles 3 and 4, the

total of the cyclic summations of the positive changes in standing crop of each species group gives an even more appropriate ANPP estimate of 1940 kg/ha.

This estimate of ANPP in HPSDG (1940 kg/ha) is 9% less than the ungrazed treatment estimate (2144 kg/ha), suggesting that in these studies, the greater attained stocking rates in HPSDG compared to RSG were probably not due to an increase in ANPP but rather due to greater use of shortgrasses and the improved spatial distribution of grazing observed in short-duration systems. This however, cannot be conclusive as no estimate of RSG ANPP was available in these studies.

Table 1. Least-squares means and standard errors of end-of-season use (%) estimates of midgrasses and shortgrasses in RSG and HPSDG systems, 1983.

MIDGRASSES[1]

Treatment	Strata: Mid[3]	Strata: Mixed[4]	Treatment Means[6] ±SE
RSG	41.4	45.5	43.5[A] ±0.9
HPSDG	37.7	47.1	42.4[A] ±0.9
Strata Means[6] ±SE	39.6[A] ±1.1	46.3[B] ±0.6	

SHORTGRASSES[2]

Treatment	Strata: Mid[3]	Strata: Mixed[4]	Strata: Short[5]	Treatment Means[6] ±SE
RSG[7]	17.2[a]	20.3[a]	33.9[a]	23.8[A] ±0.9
HPSDG[7]	22.7[b]	32.1[b]	55.7[b]	36.8[B] ±1.1
Strata Means[6] ±SE	19.9[A] ±1.2	26.2[B] ±0.7	44.8[C] ±1.6	

[1] Western wheatgrass was the predominant midgrass.
[2] Buffalograss and blue grama were the predominant shortgrasses.
[3] Mid strata refers to areas dominated by midgrasses.
[4] Mixed strata refers to areas with about equal proportion of midgrasses and shortgrasses.
[5] Short strata refers to areas dominated by shortgrasses.
[6] Within forage category, treatment or strata means with unlike letters differ, (P<.05).
[7] Treatment within strata means with unlike letters differ, (P<.05).

Table 2. Live plus recent-dead standing crop and apparent cumulative forage use immediately before and after subunit occupation for each cycle in HPSDG, 1984.[1]

TOTAL[2]

Cycle	Occupation Days	Occupation Sets[3]	Standing Crop Before (kg/ha)	Standing Crop After (kg/ha)	Disappearance (kg/ha)	Disappearance (%)	+ Change Standing Crop[4]	Apparent Cumulative Use Percent Before	Apparent Cumulative Use Percent After	Apparent Cumulative Use Percent Cycle[5]
1	1	2	656	589	67	10.2	656	0	13.1	13.1
2	2	2	920	746	174	18.9	331	0	23.6	23.6
3	2	1	1452	1317	135	9.3	706	7.3	19.6	12.3
4	3	1	1472	1222	250	17.0	155	19.6	38.3	19.7
Totals					626		1848			

WESTERN WHEATGRASS

Cycle	Occupation Days	Occupation Sets[3]	Standing Crop Before (kg/ha)	Standing Crop After (kg/ha)	Disappearance (kg/ha)	Disappearance (%)	+ Change Standing Crop[4]	Apparent Cumulative Use Percent Before	Apparent Cumulative Use Percent After	Apparent Cumulative Use Percent Cycle[5]
1	1	2	252	236	16	6.4	252	0	13.2	13.2
2	2	2	324	272	52	16.1	88	0	28.7	28.7
3	2	1	564	512	52	9.2	292	7.9	21.8	13.9
4	3	1	732	604	128	17.5	220	16.5	40.2	23.7
Totals					248		852			

(continued)

Table 2 (continued)

SHORTGRASSES

Occupation Cycle	Occupation Days	Occupation Sets[3]	Standing Crop Before (kg/ha)	Standing Crop After (kg/ha)	Disappearance (kg/ha)	Disappearance (%)	+ Change Standing Crop[4]	Apparent Cumulative Use Percent Before	Apparent Cumulative Use Percent After	Apparent Cumulative Use Percent Cycle[5]
1	1	2	144	136	8	5.6	144	0	7.4	7.4
2	2	2	280	240	40	14.3	144	0	17.4	17.4
3	2	1	480	432	48	10.0	240	6.2	16.4	10.2
4	3	1	452	372	80	17.7	20	14.1	35.8	21.7
Totals					176		548			

[1] Standing crop and use estimates are means of five plots per subunits 2, 6, 10 and 14 per replication.

[2] Live + recent-dead of all species.

[3] 1 set = 1 calf and 3 lambs.

[4] Before residue of cycle (N) minus after residue of cycle (N-1).

[5] After minus before apparent cumulative percent use.

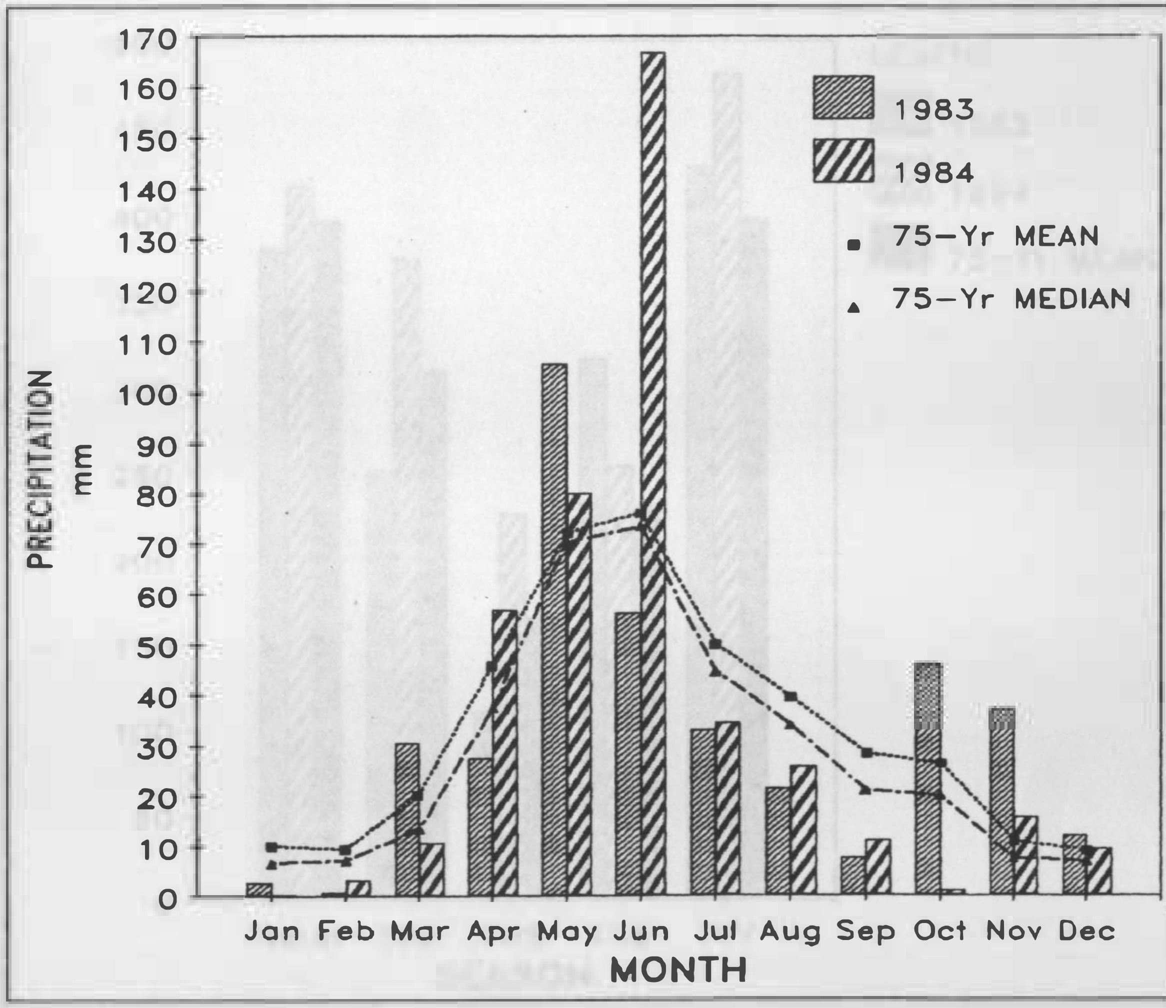

Figure 1. 1983, 1984 and 75-year means and medians of monthly precipitation at the Cottonwood Range and Livestock Research Station.

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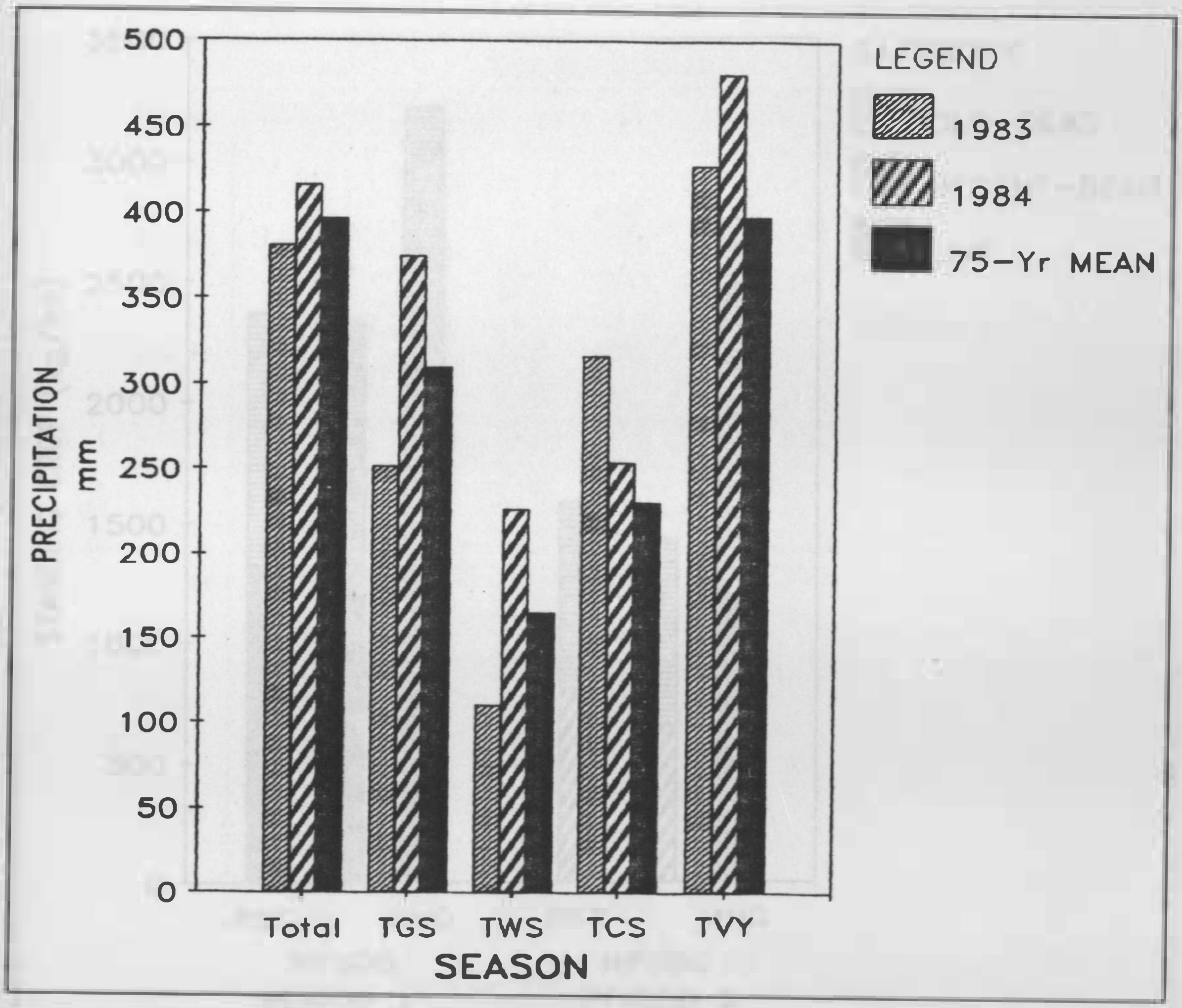

Figure 2. 1983, 1984 and 75-year means of total and seasonal precipitation at the Cottonwood Range and Livestock Research Station.

Total = Total annual.
TGS = Total Growing Season (April through September).
TWS = Total Warm Season (June, July and August).
TCS = Total Cool Season (previous September through May).
TVY = Total Vegetative Year (previous September through August).

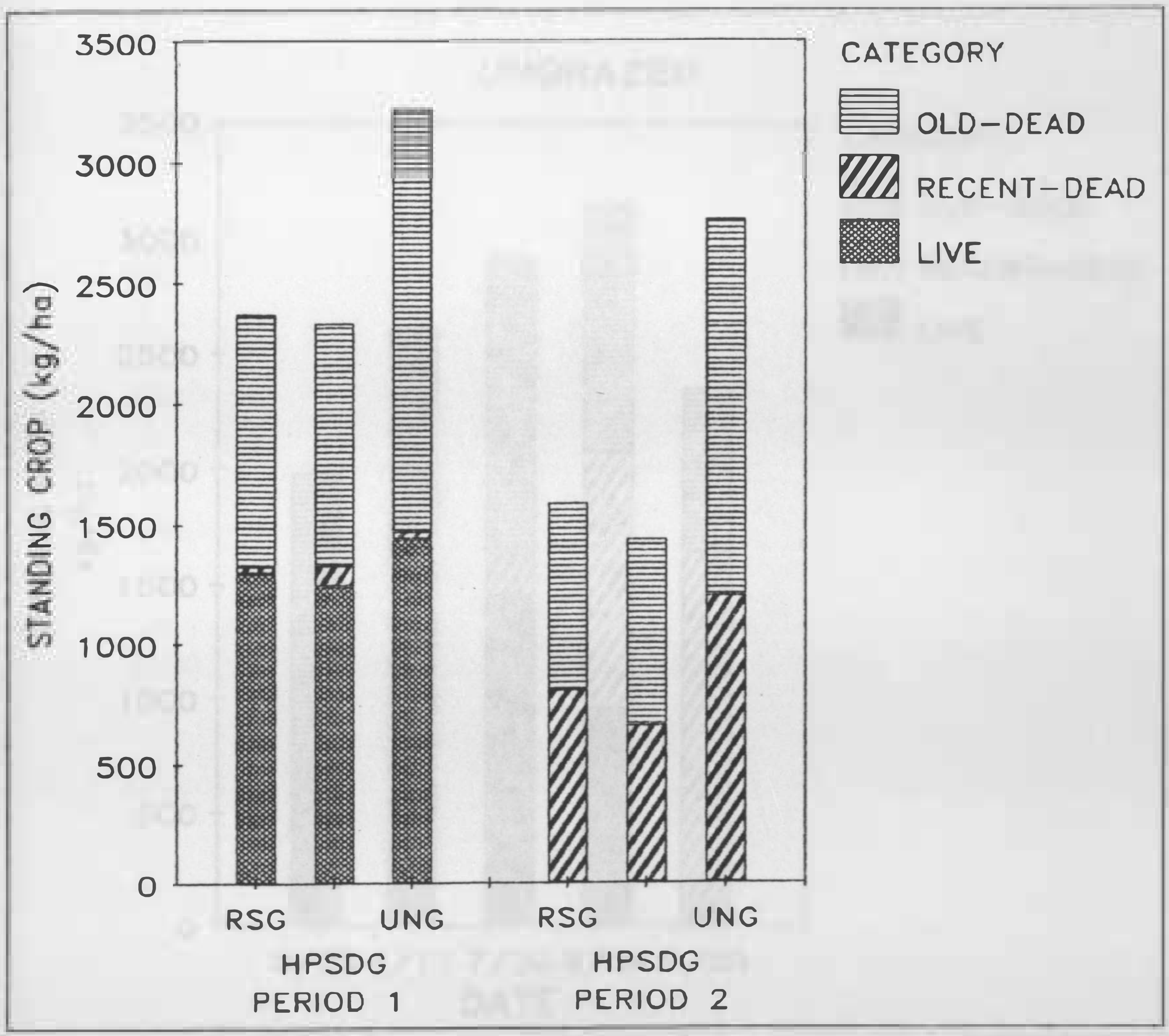

Figure 3. Live, recent-dead and old-dead standing crop in RSG, HPSDG and ungrazed (UNG) treatments, 1983.

Period 1 = June 28 to July 5.
Period 2 = Sept 29 to October 3 (end of season).

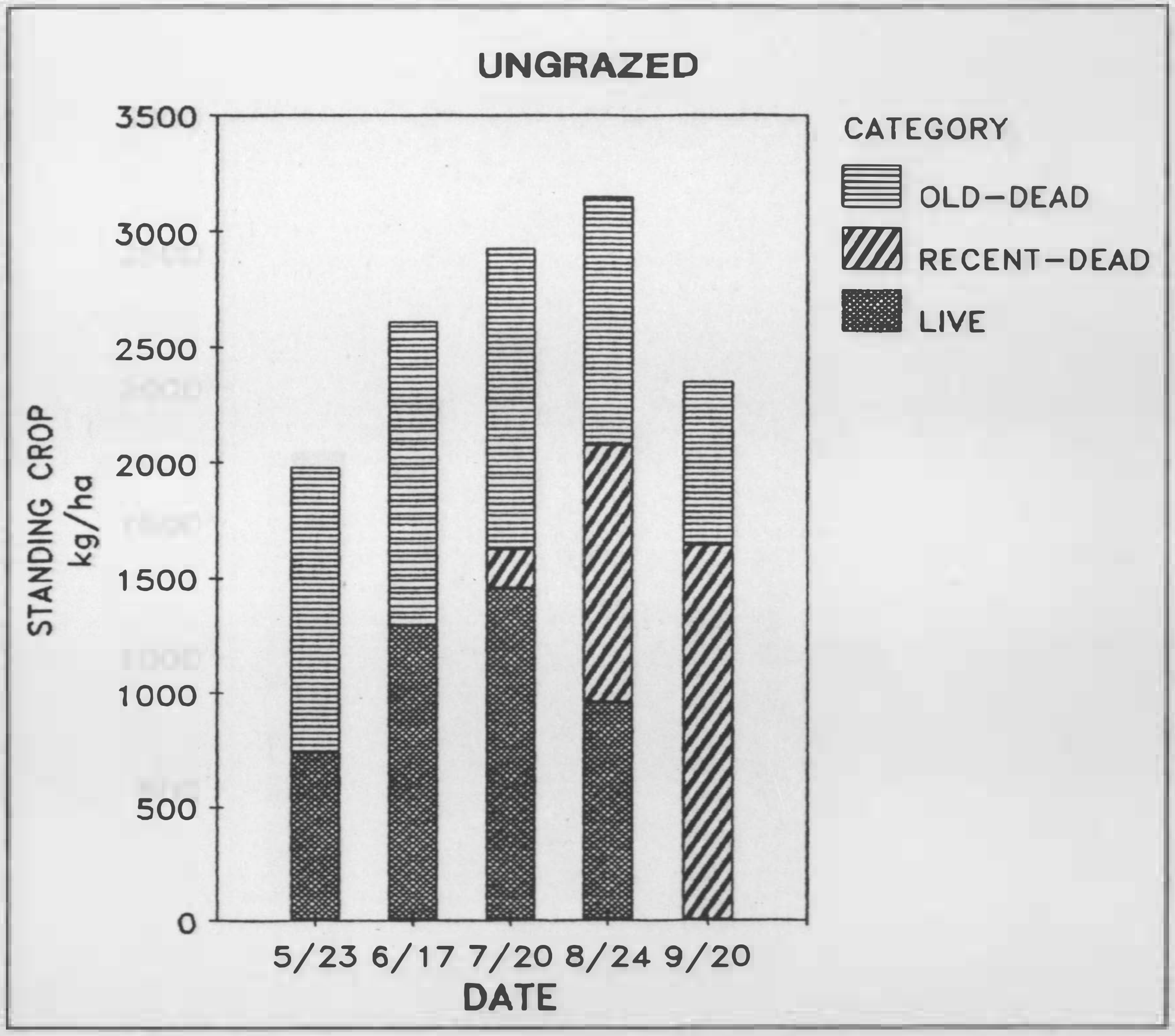

Figure 4. Live, recent-dead and old-dead standing crop at five sampling dates in an ungrazed treatment, 1984.

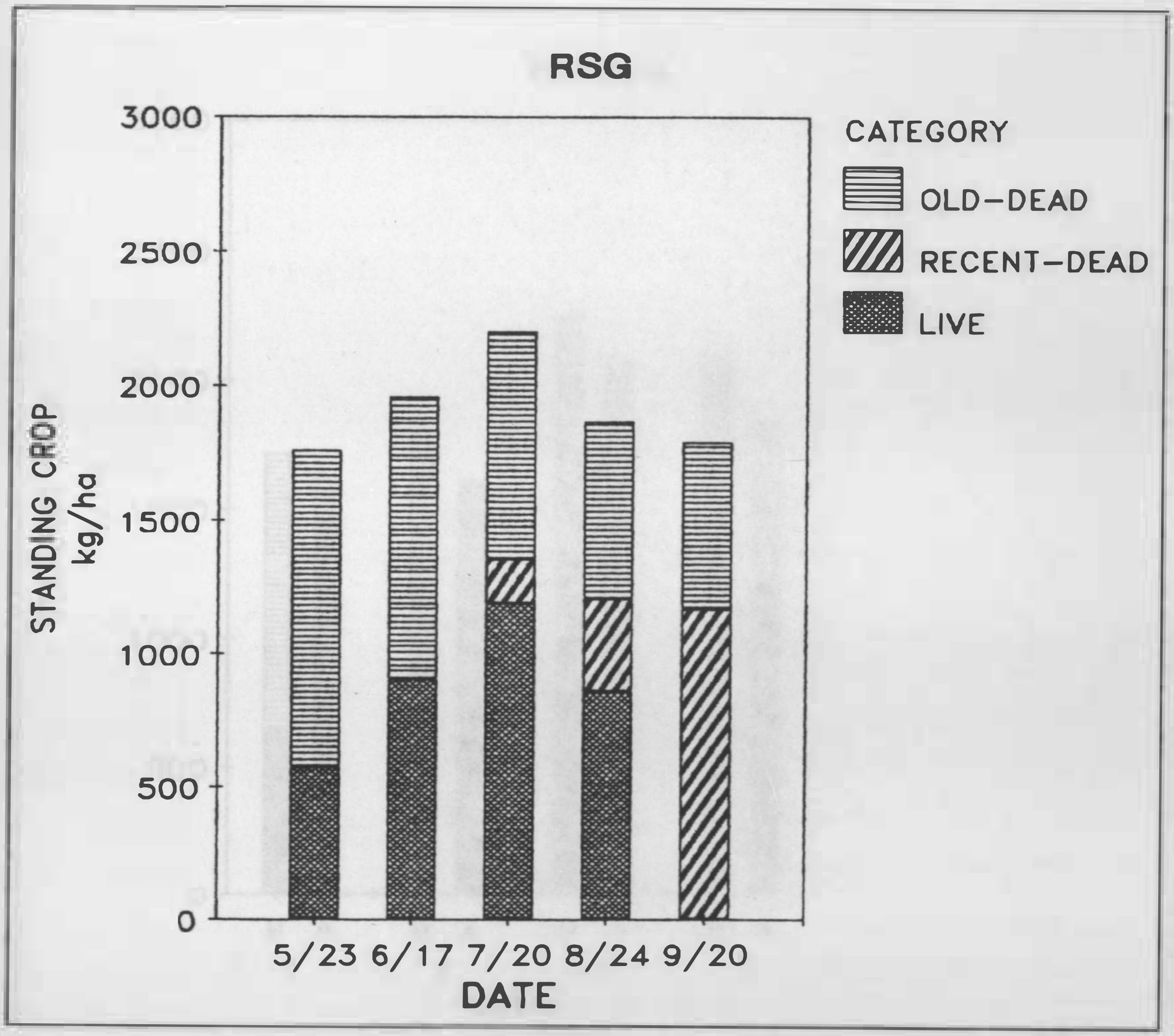

Figure 5. Live, recent-dead and old-dead standing crop at five sampling dates in RSG treatment, 1984.

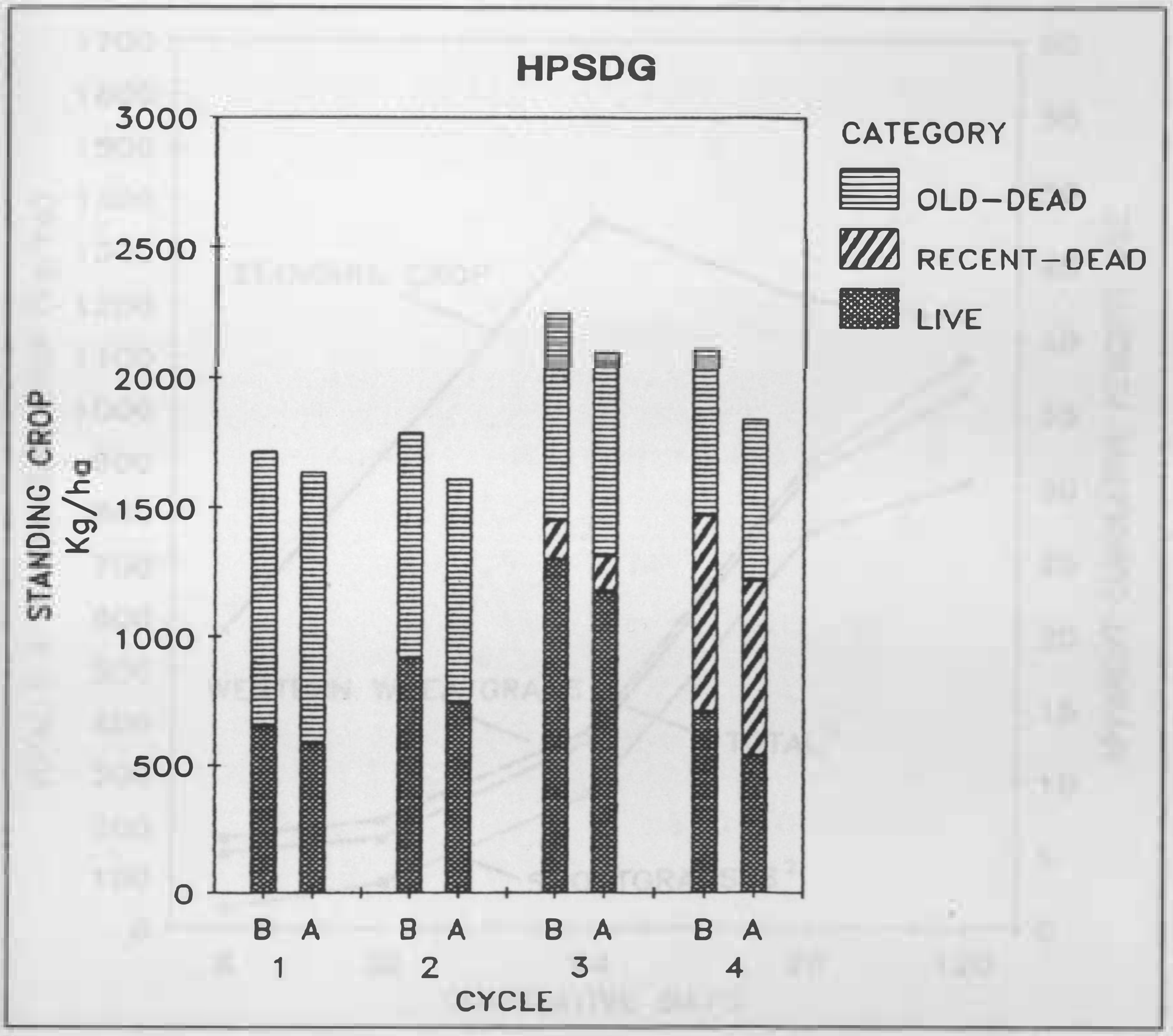

Figure 6. Live, recent-dead and old-dead standing crop immediately before (B) and after (A) subunit occupation in HPSDG, 1984.[1]

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[1] Values are means of five plots per subunits 2, 6, 10 and 14 per replication.

