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Animal Nutritional Response to Sward Structure Under Short Duration Grazing Management

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ANIMAL NUTRITIONAL RESPONSE TO SWARD STRUCTURE UNDER SHORT DURATION GRAZING MANAGEMENT

by

Kenneth C. Olson

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Range Science

Approved:

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ABSTRACT

Animal Nutritional Response to Sward Structure Under Short Duration Grazing Management

by

Kenneth C. Olson, Doctor of Philosophy

Utah State University, 1986

Major Professor: Dr. John C. Malechek
Department: Range Science

A ten-paddock short duration grazing cell was stocked with yearling heifers at a stocking rate of 0.7 ha per animal unit month and a stocking density of 0.14 ha per animal unit. A continuously-season-long-grazed (CSLG) pasture was used as a control. It was stocked at the same stocking rate, but at a stocking density of 1.4 ha per animal unit. Grazing periods in SDG paddocks were two or three days. Dietary quality was assessed by crude protein content and *in vitro* digestibility of esophageal fistula estrusa samples. Three variables of ingestive behavior were measured, including ingestion rate, biting rate, and grazing time. Daily forage intake was estimated by multiplying ingestion rate by grazing time.

Animals in CSLG gained significantly more weight in 1983, no statistical differences were detected in 1984, and, in 1985, animals gained more in SDG. No differences were detected in diet quality between SDG and CSLG throughout the study. No treatment differences were detected in ingestive behavior variables in 1984, but ingestion rate was significatantly higher and grazing time significantly less in SDG during 1985. Differences in diet quality and ingestive behavior between SDG and CSLG at the beginning and end of the grazing season were evaluated for indications of possibly extending the season of nutritious forage. Such differences were few and inconsistent.

Daily changes in diet quality and ingestive behavior during the grazing period within SDG paddocks were large. Diet quality declined significantly during the grazing period in all three years. Ingestive behavioral responses changed significantly, including declines in ingestion rate and increases in grazing time. Forage intake declined during the grazing period on a particular paddock.

A model was developed that related behavioral responses to sward characteristics. Ingestion rate and grazing time were predicted from available biomass and herbage crude protein content. The model indicated that declines in biomass and herbage crude protein content translate into rapid declines in ingestion rate, and thus, forage intake.

Based on the system studied, grazing periods in SDG paddocks should be two days or less to maintain high levels of livestock performance.

(127 pages)

INTRODUCTION

Most grazing systems have been developed to benefit the vegetation on rangelands with concern for effects on livestock nutrition or performance being secondary. For example, rest rotation grazing uses extended rest periods of up to one year or more that allow forage in particular pastures to mature and decline in nutritive quality before livestock are allowed to graze it (Kothmann 1980). Short duration grazing (SDG) has been rapidly gaining popularity as a method to improve both livestock performance and range condition (Savory 1978, Savory 1979, Savory and Parsons 1980). Savory attributes improved livestock performance under SDG to three components of the method, these being reduction of animal stress by use of the cell design of pasture layout (Savory and Parsons 1980), allowance for maximal diet selectivity by use of rapid rotation (Savory 1978, Savory 1979), and increased uniformity of use of the entire plant community throughout the year by increased livestock density (Savory 1978).

Two considerations warrant the study of SDG in Utah. First, the principles of SDG were developed and have been used mostly in locations where year long grazing is possible and many of the grass species are warm season sod-formers. It has not been tested under conditions of caespitose grass stands or where seasonal grazing is necessitated due to topographic and climatic limitations, as is the case in the Intermountain West. Second, winter-spring range is the major forage supply constraint on cow herd size and livestock production in the Intermountain West (Banner 1981, Cook and Harris 1968). Spring range is typically foothill range that has been renovated by removal of unpalatable shrubs and seeding to introduced wheatgrasses, particularly crested wheatgrass (*Agropyron desertorum* (Fisch.)Schult. and *A. cristatum* (L.)Gaertn.).

The constraint on spring range is two-fold in nature. First, there is a limited amount of this seeded foothill range (Cook and Harris 1968). Second, crested wheatgrass starts growth early, but matures rapidly, with a concomitant rapid decline in nutritive quality (Cook and Harris 1968). This results in a failure to meet nutrient requirements relatively early in the summer grazing period, usually by early June for lactating females. Because of these conditions, we proposed to evaluate the use of SDG as a potential means of increasing the carrying capacity and length of grazing season on spring range in Utah. The opportunity for this endeavor was provided by Utah Agricultural Experiment Station Project 780. This dissertation documents a study of the animal nutrition component of UAES 780.

Objectives

1. Determine if SDG alters dietary quality (*in vitro* organic matter digestibility (IVOMD) and crude protein), daily forage intake, and three components of ingestive behavior (ingestion rate, grazing time, and biting rate) relative to continuous season long grazing (CSLG).

2. Assess whether SDG can extend the season of nutritious forage for grazing as compared to CSLG.
3. Determine if SDG causes changes, and what those changes are, in dietary quality, forage intake, and ingestive behavior during the grazing period of individual paddocks.
4. Develop a mathematical model that predicts ingestive behavior and forage intake from sward characteristics, including total available biomass, plant height, forage bulk density, crude protein content, IVOMD, and Van Soest fiber fractions.
5. Define management guidelines for length of grazing period in individual paddocks to maintain nutrient intake at high levels.

LITERATURE REVIEW

Livestock Response to SDG

Livestock performance is typically measured as weight change of animals and reported as gain, or loss, per individual per unit time. However, gain per unit land is more important than gain per individual animal for economic evaluation of grazing management practices (Savory 1978). Gain per unit land is a function of both gain per animal and carrying capacity of the range.

SDG is purported as a grazing method that allows, even requires, an increase in stocking rate (Savory 1978), resulting in increased carrying capacity. Three factors that influence carrying capacity are forage production, forage quality, and efficiency of forage harvest by livestock (Heitschmidt et al. 1982a). Efficiency of forage harvest is defined as the amount of forage disappearance that can be attributed to forage intake by livestock. Heitschmidt et al. (1982a) considered efficiency of forage harvest to be the principle basis of SDG, because the increase in grazing pressure due to increased stocking density will increase the percentage of available forage consumed. They concluded that there is an interaction between these three factors under grazing and suggested that SDG can control grazing in a manner that uses all three factors to increase carrying capacity. Further discussion of the interaction between grazing pressure and efficiency of forage harvest is provided by Allison et al. (1982). They compared forage intake with forage disappearance at four levels of grazing pressure to determine efficiency of forage harvest. They found that efficiency of forage harvest was increased by increasing grazing pressure. For example, 99 percent of the forage that disappeared was attributed to intake at the highest grazing pressure (10 kg / AUD), while only 53 percent could be attributed to intake at the lowest grazing pressure (50 kg / AUD). They also felt that this may offer the possibility of increasing carrying capacity under SDG through increased stocking density.

A salient feature of SDG is the effect of rapid rotation on dietary quality (Savory 1979). Animals are allowed maximal selectivity for the most nutritious, youngest plant parts, and then moved to new, ungrazed vegetation. During the rest period, the plants are allowed time to recover from grazing and provide regrowth that is once again young and nutritious forage. Thus, individual animal performance under SDG is expected to be better than under traditional grazing schemes.

Only a few published results of scientific studies are currently available concerning SDG. Most of these report weight gains as a measure of livestock performance. A limitation of these studies for comparison to our situation is that most were conducted on native range. Only one study was done on crested wheatgrass (Daugherty et al. 1982). Daugherty et al. (1982) reported on a two year study of spring grazing with yearling heifers. They reported higher average daily gains (ADG) on yearling cattle under SDG than under CSLG, but only during the latter part of the grazing season. They attributed this delayed response to the animals' need to become accustomed to the frequent moves typical of SDG. Another study on a tame monoculture of smooth brome (*Bromus inermis* Leyss.) in Nebraska showed no differences in ADG between SDG and CSLG (Jung et al. 1985). This held when the treatments were stocked equally in 1982, as well as when the SDG treatment was stocked at 131 percent of the CSLG treatment in 1983. This difference resulted in a significant increase in gain per area from SDG in 1983. They concluded that this result supported the claims of Savory (1978) that carrying capacity could be increased by using SDG with no decline in individual animal gain.

Studies on native range have shown mixed results. In western South Dakota, there was no significant difference in ADG of sheep or calves between SDG and CSLG, with the stocking rate being doubled on SDG (Bilger et al. 1983, Volesky et al. 1983). In northern Texas, Heitschmidt et al. (1982a) found that individual animal weight gains were the same between SDG and continuous grazing, when the stocking rate was doubled under SDG. In eastern Wyoming, weight gains were significantly less for SDG than for either CSLG or deferred rotation grazing during the first year of the study. But, in the second year, weight gains under SDG were intermediate, with those under deferred rotation being lowest and those under CSLG being highest (Hart et al. 1983). These results held at two different stocking rates used in all three treatments. On the Oregon coast, Sharrow (1983) reported greater weight gains of sheep under a five pasture rotational grazing scheme than under CSLG, but only during the growing season. These results indicate the possibility of increasing carrying capacity without harming gain per animal, thereby allowing an increase in gain per area. However, a mechanistic approach needs to be taken to determine what is causing the weight response and to determine if changes in management (length of graze period, length of rest, and stocking density) will affect weight gains and carrying capacity. This approach should involve the use of nutritional and behavioral information to provide explanations for livestock performance under various SDG management strategies.