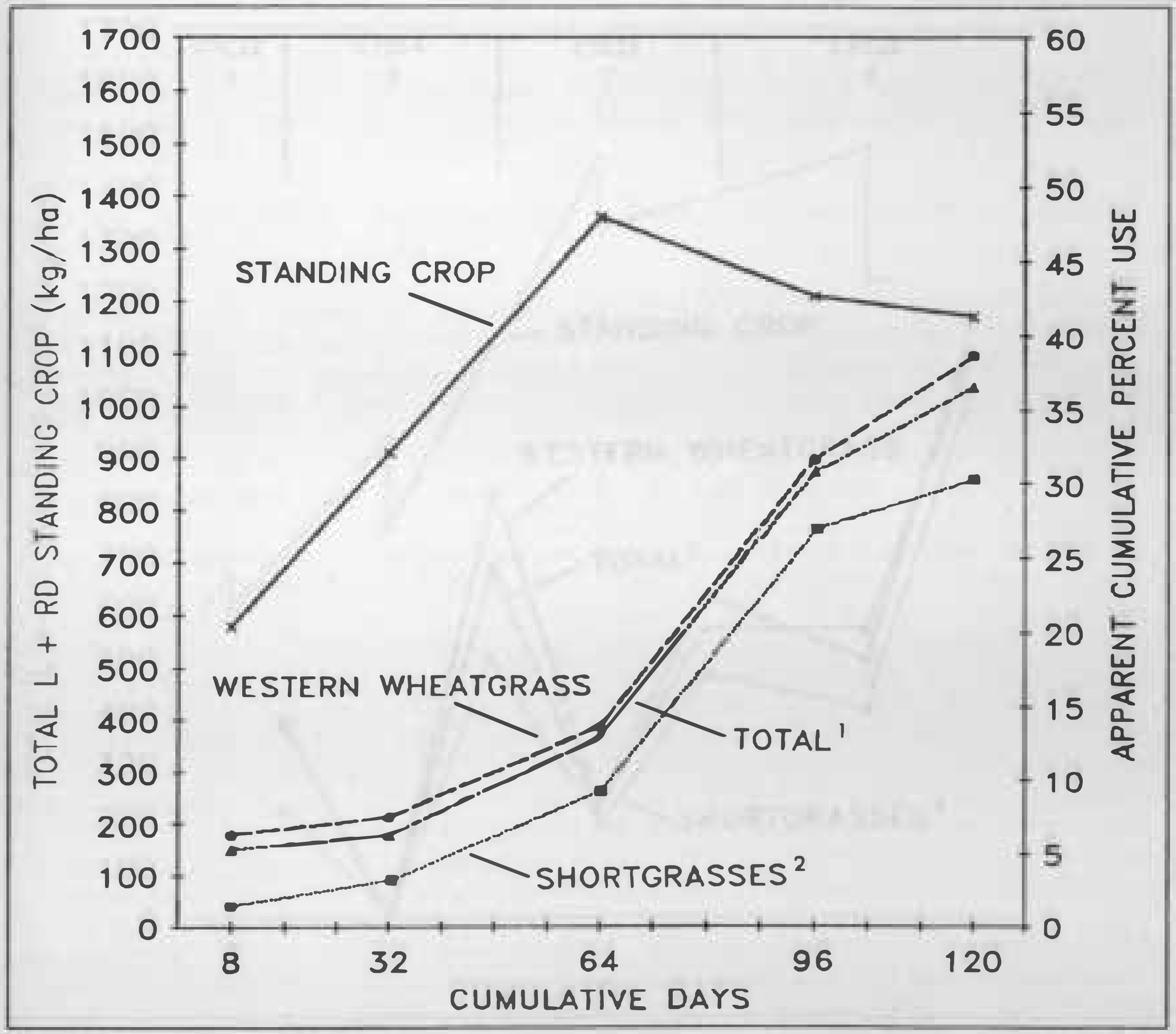

Figure 7. Total live plus recent-dead standing crop dynamics and apparent cumulative percent use of western wheatgrass, shortgrasses and total components in RSG, 1984.

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[1] L + RD of all species.
[2] Buffalograss and blue grama.

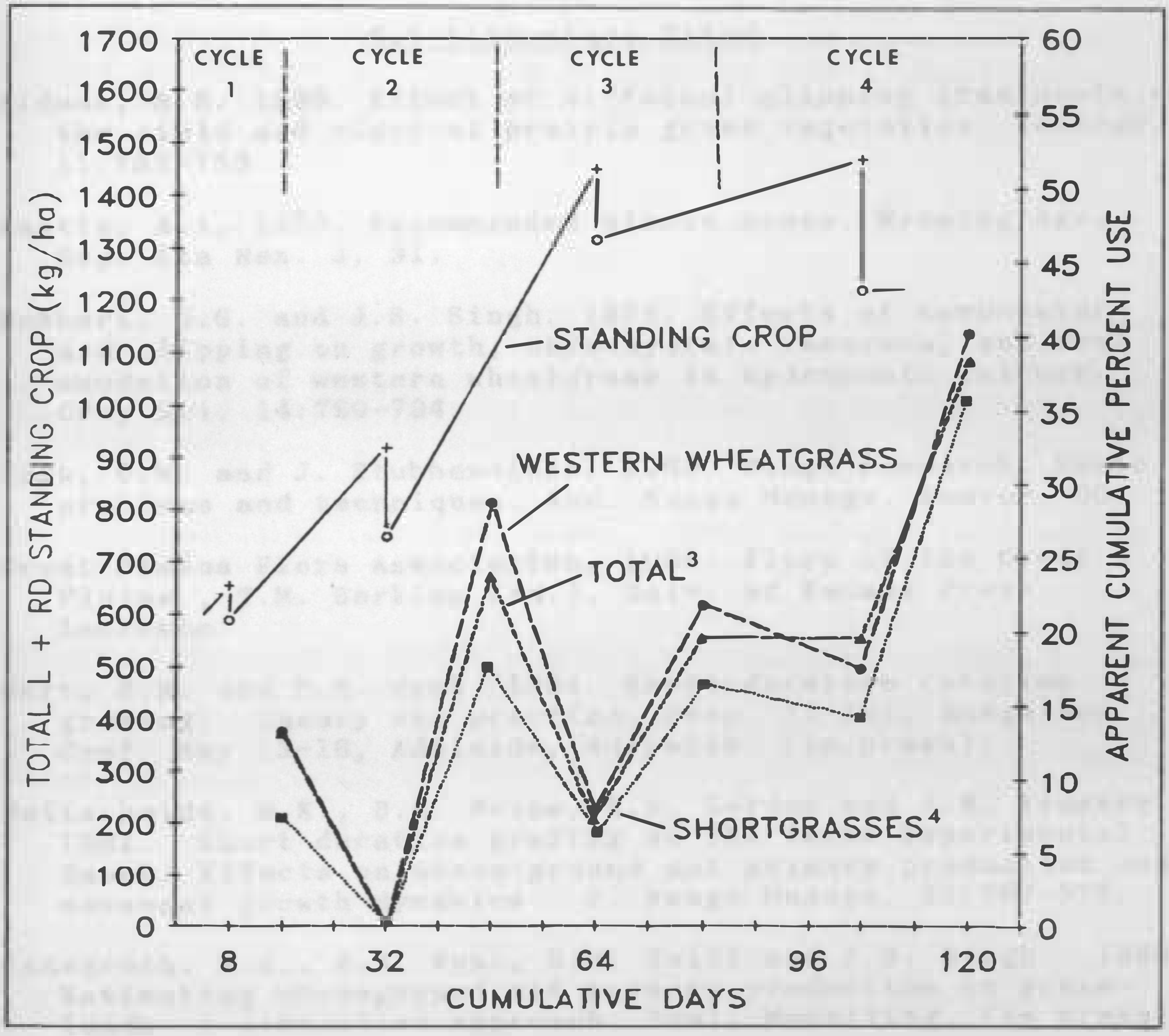

Figure 8. Total live plus recent-dead standing crop dynamics and apparent cumulative percent use of western wheatgrass, shortgrasses and total components in HPSDG, 1984.[1,2]

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[1] Mean standing crop estimated immediately before (+) and after (−) occupation in subunits 2, 6, 10 and 14 is plotted at cycle midpoints.

[2] Before and after apparent cumulative percent use plotted at cycle midpoints and ends respectively.

[3] L + RD of all species.

[4] Buffalograss and blue grama.

6.5 Literature Cited

Aldous, A.E. 1930. Effect of different clipping treatments on the yield and vigor of prairie grass vegetation. Ecology. 11:752-759.

Beetle, A.A. 1970. Recommended plants names. Wyoming Agr. Exp. Sta Res. J. 31.

Bokhari, U.G. and J.S. Singh. 1974. Effects of temperature and clipping on growth, carbohydrate reserves, and root exudation of western wheatgrass in hydroponic culture. Crop Sci. 14:790-794.

Cook, C.W. and J. Stubbendieck. 1986. Range research: basic problems and techniques. Soc. Range Manage. Denver, CO.

Great Plains Flora Association. 1986. Flora of the Great Plains., T.M. Barkley (ed.), Univ. of Kansas Press. Lawrence.

Hart, R.H. and P.S. Test. 1984. Short-duration rotation grazing: theory vs. practice. Proc. II Int. Rangeland Conf. May 13-18, Adelaide, Autralia. (in press).

Heitschmidt, R.K., D.L. Price, R.A. Gorden and J.R. Frasure. 1982. Short duration grazing at the Texas Experimental Ranch: Effects on above-ground net primary production and seasonal growth dynamics. J. Range Manage. 35:367-372.

Lauenroth, W.K., H.W. Hunt, D.M. Swift and J.S. Singh. 1986. Estimating aboveground net primary production in grasslands: A simulation approach. Ecol. Modelling. (in press).

Lewis, J.K., L.S. Bilger, D.M. Engle, T.P. Weber and L. Blome. 1982. Comparison of high-performance short-duration and repeated-seasonal grazing in the northern mixed prairie. p.193-196. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

McNaughton, S.J. 1979. Grazing as an optimization process: Grass ungulate relationships in the Serengeti. Amer. Natur. 113:691-703.

McNaughton, S.J., L.L. Wallace and M.B. Coughenour. 1983. Plant adaptation in an ecosystem context: Effects of defoliation, nitrogen and water on growth of an African C_4 sedge. Ecology. 64:307-318.

Singh, J.S., W.K. Lauenroth and R.K. Steinhorst. 1975. Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. Bot. Rev. 41:182-232.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. (2nd ed.) McGraw-Hill Book Co., New York.

U.S. Weather Bureau. 1967. Climatological summary: Cottonwood, South Dakota. No. 14.

U.S.D.A.-S.C.S. Staff. 1987. Soil survey of Jackson County, South Dakota. U.S. Dept. Agr. Soil Conser. Service (in press).

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

Volesky, J.D., J.K. Lewis and C.H. Butterfield. 1986. A comparison of high-performance short-duration and repeated-seasonal grazing systems: Effect on performance of calves and lambs and on indices of diet. J. Range Manage. (manuscript submitted).

7.0 ADDITIONAL RESULTS AND INTEGRATIVE DISCUSSION

7.1 Livestock

Repeated measures analysis of variance of calf and lamb weight gain and fecal nitrogen data, discussed in Section 5.4, are given in Appendix Tables 2, 3 and 4.

7.1.1 Stocking Rates and Management

The sets of livestock (1 calf and 3 lambs/set) used and resultant stocking rates (AUMs/ha) for each cycle or period during 1983 and 1984 were given in Section 5.4, Table 3. The stocking rate data are also expressed graphically in Figure 2.

Two sets were used during cycles 1 and 2 in both treatments during both years. In 1983, one additional set was placed in both treatments at the start of cycle 3, but one set was later removed from HPSDG because forage use levels were becoming excessive. At the start of cycle 3 (July 18), regrowth and recovery of vegetation in the immediate subunits about to be grazed appeared quite favorable. These first few subunits had last been grazed starting June 15 (plus 2 days/advancing subunit). The last few subunits to be grazed during cycle 3 (previously grazed about July 6 plus 2 days/advancing subunit) did not however, have regrowth and recovery anywhere comparable to that of the early grazed subunits. This was due to progressively drier conditions that

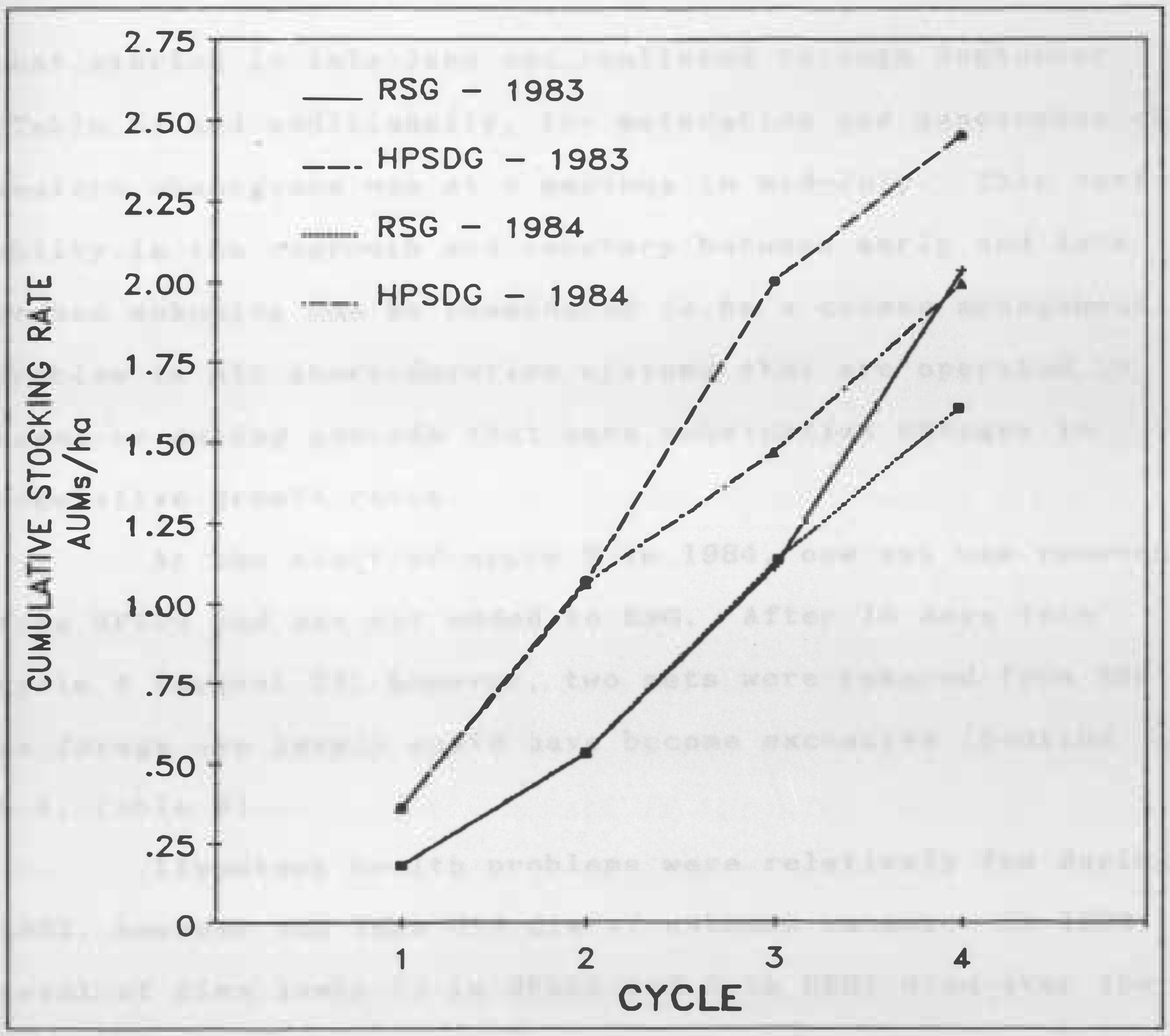

Figure 2. Comparison of RSG and HPSDG cumulative stocking rate at the end of each HPSDG cycle, 1983 and 1984.

that started in late-June and continued through September (Table 6) and additionally, the maturation and senescence of western wheatgrass was at a maximum in mid-July. This variability in the regrowth and recovery between early and late grazed subunits can be considered to be a common management problem in all short-duration systems that are operated in areas or during periods that have substantial changes in vegetative growth rates.

At the start of cycle 3 in 1984, one set was removed from HPSDG and one set added to RSG. After 16 days into cycle 4 (August 22) however, two sets were removed from RSG as forage use levels would have become excessive (Section 5.4, Table 3).

Livestock health problems were relatively few during 1983, however one lamb did die of unknown causes. In 1984, a total of five lambs (3 in HPSDG and 2 in RSG) died over the course of the grazing season. Results of a necropsy on one individual indicated the lamb had a mild non-suppurative meningitis. The four others probably had this affliction as symptoms prior to death were very similar.

There were some livestock adaptation problems to the physical constraints of the HPSDG system. The livestock, especially the calves, were initially nervous because the electric fences were in relatively close proximity. During the first couple of weeks, livestock tended to be quite

nervous and apprehensive during the scheduled subunit to subunit movements but this eventually became an unstressful routine. Many of the problems encountered may have been due in part, to the relatively small size of the experimental pastures.

There appeared to be more social interaction between calves and lambs in HPSDG, probably due to the limited area they had within a subunit. More often then not, calves and lambs in RSG tended to remain in their own species group relatively far away from each other.

7.1.2 Wool Growth

Means and standard errors of the 1983 and 1984 wool growth rates are given in Table 18 and the repeated measures analysis of variance of the data in Appendix Table 5. During 1983, season-long wool growth rates averaged 0.31 and 0.32 mm/d for lambs in the RSG and HPSDG treatments respectively. In 1984, season-long growth rates were 0.28 and 0.26 mm/d for RSG and HPSDG respectively. During 1983, the only significant effect was a period effect in which period 1 average daily wool growth was greater than the other three periods ($P<.001$). During 1984, the treatment x period interaction was approaching significance, as period 2 wool growth rates declined in HPSDG and increased in RSG from previously equal period 1 growth rates ($P=.06$). There was also a significant period x replication interaction ($P=.03$) (Appendix Table 5).

The wool growth rates and periodic changes of the

rates do not correlate well with average daily gains or fecal nitrogen indicating that in these studies, wool growth rates were not a good measure of plané of nutrition or changes in nutrition. This is most apparent during period 1 of 1983 in which mean wool growth rate was the highest (0.43 mm/d) and ADG was the lowest (5.0 g/d). Other workers (Sharkey *et al.*, 1962; Langlands and Wheeler, 1968) though, have shown a relationship to exist between plane of nutrition and wool growth. Carry-over effects of previous level of nutrition probably did not vary enough to affect wool growth rates. Error in the measurement of length of new wool growth may have been an important source of error. The wool paint did not always dry quickly and after several days could still "run" onto newly grown wool. Variations in crimp and the extent of which the wool was stretched when measuring may have added additional sampling error. The coefficient of variation was 18.7 and 16.0% in 1983 and 1984, respectively.

Table 18

Means and standard errors of average daily wool growth (mm) of lambs in RSG and HPSDG systems, 1983 and 1984.

	1983			1984		
Period[1]	RSG	HPSDG	Period Means[2] ±SE	RSG	HPSDG	Period Means[2] ±SE
1	0.44	0.43	0.43[a] ±0.02	0.26	0.26	0.26[a] ±0.02
2	0.27	0.29	0.28[b] ±0.02	0.30	0.23	0.26[a] ±0.02
3	0.28	0.32	0.30[b] ±0.04	0.29	0.27	0.28[a] ±0.03
4	0.25	0.21	0.23[b] ±0.03	0.28	0.28	0.28[a] ±0.03
Means[3] ±SE	0.31[A] ±0.01	0.32[A] ±0.01		0.28[A] ±0.01	0.26[A] ±0.01	

[1] Periods correspond to the four HPSDG cycles of rotation.
[2] Within years, period means with unlike letters differ, ($P<.05$).
[3] Within years, season means with unlike letters differ, ($P<.05$).

7.1.3 Water Intake

The 1983 and 1984 water intake measurements were expressed in liters/animal unit/day (l/AU/d) and summarized for eight periods of approximately 15 days in length. Calves and lambs drank from a common water source, thus no specific livestock class intake estimates could be derived. AU's were based on the animal unit equivalents (AUE) for the calves and lambs and these AUE's were increased corresponding to livestock growth over the course of the grazing season. Because there was no distinction between calf or lamb water intake, water intake data were not used to generate forage intake estimates. The relationship of water consumed per weight of forage dry matter at various temperatures is different for

the two livestock classes. As a result, three different analytical procedures were used on these water intake data. First, analysis of variance was used to analyze the effect of treatment, period and replication on water intake; second, multiple regression was used to examine the effect of temperature and forage dry matter on water intake; and lastly, analysis of covariance was used to adjust for the effect of temperature and forage dry matter.

7.1.3.1 Analysis of Variance

The 1983 water intake data are presented in Figure 3 and the analysis of variance in Appendix Table 6. There was substantial variation in intake between replications in both RSG and HPSDG as indicated by the significant replication effect ($P<.01$). Error in the measurement of intake probably occurred as the float-type waterers sometimes leaked or floats stuck, limiting water flow into the bowl and accessibility to the livestock. Forage dry matter was also estimated across all replicate pastures and conceivably there could have been some difference in forage dry matter between treatments and replications. Treatment means of water intake were not significantly different ($P>.05$) (33.6 in RSG vs. 32.6 l/AU/d in HPSDG, SE $\pm$1.6). There was a significant period effect with water intake being the highest during periods 3, 4, 5 and 6 and the least during periods 1 and 8 ($P<.001$) (Figure 3).

During 1984, treatment means of water intake were

again not different with 30.8 and 30.4 l/AU/d (SE ±0.7) being consumed in RSG and HPSDG respectively (P>.05). There was a significant treatment x period interaction where intake tended to be greater in HPSDG during periods 2 and 3 but greater in RSG during periods 5 and 6 (P<.001) (Figure 4 and Appendix Table 6). A significant period effect were also present with intake being the greatest during period 6 and the least during period 1 (P<.001).

7.1.3.2 Relationship of Water Intake, Forage Dry Matter and Temperature

Stepwise multiple regression analyses were to evaluate the relationship of forage dry matter, mean air temperature and water intake. The variables are graphed by periods in Figures 5 (1983) and 6 (1984). Forage dry matter data were collected every seven to 10 days during the grazing seasons and weighted averages computed to correspond with the 15 day periods for which water intake data were available. Mean air temperatures were calculated as the average of the daytime high and the night-time low for each day of the 15 day periods.

Forage dry matter increased with forage maturity and as the grazing seasons progressed. During 1983, forage dry matter was lowest (65.5%) during period 1 (early June) and highest (90.1%) during period 8 (late September). Similarly in 1984, dry matter was lowest (56.6%) during period 1 (late

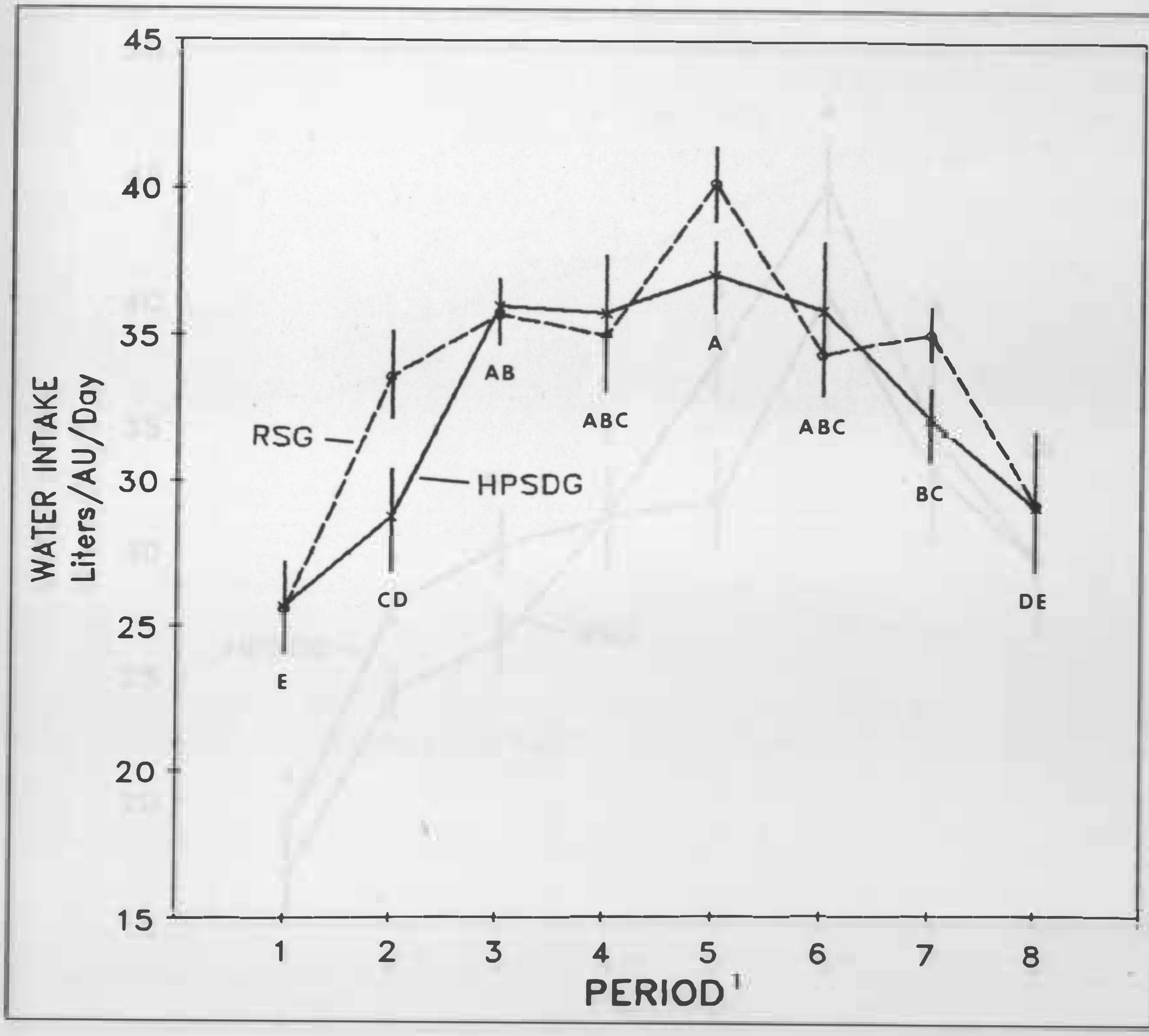

Figure 3. Water intake of calves and lambs in RSG and HPSDG systems during 1983.

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[1] Period 1 = May 29 - June 13
2 = June 14 - June 29
3 = June 30 - July 14
4 = July 15 - July 30
5 = July 31 - August 14
6 = August 15 - August 30
7 = August 31 - September 14
8 = September 15 - October 4

[ABCDE] Period means not sharing a common letter differ ($P<.05$). Vertical bars represent the standard error of the treatment by period means.