Only one study (Taylor et al. 1980) reported animal nutritional response under SDG. SDG was compared to high intensity-low frequency (HILF) and Merrill grazing systems on west Texas native range. Dietary crude protein and IVOMD were the same for SDG and Merrill grazing, but significantly lower for HILF. Taylor et al. (1980) also found no difference in dietary crude protein from the beginning to the end of grazing periods in individual paddocks, but there was a significant decline in IVOMD during these same periods, resulting in decreased nutrient intake. They felt this could be overcome by using more paddocks and therefore increasing the speed of rotation and decreasing the length of grazing period in individual paddocks.

Sward Characteristics and Their Response to SDG

Several sward features have been identified as having an effect on animal nutrition. These include nutritive quality of the vegetation on offer and variables that may affect the animal's ability to select its diet, such as aboveground biomass or plant height. Sward characteristics are important in that they determine how livestock perceive and react to their food resource. Indeed, they have been tied directly to livestock performance. For example, Ebersohn and Moir (1984) found a significant correlation between weight gain of beef cattle and plant growth rate. This relationship between sward characteristics and animal response is a two way, dynamic, interaction. Selection and grazing by animals have effects on the sward that change its character, resulting in modified animal reaction to the sward on the next encounter. McNaughton (1984) stated that heavy, intermittent grazing by wild ungulates on the Serengeti resulted in a "grazing lawn", a sward with a structure conducive to increased foraging efficiency. Foraging efficiency was defined by McNaughton (1984) as increased forage intake per mouthful bitten. The similarity between the principles of Savory's (1978, 1979) grazing methods and McNaughton's grazing lawn concept should be noted. Perhaps SDG can alter the sward to create a grazing lawn, with beneficial effects on livestock nutrition. Also, rapid changes in sward characteristics due to fast defoliation at the high stock densities typical of SDG may have a direct effect on ingestive behavior and thus on livestock nutrition and performance.

Some researchers have found that SDG increased aboveground biomass production in comparison to CSLG (Bilger et al. 1983, Volesky et al. 1983) or in comparison to grazing exclusion (Heitschmidt et al. 1982c), but only when adequate moisture was available. During periods of inadequate moisture, there were no differences between treatments. Sharrow (1983) found increased standing crop levels with rotational grazing, but this was with adequate moisture throughout the study. Bilger et al. (1983), Volesky et al. (1983), Heitschmidt et al. (1982c), and Sharrow (1983) all attributed the increased biomass production to stimulation of regrowth by grazing. Daugherty et al.

(1982), in their study on crested wheatgrass, found no difference in forage yields between SDG and CSLG early in the season, but yields were depressed under SDG late in the season as conditions became drier. This was especially true in the drier year of the two-year study. They attributed the lack of plant response under SDG to inadequate grazing pressure to stimulate tillering by reducing reproductive growth during the boot stage of phenology. Jung et al. (1985) found no differences in available forage between SDG and CSLG on smooth brome pasture. They also felt that inadequate grazing pressure was responsible for the lack of plant response. An apparent problem with SDG may be that it will exaggerate the fluctuation in forage production and therefore carrying capacity from year to year, in response to differential precipitation amounts and distribution patterns.

Three studies reported crude protein content of the available biomass as a variable to estimate forage quality. One of these (Jung et el. 1985) also considered _in vitro_ dry matter digestibility (IVDMD) and Van Soest fiber fractions. Daugherty et al. (1982) found that crude protein declined with seasonal advance, as expected from other studies of crested wheatgrass (Cook and Harris 1968). However, the decline was more rapid for SDG than for ungrazed forage. They attributed this response to livestock selection for leafy, more nutritious forage and increased leaf shatter at maturity due to livestock trampling. Jung et al. (1985) found no significant differences in crude protein, IVDMD, or fiber fractions between SDG and CSLG. They also found significant declines in crude protein and IVDMD, and increases in neutral detergent fiber, cellulose, and lignin as the season progressed, but the responses were the same for both treatments. They again attributed the lack of response to SDG to inadequate grazing pressure, as a result of understocking the pastures. Heitschmidt et al. (1982b) compared crude protein value of vegetation before animals entered a paddock and after they left it. They also compared grazed and ungrazed vegetation. Percent crude protein was significantly higher before grazing than after grazing. This again indicated selective grazing for higher quality forage. Although differences in crude protein between grazed and ungrazed plants were insignificant, there was a trend toward higher crude protein content in grazed plants (Heitschmidt et al. 1982b). They concluded that SDG appeared to improve nutrient flow by maintaining vegetation in a younger, more nutritious state and by increasing the rate of plant growth. However, they stressed that this depended upon proper rate of rotation to allow animals to graze regrowth before it senesced. The increased crude protein content in the SDG treatment may also have been due to removal of dead, poorly nutritious vegetation by trampling.

A problem with the above studies by Daugherty et al. (1982) and Heitschmidt et al. (1982b) is that they compared SDG to ungrazed vegetation, as opposed to vegetation subjected to a more traditional grazing management system. Therefore, we do not know if the response was due to SDG specifically, or to grazing in general. However, when Jung et al. (1985) compared SDG to CSLG, responses were identical between treatments, indicating that SDG may have no advantage over traditional grazing management practices, particularly on tame pasture monocultures.

There are many other characteristics of the forage sward that may affect dietary nutritional response and grazing behavior of livestock that have not been extensively studied. Some of these include herbage digestibility, green to dead ratio, leaf to stem ratio, green biomass, leaf yield, plant height, fiber characteristics, and plant toughness. There is a need to determine if any of these affect grazing behavior and dietary nutrition, and whether SDG can be managed to positively influence the characteristics of the sward that affect these variables of livestock performance.

Mechanisms of Grazing

Ingestive behavior is the interface between the forage sward and the nutrition of grazing livestock (Stobbs 1974a). Hodgson (1985), concluded that, under grazing conditions, sward structural "inhibitors" of ingestive behavior assume greater importance in determining intake than metabolic and rumen physiological factors. A great deal of research on ingestive behavior has been done in Australia by Stobbs and his associates and in Scotland by Hodgson and his associates, but little has been reported in the United States. More importantly, no literature is available on studies of ingestive behavior under SDG. A review of some of the principles of ingestive behavior are given here to illustrate its potential usefulness in studying animal response to SDG.

Stobbs (1974a) described a model to estimate intake based on three parameters of ingestive behavior:

$$I = GT \times BR \times BS$$

where: I = herbage intake

GT = grazing time

BR = biting rate

BS = bite size

He felt that food intake was probably the best indicator of the reaction of animals to their environment, and that this model provided a method to integrate factors affecting intake and determine short term changes in intake (Stobbs 1973a, Stobbs 1974a). This is not possible with other methods of measuring intake. Chacon et al. (1976) compared this method to the agronomic clipping technique of determining intake and were satisfied with its performance.

This approach has been used extensively by Stobbs and his associates to determine relationships between ingestive behavior and sward characteristics of tropical pastures. They found that cattle selected leaves out of the top of the canopy (Chacon and Stobbs 1976, Chacon et al. 1976) and selected against dead material (Chacon and Stobbs 1976). Selection for leaves has been associated with both improved chemical (nutritional) composition of the leaves and with physical attributes that decrease the effort required to shear bites of leaves (Minson 1982). Because of this selective nature of livestock grazing, variations in canopy structure, mainly determined by stage of maturity and prior grazing, affect ingestive behavior (Chacon and Stobbs 1976). Canopy structure variables include leaf yield and accessibility of leaves among standing dead and stems (Stobbs and Hutton 1974). Stobbs (1973a and b) concluded that high "sward bulk density", incorporating a high leaf to height ratio, appeared to be the major factor affecting size of bite. Sward bulk density was calculated by dividing available biomass by plant height. Increases in sward bulk density allowed increases in bite size (Stobbs and Hutton 1974). Bite size was also related to other measures of sward leafiness, including leaf to stem ratio (Stobbs 1975) and leaf availability (Stobbs and Hutton 1974). Chacon and Stobbs (1976) found a high correlation between estimated intake and leaf availability, leaf to stem ratio, leaf percentage, and sward height. Allden and Whittaker (1970) found that bite size by sheep was related to plant height. Based on manipulations of plant density, they concluded that plant height was more important than herbage availability. Stobbs (1975) reported that forage dry matter content and nitrogen content also influenced bite size. Because of these relationships, they concluded that bite size was probably the major factor influencing intake (Stobbs and Hutton 1974, Chacon and Stobbs 1976). They therefore felt that biting behavior was a better indicator of sward effects than was grazing time (Stobbs and Hutton 1974). Because of limitations on time available for grazing in the daily activity budget of a free-ranging animal, the maximum number of bites that a cow can theoretically take in a day is limited to about 36,000 bites per day. Therefore, she would need to obtain at least 0.3 grams of organic matter per bite, on the average, to maintain intake at three per cent of body weight per day (Stobbs 1973a, Stobbs and Hutton 1974). In contrast to bite size influences, Chacon and Stobbs (1976) found no correlation between number of bites taken per day and intake, although there was a good correlation between number of bites per day and grazing time.

As plant maturity increased, bite size was reduced (Stobbs and Hutton 1974), a larger number of bites were required (Stobbs 1974b), and grazing time increased (Stobbs and Hutton 1974) to satisfy intake requirements. This was attributed to declines in sward bulk density and leaf density as the sward matured (Stobbs 1973b). Stobbs (1973b) also found bite size to be restricted in very young swards, due to insufficient quantities of herbage. Therefore, he concluded that there was an optimum stage of growth for each plant species at which bite size was maximized.

Defoliation by livestock caused a reduction in leaf availability at the top of the canopy, and therefore was expected to reduce diet quality (Stobbs 1975). Chacon and Stobbs (1976) and Chacon et al. (1976) confirmed this by determining that dietary nitrogen content and IVOMD declined with the progression of defoliation. The main behavioral response of cattle to the changing canopy structure was to decrease bite size (Chacon et al. 1976, Chacon and Stobbs 1976), and to increase biting rate and grazing time, but then to allow grazing time to decrease again as defoliation continued to progress, particularly at night (Chacon and Stobbs 1976). Cattle diets shifted from leaf to stem. However, smaller bites were taken apparently in attempts to obtain the remaining leaves (Chacon and Stobbs 1976). At first, loss of herbage was compensated by increasing grazing time and biting rate, but continued defoliation caused concurrent declines in grazing time and biting rate. Hodgson (1985) stated that changes in biting are not simply compensatory for declining bite size, but are the direct result of changes in sward characteristics. As defoliation reduces the height of plants, the ratio of biting to manipulating jaw movements increases, resulting in increasing biting rate. Regardless, the net result was a decline in intake and in dietary nitrogen and IVOMD. Minson (1982) considered herbivore selectivity to be a disadvantage in situations where their intake declines due to selection for leaves when leaf availability is low. Chacon and Stobbs (1976) felt that intake was limited early in the grazing period by rumen fill, but later by a lack of desire to forage when leaf availability was low. This was supported by the greatest decline in grazing time being at night when ability to select was apparently most limited. They also felt that desire may decline due to fatigue and increased energy expenditure to harvest a nutritionally adequate diet.

A final note by Chacon and Stobbs (1976) was that there was no relationship between ingestive behavior and grazing pressure, although, as stated previously, other work in the United States showed a relationship between grazing pressure and efficiency of forage harvest (Allison et al. 1982). Therefore, it may be possible to increase harvesting efficiency without affecting ingestive behavior and concomitantly affecting individual animal performance.

These results concerning ingestive behavior have been obtained mainly on tropical pastures in Australia, with a much different sward structure than found in temperate pastures. Therefore, these results may or may not apply directly to crested wheatgrass. Scarnecchia et al. (1985) found that grazing time and biting rate both increase as available forage decreases due to defoliation of crested wheatgrass. Bite size, the principal determinant of intake, has not been measured.

Although observations of ingestive behavior have not been used to study SDG, they have been used by Jamieson and Hodgson (1979a and b) to compare strip grazing to continuous grazing with calves and lambs. Strip grazing is similar to SDG in that it concentrates the livestock in a small area and they are moved to a new "strip" of pasture at short intervals (typically every few days). They found that intake decreased as available forage decreased under strip grazing. They also found that biting rate, bite size, and grazing time all decreased as forage availability decreased. They concluded that grazing time did not increase under strip grazing because the animals anticipated the move to the next strip of fresh forage.

Freer (1981) stated that there are not techniques in existence to adequately measure bite size and biting rate separately. He therefore suggested restricting analysis to ingestion rate (g DM per min.) and grazing time to calculate intake:

$$I = IR \times GT$$

where: I = herbage intake

IR = ingestion rate

GT = grazing time

Using data from Allden and Whittaker (1970), he demonstrated a close fit of data points to regression curves relating grazing time or ingestion rate to weight of herbage on offer (Mg DM per ha).

Based on this review of literature, a mechanistic construct of animal response to SDG can possibly be defined by monitoring livestock performance, dietary quality, ingestive behavior, and sward characteristics. By monitoring animal response to sward characteristics that develop under SDG, management implications of SDG (ie. rotation rate) can also be evaluated to determine guidelines to manage for animal nutritional performance.

METHODS AND PROCEDURES

Study Site

This study was conducted on the Tintic Experimental Pastures in Juab County, Utah. The SDG cell was built in the location of pastures 7, 8, and 9 of the 24 pre-existing pastures (Cook 1966). It consisted of ten equal-sized 8.4-hectare (21 acre) paddocks arranged radially around a central watering and handling facility (Figure 1). Pasture 14 was used as the CSLG treatment.

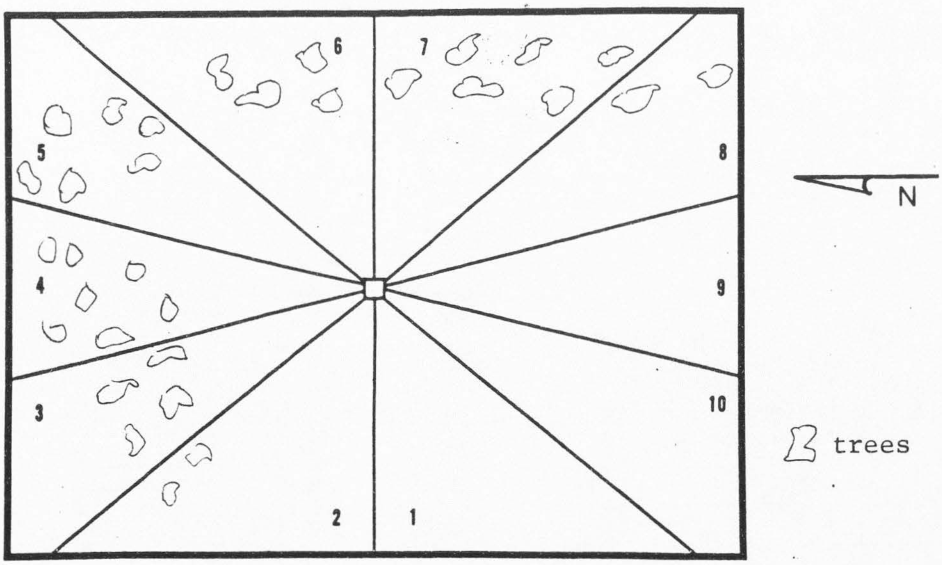

Figure 1. Layout of the short duration grazing cell.

Because the seeding prescriptions of these pastures had been different and they were seeded in 1951, the vegetation composition was somewhat different among pastures 7, 8, and 9. Pasture 7 had originally been seeded to intermediate wheatgrass (*Agropyron intermedium* (Host)Beauv.), and was primarily a mixture of intermediate wheatgrass and western wheatgrass (*Agropyron smithii* Rydb.) during this study. Pasture 8 had been seeded to crested wheatgrass, and was still primarily crested wheatgrass with localized patches of western wheatgrass. Pasture 9 had been seeded to a mixture of crested wheatgrass, intermediate wheatgrass, and tall wheatgrass (*Agropyron elongatum* Host). The current composition was dominated by crested wheatgrass, with rare plants of tall wheatgrass. Cheatgrass (*Bromus tectorum* L.) was prevalent on the site in 1983, especially in old pasture 7. Native shrubs, big sagebrush (*Artemisia tridentata* Nutt.) and rabbitbrush (*Chrysothamnus nauseosus* (Pallas)Britt.) were encroaching throughout the site. Localized stands of juniper trees (*Juniperus* spp. L.) occurred in the northern and eastern portions of the grazing cell (Figure 1).

Pasture 14 (CSLG), which had been seeded in 1954, was dominated by a mixture of crested wheatgrass and western wheatgrass. However, it was on more shallow, less developed soil types than the grazing cell. Soil types in the SDG cell were dominated by mollisols, plus inclusions of aridisols with fairly deep and well developed epipedons (Jensen 1983). However, pasture 14 was dominated by aridisols, with inclusions of a less well developed mollisol. Also, one of the dominant soil types in pasture 14 was classified as a shallow soil with a hard pan at less than 60 cm. These differences in site potential may have affected animal performance, behavior, and diet selection. These responses are discussed later.

Grazing Management

The grazing cell was stocked with 90 black Angus replacement heifers and three to five bulls, resulting in a stocking rate of 0.7 hectares (1.7 acres) per AUM (Table 1). The heifers averaged between 230 and 270 kg body weight at the beginning of each grazing season. Pasture 14 was stocked with 30 heifers and one or two bulls to achieve the same stocking rate as the SDG cell. However, the stocking density was ten times greater under SDG. The SDG stocking density was 0.14 ha (0.35 acres) per AU, while the CSLG stocking density was 1.4 ha (3.5 acres) per AU.

SDG animals were moved approximately every three days in 1983 and 1984 (Table 2). In 1985, they were moved approximately every two days during the first two cycles, and every day during the third cycle. For a summary of grazing management variables and realized days of grazing for the three years of the study, see Table 1.

Table 1. Grazing management variables and realized days of grazing for SDG and CSLG treatments for 1983, 1984, and 1985 grazing seasons.

	SDG			CSLG		
Grazing Variable	'83	'84	'85	'83	'84	'85
Stocking Rate (ha/AUM)	0.7	0.7	0.7	0.7	0.7	0.7
Stocking Density (ha/AU)	0.14	0.14	0.14	1.4	1.4	1.4
Grazing Season dates (inclusive)	5/6-7/1	5/6-7/1	4/22-6/13	5/6-7/1	5/6-7/1	4/22-6/13
days (total)	57	57	53	57	57	53
Avg. Graze Period (days/paddock)	3	3	2	n/a	n/a	n/a
Total Area (ha)	84	84	84	28	28	28
No. of Heifers	89	90	90	30	30	30
No. of Bulls	3	4	5	1	1	2

Field Methodology

Livestock Performance

All animals were weighed three times during the grazing season (Table 2). In 1983 and 1984, they were weighed at the beginning, between cycles, and at the end of the grazing season. In 1985, animals were weighed at the beginning, middle, and end of the grazing season. The mid-season weighing did not correspond with the end of a grazing cycle, because there were three cycles through the cell. Weights were measured in the morning after an overnight fast period.

Table 2. Grazing management schedule for SDG cell for 1983, 1984, and 1985. Dates of sampling for this study are denoted (see footnotes).