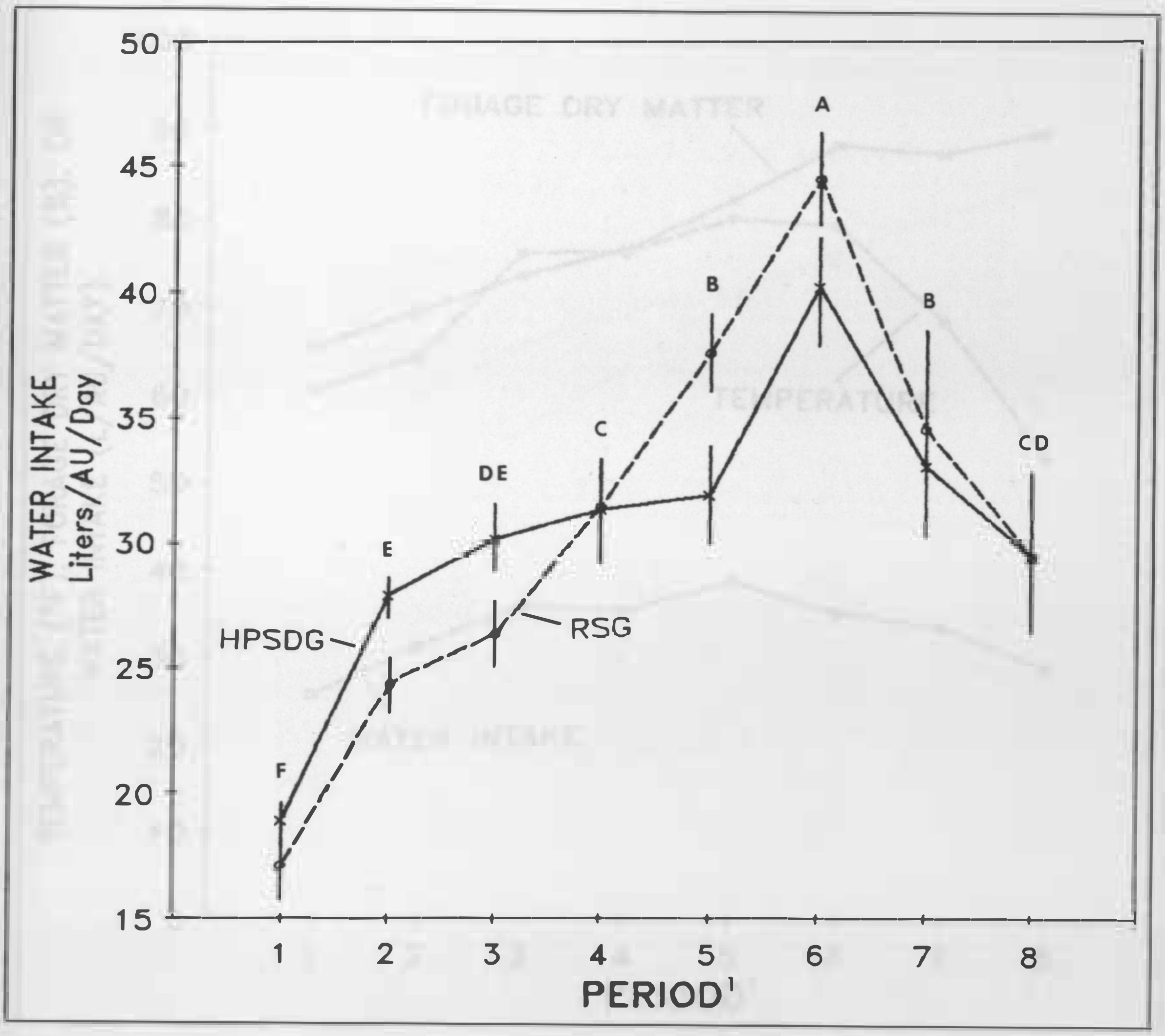

Figure 4. Water intake of calves and lambs in RSG and HPSDG systems during 1984.

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[1] Period 1 = May 15 - May 28
2 = May 29 - June 14
3 = June 15 - June 30
4 = July 1 - July 16
5 = July 17 - August 1
6 = August 1 - August 15
7 = August 16 - August 31
8 = September 1 - September 16

ABCDEF Period means not sharing a common letter differ, (P<.05).

Vertical bars represent the standard error of the treatment by period means.

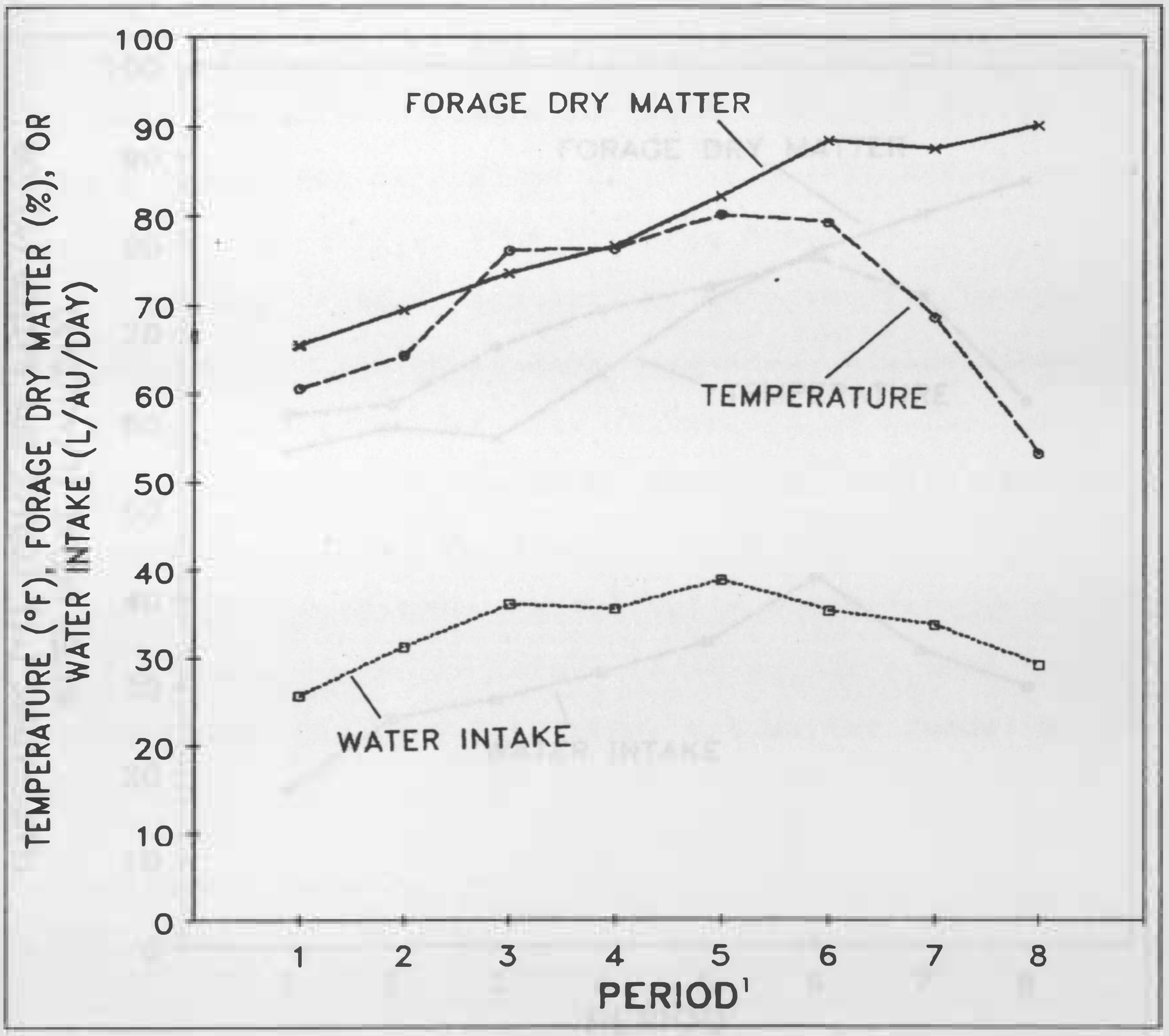

Figure 5. Water intake (l/AU/d), mean air temperature (°F) and forage dry matter (%) by periods, 1983.

[1] Period 1 = May 29 - June 13
2 = June 14 - June 29
3 = June 30 - July 14
4 = July 15 - July 30
5 = July 31 - August 14
6 = August 15 - August 30
7 = August 31 - September 14
8 = September 15 - October 4.

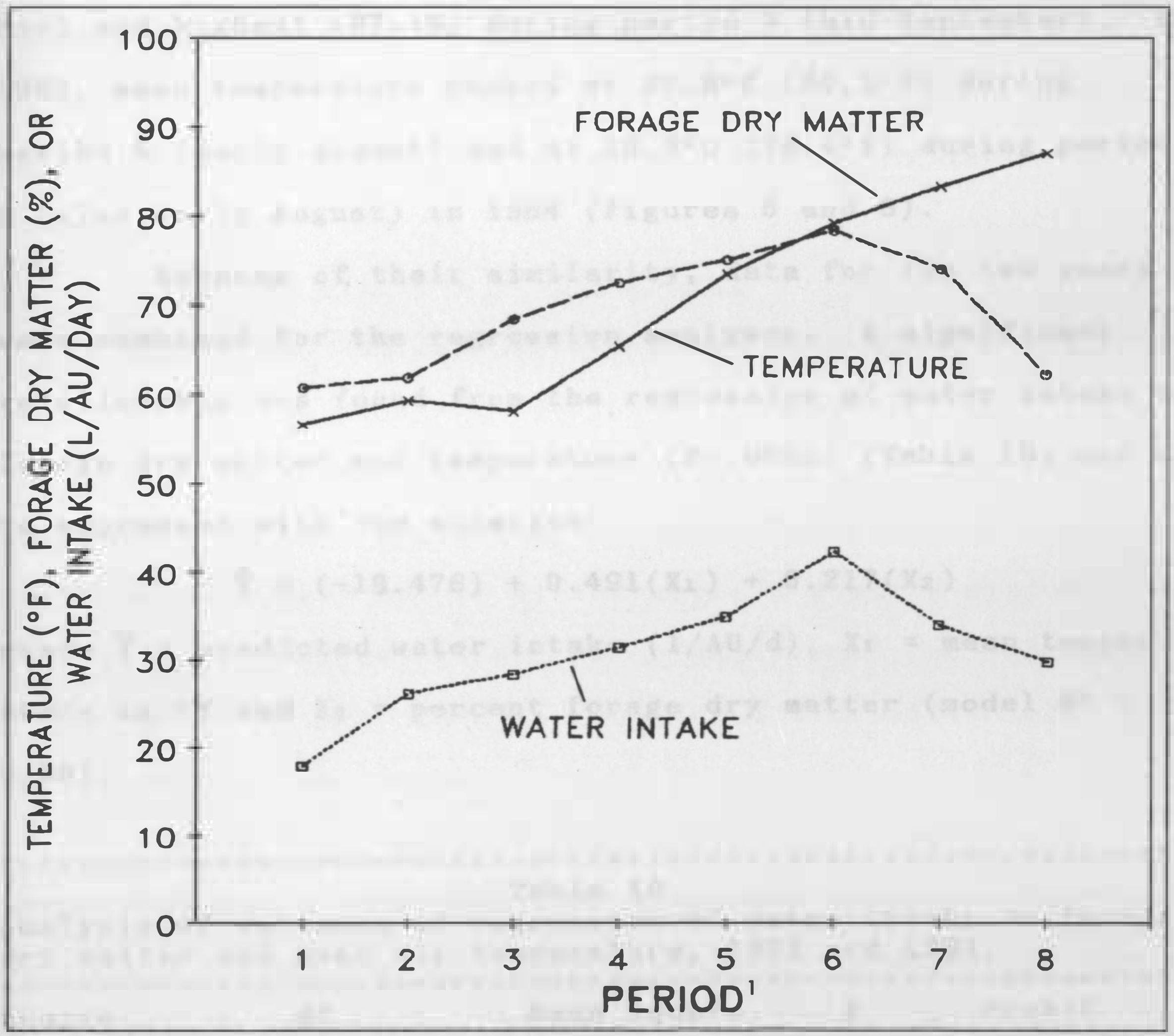

Figure 6. Water intake (l/AU/d), mean air temperature (°F) and forage dry matter (%) by periods, 1984.

[1] Period 1 = May 15 - May 28
2 = May 29 - June 14
3 = June 15 - June 30
4 = July 1 - July 16
5 = July 17 - August 1
6 = August 1 - August 15
7 = August 16 - August 31
8 = September 1 - September 16

May) and highest (87.1%) during period 8 (mid-September). In 1983, mean temperature peaked at 26.8°C (80.2°F) during period 5 (early August) and at 25.8°C (78.4°F) during period 6 (also early August) in 1984 (Figures 5 and 6).

Because of their similarity, data for the two years were combined for the regression analyses. A significant relationship was found from the regression of water intake on forage dry matter and temperature (P=.0001) (Table 19) and can be expressed with the equation:

$$\hat{Y} = (-18.476) + 0.491(X_1) + 0.217(X_2)$$

where $\hat{Y}$ = predicted water intake (l/AU/d), X_1 = mean temperature in °F and X_2 = percent forage dry matter (model R^2 = 0.80).

Table 19
Analysis of variance of regression of water intake on forage dry matter and mean air temperature, 1983 and 1984.

Source	df	Mean Square	F	Prob>F
Regression	2	200.36	25.4	0.0001
Residual	13	7.89		

Independent Variable Summary

Variable	Step	Cumulative Model R^2	F	Prob>F
Temperature	1	0.62	23.2	0.0003
Forage Dry Matter	2	0.80	11.0	0.0056

Temperature alone was a better predictor of water intake than forage dry matter alone as it was the first

variable to be introduced into the model and accounted for a greater portion of the final models R^2. This can also be interpreted from Figures 5 and 6 where in the latter periods, intake declines with temperature but forage dry matter continues to rise.

7.1.3.3 Analysis of Covariance

The 1983 and 1984 water intake data sets were also subjected to analyses of covariance. Temperature and forage dry matter were used as the covariates. These covariates could only be associated with period effects as the covariates were assumed not to differ between grazing system treatments or replications. After adjustment for the covariates, water intake could be considered a relative index of forage dry matter intake.

Years were analyzed separately, first with only temperature as a covariate, and then with with both temperature and forage dry matter as covariates. Periods in the 1983 data set were not significantly different with only temperature as the covariate ($P>.05$), as well as with both of the variables as covariates ($P>.05$) (Appendix Table 7). Conversely though, there was still a highly significant period effect in the 1984 data set even after both temperature and forage dry matter were included as covariates ($P<.001$). If water intake adjusted for temperature and forage dry matter is a valid index of forage dry matter intake, this would indicate that forage dry matter intake/AU

varied significantly over periods. This in part could be explained by variation in forage dry matter digestibilities over periods. Hyder *et al.* (1966 and 1968) also noted wide variability of water intake rate at very high temperatures or when forage had a high moisture content.

7.2 Soils

7.2.1 Soil Compaction - 1983

Indices of soil compaction were calculated as 100 minus the depth of penetration of a tapered rod dropped from a standard height. Larger indices then, are indicative of greater soil compaction.

Compaction data in 1984 were collected during two periods (early-June and mid-October) from clayey and silty range sites in RSG and HPSDG treatments. Three different strata were also delineated based on the distance from the water barrels in each treatment. Means and standard errors are given in Table 20 and the analysis of variance in Appendix Table 8.

Compaction indices were substantially higher on the June sampling date than in October ($P<.001$), but this was most likely attributable to early October rainfall and the absence of livestock in the treatment pastures for about three weeks. Compaction indices in strata 1 (closest to water) were higher than indices in strata 2 in both treatments for both soils at both dates ($P<.001$), indicating that livestock movement towards and congregation around the water-

ing facility compacted the soil. Compaction indices were also higher on the silty compared to the clayey range site soil.

Three different range sites in areas with high (>40%) and low (<10%) forage use were also evaluated for compaction (Table 21 and Appendix Table 9). A significant use-class x soil interaction was present in which the high use-class level had a greater effect on the claypan/silty soil complex than it did on the other two soils. Across use-classes, compaction indices were higher for claypan/silty soils than for the other two and as would be expected, indices from the high use-class were greater than those from the low use-class ($P<.05$).

Table 20

Means and standard errors of compaction indices of soil from two range sites and three strata within RSG and HPSDG treatments at two sampling periods, 1983.

Early-June

Treatment	Clayey 1	Clayey 2	Clayey 3	Clayey Mean	Silty 1	Silty 2	Silty 3	Silty Mean	Overall Treatment Means[1]
RSG	49.1	41.1	45.4	45.2	60.9	50.0	51.0	54.0	49.6[A] ±0.7
HPSDG	50.1	45.3	49.4	48.3	52.9	49.8	50.3	51.0	49.6[A] ±0.7
Strata Means[2]	49.6[a]	43.2[b]	47.4[a]		56.9[a]	49.9[b]	50.7[b]		
Overall Soil Means[3]				46.8[A] ±0.7				52.5[B] ±0.7	

Mid-October

Treatment	Clayey 1	Clayey 2	Clayey 3	Clayey Mean	Silty 1	Silty 2	Silty 3	Silty Mean	Overall Treatment Means[1]
RSG	24.8	20.4	21.9	22.4	37.6	29.7	28.4	31.9	27.2[A] ±0.7
HPSDG	34.9	28.0	20.5	27.8	33.5	29.8	27.0	30.1	28.9[A] ±0.7
Strata Means[2]	29.8[A]	24.2[B]	21.2[B]		35.6[A]	29.8[B]	27.0[B]		
Overall Soil Means[3]				25.1[A] ±0.7				31.0[B] ±0.7	

[1] Within sampling period, overall treatment means with unlike letters differ, (P<.01).
[2] Within sampling period, soil means with unlike letters differ, (P<.01).
[3] Within sampling period, overall strata means with unlike letters differ, (P<.01).

Table 21
Means and standard errors of compaction indices of soil from three range sites in high and low use-classes within RSG pastures, 1983.

	Range Site			
Use-class[1]	Shallow	Clayey	Claypan/Silty[2]	Use-class Means[3]
High	45.7	41.9	52.9	46.8[A] ±0.9
Low	34.1	33.3	35.9	34.4[B] ±0.9
Soil Means[4]	39.8[a] ±1.4	37.6[a] ±1.0	44.4[b] ±1.0	

[1] High and Low use-classes refer to areas with greater than 40% and less than 10% estimated forage use respectively.
[2] Complex of 60% claypan and 40% silty.
[3] Use-class means with unlike letters differ, (P<.001).
[4] Range site means with unlike letters differ, (P<.001).

7.2.2 Soil Compaction - 1984

Attempts were made during both 1983 and 1984 to establish a relationship between compaction indices and soil bulk densities (g/cubic cm). The 1983 attempt was unsuccessful, but a change in methodology in 1984 resulted in the determination of a significant relationship between the two variables (P<.01) (Figures 7 and 8). Relationships were established for clayey and silty range site soils. Slopes (b) of the two regressions lines were not different (P>.05).

Compaction indices from 1984 were converted to predicted bulk densities using the appropriate equations for the two soils (Figures 7 and 8). All compaction indices were determined when soil water conditions were the same as they were at the time data were collected for the establishment

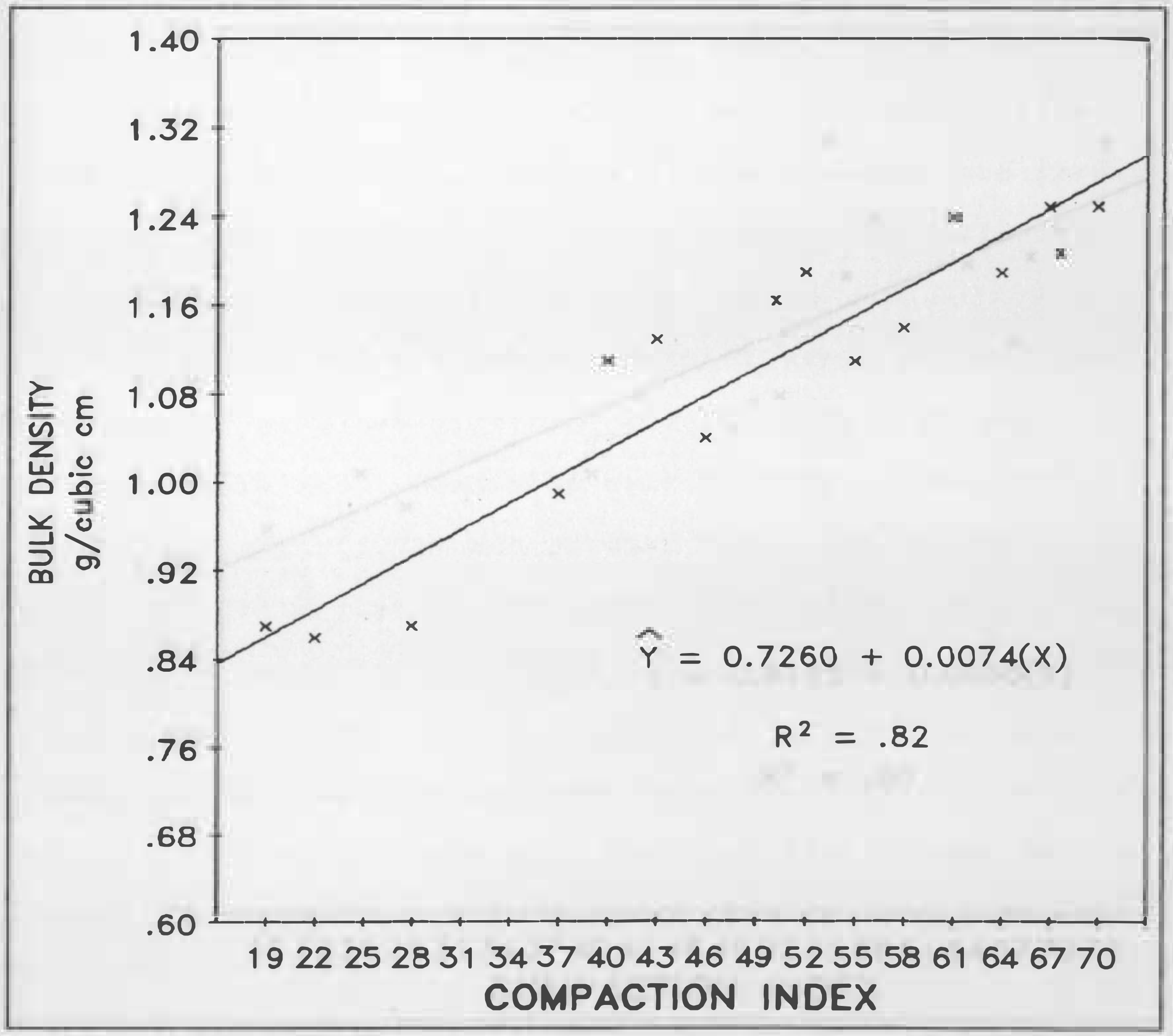

Figure 7. Relationship of compaction index to bulk density for the clayey range site soil.

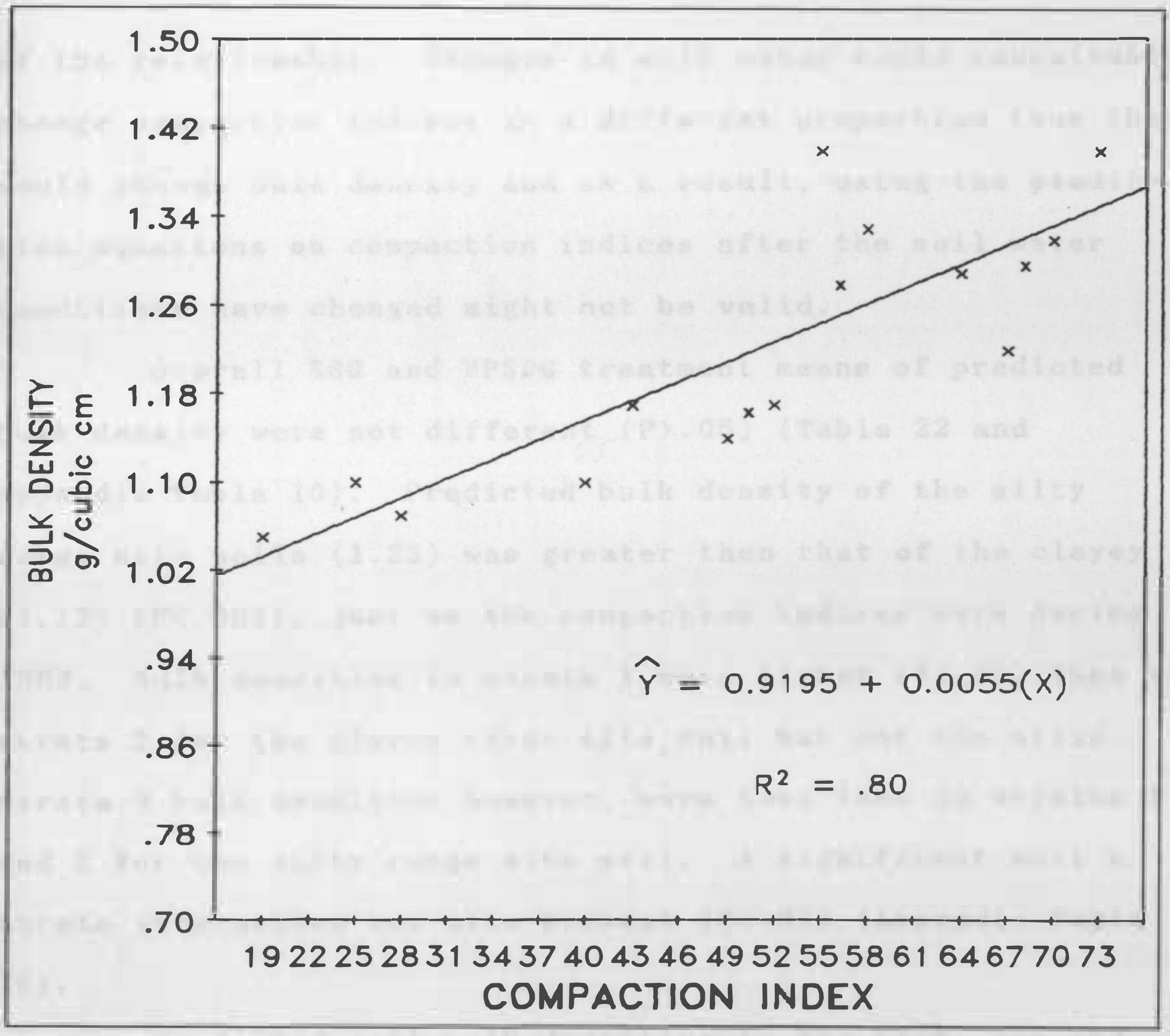

Figure 8. Relationship of compaction index to bulk density for the silty range site soil.

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of the relationship. Changes in soil water could conceivably change compaction indices in a different proportion than they would change bulk density and as a result, using the prediction equations on compaction indices after the soil water conditions have changed might not be valid.

Overall RSG and HPSDG treatment means of predicted bulk density were not different (P>.05) (Table 22 and Appendix Table 10). Predicted bulk density of the silty range site soils (1.23) was greater than that of the clayey (1.13) (P<.001), just as the compaction indices were during 1983. Bulk densities in strata 1 were higher (P<.01) than in strata 2 for the clayey range site soil but not the silty. Strata 3 bulk densities however, were less than in stratas 1 and 2 for the silty range site soil. A significant soil x strata interaction was also present (P<.01) (Appendix Table 10).

Predicted soil bulk densities in the high, low and none use-classes were 1.17, 1.10 and 0.97 g/cubic cm respectively, with each being significantly different from the other (P<.001) (Table 23 and Appendix Table 11). A significant use-class x soil interaction was present in which bulk densities were the same for both soils in the low use-class but different in the other two use-classes. As was observed when bulk density was compared from the three strata, bulk density of the silty soils was higher than the clayey range

Table 22

Means and standard errors of predicted bulk densities of soil from two range sites and three strata within RSG and HPSDG treatments, 1984.

	Clayey				Silty				
	Strata								Overall
Treatment	1	2	3	Mean	1	2	3	Mean	Treatment Means[1]
RSG	1.21	1.08	1.10	1.13	1.25	1.23	1.22	1.23	$1.18^{A} \pm 0.01$
HPSDG	1.20	1.10	1.11	1.14	1.27	1.23	1.21	1.24	$1.19^{A} \pm 0.01$
Strata Means[2]	1.20^{a}	1.09^{b}	1.10^{b}		1.26^{a}	1.23^{a}	1.22^{b}		
Overall Soil Means[3]				$1.13^{A} \pm 0.01$				$1.23^{B} \pm 0.01$	

[1] Overall treatment means with unlike letters differ, ($P < .01$).

[2] Strata means with unlike letters differ, ($P < .01$).

[3] Overall soil means with unlike letters differ, ($P < .001$).

Table 23
Means and standard errors of predicted bulk densities of soil from two range sites and high, low and none use-classes within RSG pastures, 1984.

Use-class[1]	Range Site: Clayey	Silty	Use-class Means[2]
High	1.16	1.19	1.17[A] ±0.01
Low	1.10	1.10	1.10[B] ±0.01
None	0.89	1.05	0.97[C] ±0.01
Soil Means[3]	1.04[a] ±0.01	1.11[b] ±0.01	

[1] High and Low use-classes refer to areas with greater than 40% and less than 10% estimated forage use respectively.
[2] Use-class means with unlike letters differ, (P<.001).
[3] Range site means with unlike letters differ, (P<.001).

grazing will increase soil bulk density on clayey range site soils more so than it will on silty range site soils. Lull (1959), in a review of numerous studies, reported bulk densities on "heavily" grazed areas to be an average of 1.25 times greater than ungrazed areas. These data (Table 23), suggest similar increases in bulk density.