	1983		1984		1985	
date	day	paddock	day	paddock	day	paddock
4/22					1	8#
23					2	8
24					3	7*
25					4	7*
26					5	9*
27					6	9
28					7	10
29					8	10+
30					9	1*
5/ 1					10	1*
2					11	2*
3					12	2
4					13	3
5					14	3
6	1	1#	1	10#	15	4*
7	2	1	2	10	16	4*
8	3	2	3	1	17	5*
9	4	2	4	1*	18	5
10	5	2	5	1*	19	6
11	6	2	6	2*	20	6
12	7	3*	7	2+	21	8
13	8	3	8	2	22	8
14	9	3	9	3	23	7*
15	10	4*	10	3	24	7*
16	11	4	11	3	25	9*
17	12	4	12	4	26	9
18	13	5	13	4*	27	10
19	14	5+	14	4*	28	10
20	15	5	15	5*	29	1*
21	16	6*	16	5	30	1*
22	17	6	17	5	31	2*
23	18	6	18	6	32	2+
24	19	7*	19	6	33	3#
25	20	7	20	6	34	3
26	21	7	21	7	35	4*
27	22	8	22	7*	36	4*
28	23	8+	23	7*	37	4*
29	24	8	24	8*	38	5*
30	25	9*	25	8	39	5
31	26	9	26	8	40	6
6/ 1	27	10*	27	9	41	6
2	28	10	28	9	42	8
3	29	1#	29	9	43	7*

Table 2. (continued)

	1983		1984		1985	
date	day	paddock	day	paddock	day	paddock
4	30	1	30	10#	44	9*
5	31	1	31	10	45	10
6	32	2+	32	10	46	1*
7	33	2	33	1*	47	2*
8	34	2	34	1*	48	3
9	35	3*	35	1*	49	4*
10	36	3	36	2*	50	4*
11	37	3	37	2+	51	5*
12	38	4*	38	2+	52	6+
13	39	4	39	3		#
14	40	4	40	3		
15	41	5	41	3		
16	42	5+	42	4*		
17	43	5	43	4*		
18	44	6*	44	4*		
19	45	6	45	5*		
20	46	6	46	5		
21	47	7*	47	5		
22	48	7	48	6		
23	49	7	49	6		
24	50	8	50	7		
25	51	8	51	7*		
26	52	4,5[1]	52	7*		
27	53	9*	53	8*		
28	54	9	54	8+		
29	55	10*	55	9+		
30	56	10	56	9		
7/ 1	57	1+	57	9		
2		#		#		

#weighed cattle

*sampled in SDG cell following procedures described below

+sampled in CSLG following procedures described below

[1] 1/2 day in each paddock

Dietary Quality

Heifers having permanent, surgically installed esophageal fistulae were used to collect samples of grazed forage for nutritional analysis. In 1983, three fistulated animals were used in each treatment. In 1984 and 1985, this number was increased to five animals in each treatment. These animals were cohorts of the larger herd of heifers that grazed the experimental pastures.

Samples were collected in the early morning or at the time of entry to paddocks. A five to ten hour fast was employed prior to sample collection to insure that animals would collect samples. Chacon and Stobbs (1977) found that bite size was influenced much more by stage of defoliation and individual animal variability than by fasting or diurnal variations in time of sampling, as long as a minimum fasting period was used (less than 12 hrs.). They found no effect on dietary quality due to overnight fasting. Fistula extrusa samples were frozen in the field immediately following collection by immersing them in a dry ice-alcohol bath. These samples were then stored in a freezer until laboratory analyses were done. Extrusa collections followed the sampling schedule on page 26.

Ingestive Behavior and Forage Intake

Three variables of ingestive behavior measured in 1984 and 1985 were grazing time, biting rate, and ingestion rate.

Grazing time was recorded by fitting four animals in each treatment with vibracorders. These instruments remained on the animals throughout the grazing season to continuously record grazing time.

Biting rate was measured by visual counts during the period of intense grazing in early morning. Animals to be observed were selected in a stratified manner so as to maximize independence of samples (ie. individuals separated by distance and time). The intention was to minimize possible effects of social facilitation on behavior. Individuals selected for observation were separated by distance, with other animals in between. The distance between animals was subjectively chosen, but considered large enough so that animals were not in direct eye contact with each other. Animals grazing immediately adjacent to each other were not observed subsequent to each other. An animal that had been near a previously observed animal may have been observed later, but these were considered independent samples due to animal movement and changing events over time. Animals were identified when possible by eartag numbers to avoid observing the same animal twice during the same period of observations. For a particular animal, time elapsed to prehend 100 to 200 bites was recorded with a stop watch while counts were made. Timing was interrupted during nongrazing intervals (eg.: when fighting insects or while travelling distances of several meters with the head up). This was done following the sampling schedule outlined on page 26.

Ingestion rate, or short-term intake per unit time, was measured in conjunction with collection of esophageal extrusa. Extrusa collected during timed periods of sample collection was weighed in the field with a spring scale immediately following collection. Weight was converted to an organic matter (OM) basis in subsequent laboratory analysis (Harris 1970). Ingestion rate per sample collection period was calculated for each heifer by dividing the OM weight by the grazing time during the sample collection period. Several measures were taken to improve the probability of collecting all forage ingested during an extrusa collection. In 1983, foam rubber plugs were placed in the esophagus below the fistula during collections, as recommended by Stobbs (1973a). However, animals were often observed to be irritated by the presence of the foam rubber plug, and thus, did not graze normally. In 1984 and 1985, a cannula insert was used in lieu of the foam plugs to facilitate total sample collection. The cannula was a ring-shaped device that held the fistula open, causing it to be the path of least resistance for extrusa. Tests were not conducted to insure that total collections were successfully obtained. Extrusa collections also followed the sampling schedule outlined on page 26.

I attempted to measure bite size, but was unable to accurately count bites during extrusa collections, because animals could not be kept in sight continuously to visually count bites. An apparatus to count jaw movements, similar to those described by Stobbs and Cowper (1972), proved unsuccessful due to lack of durability. Another approach attempted was to tape record the tearing sound of bites being bitten off by cattle. This was also unsuccessful due to background interference. Perhaps this method has potential if a way can be found to filter background noise.

Sward Characteristics

Total aboveground plant biomass was estimated by double sampling procedures (Pechanec and Pickford 1937). Plots were located throughout the paddocks on a stratified basis. Approximately sixty

0.5-m2 plots were estimated and every fourth one of those was harvested. The actual number estimated was determined by concurrent sample size calculations. Sample number requirements were determined so as to be at least 80 percent confident of being within 10 percent of the mean. The harvested samples were dried for 24 hours at 60°C, weighed, and saved for laboratory analyses. Plant height was measured on approximately 100 plants located on a pace transect positioned lengthwise through the center of the paddock. The height from the ground to the top of one of the tallest tillers in the plant was measured. The tiller was allowed to stand naturally while the measurement was made, rather than stretching it to its maximum height. Forage bulk density was calculated by dividing biomass by plant height, and is expressed as g dry matter (DM) per cm^3. Data were collected on the sampling schedule outline below.

Sampling Schedule

In 1983, extrusa collections and biomass estimates were done in paddocks 3, 6, and 9 of the grazing cell. Esophageal extrusa was collected and aboveground forage biomass was estimated on the days of entrance to and exit from these paddocks (Table 2). The same variables were sampled in Pasture 14 during intervening periods between sampling of SDG paddocks (Table 2). Plant heights, and ingestive behavior variables were not sampled in 1983.

In 1984 and 1985, extrusa collection, ingestive behavior measurements, and sward characteristics estimation in the SDG cell were done in paddocks 1, 4, and 7 (Table 2). In 1984, extrusa collections were done on each consecutive morning that the heifers occupied these paddocks. This meant that the initial sample in the paddock occurred approximately 19 hours after the animals had entered the paddock at noon on the previous day. Therefore, during cycle 2 of 1984 and throughout 1985, an additional collection was added at midday, immediately after movement into the paddocks, to gain information on response to ungrazed swards. Pasture 14 was sampled on three occasions evenly spaced through the grazing season (Table 2). Pasture 14 was sampled for two consecutive days during each sampling period in 1984, but only one day in 1985.

Laboratory Methodology

Subsamples of frozen extrusa samples were freeze-dried and ground through a 1 mm mesh screen in preparation for analysis. A portion of each sample was withheld from drying and grinding and was used for dry matter (DM) and organic matter (OM) determination. These DM and OM values were used to adjust weights of total extrusa collections to an OM basis for calculation of ingestion rates. Ground samples were analyzed for Kjeldahl nitrogen (Harris 1970) and IVOMD by use of a cellulase technique (McLeod and Minson 1978). Crude protein was calculated as Kjeldahl nitrogen times 6.25.

Five oven-dried sward samples from each sampling date were ground through a 1 mm mesh screen and analyzed for nutritional characteristics by near infrared reflectance (NIR) spectroscopy (Marten et al. 1985). Fifty of these samples from 1985 were randomly selected for wet chemistry analyses to develop predictive equations for the NIR spectrophotometer. These analyses included crude protein by Kjeldahl nitrogen determination, IVOMD using cellulase, neutral detergent fiber, acid detergent fiber, permanganate lignin, cellulose, and hemicellulose (Goering and Van Soest 1970). Once equations had been developed, the values for these variables were predicted by NIR for the remaining samples.

All results for extrusa and sward samples are reported on an OM basis (Harris 1970).

Vibracorder charts were analyzed following the guidelines of Scarnecchia (1980). Time was reported as hours of grazing per day. Biting rates were reduced to bites per minute. Ingestion rates were reduced to grams OM per minute. Daily forage intake was calculated by the product of ingestion rate and grazing time (Freer 1981).

Data Analysis

Differences in dietary quality and ingestive behavior between SDG and CSLG, time (of the grazing season), and days in a paddock, were analyzed using least squares procedures of analysis of variance (ANOVA). The Rummage statistical program (Bryce 1980) was used for this analysis. All ANOVA models were run separately for each year. Statistical comparisons were not made between years because of differences between years in sampling schedules (see page 26 and Table 2) and grazing management, including changes in the starting point in the grazing cell, length of grazing periods in paddocks, and number of cycles through the cell (Table 2). These differences created an unbalanced design with missing cells. Rummage is capable of analyzing unbalanced numbers within cells, but cannot handle missing cells. Also, due to these confounded comparisons between years, interpretation of ANOVA results would be difficult. Protected LSD at

$\alpha=0.05$ was used to test for significant differences among means.

In consideration of objectives one and two, the following ANOVA model was used to test for overall grazing method differences and for seasonal differences:

$$Y_{ij} = M_i + T_j + MT + E$$

where: Y_{ij} = dietary crude protein, dietary IVOMD, IR, BR, or GT
M_i = grazing method (SDG vs. CSLG)
T_j = time of sampling (season)

For 1983, j=5 because CSLG was sampled five times. The CSLG samples were paired with the nearest (in time) SDG paddock samples. Because CSLG was sampled five times and SDG was sampled six times, paddock 6, cycle 2, was not used in this analysis. It was chosen for elimination because it was most distant in time from CSLG samples. For 1984, j=3, and the following paddocks were paired with CSLG samples for comparison:

j	SDG(paddock, cycle)
1	1,1
2	1,2
3	7,2

These were the nearest SDG samples, in time, to the CSLG samples. Grazing time, which was recorded continuously, was split into three periods of equal length for each jth observation for 1984. For 1985, j=3, and all samples for each dependent variable from cycles 1, 2, and 3 were used, respectively, for each j.

To assess whether SDG could extend the season of nutritious forage over CSLG, the intent was to determine if method-by-time interactions were significant. If so, then mean differences were to be examined to determine if one treatment was significantly better for the given dependent variable at the first or last sample time, indicating that the grazing season could possibly be extended earlier or later without adversely affecting nutritional quality and ingestive behavior. However, because the treatments (SDG and CSLG) were not replicated, the mean square for the method-by-time interaction was used as the error term for the main effects (method and time). Because the method-by-time mean square had been used as an error term, it was not statistically valid to test its mean square by the subsampling error term (D. Turner, pers. comm.). Regardless, this test was done, and the results were considered in a very conservative manner.

The following ANOVA model was used to detect daily changes in SDG paddocks:

$$\begin{aligned} Y_{ijkl} = {} & Pi + Aj + PA + Ck + PC + AC \\ & + PAC + D_l + DP + DC + DPC + E \end{aligned}$$

where: Y_{ijkl} = dietary crude protein, IVOMD, IR, or GT
P_i = paddock
A_j = animal
C_k = cycle
D_l = day

The paddock-by-animal interaction term was used as the error term for the paddock and animal main effects. The remaining error term was used to test the day main effect and all interaction terms involving the day term. A reduced model without the animal-by-cycle and paddock-by-animal-by-cycle interactions terms was used to determine the mean square of these terms combined to use as the error term for the cycle main effect and paddock-by-cycle interaction term.

If the animal main effect was not significant, then the following model was substituted:

$$\begin{aligned} Y_{ijkl} = {} & Pi + Aij + Ck + PC + AC + Dl \\ & + DP + DC + DPC + E \end{aligned}$$

Because focal animals were not used for the biting rate observations, a three way complete factorial was substituted for the above equation to test for daily changes in biting rate:

$$Y_{ijk} = P_i + C_j + D_k + PC + PD + CD + PCD$$

Replicates of the experimental range units, pastures and grazing cells, were not available. Thus, these statistical models were used to provide statistical inference. It should be noted that the strength of this inference is not as good as a true replicated design.

A minimum constraint model was developed to describe the controls on ingestive behavior by sward characteristics. It described the relationship between ingestion rate or grazing time and relevant sward characteristics. The predicted ingestive behavior values for a given set of sward characteristics were multiplied to calculate forage intake. The relationships between dependent and independent variables were constructed of piecewise linear functions to approximate nonlinear relationships, with each "piece" of the regression line being the sward characteristic constraining ingestive behavior at that point on the range of possible sward characteristics. In this way, changes over time in ingestive behavior can be predicted for changes over time in sward characteristics. This approach is not the same as multivariate regression, that would use all independent variables simultaneously to predict the dependent variables. In the minimum constraint model, one independent variable at a time influences the dependent variable, depending on which is most constraining.

Optimum length of stay in a paddock was inferentially determined by consideration of daily changes in diet quality, forage intake, and ingestive behavior.

RESULTS AND DISCUSSION

SDG Versus CSLG, Overall Response

Livestock Weight Gain

Statistical comparisons were made within years only. Visual comparisons indicate that individual animal gains in both treatments appeared to be higher in 1984 (Table 3). This may have been a reflection of compensatory gain due to a particularly hard winter and short feed supplies immediately prior to the 1984 grazing season. On a relative basis, there appears to be a trend through the three years. While CSLG provided greater gains than SDG in late 1983, no differences were detected in 1984, and SDG was superior throughout 1985. There are several possible explanations for these responses. First, the effects of SDG on the vegetation may be cumulative over successive grazing seasons. Three years were required for SDG to overcome its initial lower level of animal performance in 1983, and finally gain superiority by 1985. In this case, SDG would be the superior grazing method from a biological point of view. Second, both treatments were stocked higher than the generally recommended stocking rate (0.7 ha/AUM for six weeks). We used 0.7 ha per AUM, but extended the grazing season to eight weeks. The result, based solely on visual observation, was degradation of the plant community on both

Table 3. Heifer weight responses (kg/hd/d) on SDG and CSLG crested wheatgrass during the springs of 1983, 1984, and 1985.

	SDG	CSLG
1983		
cycle 1	1.09[a]	1.21[a]
cycle 2	0.54[a]	0.94[b]
mean	0.81[a]	1.07[a]
1984		
cycle 1	1.54[a]	1.62[a]
cycle 2	0.72[a]	0.52[a]
mean	1.13[a]	1.07[a]
1985		
period 1	1.12[a]	0.96[b]
period 2	0.88[a]	0.73[b]
mean	1.03[a]	0.87[b]

[a,b] means within rows followed by different letters are significantly different ($P \leq .05$)

treatments. Visual evidence included thinning of tillers in crested wheatgrass bunches, and that western wheatgrass appeared to be more vigorous and productive than crested wheatgrass. These observations were noted in both SDG and CSLG. However, the degradation appeared to be much greater in the CSLG treatment. In CSLG, crested wheatgrass cover was disappearing, with a large increase in broom snakeweed (*Xanthocephalum sarothrae* Shinners). This was particularly evident in the half of the pasture nearest the water trough, indicating uneven distribution of grazing use. Signs of uneven distribution of grazing use were not evident in the SDG cell. This difference may have been due to superiority of SDG, or may have been due to differences in site potential of the pastures. It may be that the CSLG treatment was showing faster degradation because it was on poorer soils, as described previously in the site description, and simply was less capable of withstanding heavy use. Third, grazing management was changed in SDG during 1985, to shorter grazing periods of paddocks. The reason that weight gains were higher in the grazing cell only in 1985 may have been because animals were not forced to utilize poorer quality forage as defoliation progressed through the third day during that year.

Gain per hectare (kg/ha), calculated from seasonal mean weight gains were initially higher in CSLG, but subsequently higher in SDG in 1984 and 1985 (Table 4). Because there were no differences in stocking rates, individual weight responses are directly reflected in these production figures. If these production responses are truly due to SDG management, it should yield a meaningful economic advantage. For example, if a value of $50.00 per cwt. is placed on the difference in production in 1985, SDG will yield an additional $9.88 per hectare ($3.95 per acre). Fencing costs to build the cell in 1982 were approximately $1500.00. If we assume a thirty year life for the fences and seeding, that this relative advantage will hold through that period, and that opportunity and borrowing costs are five percent (real), the resulting present net worth would be $2,833.67 (Table 5). Even excluding other possible benefits, use of SDG under these conditions would be profitable. Other possible benefits, such as extended life of the crested wheatgrass seeding, reduced labor and management cost for such practices as artificial insemination, and possible benefits of increased growth in heifers including earlier onset of puberty, increased conception rates, earlier birth of offspring, and resultant increases in pounds of calf weaned per cow throughout her life may also be realized and would improve this economic scenario.

Table 4. Animal production (kg/ha) from heifers grazing crested wheatgrass under SDG or CSLG over a three year period.

year	SDG	CSLG
1983	50.5	65.7
1984	72.0	67.5
1985	58.4	49.5

Table 5. Calculation of present net worth of SDG if a $9.88 per ha advantage over CSLG could be maintained for thirty years.

benefit:

$PV = \$9.88 * 84\ ha * PWOP_{5\%,30} = \$829.92 * 15.372 = \$12,757.53$

cost:

fence building = $1500.00

fence upkeep: assume $100.00 per year

PV = $100.00 * 15.372 = $1,537.20

labor and management: assume 7 hours per week for an 8 week grazing season at $8.00 per hour

PV = $448.00 * 15.372 = $6886.66

NR = 12,757.53 - ($1,500 + $1,537.20 + $6,886.66) = $2,833.67

Diet Quality

No significant differences were found in crude protein (CP) and IVOMD of diets between SDG and CSLG in any of the three years (Figures 2 and 3, Appendix Tables 6 through 12). Although a large difference in CP appeared between SDG and CSLG in 1983, it was not significant. The small sample size of only three animals in 1983 and large variances made detection of statistical differences impossible. CP and IVOMD were relatively uniform among years, and sufficiently high to provide adequate nutrition for heifer growth (ie. the NRC (1976) requirement for 250 kg growing heifers to gain 1.1 kg/day is 11.4%). Apparently, animals were able to adjust for any differences in sward characteristics between treatments and maintain equal diet quality.