The effect of compaction increases the bulk density of soil by reducing pore space (Lull, 1959). Compaction may also reduce growth of vegetation through its deleterious effects on soil aeration, infiltration and soil water (Cook and Stubbendieck, 1986). Though there were no differences in compaction indices (1983) and bulk densities (1984) between RSG and HPSDG treatments for the important strata 1 (within 25 m of watering facility), approximately 16% of a wedged

shaped HPSDG subunit or 16% of the entire HPSDG unit was covered in strata 1. In RSG however, strata 1 accounted for about 2% of the entire pasture unit. One must also consider that stocking densities in HPSDG were 32 times those of RSG.

7.3 Vegetation

Forage utilization during 1983 and 1984 was reported and discussed in Section 6.4. The following sections (7.3.1 and 7.3.2) contain further discussions of the data.

7.3.1 Forage Utilization - 1983

In 1983. forage use estimates were made using a grazed-class technique (Schmutz *et al.*, 1963) in addition to a procedure where entire plants were randomly collected, dried and weighed before and after livestock occupation in selected HPSDG subunits. This latter procedure is similar to a technique where entire plots are clipped, dried and weighed before and after occupation. This procedure was not used as clipping the number of plots required would have damaged and altered a considerable portion of the vegetation in the relatively small HPSDG subunits.

The before and after collection of individual plants technique was abandoned due to extremely high coefficients of variation. A very large number of samples would have had to be collected for acceptable precision. Similar problems were encountered when grazed-class estimates were assigned to randomly selected individual plants.

End-of-season estimation of forage use involved

grazed-class estimations made on both midgrasses (predominantly western wheatgrass) and shortgrasses (predominantly buffalograss and blue grama) in 0.062 m^2 plots. Three strata, referring to the vegetation stature of the area that the plots fell were also delineated and assigned. They included: heavy (midgrass dominated), mixed (approximately equal proportions of midgrasses and shortgrasses) and short (shortgrass dominated).

The end-of-season estimates of percent use on midgrasses were not different between grazing system treatments ($P>.05$) (Table 24 and Appendix Table 12). The percentages, 43.5 in RSG and 42.4 in HPSDG, were within the preplanned goal range of 40 to 50% on a key use species. Western wheatgrass, one of the three selected key use species, made up the vast majority of this midgrass group. An interesting strata effect was present where midgrass use was higher in mixed strata than in heavy strata. Estimated use between replication within grazing system treatments also was sometimes different ($P<.05$) (Table 24). In RSG, replicate 6 had the highest estimated midgrass use (48.8%). Overall potential productivity of this replicate was calculated to be the lowest, though not substantially different from the others (Table 5).

Estimated percent use of shortgrasses was higher in HPSDG (36.8) than in RSG (23.8) ($P<.05$) (Table 25 and

Table 24
Least-squares means (LS-means) and standard errors of end-of-season forage use (%) estimates on midgrasses in RSG and HPSDG systems, 1983.

Treatment	Strata[1] Heavy	Mixed	Treatment LS-means[2]
RSG	41.4	45.5	43.5[A] ±0.9
HPSDG	37.7	47.1	42.4[A] ±0.9
Strata LS-means[3]	39.6[a] ±1.1	46.3[b] ±0.6	

[1] Heavy strata refers to an area heavily dominated by midgrasses and mixed strata is an area with about equal proportions of midgrasses and shortgrasses.
[2] Treatment LS-means with unlike letters differ,(P<.05).
[3] Strata LS-means with unlike letters differ,(P<.05).

Replication by treatment LS-means across strata

RSG Replication	RSG LS-means	±SE	HPSDG Replication	HPSDG LS-means	±SE
1	41.1[AB]	±2.2	1	40.7[B]	±2.0
2	43.9[BC]	±2.0	2	34.6[A]	±2.4
3	43.8[BC]	±2.1	3	40.2[AB]	±1.9
4	36.8[A]	±2.3	4	42.7[B]	±2.5
5	46.4[BC]	±2.1	5	51.4[C]	±2.2
6	48.8[C]	±2.1	6	44.7[B]	±2.3

[4] Within treatments, LS-means without a common letter differ, (P<.05).

Table 25

Least-squares means (LS-means) and standard errors of end-of-season forage use (%) estimates on shortgrasses in RSG and HPSDG systems, 1983.

	Strata[1]			
Treatment	Heavy	Mixed	Short	Treatment LS-means[2]
RSG	17.2^{a}	20.3^{a}	33.9^{a}	23.8^{A} ±0.9
HPSDG	22.7^{b}	32.1^{b}	55.7^{b}	36.8^{B} ±1.1
Strata LS-means[3]	19.9^{A} ±1.2	26.2^{B} ±0.7	44.8^{C} ±1.6	

[1] Heavy strata refers to an area heavily dominated by midgrasses; mixed strata is an area with about equal proportions of midgrasses and shortgrasses; and short strata is an area dominated by shortgrasses only.
[2] Treatment LS-means with unlike letters differ, (P<.05).
[3] Strata LS-means with unlike letters differ, (P<.05).
[ab] Strata within treatment LS-means with unlike letters differ, (P<.05).

Replication by treatment LS-means across strata

RSG		HPSDG	
Replication	LS-means ±SE	Replication	LS-means ±SE
1	20.1^{AB} ±2.1	1	40.1^{BC} ±2.5
2	25.8^{BC} ±2.1	2	30.8^{A} ±2.6
3	22.4^{AB} ±2.0	3	47.2^{C} ±3.4
4	18.6^{A} ±2.8	4	31.2^{A} ±2.4
5	25.6^{BC} ±2.1	5	36.2^{AB} ±2.2
6	30.4^{C} ±2.1	6	35.4^{AB} ±2.4

[4] Within treatments, LS-means without a common letter differ, (P<.05).

Appendix Table 12). This higher shortgrass use in HPSDG suggests a greater efficiency of harvest of the total complement of vegetation offered and in part, could explain why attained stocking rates in HPSDG were higher.

Shortgrass use was affected by strata with the least in the heavy and most in the short strata (P<.05) (Table 25). Shortgrasses in the heavy strata were probably "shielded" by the midgrasses limiting livestock access. Lambs were also observed to often concentrate on the shortgrass areas. As with the midgrasses, some shortgrass use estimates between replications within treatments were different (P<.05).

With regards to the mixed grazing of calves and lambs (cattle, sheep), the overall differences between midgrass and shortgrass use can lead to some further hypotheses. The preferences for shortgrasses by lambs and for midgrasses by calves have been established (Section 5.4; Table 3). With the ratio of calves to lambs in these studies being about equal on an AU basis; one would expect that a change in the ratio in favor of the lambs would bring shortgrass use up to a level equal to that of the midgrasses without causing use on either plant group to exceed some desired maximum level. This would further increase the efficiency of harvest of the total complement of vegetation. Because of the lesser estimated shortgrass use in RSG than in HPSDG, it would be necessary to increase the lamb portion of the ratio more in RSG

than in HPSDG.

7.3.2 Forage Utilization - 1984

7.3.2.1 RSG

Forage utilization in the RSG pastures was estimated in conjunction with the standing crop estimates made at the midpoints of the four HPSDG cycles and at the end of the grazing season. The percent use of western wheatgrass, shortgrasses and of the total live or live + recent-dead standing crop is plotted against the cumulative grazing days in Figure 9. Estimated end-of-season use was 38.6, 36.5 and 30.4% for the western wheatgrass, total and shortgrass categories respectively. Apparent use remained quite low through day 64 (HPSDG cycle 3 midpoint) as use was difficult to detect or was masked by rapidly growing vegetation and by regrowth of vegetation that had been previously grazed. apparent use sharply increased during the last half of the season corresponding to the declining growth rates of the maturing vegetation. The shift of western wheatgrass from the live to recent-dead state rapidly progressed starting about July 15. It was also at this time that soil water was rapidly declining (Appendix Table 13). Soil water in the first 20 cm remained very low thoughout August and combined with very warm August temperatures, depressed shortgrass growth. One additional set of livestock was put in RSG at day 48. However, two sets were removed at day 86 to prevent use from exceeding the preplanned level. The sharp increase

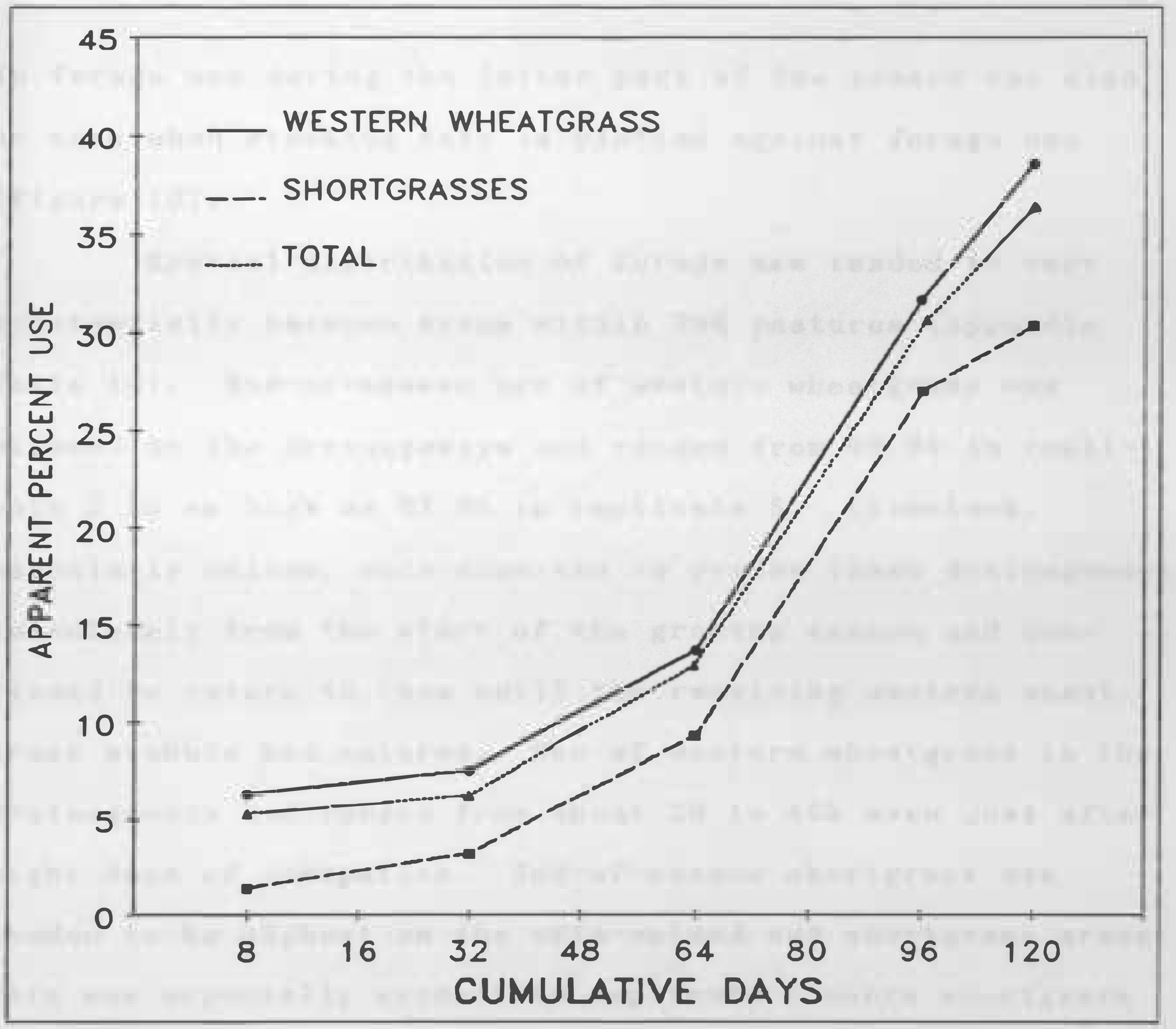

Figure 9. Apparent percent use of western wheatgrass, shortgrasses and total (all live or live + recent-dead species) at the cumulative sampling days of the grazing season in the RSG system, 1984.

in forage use during the latter part of the season can also be seen when stocking rate is plotted against forage use (Figure 10).

Spatial distribution of forage use tended to vary substantially between areas within RSG pastures (Appendix Table 14). End-of-season use of western wheatgrass was highest in the drainageways and ranged from 48.8% in replicate 3 to as high as 82.9% in replicate 5. Livestock, especially calves, were observed to prefer these drainageways immediately from the start of the grazing season and continued to return to them until the remaining western wheatgrass stubble had matured. Use of western wheatgrass in the drainageways had ranged from about 20 to 40% even just after eight days of occupation. End-of-season shortgrass use tended to be highest on the thin-upland and shortgrass areas. This was especially evident in replicate 5 where shortgrass use was estimated at 64.5% (Appendix Table 14). This high use was most likely attributable to the lambs concentrating on those areas.

7.3.2.2 HPSDG

Estimated end-of-season use in HPSDG was 40.2, 38.3 and 35.8% for the western wheatgrass, total and shortgrass categories respectively. The percent use of these three species categories after subunit occupation is graphed in Figure 11. The unusual decline in apparent use between

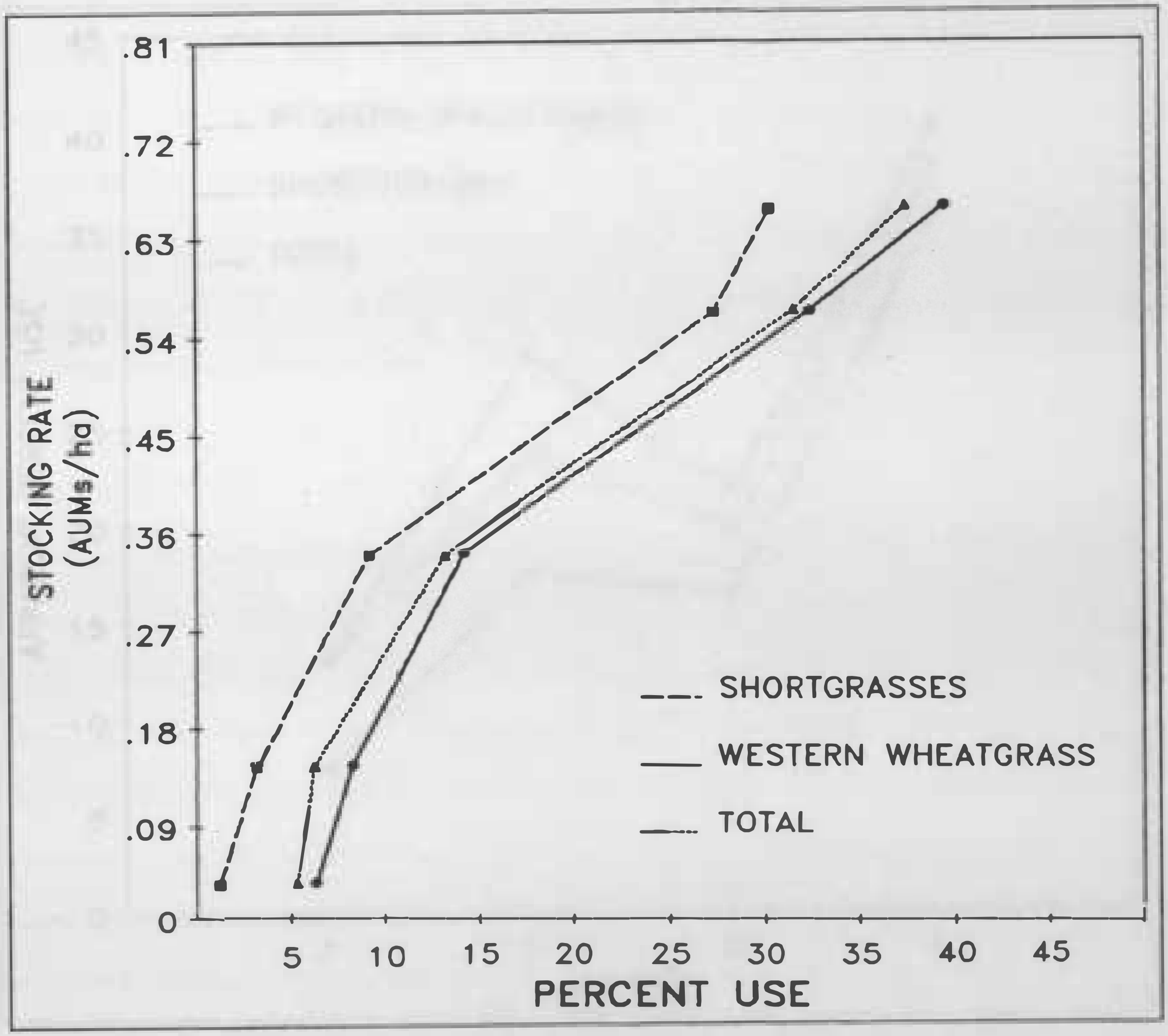

Figure 10. Stocking rate in relation to controlled utilization in RSG, 1984.

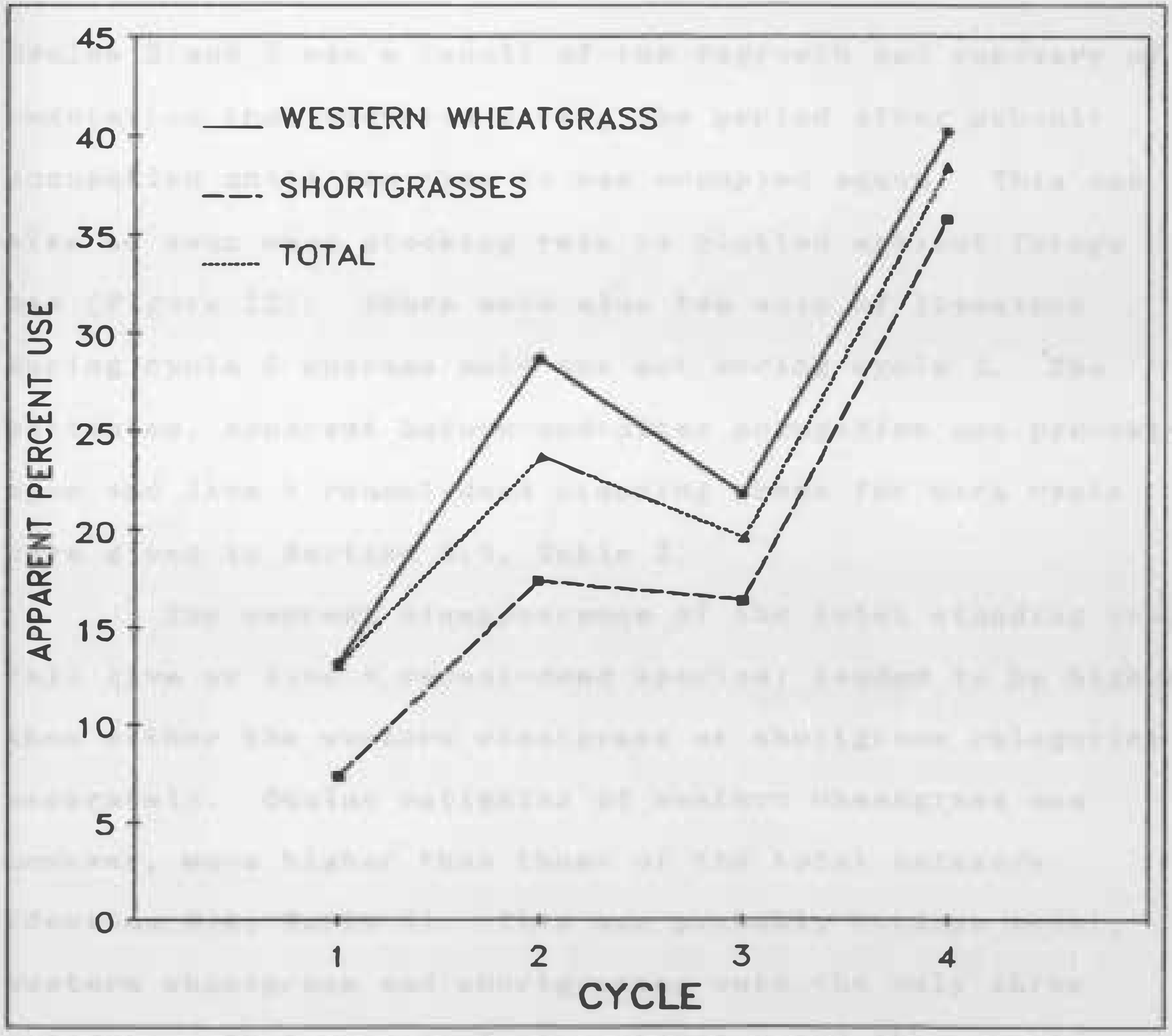

Figure 11. Apparent percent use of western wheatgrass, short-grasses and total (all live or live + recent-dead species) estimated after subunit occupation in the HPSDG system, 1984.

cycles 2 and 3 was a result of the regrowth and recovery of vegetation that occurred during the period after subunit occupation until the time it was occupied again. This can also be seen when stocking rate is plotted against forage use (Figure 12). There were also two sets of livestock during cycle 2 whereas only one set during cycle 3. The estimated, apparent before-and-after occupation use percentages and live + recent-dead standing crops for each cycle were given in Section 6.4, Table 2.

The percent disappearance of the total standing crop (all live or live + recent-dead species) tended to be higher than either the western wheatgrass or shortgrass categories separately. Ocular estimates of western wheatgrass use however, were higher than those of the total category (Section 6.4, Table 2). This was probably because total, western wheatgrass and shortgrasses were the only three categories that were ocularly estimated and there must have been substantial use of other species (*eg.* annual grasses) that was detected in the differences in the before and after standing crop. In HPSDG, annual grasses (Japanese brome and six-weeks fescue) were found to account for a moderate percent (17.1) of the mean total standing crop and the microhistological examination of fecal samples indicated they made up a substantial portion of the diet (Table 3, Section 5.4).

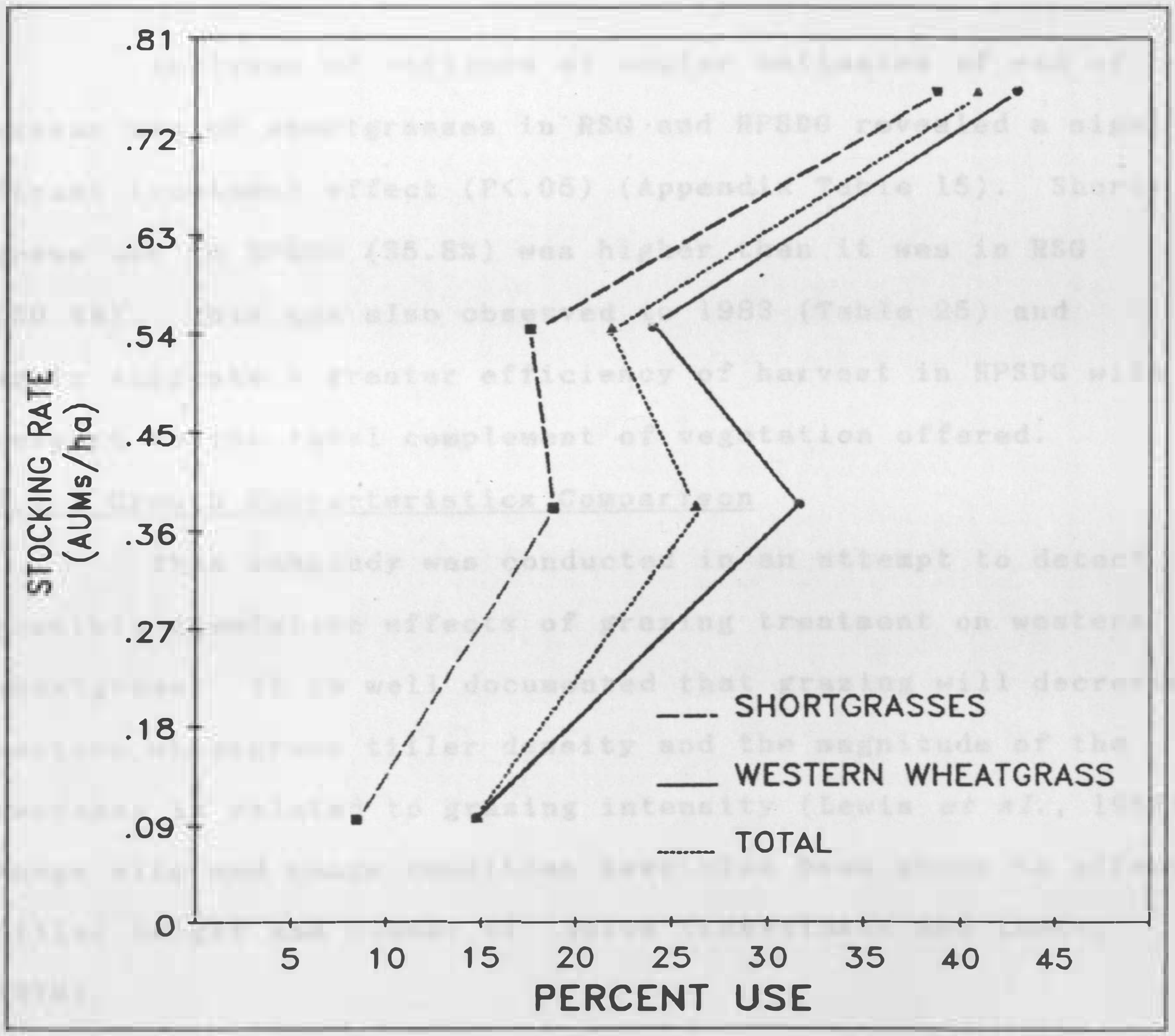

Figure 12. Stocking rate in relation to controlled utilization in HPSDG, 1984.

Analyses of variance of ocular estimates of end of season use of shortgrasses in RSG and HPSDG revealed a significant treatment effect (P<.05) (Appendix Table 15). Shortgrass use in HPSDG (35.8%) was higher than it was in RSG (30.4%). This was also observed in 1983 (Table 25) and again suggests a greater efficiency of harvest in HPSDG with respect to the total complement of vegetation offered.

7.3.3 Growth Characteristics Comparison

This substudy was conducted in an attempt to detect possible cumulative effects of grazing treatment on western wheatgrass. It is well documented that grazing will decrease western wheatgrass tiller density and the magnitude of the decrease is related to grazing intensity (Lewis *et al.*, 1956). Range site and range condition have also been shown to affect tiller height and number of leaves (Enevoldsen and Lewis, 1978).

Height, weight and number of leaves were measured on sets of grazed and ungrazed western wheatgrass tillers collected from two range sites (clayey and silty) within RSG, HPSDG and permanent exclosure (ungrazed) treatments. The percentage of leaves grazed on the grazed set (from RSG and HPSDG) of tillers was also calculated. Means and standard errors are given in two-way table form (Table 26) and the analysis of variance of the data in Appendix Table 16.

Table 26

Means and standard errors of height, weight, number of leaves and percent of leaves grazed of grazed western wheatgrass tillers; and height, weight and number of leaves of ungrazed tillers collected from clayey and silty range sites within RSG, HPSDG and ungrazed (exclosure) treatments.

GRAZED TILLERS

	Height (mm)			Weight (g)			Number of Leaves			Percent of Leaves Grazed		
Treatment	Clayey	Silty	Means[1] ±SE	Clayey	Silty	Means[1] ±SE	Clayey	Silty	Means[1] ±SE	Clayey	Silty	Means[1] ±SE
RSG	263.9	271.7	267.0^{A} ±5.4	0.25	0.26	0.25^{A} ±0.01	5.1	4.6	4.9^{A} ±0.1	61.8	62.1	61.9^{A} ±2.9
HPSDG	275.7	268.3	272.7^{A} ±5.0	0.22	0.24	0.23^{B} ±0.01	4.9	5.0	5.0^{A} ±0.1	59.4	60.2	59.7^{A} ±3.1
Means[2] ±SE	269.8^{a} ±6.9	270.0^{a} ±7.6		0.23^{a} ±.01	0.25^{a} ±.01		5.0^{a} ±0.1	4.8^{a} ±0.1		60.6^{a} ±2.5	61.1^{a} ±2.6	

UNGRAZED TILLERS

	Height (mm)			Weight (g)			Number of Leaves		
Treatment	Clayey	Silty	Means[1] ±SE	Clayey	Silty	Means[1] ±SE	Clayey	Silty	Means[1] ±SE
RSG	302.6	298.6	301.0^{A} ±4.7	0.29	0.25	0.28^{A} ±0.01	5.5	4.9	5.3^{A} ±0.1
HPSDG	317.6	288.6	306.0^{A} ±4.5	0.28	0.26	0.27^{A} ±0.01	5.7	5.2	5.5^{AB} ±0.1
Exclosure	404.3	350.9	386.5^{B} ±8.2	0.40	0.33	0.38^{B} ±0.01	5.8	5.7	5.7^{B} ±0.1
Means[2] ±SE	333.7^{a} ±7.6	305.1^{b} ±7.7		0.32^{a} ±.01	0.27^{b} ±.01		5.7^{a} ±0.1	5.2^{b} ±0.1	

[1] Treatment means not sharing a common letter differ, ($P<.05$).