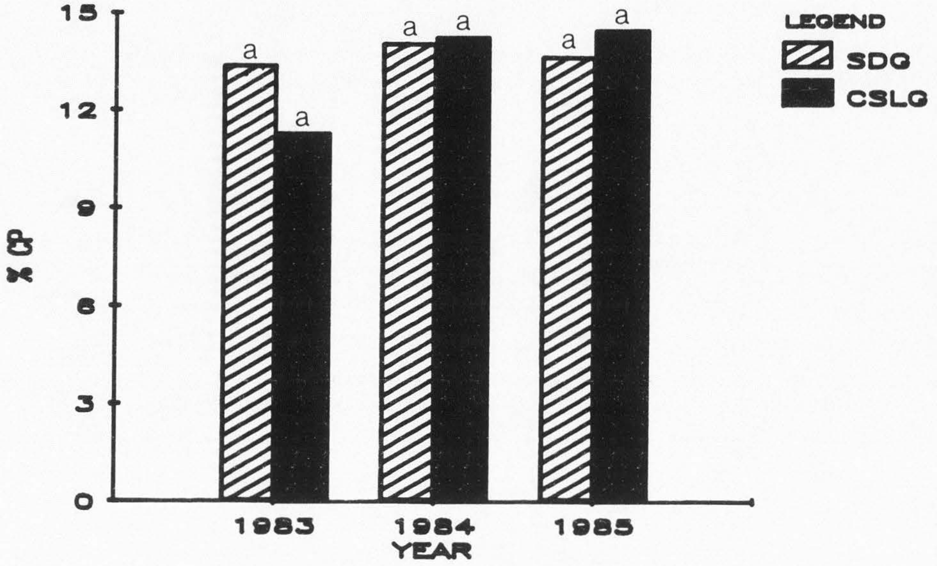

Figure 2. Comparison of crude protein content (CP) of esophageal extrusa from SDG and CSLG on crested wheatgrass, 1983 through 1985. Bars with the same letter within years indicate lack of significant differences (P>.05).

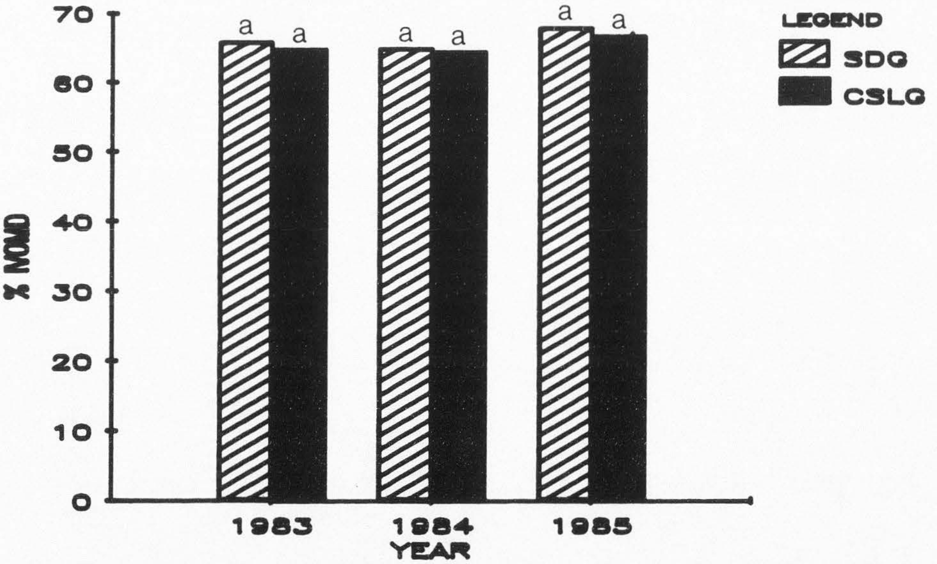

Figure 3. Comparison of IVOMD of esophageal extrusa from SDG and CSLG on crested wheatgrass, 1983 through 1985. Bars with the same letter within years indicate lack of significant differences (P>.05).

Ingestive Behavior and Daily Forage Intake

Ingestion rates were the same in both treatments in 1984, but were significantly less in CSLG in 1985 (Figure 4, Appendix Tables 13 and 14). Ingestion rate can be considered a measure of foraging efficiency, because it approximates intake of nutrients or energy per expenditure of time, with grazing time serving as an estimator of energy expenditure (Osuji 1974). Thus, animals foraged more efficiently in SDG in 1985. Biting rates were not different in either year (Figure 5, Appendix Tables 15 and 16). Grazing time was not different in 1984, but was significantly greater in CSLG in 1985 (Figure 6, Appendix Tables 17 and 18). Apparently, increased ingestion rate, as found in SDG in 1985, allows a concomitant decrease in grazing time, as stated by Chacon and Stobbs (1976). The result was that time, and thus energy, expended to graze was reduced by SDG. Interestingly, Walker et al. (1986) found that mean grazing time was an hour longer under continuous grazing than SDG (10.9 vs. 9.8). Their values are remarkably similar to my 1985 results.

Mean daily forage intake was a mathematical product of ingestion rate and grazing time (Figure 7). Because ingestion rate and grazing time were collected with two different sets of animals, the mean for each variable is used. The product is one data point for each sample date, with no valid measure of variability around that data point. Therefore, statistical analyses could not be performed on these data. These calculated intake values range from 1.3 to 2.6 percent OM of body weight. NRC (1976) recommendations for minimum dry matter intake, when converted to a percent of body weight basis, range from 2.3 to 2.9 percent DM to obtain weight gains comparable to those observed in this study. If calculated intake values are converted to a DM basis, assuming an average OM content of 90 percent, they range from 1.4 to 2.9 percent DM. Under these conditions, all values except intake under CSLG in 1985 fall between 2.4 and 2.9 percent DM. These values are very similar to expectations based on NRC (1976) requirements. These results lend credibility to these calculated values as estimates of daily forage intake.

It appears that forage intake was largely a function of ingestion rate, with the compensatory response of increased grazing time in CSLG during 1985 having little effect on the decline in forage intake as ingestion rate declined. This agrees with conclusions of Stobbs and Hutton (1974) and Chacon and Stobbs (1976) that bite size was a better indicator of sward effects on intake than was grazing time. Because biting rate showed no differences in this study, changes in ingestion rate are direct reflections of bite size dynamics.

The ingestive behavior and resultant forage intake responses provide an apparent explanation for the differences in animal performance (Figures 4, 6, and 7). This is in contrast to the lack of differences in diet quality (Figures 2 and 3). In 1985, animals in SDG appeared to forage more efficiently, with a higher intake per unit time (Figure 4), and lower time (energy) expended grazing (Figure 6) to gain a higher total daily forage intake (Figure 7). Apparently, sward characteristics that determine ingestive behavior can have a direct effect on animal performance. If these sward attributes can be identified, conceivably, grazing management methods (SDG or others) can be built upon them to further improve animal performance. These relationships will be discussed in detail subsequently (see page 67).

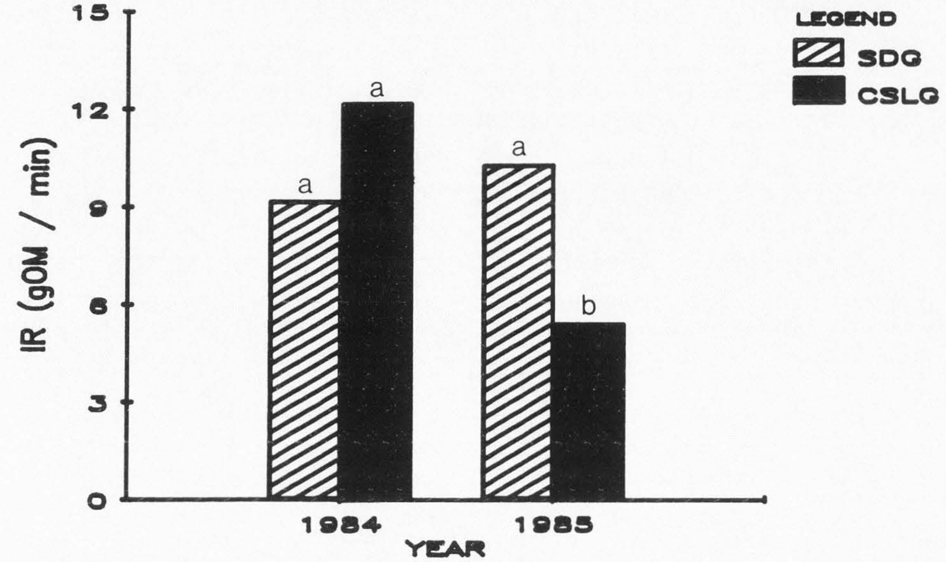

Figure 4. Comparison of ingestion rates (IR, g OM/ min) of heifers grazing crested wheatgrass under SDG and CSLG, 1984 and 1985. Bars with different letters within years are significantly different ($P \leq .05$).