[2] Range site means with unlike superscripts differ, ($P<.05$).

For the grazed tillers, weight of RSG tillers were greater than those from HPSDG (P<.05) (Table 26). A significant treatment x range site interaction was also present for the dependent variable number of leaves (P<.05) (Appendix Table 16). Treatment and range site means of height, number of leaves and percent of leaves grazed were all similar.

For the ungrazed tillers, treatment and range site had significant effects on height, weight and number of leaves and a significant treatment x range site effect on height was also present (Appendix Table 16). Tillers in the exclosure were taller and weighed more than those from RSG and HPSDG and had more leaves than those from RSG but not HPSDG (P<.05) (Table 26). Ungrazed tillers from the clayey range site were greater with respect to all three attributes measured than those from the silty range site (P<.05). This may appear unusual as overall production on silty range sites is generally considered to be higher than on clayey range sites (U.S.D.A.-S.C.S., 1979), but several species other than western wheatgrass are more abundant on silty than on clayey range sites.

7.3.4 Emergence, Growth and Developmental Characteristics

The intent of these studies was to evaluate the cumulative effects of the grazing treatments on the emergence, growth and developmental characteristics of western wheatgrass, buffalograss and blue grama. Previous years grazing intensity has been shown to influence the elongation of grasses (Short and Woolfolk, 1956), the number of leaves per tiller (Reed and Peterson, 1961), and Tallowin (1981), concluded different grazing systems will cause marked differences in tiller densities.

7.3.4.1 Western Wheatgrass - 1984

Sampling of western wheatgrass was begun on March 30 in the permanent exclosure study area and on April 6 in all other study areas as very few or no newly emerged tillers were observed in areas other than the exclosure on March 30. Subsequent median sampling dates were April 17, May 5 and May 23. Duration of sampling was two to three days. The four groups of tillers observed were: 1) those that emerged from date 0 to March 30 (permanent exclosure only), 2) those emerging between March 31 and April 6; 3) those emerging between April 7 and April 17; and 4) those emerging between April 18 and May 5.

There was no overall difference in the mean density at time of first sampling of western wheatgrass tillers of the three study areas in RSG and the three in the HPSDG treatment (P>.05) (Table 27). As would be expected, density

Table 27

Tiller density, height, leaves per tiller and length of first leaf of western wheatgrass in the eight study areas, 1984.

Study Area	Density[1,2] (no./sq m)	Height[3] (mm)	No. Leaves per tiller[3]	Length of First Leaf[3] (mm)
RSG-Light[4]	195[a]	142	3.8	81
RSG-Heavy[4]	279[a]	154	3.9	78
RSG-Shortgrass	44[c]	133	4.3	75
RSG Means[5] ±SE	173[A] ±55	143[A] ±7	4.0[A] ±.2	78[A] ±3
HPSDG-Early[6]	105[b]	122	3.7	77
HPSDG-Late[6]	254[a]	130	3.8	77
HPSDG-Shortgrass	46[c]	115	4.2	76
HPSDG Means[5] ±SE	135[A] ±53	122[B] ±6	3.9[A] ±.1	77[A] ±4
Permanent Exclosure	322[a]	128	3.2	75
RSG-Moderate[7]	223[a]	148	3.9	83

[1] Density on March 30 for the Exclosure and April 6 for the remaining study areas.
[2] Study area means of density with unlike superscripts differ, (P<.05).
[3] Means of height, leaves and length of first leaf on May 23 of tillers from the three emergence periods.
[4] Light or Heavy grazing the previous three years.
[5] RSG and HPSDG means of density, height, leaves and length with unlike superscripts differ, (P<.05).
[6] Grazed Early or Late during the initial HPSDG rotation cycle.
[7] Grazed moderately by steers June through August (Range Condition study).

in the shortgrass study areas was lowest compared to the other study areas. Density in HPSDG-grazed early (105) was less than the density in HPSDG-grazed late (254 tillers/m^2) ($P<.05$). Due to the sampling procedure, density could be calculated for the first date only. The height of the tillers on the last sampling date (May 23) was greater in RSG than in HPSDG ($P<.05$). The other two characteristics, number of leaves and length of the first leaf, were similar when study areas were averaged into the two grazing system treatments (Table 27). Across study areas, tillers in the shortgrass areas tended to have more leaves but were slightly shorter on the last sampling date than tillers from other study areas.

Across all study areas, the length of the first leaf on May 23 was greater on tillers emerging during periods 3 and 4 than tillers emerging during the first period ($P<.05$) (Figure 13). Rate of elongation of the first leaf as interpreted from the length changes between observation dates was always greatest during the initial period of growth of the tiller. Rate of elongation was highest for emergence group 4 tillers during their initial period. This probably result- from the warmer temperatures, a longer photoperiod and favorable moisture conditions present in late April.

Heights of the tillers on the last sampling date (May 23) were 135, 136, 134 and 131 mm for emergence groups 1

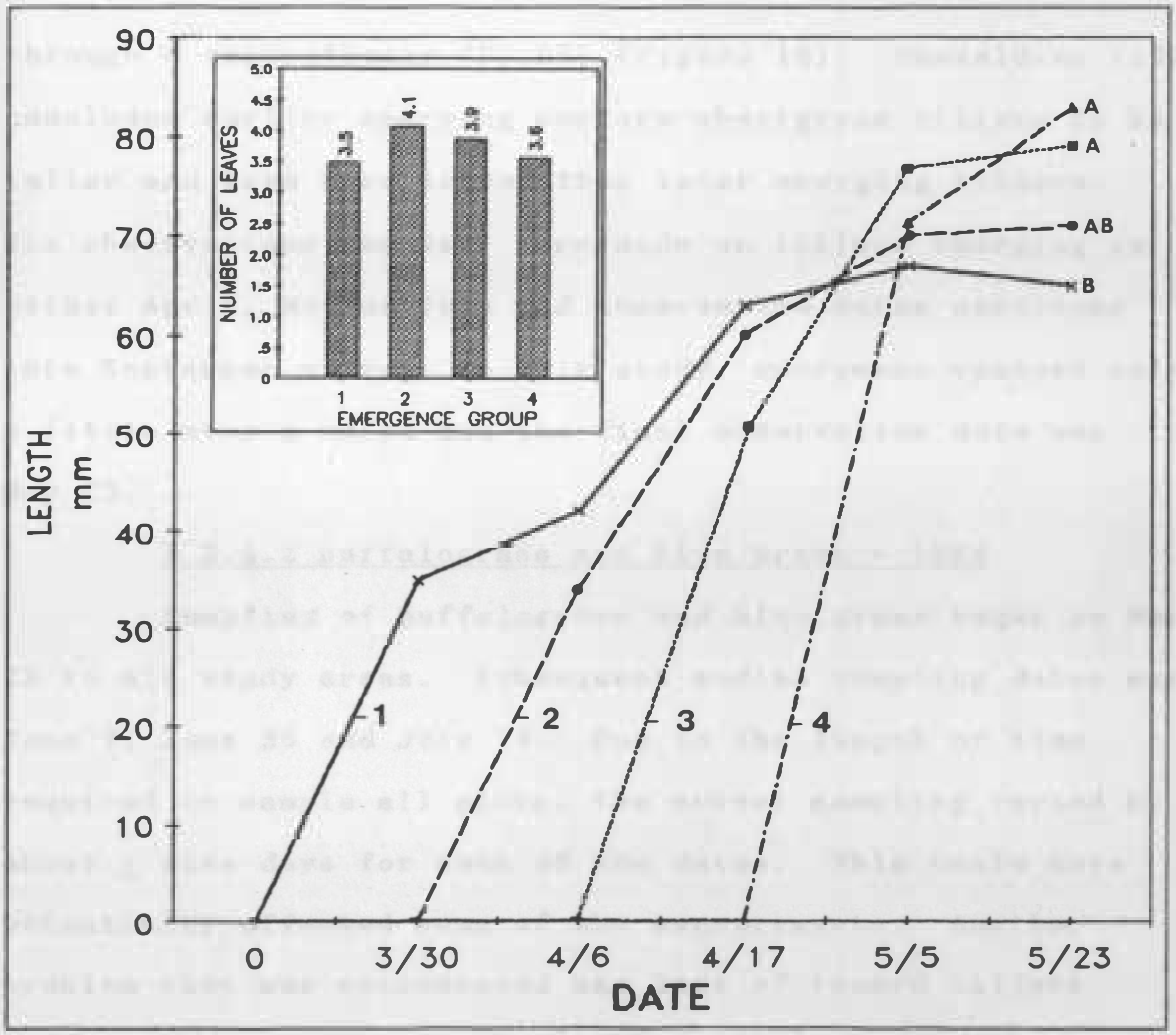

Figure 13. Length of the first leaf of emergence groups 1, 2, 3 and 4 western wheatgrass tillers at each observation date and number of leaves per tiller on the final observation date (inset), 1984.

Group 1: emerged date 0 to 3/30 (exclosure only).
Group 2: emerged 3/31 to 4/6.
Group 3: emerged 4/7 to 4/17.
Group 4: emerged 4/18 to 5/5.
[AB] Lengths on May 23 with an uncommon letter differ, (P<.05).

through 4 respectively (P>.05) (Figure 16). Enevoldsen (1967) concluded earlier emerging western wheatgrass tillers to be taller and have more leaves than later emerging tillers. His observations however, were made on tillers emerging in either April, May or June and observation dates continued into September whereas in this study, emergence spanned only a little over a month and the final observation date was May 23.

7.3.4.2 Buffalograss and Blue Grama - 1984

Sampling of buffalograss and blue grama began on May 23 in all study areas. Subsequent median sampling dates were June 7, June 20 and July 10. Due to the length of time required to sample all plots, the actual sampling varied by about ± five days for each of the dates. This could have potentially affected some of the measurements. Another problem that was encountered was loss of record tillers between the initial and final observation dates. Once livestock occupation had begun, some tillers and leaves were undoubtedly lost to grazing, trampling and other grazed by insects. Additionally, application of the spot of paint to distinguish record tillers may have affected plant growth.

Densities, height, leaves per tiller and length of first leaf of buffalograss and blue grama are summarized in Table 28. There were no differences in tiller densities of buffalograss or blue grama between RSG and HPSDG treatments

Table 28

Tiller density, height, leaves per tiller and length of first leaf of buffalograss and blue grama in eight study areas, 1984.

Study Area	Buffalograss Density[1,2] (no./sq m)	Height[3] (mm)	No. Leaves per Tiller[3]	Length of First Leaf[3]	Blue Grama Density[1,2] (no./sq m)	Height[3] (mm)	No. Leaves per Tiller[3]	Length of First Leaf[3]
RSG-Light[4]	1137^{a}	99	4.8	48	430^{bc}	94	3.9	59
RSG-Heavy[4]	910^{a}	92	4.5	48	758^{bc}	97	4.3	56
RSG-Shortgrass	1800^{a}	82	5.1	41	175^{c}	70	3.8	48
RSG Means[5] ±SE	1282^{A} ±434	96^{A} ±3	4.7^{A} ±.1	46^{A} ±3	454^{A} ±158	98^{A} ±4	4.0^{A} ±.2	59^{A} ±3
HPSDG-Early[6]	1073^{a}	82	4.4	44	209^{c}	106	3.7	65
HPSDG-Late[6]	587^{ab}	78	4.5	44	221^{c}	124	4.0	77
HPSDG-Shortgrass	1820^{a}	83	4.1	46	1540^{a}	67	3.7	42
HPSDG Means[5] ±SE	1160^{A} ±334	81^{B} ±4	4.4^{B} ±.1	45^{A} ±4	657^{A} ±214	101^{A} ±4	3.8^{A} ±.1	65^{A} ±3
Permanent Exclosure	40^{b}	97	4.4	52	82^{c}	83	3.7	54
RSG-Moderate[7]	862^{a}	82	4.4	46	977^{ab}	108	3.9	69

[1] Density on May 23.
[2] Study area means of density not sharing a common letter differ, (P<.05).
[3] Means of height, leaves and length of first leaf on July 10 of all tillers from the three emergence periods.
[4] Light or Heavy grazing the previous three years.
[5] RSG and HPSDG means of density, height, leaves and length with unlike superscripts differ, (P<.05).
[6] Grazed Early or Late during the initial HPSDG rotation cycle.
[7] Grazed moderately by steers June through August (Range Condition study).

(P>.05). The height of buffalograss on the last sampling date (7/10) and the number of leaves were however, greater in RSG than in HPSDG (P<.05) (Table 28). Height, number of leaves and length of first leaf of blue grama tillers were not different between RSG and HPSDG (P>.05). Between study areas, the permanent exclosure had the least buffalograss with only 40 tillers/m² being observed. The HPSDG shortgrass study area surprisingly had substantially more blue grama tillers/m² (1540) than the RSG shortgrass area (175). This however, was probably a peculiarity of the selected sites.

With regard to the characteristics and comparing buffalograss and blue grama overall, it can be seen that blue grama tillers were generally taller, had longer first leaves, but had fewer leaves than buffalograss tillers (Figures 14, 15 and 16).

The length of the first leaves of buffalograss that emerged last (between 6/7 and 6/20) were longer on July 10 than tillers emerging during the two earlier periods (P<.05) (Figure 14). Number of leaves per tiller however, were similar on all three groups of tillers (Figure 15). First leaves of blue grama tillers emerging during the latter two periods were longer on July 10 than leaves of tillers from the first emergence period, but tillers from the first emergence period had more leaves (P<.05) (Figure 14).

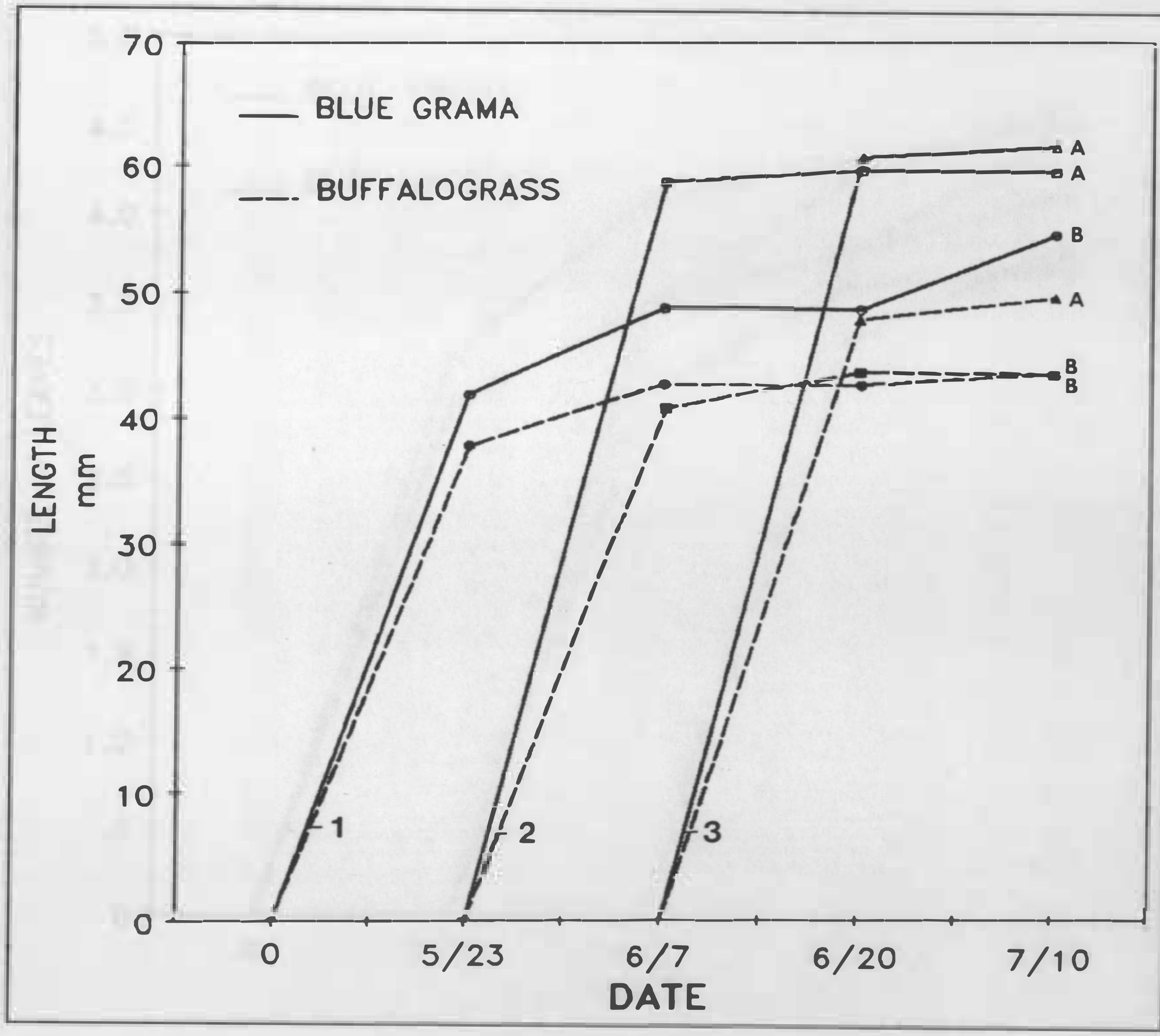

Figure 14. Length of the first leaf of emergence groups 1, 2, and 3 buffalograss and blue grama tillers at each observation date, 1984.

Group 1: emerged date 0 to 5/23.
Group 2: emerged 5/24 to 6/7.
Group 3: emerged 6/8 to 6/20.
AB Within species, lengths on July 10 with unlike letters differ, (P<.05).

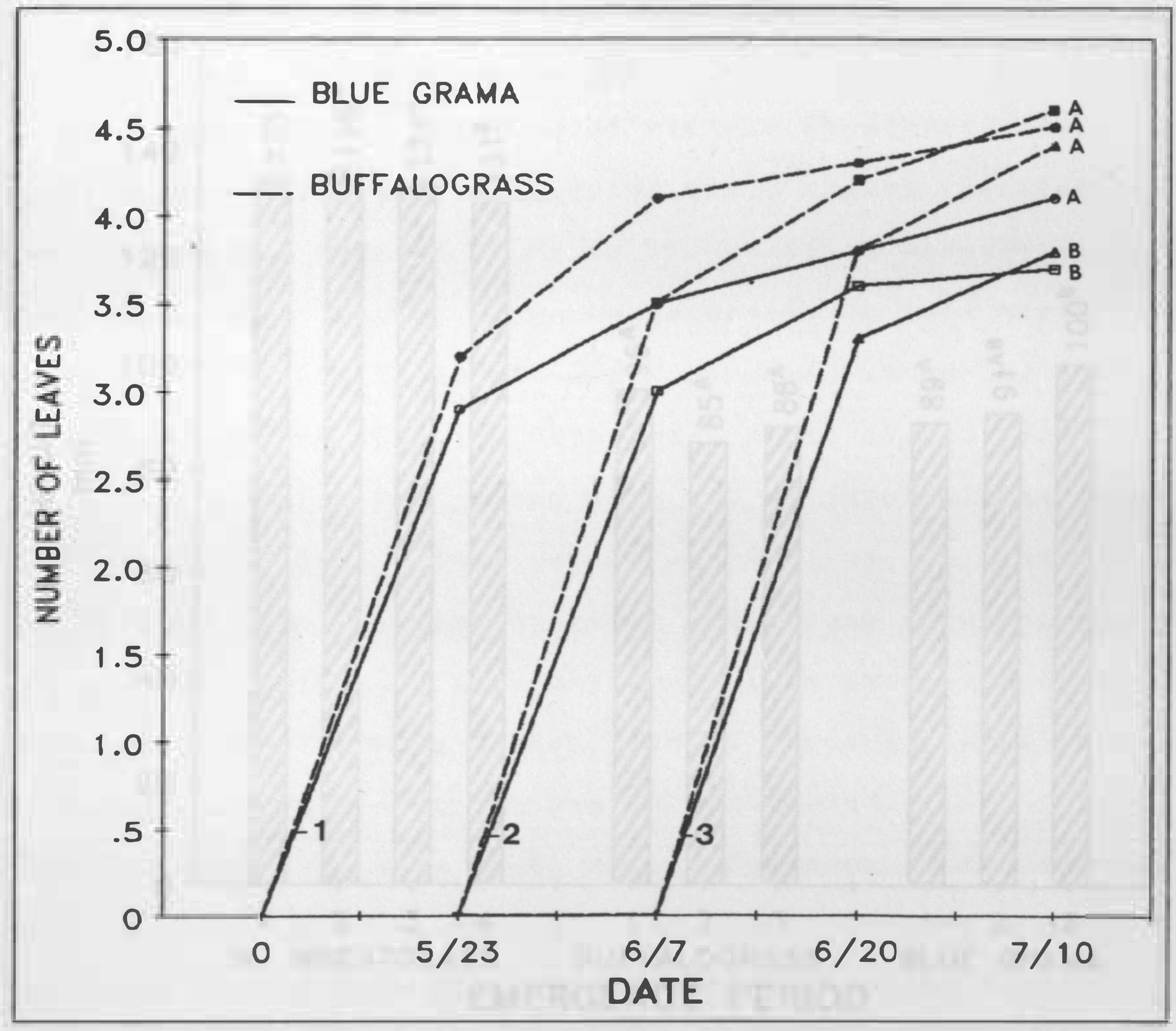

Figure 15. Number of leaves per tiller of emergence groups 1, 2, and 3 buffalograss and blue grama tillers at each observation date.

Group 1: emerged date 0 to 5/23.
Group 2: emerged 5/24 to 6/7.
Group 3: emerged 6/8 to 6/20.
[AB] Within species, number of leaves on July 10 with unlike letters differ, ($P<.05$).

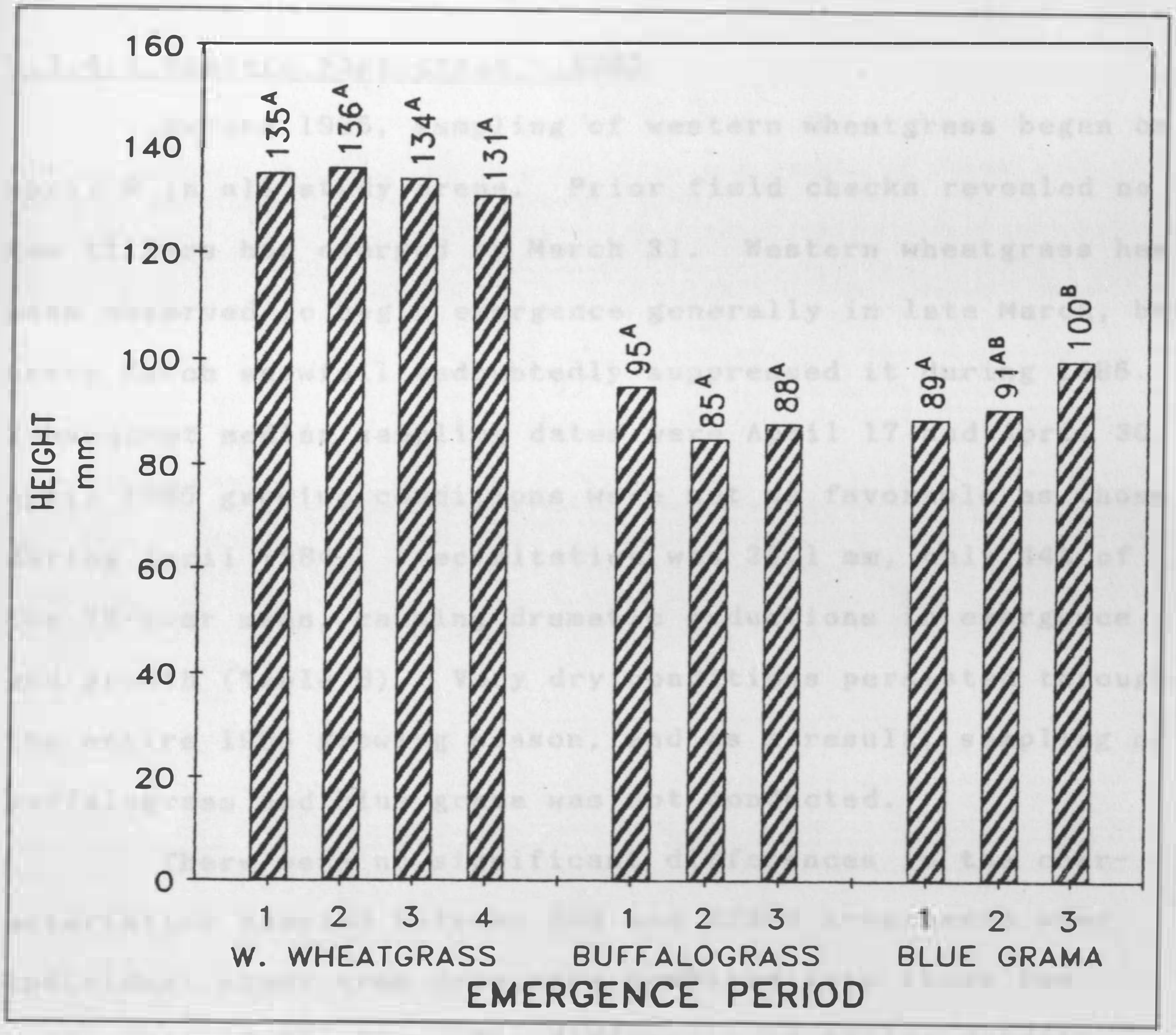

Figure 16. Height of each emergence group of western wheatgrass tillers on May 23 and of each emergence group of buffalograss and blue grama tillers on July 10, 1984.

Western wheatgrass

Group 1: emerged date 0 to 3/30 (exclosure only)
Group 2: emerged 3/31 to 4/6
Group 3: emerged 4/7 to 4/17
Group 4: emerged 4/18 to 5/5

Buffalograss and blue grama

Group 1: emerged date 0 to 5/23.
Group 2: emerged 5/24 to 6/7.
Group 3: emerged 6/8 to 6/20.

[AB] Within species, heights with an uncommon letter differ, ($P<.05$).

7.3.4.3 Western Wheatgrass - 1985

During 1985, sampling of western wheatgrass began on April 6 in all study areas. Prior field checks revealed no new tillers had emerged by March 31. Western wheatgrass has been observed to begin emergence generally in late March, but heavy March snowfall undoubtedly suppressed it during 1985. Subsequent median sampling dates were April 17 and April 30. April 1985 growing conditions were not as favorable as those during April 1984. Precipitation was 20.1 mm, only 44% of the 75-year mean, causing dramatic reductions in emergence and growth (Table 8). Very dry conditions persisted through the entire 1985 growing season, and as a result, sampling of buffalograss and blue grama was not conducted.

There were no significant differences in the characteristics sampled between RSG and HPSDG treatments when individual study area data were combined into those two treatments (Table 29). The difference in tiller density (323 in RSG vs. 262/m² in HPSDG) was large, but not significantly different (P=.16).

Western wheatgrass tiller densities in the specific study areas are summarized in Tables 29 and 30. The exclosure density of 524 tillers/m² was greater than that of the other five study areas (P<.05). The RSG and HPSDG drainageway densities of 632 and 630 tillers/m² were comparable to the permanent exclosure but these two study areas,

Table 29

Tiller density, height, leaves per tiller and length of first leaf of western wheatgrass in 10 study areas, 1985.