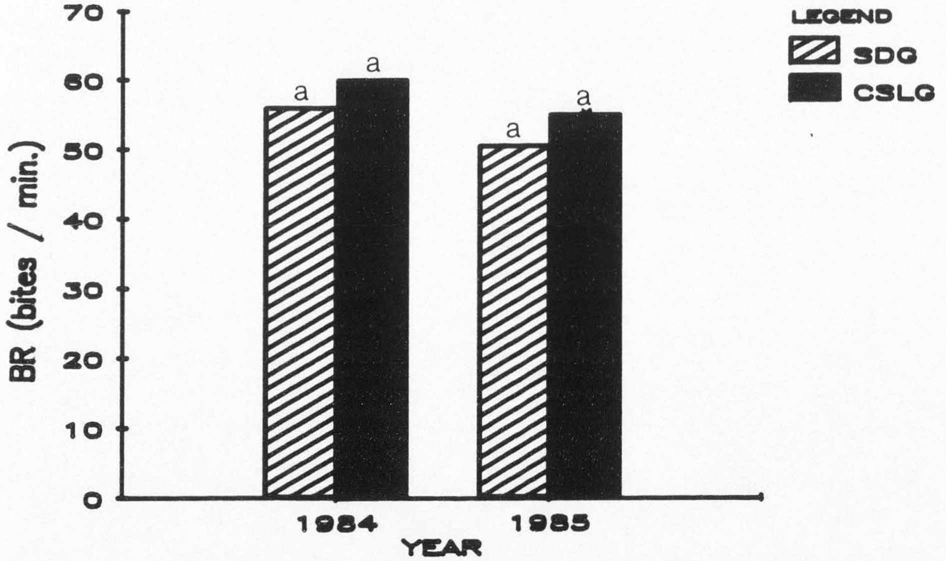

Figure 5. Comparison of biting rates (BR, bites/ min) of heifers grazing crested wheatgrass under SDG and CSLG, 1984 and 1985. Bars with the same letter within years indicate lack of significant differences ($P > .05$).

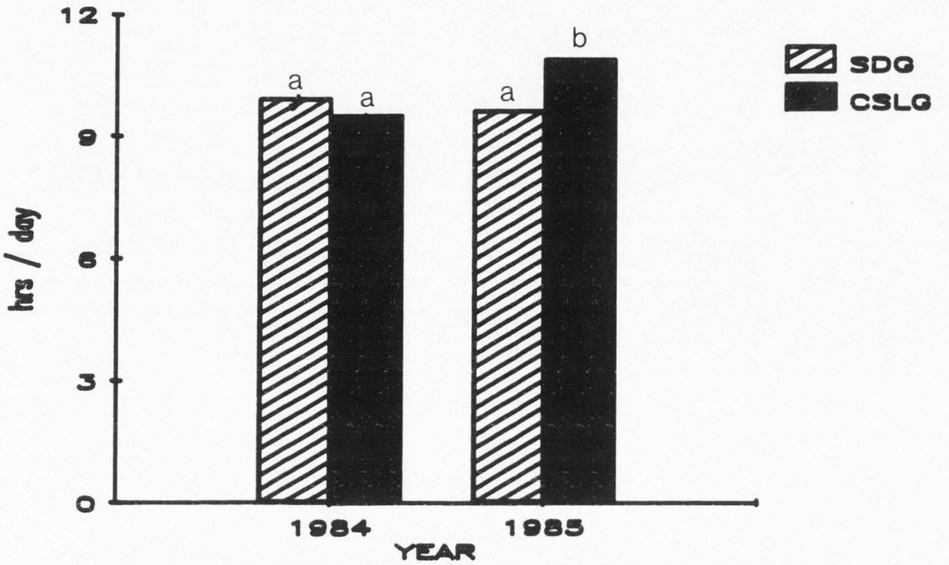

Figure 6. Comparison of grazing time (GT, hrs/ day) of heifers grazing crested wheatgrass under SDG and CSLG, 1984 and 1985. Bars with different letters within years are significantly different ($P \leq .05$).

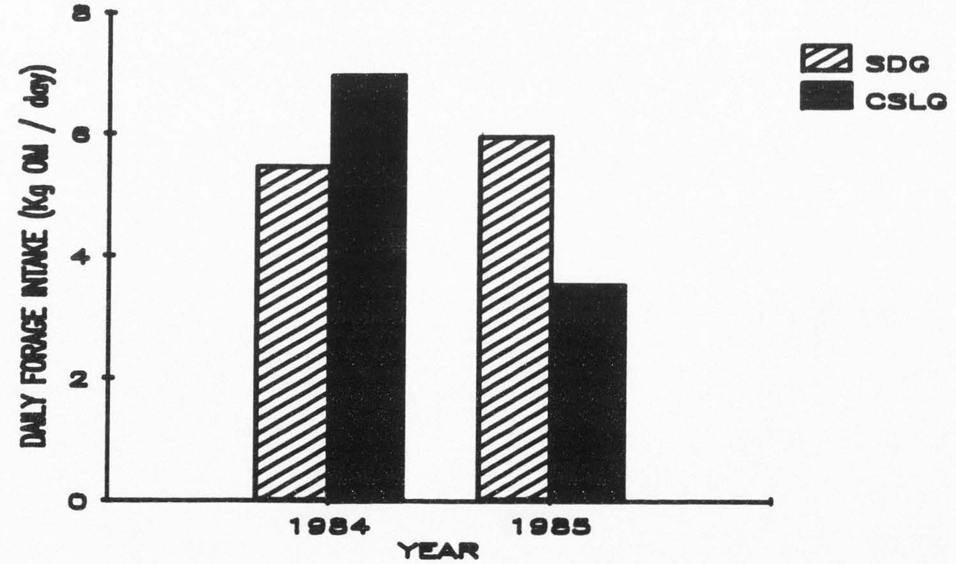

Figure 7. Comparison of daily forage intake (Kg OM/ day) of heifers grazing crested wheatgrass under SDG and CSLG, 1984 and 1985.

SDG Versus CSLG, Implications for Extending the Grazing Season

Diet Quality

Significant grazing-method-by-time-of-sampling interactions for crude protein and IVOMD occurred only in 1984 (Figures 8 through 13, Appendix Tables 7 through 12). For crude protein, the only difference between SDG and CSLG was in the middle of the season. Differences at the beginning or end of the season, that might provide an indication of the possibility of extending the season, were not evident. IVOMD was significantly lower in SDG at the beginning, but significantly higher in SDG for the remainder of the season.

When consideration is given to all three years, no strong indication is evident that SDG had any effect of lengthening the season over which a diet of equal quality, in relation to CSLG, could be attained.

While comparisons of seasonal responses among years were similar for IVOMD, CP responses varied from year to year (Figures 8, 10, and 12). The response in CSLG in 1983 appears very odd. Because of the limited sample size of three fistulated animals, and aberrant behavior of the fistulated heifers used in CSLG in 1983, the accuracy of this response is questionable. Still unexplainable is the difference in CP response between 1984 and 1985, where large and significant ($P<.10$) declines in CP in both SDG and CSLG occurred in 1984, contrasted with small, insignificant ($P>.10$) declines in 1985.

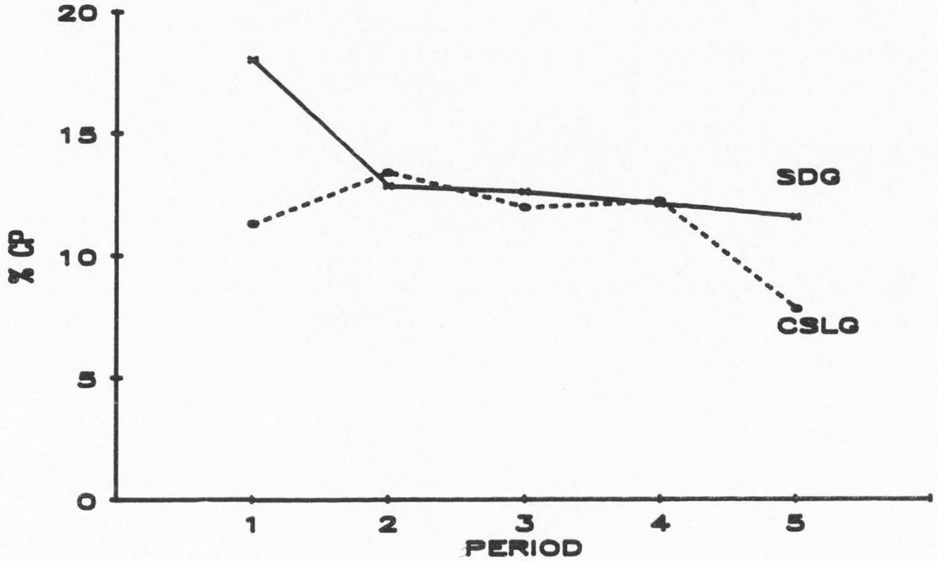

Figure 8. Comparison of method-by-time-of-sampling interaction means for crude protein content (CP) of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1983.