Study Area	Density[1] (no./sq m)	Height[2] (mm)	No. Leaves per Tiller[2]	Length of First Leaf[2]
RSG-Light[3]	294	80	2.7	38
RSG-Heavy[3]	238	95	2.7	47
RSG-Shortgrass	128	70	2.6	45
RSG-Drainageway	632	70	2.9	35
RSG Means[4] ±SE	323^A ±43	79^A ±3	2.7^A ±.3	41^A ±4
HPSDG-Early[5]	243	81	2.6	42
HPSDG-Late[5]	137	83	2.7	42
HPSDG-Shortgrass	38	74	2.6	34
HPSDG-Drainageway	630	76	2.6	45
HPSDG Means[4] ±SE	262^A ±39	79^A ±4	2.6^A ±.2	41^A ±4
Permanent Exclosure	524	88	2.5	45
RSG-Moderate[6]	227	85	2.6	46

[1] Density on April 30.
[2] Means of height, leaves and length of first leaf of all tillers on April 30 for the three emergence periods.
[3] Light or Heavy grazing the previous four years.
[4] RSG and HPSDG means of density, height, leaves and length with unlike superscripts differ, ($P<.05$).
[5] Grazed Early or Late during the initial HPSDG rotation cycle.
[6] Grazed moderately by steers June through August (Range Condition study).

Table 30

Western wheatgrass tiller density on April 30, 1985 and percent emerged at earlier observation dates.

Study Area	Percent Emerged 4/6	Percent Emerged 4/17	Density[1] (no./sq m) ±SE
Permanent Exclosure	8.4	52.1	524[A] ±45
RSG-Light[2]	11.6	92.8	294[B] ±65
HPSDG-Early[3]	4.9	84.8	243[BC] ±34
RSG-Heavy[2]	18.1	92.4	238[BC] ±56
RSG-Moderate[4]	19.4	59.5	227[BC] ±42
HPSDG-Late[3]	19.7	88.3	137[C] ±20
RSG-Drainageway[5]	13.6	95.6	632 ±96
HPSDG-Drainageway[5]	19.7	96.2	630 ±81
RSG-Shortgrass[5]	20.3	90.6	128 ±58
HPSDG-Shortgrass[5]	31.6	89.5	38 ±24

[1] Density means with an uncommon letter differ, ($P<.05$).
[2] Light or Heavy grazing the previous four years.
[3] Grazed Early or Late during the initial HPSDG rotation cycle.
[4] Grazed moderately by steers June through August.
[5] Drainageway and Shortgrass study areas analyzed separately, differences were not significant, ($P>.05$).

established in 1985, were analyzed separately as they had only five plots each compared to 10 in the other areas. The percentage of the total tillers emerged at earlier sampling dates was comparable between all study areas except in the permanent exclosure on April 17 (Table 30). At that date, only 52.1% of the tillers were emerged probably due to reduced soil temperatures caused by a large amount of old-dead residue.

Although tiller density differences on April 30 in HPSDG-early and late were large, they were not significantly different (P>.05). HPSDG-early did have a much smaller percent (4.9) of the total tillers emerged by April 6 compared to HPSDG-late (19.7). Similarly in 1983, densities on April 6 were less in HPSDG-early than HPSDG-late (P<.05) (Table 27). This suggests that the early season grazing of western wheatgrass may be reducing its vigor and resulting in less dense stands in the initial subunits of HPSDG. Although the percentage of use of western wheatgrass has been relatively low during the initial cycle the number of plants grazed was observed to be quite high.

As was observed in 1984, elongation rates of the first leaf were greatest during the initial period of emergence (P<.05) (Figure 17 and Table 31). There were no significant differences in length of the first leaf at the last observation date (April 30) between the three emergence

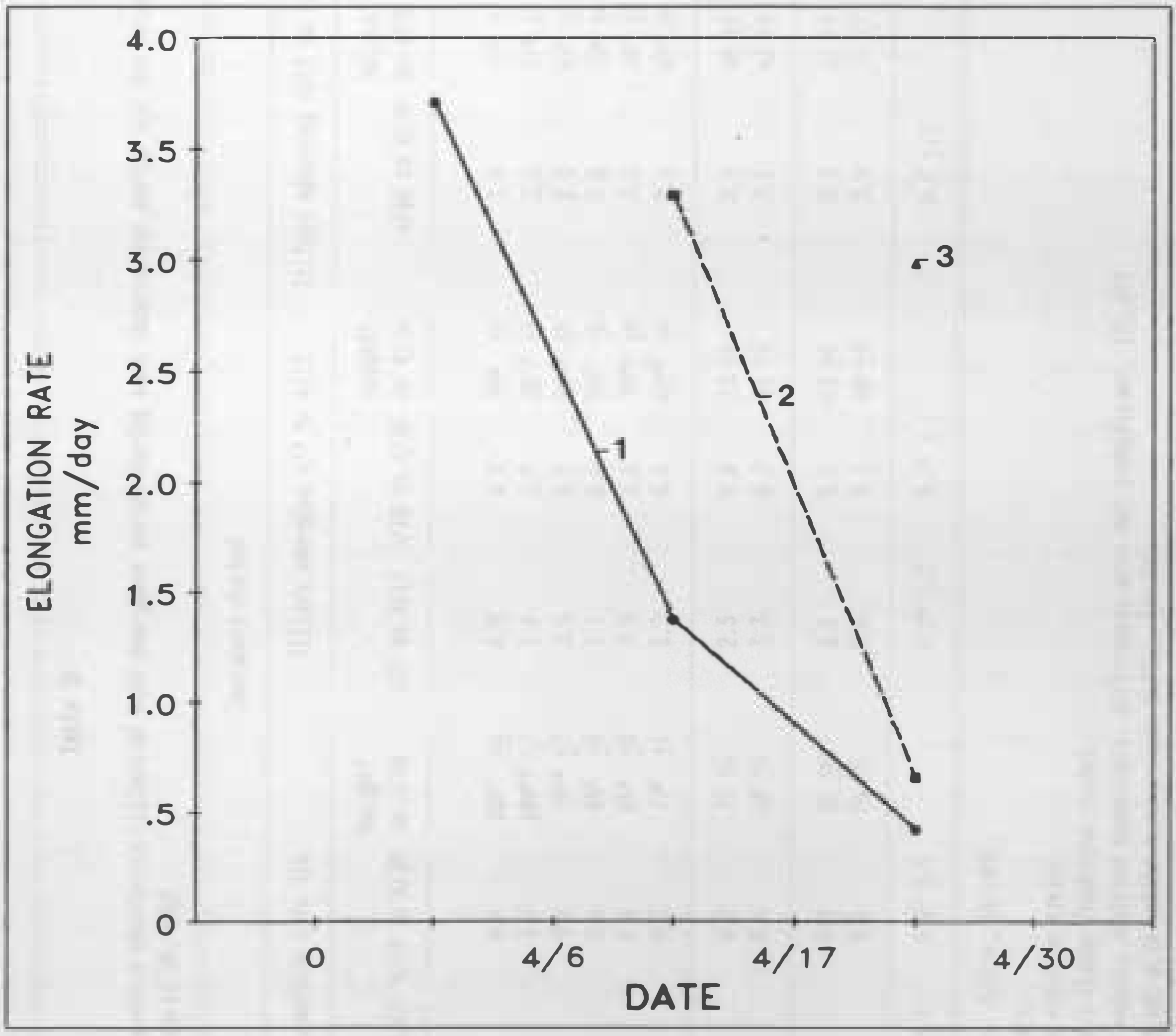

Figure 17. Elongation rate of the first leaf of emergence groups 1, 2 and 3 western wheatgrass tillers, 1985.

Group 1: Emerged date 0 to 4/6.
Group 2: Emerged 4/7 to 4/17
Group 3: Emerged 4/17 to 4/30.

Table 31

Elongation rate (mm/day) of the first leaf of western wheatgrass tillers of each emergence period during each observation period and the height (mm) of tillers from each emergence period on April 30, 1985.

	Emergence Period								
	Tillers emerging 0 to 4/6				Tillers emerging 4/7 to 4/17			Tillers emerging 4/18 to 4/30	
Observation Period ==> Study Area	0 to 4/6	4/7 to 4/17	4/18 to 4/30	Height[1] on 4/30	4/7 to 4/17	4/18 to 4/30	Height[1] on 4/30	4/18 to 4/30	Height[1] on 4/30
RSG-Heavy[2]	3.9	1.5	0.6	$109^{A} \pm 6$	4.0	0.7	$99^{A} \pm 4$	3.0	$78^{A} \pm 7$
Permanent Exclosure	3.8	1.5	0.7	$104^{AB} \pm 7$	2.7	0.9	$88^{AB} \pm 4$	3.6	$77^{A} \pm 4$
HPSDG-Late[3]	5.0	1.5	0.5	$94^{AB} \pm 7$	3.5	0.5	$89^{AB} \pm 5$	2.3	$69^{A} \pm 7$
HPSDG-Early[3]	4.1	1.3	0.6	$85^{B} \pm 8$	3.1	0.8	$84^{B} \pm 4$	2.8	$75^{A} \pm 5$
RSG-Moderate[4]	3.7	1.6	0.4	$85^{B} \pm 5$	3.8	0.6	$93^{AB} \pm 4$	3.6	$78^{A} \pm 5$
RSG-Light[2]	3.4	1.6	0.3	$77^{B} \pm 6$	3.2	0.6	$89^{AB} \pm 4$	2.3	$69^{A} \pm 6$
RSG-Drainageway[5]	3.7	1.5	0.2	77 ± 6	2.5	0.8	73 ± 4	2.0	60 ± 5
HPSDG-Drainageway[5]	4.1	1.5	0.6	82 ± 5	3.3	0.7	82 ± 5	3.1	63 ± 4
RSG-Shortgrass[5]	3.6	1.6	0.2	86 ± 4	3.1	0.5	63 ± 6	3.3	61 ± 7
HPSDG-Shortgrass[5]	2.9	1.1	0.1	86 ± 6	2.6	0.5	60 ± 4	3.9	75 ± 7
Observation Period Means[6]	$3.8^{a} \pm .2$	$1.5^{b} \pm .2$	$0.4^{c} \pm .1$		$3.2^{a} \pm .2$	$0.7^{b} \pm .1$		$3.0 \pm .2$	

[1] Tiller heights on 4/30 with an uncommon letter differ, $(P<.05)$.

[2] Light or Heavy grazing the previous three years.

[3] Grazed Early or Late during the initial HPSDG rotation cycle.

[4] Grazed moderately by steers June through August (Range Condition study).

[5] Drainageway and Shortgrass study area tiller heights analyzed separately, differences were not significant, $(P>.05)$.

[6] Observation period means within emergence periods with unlike superscripts differ, $(P<.05)$.

groups, but the number of leaves per tiller was highest for the first emergence group and least for the third (P<.05) (Figure 18). Over all study areas, heights of the tillers on April 30 were 89, 89 and 73 mm for emergence groups 1, 2 and 3, respectively, with the group 1 and 2 heights being significantly greater than the third (P<.05). Additional sampling dates would have been desirable to see if this trend continued.

Some differences in tiller height between study areas were present, many of which were unusual. Emergence group 1 and 2 tillers in RSG-heavy for example, were taller than those in RSG-light, had more and longer first leaves, but densities were similar (Tables 29 and 31). Other work (Lewis *et al.*, 1956), has shown western wheatgrass to decrease under heavy grazing. Also in contrast, Short and Woolfolk (1956) found the mean maximum height of western wheatgrass to be almost 20% greater in areas in good range condition than in areas in poor range condition. Reed and Peterson (1961) reported fewer leaves per tillers in heavily grazed pastures than in lightly grazed pastures.

Another unexpected finding in this substudy was the similarity of western wheatgrass tiller density in RSG and HPSDG drainageways. During both 1983 and 1984, RSG livestock, especially calves, were observed to prefer the drainageways and would continue to return to them to graze

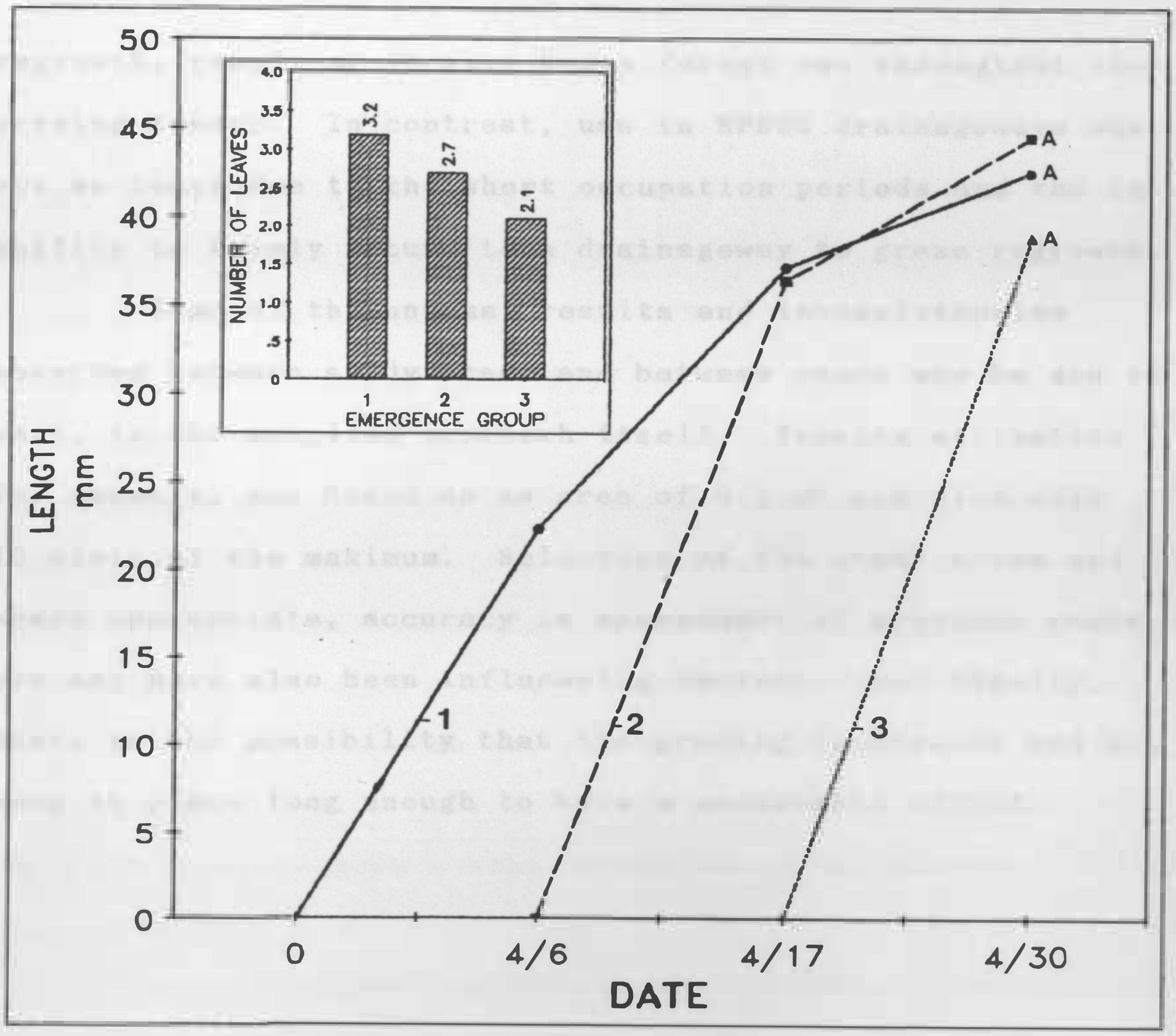

Figure 18. Length of the first leaf of emergence groups 1, 2 and 3 western wheatgrass tillers at each observation date and number of leaves per tiller on the final observation date (inset), 1985.

Group 1: Emerged date 0 to 4/6.
Group 2: Emerged 4/7 to 4/17
Group 3: Emerged 4/17 to 4/30.
[A] Lengths on April 30 were not different, (P>.05).

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regrowth, resulting in very heavy forage use throughout the grazing season. In contrast, use in HPSDG drainageways was not as heavy due to the short occupation periods and the inability to freely return to a drainageway to graze regrowth.

Some of the unusual results and inconsistencies observed between study areas and between years may be due in part, to the sampling approach itself. Density estimation for example, was based on an area of 0.1 m² per plot with 10 plots at the maximum. Selection of the study areas and where appropriate, accuracy in assessment of previous years use may have also been influencing factors. And finally, there is the possibility that the grazing treatments had not been in place long enough to have a measurable effect.

8.0 SUMMARY AND CONCLUSIONS

Six replications of Repeated-Seasonal (RSG) (May-September) and 16-subunit, 1-herd High-Performance Short-Duration (HPSDG) grazing system treatments were compared during 1981 through 1984 at the Cottonwood Range and Livestock Research Station. Data for 1983 and 1984 are reported here. Calves and lambs were the experimental animals and were allotted to the experimental pastures in sets approximately equal on an animal unit basis. Animal numbers were adjusted with put-and-take sets to attain planned forage use levels for each cycle of rotation in HPSDG and comparable end-of-season forage use levels in both treatments. The HPSDG system was operated with four cycles of rotation that had 1, 2, 2 and 3 occupation days and 15, 30, 30 and 45 nonuse days during cycles one through four, respectively.

Early growing season growing conditions were quite favorable during 1983 and 1984 with precipitation above the long-term mean. July, August and September precipitation however, ranged from 27 to 69% of the long-term mean both years (Tables 6 and 7).

Seasonal average daily gains (ADG) of both RSG calves and lambs in 1983 and calves in 1984 were greater than their HPSDG counterparts (P<.05) (Section 5.4, Tables 1 and 2). End of season attained stocking rates were 24 and 21% higher in HPSDG in 1983 and 1984, respectively (Section 5.4, Table

3). Gain per hectare however, was similar during 1983, but was greater for the HPSDG calves and the calves and lambs combined during 1984 ($P<.05$) (Section 5.4, Figure 1). In general, this indicates that the reduced animal performance in HPSDG then, may or may not be made up with the moderate increases in stocking rate to obtain greater livestock gain or production per hectare. During 1983, wool growth rates (mm/d) were greater during period 1 than the other three periods ($P<.05$). There were no other significant treatment or period effects ($P>.05$) (Table 18).

During 1984, fecal samples were collected from the individual calves and lambs at four dates corresponding to the midpoints of the four HPSDG cycles. Fecal nitrogen (N) (organic matter basis) declined at each successive sampling date corresponding to increasing forage maturity and decreasing forage N. The mean percent fecal N was greater in both RSG calf and lamb samples than in samples of their HPSDG counterparts ($P<.05$) (Section 5.4, Table 5). This suggests RSG livestock were able to select a diet higher in quality (or at least N) and may in part, account for the greater individual RSG animal performance. In contrast, Jung *et al.* (1985) and Heitschmidt *et al.* (1982b) hypothesized that average forage quality may be higher in short-duration systems as a larger percentage of plants should have been grazed and therefore, retarded in maturity. However, regrowth and delay in maturity would also occur in preferred

areas in RSG and in these studies, RSG livestock tended to concentrate in the preferred drainageways, especially during the first half of the grazing season.

Botanical composition of the feces determined by microhistological examination was used as an index of the botanical composition of the diet. Annual grasses (Japanese brome and six-weeks fescue) and western wheatgrass were the major components of calf diets and shortgrasses were the major component in lamb diets in both treatments (Section 5.4, Figures 2 and 3). RSG calf samples did contain a greater percentage of western wheatgrass and forbs and less annual grasses than HPSDG samples ($P<.05$). RSG lamb samples also contained a greater percentage of forbs and additionally, less sedges than HPSDG lamb samples. Important date effects for both the calves and lambs included a greater percentage of western wheatgrass from the May and August than from the June and July sampling dates ($P<.05$) and percentage of shortgrasses were least from the May sampling date ($P<.01$). For the lambs, percentages of forbs and sedges were greater from the first two than from the last two sampling dates ($P<.05$). Calf and lamb selection indices were surprisingly high for annual grasses in both treatments. Lambs also exhibited selection for the shortgrasses and a strong avoidance for western wheatgrass. Similarity indices (between lambs and calves) show compatibility of the combination of lambs and calves in both grazing system treatments (Section

5.4, Table 4). From these data and considering forage use data, it can be concluded that calves and lambs grazing in combination will result in a greater efficiency of harvest of the total complement of vegetation than the use of either calves or lambs alone.

There were no treatment differences in water intake of livestock between RSG and HPSDG treatments either year. Across treatments, average consumption was estimated at 33.1 and 30.6 l/AU/d during 1983 and 1984 respectively. Consumption tended to be the least during the initial two week period of grazing, peaked during the first half of August and then declined (Figures 3 and 4). Both forage dry matter and mean air temperature were found to influence water intake with the latter of the two variables having the greater effect (Table 19; Figures 5 and 6).

During 1983, live (L), recent-dead (RD) and old-dead (OD) standing crop was quantified during early July and at the end of the grazing season. L + RD standing crop was similar in RSG and HPSDG in early July but less than in the permanent exclosure. End of season L + RD standing crop was 148 kg/ha less in HPSDG compared to RSG (Section 6.4, Figure 3). End of season use of midgrasses (primarily western wheatgrass) was not different between treatments ($P>.05$), but use of shortgrasses was higher in HPSDG ($P<.05$) (Tables 24 and 25).

During 1984, peak L + RD standing crops were 2080

(Aug. 24), 1358 (Jul. 20) and 1472 kg/ha (immediately before cycle 4 occupation) in the permanent exclosure, RSG and HPSDG treatments, respectively (Section 6.4, Figures 4, 5 and 6). Western wheatgrass, buffalograss and blue grama were found to account for about 80 to 82% of the peak standing crop in all three treatments. Distinct periodic (cyclic) dynamics of standing crop and forage use were characterized in both RSG and HPSDG (Section 6.4, Table 2, Figures 6, 7 and 8). End of season use of western wheatgrass was not different between grazing system treatments (P>.05), but use of short-grasses was higher in HPSDG (P<.05) (Appendix Table 15), suggesting that with the combination of calves and lambs, there was an even greater efficiency of harvest of the total complement of vegetation in HPSDG. Spatial distribution of forage use tended to vary substantially between areas within RSG with use of western wheatgrass as high as 83% in the drainageways (Appendix Table 14).

In 1984, above-ground net primary production (ANPP) in the permanent exclosure as estimated by the summation of L + RD standing crops of one individual species and five species groups was 2144 kg/ha. ANPP in HPSDG as estimated by totaling the cyclic summations of the positive changes in standing crop of each species group was 1940 kg/ha. Previous studies at the Research Station reported substantially greater differences between the permanent exclosure in high range condition and RSG in low condition than were observed

between the permanent exclosure and the HPSDG treatment with both in high range condition in this study (Section 6.4).

Indices of soil compaction were determined from the depth of penetration of a tapered rod dropped from a standard height. Within RSG and HPSDG treatments, three strata based on distance from water were studied and additionaly in RSG, data were collected from areas with high (>40%) and low (<10%) forage use as well as in an ungrazed exclosure. Significant relationships were established between bulk density and compaction indices for soils from clayey and silty range sites (Figures 7 and 8). Soil compaction was greater in strata 1 (closest to water) than in the other two strata (Tables 20 and 22). Although overall soil compaction were not different between RSG and HPSDG treatments (P<.05), strata 1 did encompass a substantially larger percentage of the entire HPSDG pasture than it did in RSG. This greater compaction could potentially have detrimental effects on many hydrological parameters as well as the vegetation. Within RSG, compaction was found to be greater in high-use areas than in low-use areas (Tables 21 and 23). Compaction indices and predicted soil bulk densities were also found to be greater for soils from the silty range site than for soils from the clayey range sites (P<.05) (Tables 20 and 22).

Heights, weights and number of leaves of grazed and ungrazed western wheatgrass tillers collected from clayey and silty range sites within RSG, HPSDG and ungrazed treatments

were compared. Tillers were collected in mid-July, 1984. There were no differences in the mean heights and number of leaves of grazed tillers from RSG and HPSDG ($P>.05$). Weight of RSG grazed tillers (0.25 g) was however, greater than those from HPSDG (0.23 g) ($P<.05$). There were no differences in the characteristics measured on grazed tillers between the clayey and silty range sites (Table 26). Height (386.5 mm), weight (0.38 g) and number of leaves (5.7) of ungrazed tillers from the permanent exclosure were greater than the same characteristics of ungrazed tillers from RSG or HPSDG ($P<.05$). Ungrazed tillers from the clayey range site were taller, heavier and had more leaves than those from the silty range site (Table 26). With regards to the RSG and HPSDG treatment comparisons, these data, aside from the weight difference of grazed tillers, suggest that at the time of sampling, both treatments had about an equal effect on the characteristics measured. Calves, however, the primary consumers of western wheatgrass, had only been in these systems one and one-half grazing seasons, and the appearance of measurable cumulative effects might require several years.

Emergence, growth and developmental characteristics of western wheatgrass (1984 and 1985) and buffalograss and blue grama (1984) in ten study areas were also studied to evaluate possible cumulative effects of the grazing treatments. Overall densities, heights, number of leaves and length of first leaves of western wheatgrass were similar in

RSG and HPSDG treatments (P>.05). In 1985, the density difference between RSG (323 tillers/m^2) and HPSDG (262 tillers/m^2) was large, but not significantly different (P=.16) (Table 29). Western wheatgrass tiller densities in the HPSDG subunits that were grazed early in the initial cycle of rotation tended to be less than in subunits grazed late (Tables 27 and 30), suggesting early season grazing of western wheatgrass in HPSDG may be reducing the vigor and resulting in less dense stands of western wheatgrass, thus lowering range condition. Western wheatgrass tiller densities in RSG and HPSDG drainageways were not different (P>.05) (Table 30), but may possibly decrease in RSG drainageways in future years as a result of overutilization (Appendix Table 14). Overall densities of buffalograss and blue grama were not different between RSG and HPSDG treatments (P>.05). Several study area differences were however, observed (Table 28).

The overall results of these studies comparing HPSDG and RSG systems do not convincingly characterize one system or the other as being "better" in terms of what it could do for the ranch or range manager, but rather reveal some advantages and disadvantages of each. Favorable animal performance and management simplicity are advantageous characteristics of RSG. Conversely, possible reduced animal performance and the need for flexibility and intensive management are disadvantageous characteristics of HPSDG. Improved harvesting

efficiency and spatial distribution of grazing are positive aspects of HPSDG and may lead to greater gain per hectare.

HPSDG performed well during periods of rapid vegetation growth but drought-induced or natural dormancy will cause a need for some careful management decisions. Observations from these studies indicate that if the typical dormant period begins in August, HPSDG's final cycle of rotation could be planned to occur during that month, and the system would essentially become a tool for uniform harvest of the pasture to some desired level.

Either of the two systems are compatible components of a grazing management plan. Future studies are needed however, especially with HPSDG systems, to investigate the operational intricacies, long-term effects on the range ecosystem and economic feasibility and aspects within the ranch operation. These studies have provided baseline data and information that could be applied to the needed large-scale studies at experiment stations or cooperating ranches.

9.0 REFERENCES

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

Aldous, A.E. 1930. Effect of different clipping treatments on the yield and vigor of prairie grass vegetation. Ecology. 11:752-759.

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

Allen, O.B. 1982. A guide to the analysis of growth curve data with special reference to SAS. Computers Biomed. Res. 16:101-115.

A.O.A.C. 1980. Official methods of analysis. (13th ed.) Assoc. Official Agr. Chem. Washington, DC.

Anderson, D.M. 1982. Seasonal grazing of semidesert tobosa rangeland in southern New Mexico. p. 137-142. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

Anderson, D.M. 1977. Standing crop, diets, travel and weight changes under short-duration and continuous grazing. Ph.D. Thesis. Texas A & M Univ., Diss. Abst. Int. 38:1490.

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, K.M. 1940. Deferred grazing of bluestem pastures. Kansas Agr. Exp. Sta. Bull. 291.

Arave, C.W. and J.L. Albright. 1981. Cattle behavior. J. Dairy Sci. 64:1318-1329.

Arizona Interagency Range Committee. 1973. Grazing systems for Arizona ranges. S.C. Martin and C.R. Whitefield, co-chairman. (mimeo.).

Baker, R.D., J.M. Barker and Y.L.P. LeDu. 1982. The influence of winter nutrition, grazing system and stocking rate on the performance of spring-grazed Hereford X Friesian cows and their calves. II: Grazing system and stocking rate. Anim. Prod. 34:225-237.

Bareiss, L.J., P. Schulz and F.G. Guthery. 1986. Effects of short-duration and continuous grazing on bobwhite and wild turkey nesting. J. Range Manage. 39:259-260.

Beetle, A.A. 1970. Recommended plant names. Wyoming Agr. Exp. Sta. Res. J. 31.

Beranger, C. and D. Micol. 1981. Importance of stocking rate and management methods. (In French) Fourrages. No. 85. 73-93.

Bilger, L.S., J.K. Lewis, D.M. Engle, T.P Weber and L.C. Blome 1983. Comparison of repeated-seasonal and high-performance short-duration grazing with sheep, 1981, 1982. Proc:. Cottonwood Range and Livestock Research Station Research Day. Oct. 5, 1983. Philip, SD. CO 83-6.

Bokhari, U.G. and J.S. Singh. 1974. Effects of temperature and clipping on growth, carbohydrate reserves, and root exudation of western wheatgrass in hydroponic culture. Crop Sci. 14:790-794.

Booysen, P. De V. 1969. An analysis of the fundamentals of grazing management systems. Proc. Grassland Soc. S. Afr. 4:84-91.

Booysen, P. De V. and N.M. Tainton. 1978. Grassland management: Principles and practice in South Africa. p. 551-554. *IN*: D.N. Hyder (ed.) Proc., First Int. Rangeland Cong. Denver, CO.

Boryslawski, Z. and B.L. Bentley. 1985. The effect of nitrogen and clipping on interference between C_3 and C_4 grasses. J. Ecol. 73:113-121.

Bowman, G.B. and L.D. Harris. 1980. Effects of spatial heterogeneity on ground-nest depredation. J. Wildl. Manage. 44:806-813.

Briske, D.D. and J.W. Stuth. 1982. Tiller defoliation in a moderate and heavy grazing regime. J. Range Manage. 35:511-514.

Brundage, A.L. and W.E. Petersen. 1952. A comparison between daily rotational and continuous grazing. J. Dairy Sci. 30:623-630.

Burns, J.C., R.D. Mochrie, H.D. Gross, H.L. Lucas and R. Teichman. 1970. Comparison of set-stocked and put-and-take systems with growing heifers grazing Coastal bermuda grass (*Cynodon dactylon* L. Per.). p. 904-909 *IN*: Proc. XI Int. Grassland Cong., Apr. 13-23, Surfers Paradise, Queensland, Australia.

Cable, D.R. 1982. Partial defoliation stimulates growth of Arizona cottontop. J. Range Mange. 35:591-593.

Castle, M.E. and J.N. Watson. 1973. A comparison between a paddock system and a Wye College system of grazing for milk production. J. Brit. Grassland Soc. 28:7-11.

Clarke, S.E., E.W. Tisdale and N.A. Skoglund. 1943. The effects of climate and grazing practices on short-grass prairie vegetation. Canada Dept. Agr. Tech. Bull. 46.

Clements, F.E. 1920. Plant indicators. Carnegie Inst., Wash. Publ. 290.

Cohen, W.E. and F.C. Bryant. 1985. Effect of short duration grazing on white-tailed deer home range and travel distance. Proc.: 38th Annual Meeting, Society for Range Management, Feb. 11-15, 1985. Salt Lake City, UT. Abst. 243.

Colburn, M.W. and J.L. Evans. 1968. Reference base, W^b, of growing steers determined by relating forage intake to body weight. J. Dairy Sci. 51:1073-1076.

Cole, J.W.L. and J.E. Grizzle. 1966. Applications of multivariate analysis of variance to repeated measures experiments. Biometrics. 22:810-828.

Conner, J.R., R.K. Heitschmidt and J.W. Walker. 1986. Effects of rotational grazing on economic profits. Proc.: 39th Annual Meeting, Society for Range Management, Feb. 9-14, 1986. Orlando, FL. Abst. 165.

Cook, C.W. and J. Stubbendieck. 1986. Range research: basic problems and techniques. Soc. Range Manage. Denver, CO.

Denny, R.P., D.L. Barnes and T.C.D. Kennan. 1977. Trials of multi-paddock grazing systems on veld: I. An exploratory trial of systems involving twelve paddocks and one herd. Rhodesia J. Agr. Sci. 15:11-23.

Detling, J.K., M.I. Dyer and D.T. Winn. 1979. Net photosynthesis, root respiration, and regrowth of *Bouteloua gracilis* following simulated grazing. Oecologia. 41:127-134.

Dodd, J.L., J.K. Lewis, H.L. Hutcheson and C.L. Hanson. 1974. Abiotic and herbage dynamics studies at Cottonwood, 1971. U.S.I.B.P. Grassland Biome Tech. Rep. 250.

Dowhower, S.L., R.K. Heitschmidt and J.W. Walker. 1986. Effects of rotational grazing on aboveground biomass dynamics and ANPP. Proc.: 39th Annual Meeting, Society for Range Management, Feb. 9-14, 1986. Orlando, FL. Abst. 026.

Drasz, O. 1978. Revival of the "Hema" systems of range reserves as a basis for Syrian Range Development Program. p. 100-103. *IN*: D.N. Hyder (ed.) Proc., First Int. Rangeland Cong. Denver, CO.

Enevoldsen, M.E. 1967. The effect of range site and range condition on the growth and development of western wheatgrass. M.S. Thesis, S. Dak. State Univ., Brookings.

Enevoldsen, M.E. and J.K. Lewis. 1978. Effect of range site and range condition on height and location of the shoot apex in vegetative shoots of western wheatgrass. p. 387-391. *IN*: D.N. Hyder (ed.) Proc., First Int. Rangeland Cong. Denver, CO.

Fels, H.E., R.J. Moir and R.C. Rossiter. 1959. Herbage intake of grazing sheep in southwestern Australia. Aust. J. Agr. Res. 10:237-247.

Forbes, J.M. 1968. The water intake of ewes. Brit. J. Nutr. 22:33-43.

Gammon, D.M. and B.R. Roberts. 1978a. Patterns of defoliation during during continuous and rotational grazing of the Matopos sandveld of Rhodesia. I: Selectivity of grazing. Rhodesian J. Agr. Res. 16:117-131.

Gammon, D.M. and B.R. Roberts. 1978b. Patterns of defoliation during during continuous and rotational grazing of the Matopos sandveld of Rhodesia. II: Severity of defoliation. Rhodesian J. Agr. Res. 16:133-145.

Gammon, D.M. and B.R. Roberts. 1978c. Patterns of defoliation during during continuous and rotational grazing of the Matopos sandveld of Rhodesia. III: Frequency of defoliation. Rhodesian J. Agr. Res. 16:147-164.

Gammon, D.M. and B.R. Roberts. 1980a. Grazing behaviour of cattle during continuous and rotational grazing of the Matopos sandveld of Zimbabwe. Zimbabwe J. Agr. Res. 18:13-27.

Gammon, D.M. and B.R. Roberts. 1980b. Aspects of defoliation during short duration grazing of the Matopos sandveld of Zimbabwe. Zimbabwe J. Agr. Res. 18:29-38.

Gamougoun, N.D., R.P. Smith, M.K. Wood and Rex D. Pieper. 1984. Soil, vegetation, and hydrologic responses to grazing management at Fort Stanton, New Mexico. J. Range Manage. 37:538-541.

Gill, J.L. 1978. Design and analysis of experiments in the animal and medical sciences. (vol. 2) Iowa State Univ. Press. Ames, IA.

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

Gray, J.R, C. Steiger and J.M. Fowler. 1982. Characteristics of grazing systems. New Mexico State Univ. Agr. Exp. Sta. Res. Rep. 467.

Gray, J.R. and J.M. Fowler. 1980. Requirements for economic analyses of grazing systems. p. 95-109. *IN*: K.C. McDaniel and C. Allison (eds.). Proc. Grazing Management Systems for Southwest Rangelands Symposium. Apr. 1-2. Albuquerque, NM.

Great Plains Flora Association. 1986. Flora of the Great Plains., T.M. Barkley (ed.), Univ. of Kansas Press. Lawrence.

Grosz, K. and D.R. Kirby. 1986. Impact of four short duration grazing treatments stocked with cattle on simulated ground nests. Proc.: 39th Annual Meeting, Society for Range Management, Feb. 9-14, 1986. Orlando, FL. Abst. 333.

Hansen, R.M., T.M. Foppe, M.B. Gilbert, R.C. Clark and H.W. Reynolds. 1985. The microhistological analyses of feces as an estimator of herbivore dietary. Comp. Anal. Lab., Colo. State Univ. (mimeo.).

Hanson, C.L., A.R. Kuhlman and J.K. Lewis. 1978. Effect of grazing intensity and range condition on hydrology of western South Dakota ranges. S. Dak. State Univ. Agr. Exp. Sta. Bull. 647.

Hanson, H.C., L.D. Love and M.S. Morris. 1931. Effects of different systems of grazing by cattle upon western wheat-grass type of range. Colorado Agr. Exp. Sta. Bull. 377.

Hart, R.H. 1978. Stocking rate theory and its application to grazing on rangelands. p. 547-550. *IN*: D.N. Hyder (ed.) Proc. First Int. Rangeland Cong. Denver, CO.

Hart, R.H., P.S. Test and J.W. Waggoner. 1983. Steer gains under three grazing systems and two stocking rates. Stockman's Homecoming Roundup, Prog. Rep. Coll. Agr., Univ. Wyoming. pp. 25-28.

Hart, R.H. and P.S. Test. 1984. Short-duration rotation grazing: theory vs. practice. Proc. II Int. Rangeland Cong. May 13-18. Adelaide, Australia. (in press).

Hart, R.H. G.E. Schuman, M.J. Samuel and M.A. Smith. 1986. Time-controlled grazing research in Wyoming. *IN*: Proc. Short-Duration Grazing and Issues in Grazing Management Workshop. Jan. 21-23. Kennewick, WA. (in press).

Havstad, K.M. and J.C. Malechek. 1982. Energy expenditure by heifers grazing crested wheatgrass of diminishing avail-ability. J. Range Manage. 35:447-450.

Heady, H.F. 1961. Continuous vs. specialized grazing systems: A review and application to the California annual type. J. Range Manage. 14:182-193.

Heady, H.F. 1970. Grazing systems: Terms and definitions. J. Range Manage. 23:59-61.

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

Heitschmidt, R.K., D.L. Price, R.A. Gorden and J.R. Frasure. 1982a. Short duration grazing at the Texas Experimental Ranch: Effects on above-ground net primary production and seasonal growth dynamics. J. Range Manage. 35:367-372.

Heitschmidt, R.K., R.A Gorden and J.S. Bluntzer. 1982b. Short duration grazing at the Texas Experimental Ranch: Effects on forage quality. J. Range Manage. 35:372-374.

Heitschmidt, R.K., J.R. Frasure, D.L. Price and L.R. Rittenhouse. 1982c. Short duration grazing at the Texas Experimental Ranch: Weight gains of heifers. J. Range Manage. 35:375-379.

Hodgson, J. 1979. Nomenclature and definitions in grazing studies. Grass and Forage Sci. 34:11-18.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by lambs and calves. Grass and Forage Sci. 36:49-57.

Holderman, C.A. and H. Goetz. 1981. Response of western North Dakota mixed prairie to intensive clipping and five stages of development. J. Range Manage. 34:188-193.

Holechek, J.L. 1983. Considerations concerning grazing systems. Rangelands. 5:208-211.

Holmes, W., R. Waite, D.L. Fergusson and J.I. Campbell. 1950. Studies in grazing management. I. A comparison of the production obtained from close-folding and rotational grazing of dairy cows. J. Agr. Sci. 40:381-391.

Hormay, A.L. 1970. Principles of rest-rotation grazing and multiple-use land management. U.S.D.A.-F.S. Training Text 4 (2200).

Humann, M., D.R. Kirby, T.Faller, D. Landblom and T. Conlon. 1985. Sheep diets on short duration and seasonlong grazing treatments in western North Dakota. Proc.: 38th Annual Meeting, Society for Range Management, Feb. 11-15, 1985. Salt Lake City, UT. Abst. 327.

Hyder, D.N., R.E. Bemet and J.J. Norris. 1968. Sampling requirements of the water-intake method of estimating forage intake by grazing cattle. J. Range Manage. 21:392-397.

Hyder, D.N., R.E. Bemet, J.J. Norris and M.J. Morris. 1966. Evaluating herbage species by grazing cattle. p. 970-977. *IN*: Proc. Tenth Int. Grassland Congress, Helsinki, Finland.

Jamieson, W.S and J. Hodgson. 1979. The effects of variation in sward characterisitics upon the ingestive behaviour and herbage intake of calves and lambs under a continuous stocking management. Grass and Forage Sci. 34:273-282.

Jardine, J.T. and M. Anderson. 1919. Range management on the National Forests. U.S.D.A. Agr. Bull. 790.

Johnson, W.L., T.R. Javier, W.A. Hardison and A.L. Ordovesa. 1966. The effects of restricted water intake on food intake, digestibility and nitrogen balance with cattle and carabao. Philippine Agr. 49:688.

Johnson, W.M. 1956. The effect of grazing intensity on plant community composition, vigor and growth of pine-bunchgrass ranges in central Colorado. Ecology 37:790-798.

Jung, H.G., R.W. Rice and L.J. Koong. 1985. Comparison of heifer weight gains and forage quality for continuous and short-duration grazing systems. J. Range Manage. 38:144-148.

Kirby, D.R., D. Landblom and T. Conlon. 1985. Livestock performance on short duration and repeated season-long grazing treatments in western North Dakota. Proc.: 38th Annual Meeting, Society for Range Management, Feb. 11-15, 1985. Salt Lake City, UT. Abst. 328.

Kirby, D. and P.M. Bultsma. 1984. Implementing and evaluating short-duration grazing systems. N. Dak. State Univ., Coop. Ext. Ser. Special Rep. No. 1.

Kirby, D.R., M.D. Parman, T.J. Conlon and P.E. Nyren. 1982. Short duration grazing in the mixed grass prairie of North Dakota. p. 186-189. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

Klebenow, D.A. 1980. The impacts of grazing systems on wildlife. p. 153-162. *IN*: K.C. McDaniel and C. Allison (eds.) Proc. Grazing Management Systems for Southwest Rangelands Symposium. April 1-2, Albuquerque, NM.

Koerth, B.H., W.M. Webb, F.C. Bryant, and F.S. Guthery. 1983. Cattle trampling of simulated ground nests under short duration and continuous grazing. J. Range Manage. 36:385-386.

Kothmann, M.M. 1980. Integrating livestock needs to the grazing system. p. 65-83. *IN*: K.C. McDaniel and C. Allison (eds.). Proc. Grazing Management Systems for Southwest Rangelands Symposium. April 1-2, Albuquerque, NM.

Kothmann, M.M. 1974. Grazing management terminology. J. Range Manage. 27:326-327.

Kothmann, M.M., R.T. Hinnant and J.F. Casco. 1986a. Vegetation responses under short-duration grazing. Proc.: 39th Annual Meeting, Society for Range Management, Feb. 9-14, 1986. Orlando, FL. Abst. 025.

Kothmann, M.M., E.A. de Moraes, R.K. Heitschmidt and J.W. Walker. 1986b. Diet selection and quality under rotational grazing in Texas. Proc.: 39th Annual Meeting, Society for Range Management, Feb. 9-14, 1986. Orlando, FL. Abst. 025.

Kothmann, M.M., G.W. Mathis and W.J. Waldrip. 1971. Cow-calf response to stocking rates and grazing systems on native range. J. Range Manage. 24:100-105.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. Amer. Geog. Soc. Spec. Publ. 36.

Lacey, J.R. and H.W. Van Poollen. 1979. Grazing system identification. J. Range Manage. 32:38-39.

Langlands, J.P. and J.L. Wheeler. 1968. The dyebanding and tattooed patch procedures for estimating wool production and obtaining samples for the measurement of fiber diameter. Aust. J. Exp. Agr. Anim. Husbd. 8:265-269.

Larin, I.V. 1962. Pasture economy and meadow cultivation. Israel Prog. for Sci. Translations. Jerusalem.

Latour, S.A. and P.W. Miniard. 1983. The misuse of repeated measures analysis in marketing research. J. Marketing Res. 20:45-57.

Lauenroth, W.K., H.W. Hunt, D.M. Swift and J.S. Singh. 1987. Estimating aboveground net primary production in grasslands: A simulation approach. Ecol. Modelling. (in press).

Launchbaugh, J.L., C.E. Owensby, J.R. Brethour and E.F. Smith. 1983. Intensive - early stocking studies on Kansas ranges. Kansas Agr. Exp. Sta. Prog. Rep. 441.

Leconte, D. 1982a. Comparison of intensive continuous and intensive rotational grazing systems for beef production. Trials conducted in 1978-1979-1980-1981. (In French). Centre de Recherches Zootechniques et Veterinairies de Theix. Bull. No. 15. pp. 51-55.

Leconte, D. 1982b. Comparison of intensive continuous and intensive rotational grazing systems for beef production. (In French). Fourrages. No. 89. 37-48.

Lewis, J.K. 1969. Range management viewed in the ecosystem framework. *IN*: G.M. Van Dyne (ed.) The Ecosystem Concept in Natural Resource Management. Academic Press, New York.

Lewis, J.K. 1981. Grazing systems. Proc.: The Range Beef Cow Symposium VII. Dec. 7-9, 1981. Rapid City, SD.

Lewis, J.K. 1982a. Grazing systems review. Third Annual Rangeland Symposium. Univ. of Nebr. Apr. 9, 1982. Lincoln, NE. (mimeo.)

Lewis, J.K. 1982b. Criteria for naming and comparing grazing systems. Poster Session. A National Conference on Grazing Management Technology. Nov. 10-12, 1982. Texas A & M Univ. College Station, TX. (mimeo.)

Lewis, J.K. 1983a. Tentative classification of grazing systems. Proc.: 36th Annual Meeting, Society for Range Management, Feb. 14-17, 1983. Albuquerque, NM. Abst. 231. (mimeo.)

Lewis, J.K. 1983b. Kinds of grazing systems and their use in the Northern Great Plains. Proc:. Cottonwood Range and Livestock Research Station Research Day. Oct. 5, 1983. Philip, SD. CO 83-5.

Lewis, J.K. 1984. Classification and application of grazing systems. Proc:. 37th Annual Meeting, Society for Range Management, Feb. 12-17, 1984. Rapid City, SD. Abst. 87. (mimeo.)

Lewis, J.K., G.M. Van Dyne, L.R. Albee and F.W. Whetzal. 1956. Intensity of grazing: Its effect on livestock and forage production. S. Dak. State Col. Agr. Exp. Sta. Bull. 459.

Lewis, J.K., J.L. Dodd, H.L. Hutcheson and C.L. Hanson. 1971. Abiotic and herbage dynamics studies on the Cottonwood site, 1970. U.S.I.B.P. Grassland Biome Tech. Rep. 111.

Lewis, J.K., L.S. Bilger, D.M. Engle, T.P. Weber and L. Blome. 1982. Comparison of high-performance short-duration and repeated seasonal grazing in the northern mixed prairie. p. 193-196. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

Lull, H.W. 1959. Soil compaction on forests and range lands. U.S.D.A., Misc. Publ. No. 768. Washington, DC.

Lynch, J.J. and D.A. Hedges. 1979. The influence of shape of paddock, type of fence and stocking rate on grazing behavior and social facilitation in Merino sheep. Appl. Anim. Ethology. 5:321-331.

McCalla, G.R., W.H. Blackburn and L.B. Merrill. 1984a. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:265-269.

McCalla, G.R., W.H. Blackburn and L.B. Merrill. 1984b. Effects of livestock grazing on sediment production, Edwards Plateau of Texas. J. Range Manage. 37:291-294.

McNaughton, S.J. 1979. Grazing as an optimization process: Grass ungulate relationships in the Serengeti. Amer. Natur. 113:691-703.

McNaughton, S.J., L.L. Wallace and M.B. Coughenour. 1983. Plant adaptation in an ecosystem context: Effects of defoliation, nitrogen and water on growth of an African C_4 sedge. Ecology 64:307-318.

Menke, J.W. and M.J. Trlica. 1981. Carbohydrate reserve, phenology, and growth cycles of nine Colorado range species. J. Range Manage. 34:269-277.

Menke, J.W. and M.J. Trlica. 1983. Effects of single and sequential defoliations on the carbohydrate reserves of four range species. J. Range Manage. 36:70-74.

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

Morley, F.H.W. 1981. Management of grazing systems. p.379-400. *IN*: F.H.W. Morley (ed.), World Animal Science: Grazing Animals. Vol. B-1. Elsevier Scientific Publ. Co. Amsterdam, The Netherlands.

Mott, G.O. 1960. Grazing pressure and the measurement of pasture production. p. 606-611. *IN*: Proc. VIII Int. Grassland Cong. July 11-21, Univ. of Reading, England.

N.R.C. 1975. Nutrient requirements of sheep. Sixth Revised Ed. National Academy of Sciences-National Research Council. Washington, DC.

Oosting, H.J. 1956. The study of plant communities. W.H. Freeman and Co., San Francisco.

Ottosen, E.M., G.W. Brown and M.R. Maraske. 1975. Strip grazing - advantage or disadvantage. Queensland Agr. J. 101:569-570.

Painter, E.L. and J.K. Detling. 1981. Effects of defoliation on net photosynthesis and regrowth of western wheatgrass. J. Range Manage. 34:68-71.

Phillips, G.D. 1960. The relationship between water and food intakes of European and Zebu type steers. J. Agr. Sci. 54:231.

Pieper, R.D. 1980. Impacts of grazing systems on livestock. p. 133-151. *IN*: K.C. McDaniel and C. Allison (eds.), Proc. Grazing Management Systems for Southwest Rangelands Symposium. Apr. 1-2. Albuquerque, NM.

Pitts, J.S. and F.C. Bryant. 1982. Steer and vegetation response to short duration and continuous, yearlong grazing on the southern High Plains of Texas. p. 201-202. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

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

Pluhar, J.J., R.W. Knight and R.K. Heitschmidt. 1984. Hydrologic impacts of selected grazing systems on the Texas Rolling Plains. Proc.: 37th Annual Meeting, Society for Range Management, Feb. 12-17, 1984. Rapid City, SD. Abst. 190.

Ralphs, M., M.M. Kothmann and L.B. Merrill. 1986. Cattle and sheep diets under short-duration grazing. J. Range Manage. 39:217-223.

Ribeiro J.M. de C.R., J.M. Brockway and A.J.E. Webster. 1977. A note on the energy cost of walking in cattle. Anim. Prod. 25:107-110.

Range Term Glossary Committee. 1974. A glossary of terms used in range management. Society for Range Management. Denver, Colo.

Reece, P.E. 1985. Short duration grazing: concepts and case studies. p. 49-84. *IN*: Proc. The Range Beef Cow Symposium IX. Dec. 2-4, Chadron, NE.

Reed, M.J. and R.A. Peterson. 1961. Vegetation, soil and cattle responses to grazing on Northern Great Plains range. U.S.D.A. Tech. Bull. 818.

Rodgers, D.W. 1972. The effect of range condition and season of grazing on the amount and quality of the diet selected by grazing steers. M.S. Thesis. S. Dak. State Univ., Brookings.

Sampson, A.W. 1913. Range improvement by deferred and rotational grazing. U.S.D.A. Bull. 34.

Sampson, A.W. 1951. A symposium on rotation grazing in North America. J. Range Manage. 4:19-24.

Sarvis, J.T. 1941. Grazing investigation on the Northern Great Plains. N. Dak. Agr. Exp. Sta. Bull. 308.

SAS Institute Inc., 1985. SAS user's guide: statistics. (version 5 ed.) SAS Institute Inc., Cary, NC.

Savory, A. 1978. A holistic approach to range management using short duration grazing. p. 555-557. *IN*: D.N. Hyder (ed.) Proc. First Int. Rangeland Cong. Denver, CO.

Savory, A. 1983. The Savory Grazing Method or Holistic Resource Management. Rangelands. 5:155-159.

Savory, A. and S.D. Parsons. 1980. The Savory Grazing Method. Rangelands, 2:234-237.

Scarnecchia, D.L. 1985. The relationship of stocking intensity and stocking pressure to other stocking variables. J. Range Manage. 38:558-559.

Scarnecchia, D.L. and M.M. Kothmann. 1982. A dynamic approach to grazing management terminology. J. Range Manage. 35:262-264.

Schmidt, D., J.R. Johnson, R. Baumberger and J.K. Lewis. 1985. Western wheatgrass *(Agropyron smithii)* response to clipping treatments. Proc.: 38th Annual Meeting, Society for Range Management, Feb. 11-15, 1985. Salt Lake City, UT. Abst. 022.

Schmutz, E.M., G.A. Holt and C.C. Michaels. 1963. Grazed-class method of estimating forage utilization. J. Range Manage. 16:54-60.

Semple, A.T. 1970. Grassland improvement. (Plant Science Monographs). Leonard Hill Books, London. 400 pp.

Shantz, H.L. and R. Zon. 1924. Atlas of American Agriculture. Part I: The physical basis of agriculture. Advance Sheet 6, Section E. Natural vegetation. U.S.D.A. Bureau Agr. Econ., Wash.

Sharkey, M.J., I.F. Davis and P.A. Kenney. 1962. The effect of previous and current nutrition on wool production in southern Victoria. Aust. J. Exp. Agr. Anim. Husbd. 2:160.

Sharrow, S.H. 1983a. Forage standing crop and animal diets under rotational vs. continuous grazing. J.Range Manage. 36:447-450.

Sharrow, S.H. 1983b. Rotational vs. continuous grazing affects animal performance on annual grass-subclover pasture. J. Range Manage. 36:593-595.

Sharrow, S.H. and W.C. Krueger. 1979. Performance of sheep under rotational and continuous grazing on hill pastures. J. Anim. Sci. 49:893-899.

Shaw, N.H. 1970. The choice of stocking rate treatments as influenced by the expression of stocking rate. p. 909-913. *IN*: Proc. XI Int. Grassland Cong. Apr. 13-23. Surfers Paradise, Queensland, Australia.

Short, L.R. and E.J. Woolfolk. 1956. Plant vigor as a criterion of range condition. J. Range Manage. 9:66-69.

Sims, P.L. and J.S. Singh. 1978a. The structure and function of ten western North American grasslands: II. Intra-seasonal dynamics in primary producer compartments. J. Ecol. 66:547-572.

Sims, P.L. and J.S. Singh. 1978b. The structure and function of ten western North American grasslands: III. Net primary production, turnover and efficiencies of energy capture and water use. J. Ecol. 66:573-597.

Sims, P.L., J.S. Singh and W.K. Lauenroth. 1978. The structure and function of ten western North American grasslands: I. Abiotic and vegetational characters. J. Ecol. 66:251-285.

Singh, J.S., W.K. Lauenroth, and R.K. Steinhorst. 1975. Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. Bot. Rev. 41:182-232.

Smith, J.G. 1895. Forage conditions of the prairie region. U.S.D.A. Yearbook 1895.

Sparks, D.R. and J.C. Malechek. 1968. Estimating percentage dry weight in diets using a microscope technique. J. Range Manage. 21:264-265.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. (2nd ed.) McGraw-Hill Book Co., New York.

Stoddart, L.A., A.D. Smith and T.W. Box. 1975. Range management. McGraw-Hill Inc. New York. 532 pp.

Stroud, D.O., R.H. Hart, M.J. Samuel and J.D. Rodgers. 1985. Western wheatgrass response to simulated grazing. J. Range Manage. 38:103-108.

Tainton, N.M. 1974. Effects of different grazing rotations on pasture production. J. Brit. Grassland Soc. 29:191-202.

Tallowin, J.R.B. 1981. An interpretation of tiller number changes under grazing. p 77-78. *IN*: C.E. Wright (ed.), Plant Physiology and Herbage Production. Brit. Grassland Soc. Occasional Symp. No. 13. April 7-9.

Taylor, C.A., M.M. Kothmann, L.B. Merrill and D. Elledge. 1980. Diet selection by cattle under high-intensity low-frequency, short duration and Merrill grazing systems. J. Range Manage. 33:428-434.

Tribe, D.E. 1950. The behavior of the grazing animal: A critical review of present knowledge. J. Brit. Grassland Soc. 5:209-224.

U.S.D.A.-S.C.S. Staff. 1979. South Dakota technical guide, (west-central). Section II-D-1. U.S. Dept. Agr.-Soil Conser. Service.

U.S.D.A.-S.C.S. Staff. 1987. Soil survey of Jackson County, South Dakota. U.S. Dept. Agr. Soil Conser. Service. (in press).

U.S. Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Ag. Handb. No. 436. U.S.D.A.-S.C.S. U.S. Govern. Printing Office. Washington, D.C.

U.S. Weather Bureau. 1968 - 1985. Climatological data for South Dakota: Annual Summary. Vol. 73-90.

U.S. Weather Bureau. 1967. Climatological summary: Cottonwood, South Dakota. No. 14.

Van Dyne, G.M., N.R. Brockington, Z. Szocs, J. Duek and C.A. Ribic. 1978. Large herbivore subsystem. p. 269-537. *IN*: A.I. Breymeyer and G.M. Van Dyne (eds.) Grasslands, Systems Analysis and Man. Int. Biol. Prog. 19. Cambridge University Press, Cambridge, England.

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

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

Voisin, A. 1959. Grass productivity. Philosophical Library, New York. 353 pp.

Voisin, A. 1962. Rational Grazing. Crosby Lockwood and Son Ltd. London, England.

Walker, J.W., R.K. Heitschmidt, A.B. Johnson and S.L. Dowhower. 1982. Short duration grazing at the Texas Experimental Ranch: Animal behavior. p. 178-180. *IN*: D.D. Briske and M.M. Kothmann (eds.) Proc. A National Conference on Grazing Management Technology. Nov. 10-12. Texas A&M Univ., College Station, TX.

Walker, J.W., R.K. Heitschmidt and S.L. Dowhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. J. Range Manage. 38:90-93.

Waller, S.S. and Lewis, J.K. 1979. Occurrence of C_3 and C_4 photosynthetic pathways in North American grasses. J. Range Manage. 32:12-28.

Waller, S.S., M.A. Brown and J.K. Lewis. 1981. Factors involved in estimating green biomass by canopy spectroreflectance measurements. J. Range Manage. 34:105-108.

Walter, J. 1984. Rangeland revolutionary: An interview with Allan Savory. J. Soil Water Cons. 39:235-240.

Walton, P.D., R. Martinez and A.W. Bailey. 1981. A comparison of continuous and rotational grazing. J. Range Manage. 34:19-21.

Weitz, M. and M.K. Wood. 1986. Short duration grazing in cemtral New Mexico: Effects on infiltration rates. J. Range Manage. 39:365-368.

Westin. F.C. and D.D. Malo. 1978. Soils of South Dakota. S. Dak. State Univ. Agr. Exp. Stat. Bull. 656.

Westmoreland, G., H. Dietz, R. Johnson, H. Senne, J. Norris, F. Sprague, J. Henson and G. Valentine. 1981. Evaluation of cell grazing systems. U.S.D.A.-S.C.S. Tech. Note - Range TX-1.

White, E.M. 1965. Soils legend for the Cottonwood Range Field Station soil map. Dept. Rep. (unpublished mimeo).

Whitson, R.E., R.K. Heitschmidt, M.M. Kothmann and G.K. Lundgren. 1982. The impact of grazing systems on the magnitude and stability of ranch income in the Rolling Plains of Texas. J. Range Manage. 35:526-532.

Wilm, H.G., D.F. Costello and G.E. Klipple. 1944. Estimating forage yield by the double-sampling method. Agron. J. 36:194-203.

Wofford, H., J.L. Holechek, M.L. Galyean, J.D. Wallace and M. Cardenas. 1985. Evaluation of fecal indices to predict cattle diet quality. J. Range Manage. 38:450-454.

Winchester, C.F. and M.J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15:722-740.

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

Wood, M.K. and W.H. Blackburn. 1981b. Grazing systems: their influence on infiltration rates in the Rolling Plains of Texas. J. Range Manage. 34:331-335.

Youngner, V.B., R. Nudge and R. Ackerson. 1976. Growth of Kentucky bluegrass leaves and tillers with and without defoliation. Crop Sci. 16:110-113.

10.0 APPENDICES

Appendix Table 1

Major plant species identified in the experimental pastures at the Cottonwood Range and Livestock Research Station.[1,2,3]

Scientific Name - Authority	Common Name
Grasses and Grass-like Plants	
Perennials	
Agropyron smithii Rydb.	Western Wheatgrass
Agropyron caninum (L.) Beauv. subsp *majus* (Vasey) C.L. Hitchc.	Slender Wheatgrass
Andropogon gerardii Vitman	Big Bluestem
Andropogon scoparius Michx.	Little Bluestem
Aristida purpurea var *robusta* (Merril) A. & N. Holmgren	Red Threeawn
Bouteloua curtipendula (Michx.) Torr.	Sideoats Grama
Bouteloua hirsuta Lag.	Hairy Grama
Bouteloua gracilis (H.B.K.) Lag. ex Griffiths	Blue Grama
Buchloe dactyloides (Nutt.) Engelm.	Common Buffalograss
Calamovilfa longifolia (Hook.) Scribn.	Prairie Sandreed
Carex brevior (Dew.) Mack. ex Lunell	Fescue Sedge
Carex eleocharis Bailey	Needleleaf Sedge
Carex filifolia Nutt.	Threadleaf Sedge
Carex gravida Bailey	Plumpseed Sedge
Distichlis spicata (L.) Greene var *stricta* (Torr.) Beetle	Inland Saltgrass
Elymus canadensis L.	Canada Wildrye
Hordeum jubatum L.	Foxtail Barley
Koeleria pyramidata (Lam.) Beauv.	Prairie Junegrass
Muhlenbergia cuspidata (Torr.) Rydb.	Plains Muhly
Muhlenbergia pungens Thurb.	Sandhill Muhly
Panicum virgatum	Switchgrass Panic
Poa glaucifolia Scribn. & Williams	Swallen Bluegrass
Poa sandbergii Vasey	Sandburg Bluegrass
Sporobolus asper (Michx.) Kunth	Tall Dropseed
Sporobolus cryptandrus (Torr.) A. Gray	Sand Dropseed
Stipa comata Trin. and Rupr.	Needle-and-thread
Stipa viridula Trin.	Green Needlegrass
Annuals	
Alopecurus geniculatus L.	Water Foxtail
Bromus japonicus Thunb. ex Murr.	Japanese Brome
Bromus tectorum L.	Cheatgrass Brome
Echinochloa crusgalli (L.) Beauv.	Common Barnyardgrass

(continued)

Appendix Table 1 (continued)

Scientific Name	Common Name
Eragrostis cilianensis (All.) E. Mosher	Stink Lovegrass
Festuca octoflora Walt.	Sixweeks Fescue
Hordeum pusillum Nutt.	Little Barley
Panicum capillare L.	Witchgrass Panic
Schedonnardus paniculatus (Nutt.) Trel.	Common Tumblegrass
Sporobolus neglectus Nash.	Baldgrass Dropseed
Forbs and Half Shrubs	
Perennials	
Achillea millefolium L.	Common Yarrow
Agoseris glauca (Pursh) Dietr.	Pale Agoseris
Allium textile A. Nels. & Macbr.	Textile Onion
Antennaria neglecta Greene	Field Pussytoes
Antennaria parvifolia Nutt.	Small-leaf Pussytoes
Apocynum cannabinum L.	Indianhemp Dogbane
Asclepias pumila (A. Gray) Vail	Plains Milkweed
Asclepias viridiflora Raf.	Green Milkweed
Aster ericoides L.	White Aster
Astragalus crassicarpus Nutt.	Groundplum Milkvetch
Astragalus gilviflorus Sheld.	Three-leaved Milkvetch
Astragalus missouriensis Nutt.	Missouri Milkvetch
Artemisia frigida Willd.	Fringed Sagewort
Artemisia ludoviciana Nutt.	Louisiana Sagewort
Bahia oppositifolia (Nutt.) Rydb.	Plains Bahia
Calochortus nuttallii T. & G.	Sego Mariposalily
Chrysopsis villosa (Pursh.) Nutt.	Hairy Goldenaster
Comandra umbellata (L.) Nutt.	Common Comandra
Convolvulus arvensis L.	Field Bindweed
Dalea aurea Nutt. ex Pursh	Silktop Dalea
Dalea enneandra Nutt.	Bigtop Dalea
Dalea purpurea Vent.	Purple Prairieclover
Dalea candida Michx. ex. Willd.	White Prairieclover
Delphinium virescens Nutt.	Plains Larkspur
Echinacea angustifolia DC.	Blacksampson Echinacea
Erigeron canus A. Gray	Hoary Fleabane
Gaura coccinea Pursh.	Scarlet Gaura
Glycyrrhiza lepidota Pursh.	Wild Licorice
Geranium carolinianum L.	Carolina Geranium
Gutierrezia sarothrae (Pursh.) Brit. & Rusby	Broom Snakeweed
Haplopappus spinulosus (Pursh.) DC.	Ironplant Goldenweed
Hymenopappus filifolius Hook	Fineleaf Hymenopappus
Kuhnia eupatoriodes L.	False Prairiebonset
Lactuca oblongifolia Nutt.	Blue Lettuce

(continued)

Appendix Table 1 (continued)

Scientific Name	Common Name
Lesquerella ludoviciana (Nutt.) S. Wats.	Foothill Bladderpod
Leucocrinum montanum Nutt.	Common Starlily
Liatris punctata Hook.	Dotted Gayfeather
Lithospermum incisum Lehm.	Narrowleaf Gromwell
Lomatium foeniculaceum (Nutt.) Coult. & Rose	Hairy-fruited Lomatium
Lomatium orientale Coult. and Rose.	White-flowered Lomatium
Lygodesmia juncea (Pursh.) Hook.	Rush Skeletonplant
Miralbus linearis (Pursh.) Heimerl.	Narrowleaf Four-o-clock
Musineon divaricatum Nutt.	Wild Parsley
Penstemom albidus Nutt.	White Penstemon
Penstemom gracilis Nutt.	Slender Penstemon
Penstemon pallidus Small.	Pale Penstemon
Phlox andicola Nutt. ex A. Gray	Plains Phlox
Polygala alba Nutt.	White Milkwort
Potentilla gracilis Dougl. ex Hook.	Northwest Cinquefoil
Psoralea agophylla Pursh.	Silverleaf Scurfpea
Psoralea esculenta Pursh.	Breadroot Scurfpea
Psoralea cuspidata Pursh.	Tallbread Scurfpea
Psoralea tenuiflora Pursh.	Slimflower Scurfpea
Ratibida columnifera Woot. & Standl.	Prairie Coneflower
Rorippa sinuata (Nutt.) Hitchc.	Spreadingyellow Watercress
Rumex altissimus Wood.	Pale Dock
Rumex crispus L.	Curly Dock
Rumex mexicanus Meisn.	Mexican Dock
Solidago sparsiflora A. Gray	Three-nerve Goldenrod
Schrankia nuttallii (DC.) Standl.	Catclaw Sensitivebriar
Sphaeralcea coccinea (Pursh.) Rydb.	Scarlet Globemallow
Taraxacum officinale Weber	Common Dandelion
Tradescantia bracteata Small.	Bracted Spiderwort
Verbena bracteata Lag. and Rodr.	Prostrate vervain
Vicia americana Muhl. ex Willd.	American Vetch
Viola nuttallii Pursh.	Nuttall's Violet
Yucca glauca Nutt.	Small Soapweed
Zigadenus nuttallii A. Gray	Nuttall's Deathcamas
Zigadenus venenosus S. Wats.	Meadow Deathcamas
Biennials	
Cirsium vulgare (Savi.) Ten.	Bull Thistle
Cryptantha celosioides (Eastw.) Pays.	Northern Cryptantha
Descurainia richardsonii (Sweet) O.E. Schulz	Richardson Tansymustard
Erysimum asperum (Nutt.) DC.	Plains Wallflower
Grindelia squarrosa (Pursh.) Dun.	Curlycup Gumweed
Hackelia deflexa (Wahl.) Opiz.	Western Tickweed

(continued)

Appendix Table 1 (continued)

Scientific Name	Common Name
Tragopogon pratensis L.	Meadow Salsify
Tragopogon porrifolius L.	Vegetable-oyster Salsify
Annuals	
Amaranthus retroflexus L.	Redroot Pigweed
Ambrosia artemisifolia L.	Common Ragweed
Androsace occidentalis Pursh.	Western Rockjasmine
Camelina sativa (L.) Crantz	Bigseed Falseflax
Chenopodium album L.	Lambsquarters Goosefoot
Chenopodium leptophyllum Nutt. ex Moq.	Narrowleaf Goosefoot
Collomia linearis Nutt.	Narrowleaved Collomia
Conyza canadensis (L.) Cronq.	Canada Horseweed
Draba nemorosa L.	Wood's Draba
Ellisia nyctelea L.	Common Waterpod
Euphorbia glyptosperma Engelm.	Ridgeseed Spurge
Euphorbia marginata Pursh.	Snow-on-the-mountain Spurge
Euphorbia spathulata Lam.	Nettedseed Spurge
Erigeron annuus (L.) Pers.	Annual Fleabane
Erigeron strigosus Muhl. ex Wild.	Daisy Fleabane
Hedeoma hispida Pursh.	Rough False-pennyroyal
Helianthus annuus L.	Common Sunflower
Kochia scoparia (L.) Schrad.	Fireweed Summercypress
Lactuca serriola L.	Prickly Lettuce
Lappula echinata Gilib.	European Stickseed
Lappula redowski (Hornem.) Greene	Bluebur Stickseed
Lepidium densiflorum Schrad.	Prairie Pepperweed
Linum sulcatum Riddell	Grooved Flax
Lotus purshianus Clem. & Clem.	Pursh Deervetch
Monolepis nuttalliana (R. & S.) Greene	Nuttall Monolepis
Plantago major L.	Common Plantain
Plantago patagonia Jacq. var *spinulosa* (Dcne.) A. Gray	Woolly Plantain
Polygala verticillata L.	Whorled Polygala
Polygonum aviculare L.	Prostrate Knotweed
Polygonum erectum L	Erect Knotweed
Portulaca oleracea L.	Common Purslane
Salsola iberica Senn. & Pau.	Russian Thistle
Solanum rostratum Dun.	Buffalobur Nightshade
Thlaspi arvense L.	Field Pennycress
Triodanis leptocarpa (Nutt.) Nieuw.	Slender Venuslookingglass
Triodanis perfoliata (L.) Nieuw.	Clasping Venuslookingglass

(continued)

Appendix Table 1 (continued)

Scientific Name	Common Name
Woody Plants and Succulents	
Perennials	
Amorpha canescens Pursh.	Leadplant Amorpha
Amorpha nana Nutt.	Dwarfindigo Amorpha
Artemisia cana Pursh.	Silver Sagebrush
Coryphantha missouriensis (Sweet) Britt. & Rose.	Missouri Mammillaria
Coryphantha vivipara (Nutt.) Britt. & Rose	Purple Mammillaria
Opuntia fragilis (Nutt.) Haw.	Brittle Pricklypear
Opuntia humifusa Raf.	Common Pricklypear
Opuntia polyacantha Haw.	Plains Pricklypear
Prunus americana Marsh.	American Plum
Prunus virginiana L.	Common Chokecherry
Rhus aromatica Ait. var *trilobata* (Nutt.) A. Gray	Skunkbush Sumac
Ribes odoratum Wendl.	Clove Currant
Rosa woodsii Lindl.	Wood's Wildrose
Symphoricarpos occidentalis Hook.	Western Snowberry

[1] Adapted from Lewis *et al.*, 1956.
[2] Scientific names and authorities have been updated from Great Plains Flora Association, 1986.
[3] Common Names follow Beetle, 1970.

Appendix Table 2

Repeated measures analyses of variance of average daily gain of calves (kg) in RSG and HPSDG treatments, 1983 and 1984.

Source	df	Mean Squares 1983 ADG	df	Mean Squares 1984 ADG
(Between subjects)				
Treatment (T)	1	1.3605*	1	0.2738*
Replication (R)	5	0.2797	5	0.1654
Residual	11	0.2949	5	0.0383
(Within subjects)				
Date (D)	3	6.6848***	3	2.7857***
D x T	3	0.2641	3	0.2455
D x R	15	0.2124	15	0.1226
Residual:Date	33	0.5202	15	0.0970

Multivariate Analysis of Variance Test Criteria

1983

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	3.572	10.721	3	9	0.0025
D x T	0.295	0.885	3	9	0.4848
D x R	0.517	1.138	5	11	0.3966

1984

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	38.897	38.897	3	3	0.0067
D x T	6.102	6.102	3	9	0.0858
D x R	5.134	5.134	5	5	0.0484

* Significant (P<.05).
*** Significant (P<.001).
[1] Roy's Greatest Root.

Appendix Table 3

Repeated measures analyses of variance of average daily gain of lambs (g) in RSG and HPSDG treatments, 1983 and 1984.

		Mean Squares		
Source	df	1983 ADG	df	1984 ADG
(Between subjects)				
Treatment (T)	1	0.1844***	1	0.0365
Replication (R)	5	0.0430**	5	0.0117
Residual	46	0.0121	27	0.0119
(Within subjects)				
Date (D)	3	1.1165***	3	1.2861***
D x T	3	0.0881**	3	0.0382
D x R	15	0.0336	15	0.0362
Residual:Date	138	0.0258	81	0.0260

Multivariate Analysis of Variance Test Criteria

1983

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	4.760	69.812	3	44	0.0001
D x T	0.144	2.107	3	44	0.1130
D x R	0.338	3.115	5	46	0.0167

1984

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	5.327	44.394	3	25	0.0001
D x T	0.359	2.992	3	25	0.0500
D x R	0.542	2.926	5	27	0.0308

** Significant (P<.01).
*** Significant (P<.001).
[1] Roy's Greatest Root.

Appendix Table 4

Repeated measures analyses of variance of nitrogen (%) in fecal samples of calves and lambs in RSG and HPSDG treatments, 1984.

		Mean Squares		
		Calves		Lambs
Source	df	% N	df	% N
(Between subjects)				
Treatment (T)	1	0.4700*	1	0.4270*
Replication (R)	5	0.0408	5	0.0218
Residual	5	0.0700	5	0.0552
(Within subjects)				
Date (D)	3	3.8021***	3	5.6134***
D x T	3	0.0839**	3	0.2862**
D x R	15	0.0206	15	0.0163
Residual:Date	15	0.0130	15	0.0424

Multivariate Analysis of Variance Test Criteria

CALF

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	416.91	416.91	3	3	0.0002
D x T	4.75	4.75	3	3	0.1166
D x R	4.12	4.12	5	5	0.0732

LAMB

Effect	Value[1]	F	Numerator df	Denominator df	P>F
Date (D)	71.79	79.79	3	3	0.0027
D x T	2.17	2.17	3	3	0.2709
D x R	2.52	2.52	5	5	0.1659

* Significant (P<.05).
** Significant (P<.01).
*** Significant (P<.001).
[1] Roy's Greatest Root.

Appendix Table 5

Repeated measures analyses of variance of average daily wool growth (mm/day) of lambs in RSG and HPSDG treatments, 1983 and 1984.

		Mean Squares		
Source	df	1983 Wool growth	df	1984 Wool growth
(Between subjects)				
Treatment (T)	1	0.0038	1	0.0207
Replication (R)	5	0.0107	5	0.0025
Residual	46	0.0097	27	0.0065
(Within subjects)				
Date (D)	3	0.3507***	3	0.0029
D x T	3	0.0151	3	0.0116
D x R	15	0.0202	15	0.0089
Residual:Date	138	0.0151	81	0.0057

Multivariate Analysis of Variance Test Criteria

Effect	Value[1]	F	Numerator df	Denominator df	P>F
1983					
Date (D)	1.583	23.218	3	44	0.0001
D x T	0.061	0.892	3	44	0.4529
D x R	0.205	1.887	5	5	0.1150
1984					
Date (D)	0.085	0.713	3	25	0.5535
D x T	0.344	2.867	3	25	0.0567
D x R	0.551	2.974	5	27	0.0289

*** Significant ($P<.001$).
[1] Roy's Greatest Root.

Appendix Table 6

Analysis of variance of water intake (l/AU/d) of calves and lambs in RSG and HPSDG treatments, 1983 and 1984.

Source	df	Mean Squares: Water intake (L/AU/d) 1983	1984
Replication (R)	5	66.00**	45.52***
Treatment (T)	1	24.62	2.26
T x R	5	119.51	21.07
Period (P)	7	209.73***	608.01***
T x P	7	15.42	34.74***
R x P	35	13.28	5.68
Residual	35	20.00	5.40

** Significant (P<.01).
*** Significant (P<.001).

Appendix Table 7

Analysis of covariance of water intake (l/AU/d) of calves and lambs in RSG and HPSDG treatments, 1983 and 1984.

Covariate = Temperature

Source	df	Mean Squares: Water intake (L/AU/d) 1983	1984
Replication (R)	5	66.00**	45.52***
Treatment (T)	1	24.62	2.26
T x R	5	119.51	21.07
Period (P)	7	52.23	159.86***
T x P	7	15.42	34.74***
R x P	35	13.28	5.68
Residual	35	20.00	5.40

Covariates = Temperature and Forage Dry Matter

Source	df	Mean Squares: Water intake (L/AU/d) 1983	1984
Replication (R)	5	66.00**	45.52***
Treatment (T)	1	24.62	2.26
T x R	5	119.51	21.07
Period (P)	7	42.54	106.45***
T x P	7	15.42	34.74***
R x P	35	13.28	5.68
Residual	35	20.00	5.40

** Significant (P<.01).
*** Significant (P<.001).

Appendix Table 8

Analysis of variance of compaction indices of two range site soils from three strata within RSG and HPSDG treatments at early-June and mid-October sampling dates, 1983.

Source	df	Mean Squares Compaction Index
Treatment (T)	1	125.13
Soil (S)	1	5115.84***
T x S	1	1633.50***
Strata (St)	2	2591.69***
T x St	2	152.81
S x St	2	36.56
T x S x St	2	271.14*
Date	1	69811.21***
Residual	587	73.14

*** Significant (P<.001).
* Significant (P<.05).

Appendix Table 9

Analysis of variance of compaction indices of three range site soils from two forage use-classes within the RSG treatment, 1983[1].

Source	df	Mean Squares Compaction Index
Use-class (U)	1	6975.11***
Soil (S)	2	951.86***
U x S	2	354.37**
Residual	194	77.37

[1] High and Low use-classes correspond to areas with greater than 40 and less than 10% forage use respectively.
*** Significant (P<.001).
** Significant (P<.01).

Appendix Table 10

Analysis of variance of predicted bulk density of two range site soils from three strata within RSG and HPSDG treatments, 1984.

Source	df	Mean Squares Bulk density (g/cc)
Treatment (T)	1	0.00496
Soil (S)	1	0.80475***
T x S	1	0.00027
Strata (St)	2	0.15950***
T x St	2	0.00014
S x St	2	0.04592***
T x S x St	2	0.00413
Residual	288	0.00648

*** Significant (P<.001).

Appendix Table 11

Analysis of variance of predicted bulk density of two range site soils from three forage use-classes, 1984[1].

Source	df	Mean Squares Bulk density (g/cc)
Use-class (U)	2	0.89534***
Soil (S)	1	0.20134***
U x S	2	0.19159***
Residual	244	0.00762

[1] High and Low use-classes correspond to areas with greater than 40 and less than 10% forage use respectively.
*** Significant (P<.001).

Appendix Table 12

Analysis of variance of estimated end-of-season forage use of mid-grasses and shortgrasses in RSG and HPSDG treatments, 1983.

Mid-grasses

Source	df	Mean Squares Forage Use (%)
Replication (R)	5	966.46***
Treatment (T)	1	109.41
Strata (S)	1	4250.70***
T x R	5	501.57**
T x S	1	671.92*
S x R	5	424.74*
T x S x R	5	203.28
Residual	489	148.20

Shortgrasses

Source	df	Mean Squares Forage Use (%)
Replication (R)	5	637.04**
Treatment (T)	1	15245.16***
Strata (S)	2	14287.19***
T x R	5	910.32**
T x S	2	1486.85***
S x R	10	146.01
T x S x R	10	165.19
Residual	564	176.07

* Significant (P<.05).
** Significant (P<.01).
*** Significant (P<.001).

Appendix Table 13

Percent soil water in the zero to 20 centimeter depth by sampling date, 1984.[1]

Date	Percent Soil Water[2]
May 17	15.75
May 27	21.58
June 6	22.93
June 16	22.71
June 26	18.76
July 7	16.07
July 17	13.15
July 27	12.27
August 6	8.78
August 16	8.58
August 26	8.41

[1] Clayey range site with a 4% slope.
[2] Values are means of four samples.

Appendix Table 14

Estimated percent use of forage and live + recent-dead residue (kg/ha) within delineated areas of RSG replicate pastures at the end of the grazing season, 1984.

	Replication											
	1		2		3		4		5		6	
Area	==)					A						(==
% of Total Pasture	6[U/S]		24[D]		6[U/S]		33		18		13[U/S]	
	Use	Residue	Use	Residue	Use	Residue	Use	Residue	Use	Residue	Use	Residue
Western Wheatgrass	53.1	482	52.1	622	21.1	143	30.4	976	46.1	634	24.7	205
Shortgrasses	34.6	200	48.5	121	24.6	364	21.4	229	32.6	261	34.5	328
Total[1]	46.6	705	50.5	745	24.1	769	29.1	1340	40.8	948	31.5	654
Area	==)					B						(==
% of Total Pasture	83		4		8[D]		11[U/S]		16[D]		55	
Western Wheatgrass	36.2	846	20.0	217	48.8	284	25.0	440	82.9	168	40.2	866
Shortgrasses	30.0	314	24.5	355	35.0	320	48.3	225	55.5	135	24.4	349
Total[1]	35.1	1297	23.4	772	40.3	720	37.4	680	72.9	309	34.5	1346
Area	==)					C						(==
% of Total Pasture	11[D]		5		9		33		60		10[D]	
Western Wheatgrass	51.1	644	23.1	268	63.3	626	31.7	837	32.0	619	62.1	581
Shortgrasses	32.4	351	31.1	643	36.9	328	24.3	224	23.6	302	29.4	283
Total[1]	45.1	1161	29.9	945	51.1	1096	30.1	1252	29.7	1032	51.9	963
Area	==)					D						(==
% of Total Pasture	-		57		77		10[D]		10[U/S]		22	
Western Wheatgrass			20.4	1351	37.8	653	76.0	205	45.8	143	40.2	205
Shortgrasses			16.8	301	27.1	377	60.2	229	64.5	175	26.0	328
Total[1]			19.1	1748	33.5	1164	66.6	466	58.7	334	35.4	654
Area	==)					E						(==
% of Total Pasture	-		10[U/S]		-		13		-		-	
Western Wheatgrass			25.0	283			44.2	1197				
Shortgrasses			54.9	229			32.1	202				
Total[1]			44.3	640			45.2	1410				

continued

Appendix Table 14 (continued)

<u>Replication Summary</u>[2]

	Replication											
	1		2		3		4		5		6	
	Use	Residue	Use	Residue	Use	Residue	Use	Residue	Use	Residue	Use	Residue
Western Wheatgrass	39.9	802	29.6	969	40.0	590	37.6	839	43.5	545	41.4	607
Shortgrasses	31.5	311	26.5	270	29.5	367	31.6	228	35.1	267	28.6	335
Total[1]	38.0	1246	28.0	1317	36.2	1098	37.3	1185	42.2	891	37.1	1066

[1] Total includes the live + recent-dead of all species.

[2] Mean forage use percent and residue calculated from the area values weighted for the size of each of the areas.

[D] Refers to a drainageway area.

[U/S] Refers to a thin-upland or shortgrass area.

Appendix Table 15

Analysis of variance of estimated end-of-season forage use of western wheatgrass, shortgrasses and total (all species) in RSG and HPSDG treatments, 1984.[1]

Western wheatgrass

Source	df	Mean Squares Forage Use (%)
Replication (R)	5	7.05
Treatment (T)	1	17.20
Residual	5	11.38

Shortgrasses

Source	df	Mean Squares Forage Use (%)
Replication (R)	5	10.65
Treatment (T)	1	85.87*
Residual	5	13.07

Total

Source	df	Mean Squares Forage Use (%)
Replication (R)	5	8.67
Treatment (T)	1	18.32
Residual	5	12.60

[1] Observations used in the analysis were the replicate pasture means for each of the species categories.

* Significant (P<.05).

Appendix Table 16

Analysis of variance of weight, height and number of leaves of grazed and ungrazed western wheatgrass tillers from clayey and silty range sites within RSG, HPSDG and permanent exclosure treatments, 1984.

Source	df	Mean Squares: Height (mm)	Weight (g)	Number of Leaves
Grazed				
Treatment (T)	1	1488.5	0.044*	1.60
Range Site (R)	1	3.4	0.017	2.20
T x R	1	4755.1	0.001	7.09*
Residual	346	4711.2	0.012	1.52
Ungrazed				
Treatment (T)	2	209902.6**	0.621**	16.66**
Range Site (R)	1	82725.9**	0.211**	16.55**
T x R	2	19031.4**	0.039	3.75
Residual	449	4296.5	0.018	1.23

* Significant (P<.05).
** Significant (P<.01).