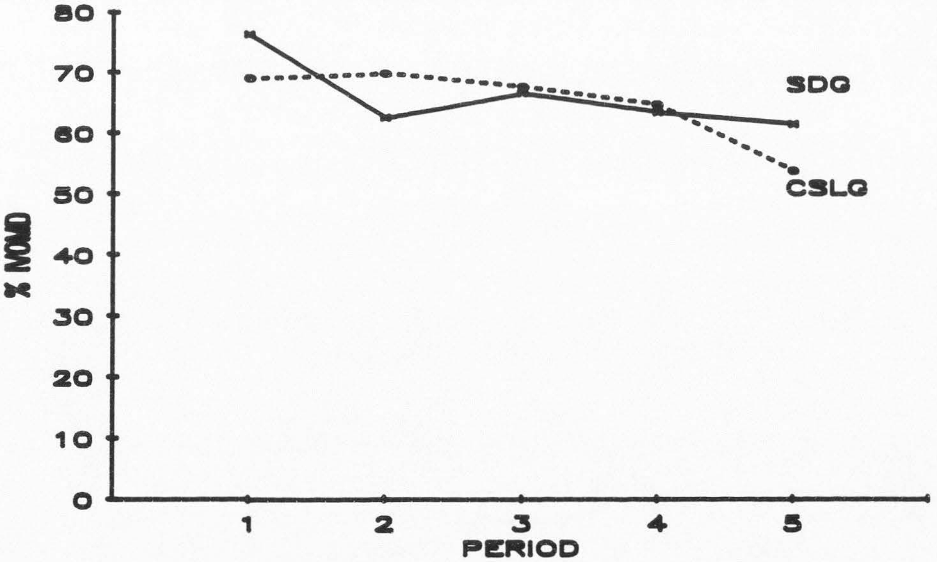

Figure 9. Comparison of method-by-time-of-sampling interaction means for IVOMD of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1983.

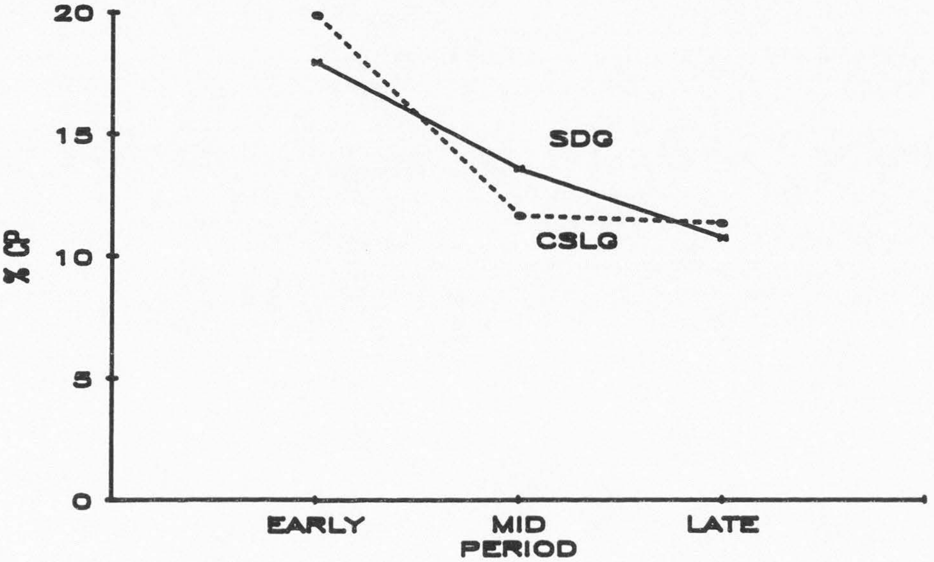

Figure 10. Comparison of method-by-time-of-sampling interaction means for crude protein content (CP) of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1984.

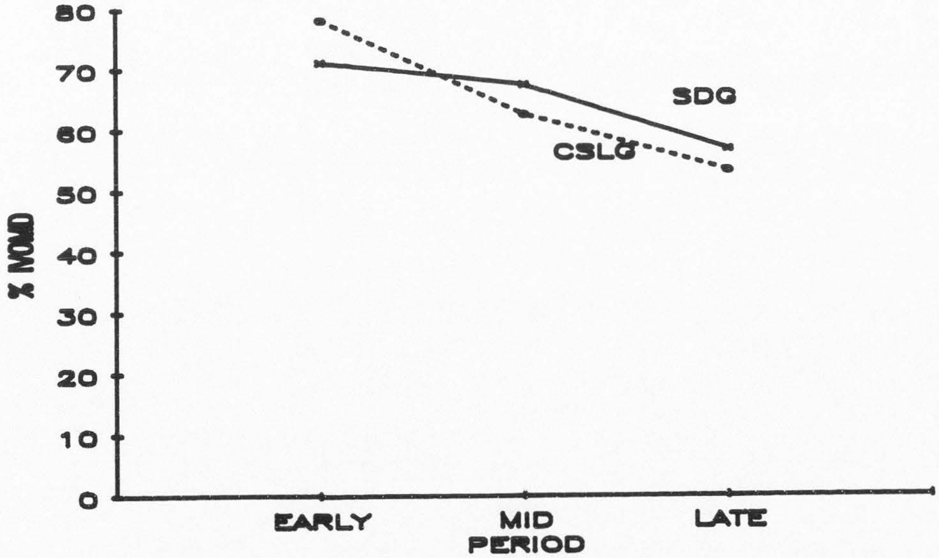

Figure 11. Comparison of method-by-time-of-sampling interaction means for IVOMD of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1984.

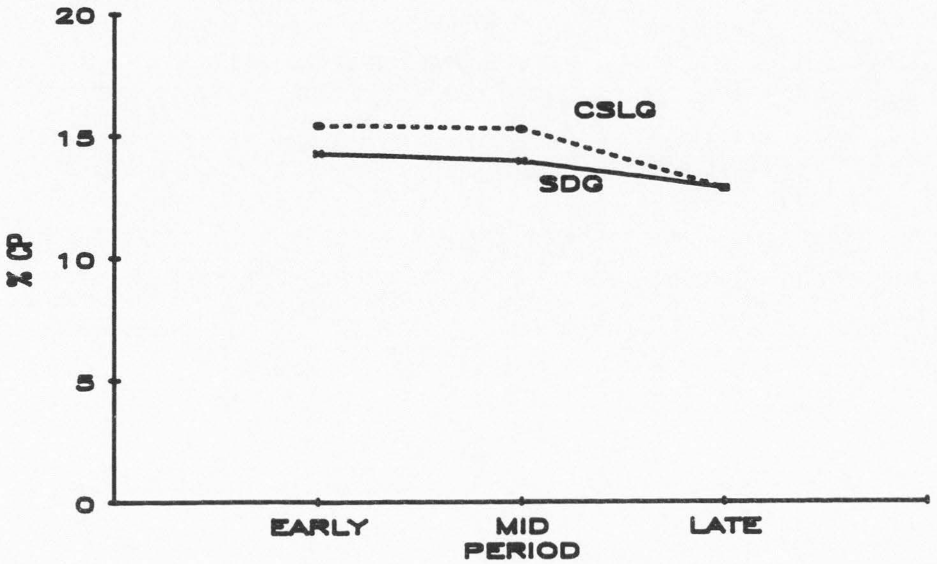

Figure 12. Comparison of method-by-time-of-sampling interaction means for crude protein content (CP) of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1985.

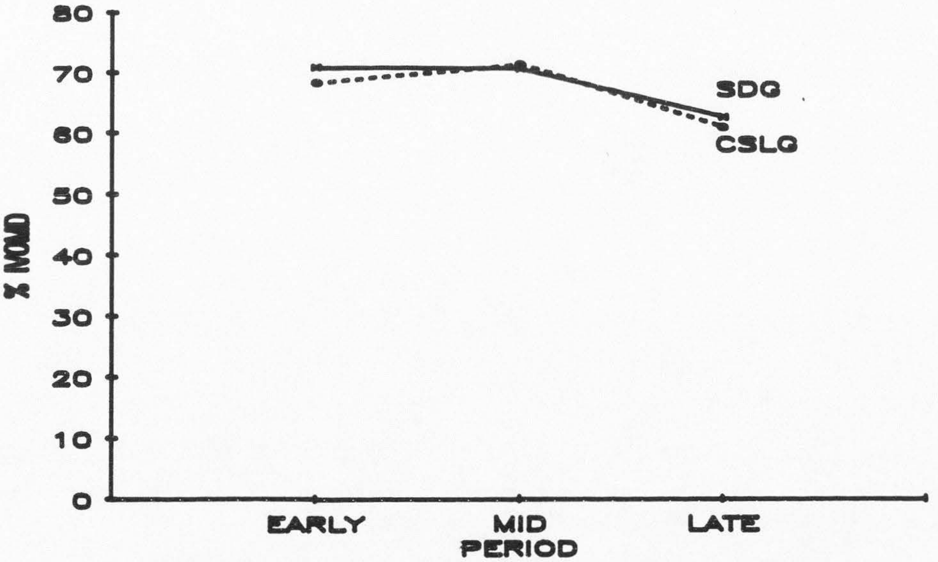

Figure 13. Comparison of method-by-time-of-sampling interaction means for IVOMD of esophageal extrusa from crested wheatgrass under SDG and CSLG in 1985.

Ingestive Behavior and Forage Intake

No differences occurred in method-by-time interactions means for ingestion rate for either year (Figures 14 and 15, Appendix Tables 13 and 14). Significant differences in biting rate occurred only in 1984, and these were during the latter two sample periods (Figures 16 and 17, Appendix Tables 15 and 16). These differences seem inconsequential in light of no differences in ingestion rates. Recall that biting rate is a component of ingestion rate. No differences were detected in grazing time method-by-time interactions in 1984 (Figure 18, Appendix Table 17). Grazing time was significantly shorter in SDG for all three sample times in 1985 (Figure 19, Appendix Table 18).

Based on the conclusion of Stobbs and Hutton (1974) that bite size, a component of ingestion rate, is the primary determinant of forage intake, the lack of response in ingestion rate indicates that forage intake was probably not different, either.

Once again, when considering both years, no strong indication is given that SDG alters the seasonal dynamics of the ingestive behavioral response of heifers in comparison to CSLG.

Because the subsampling error term was used for these tests, the degrees of freedom associated with the denominator of the F ratio were inflated in comparison to those that would have been available with reasonable numbers of replicates. This resulted in a more liberal F test. Even under these liberal test circumstances, few significant differences were found. In addition, these few differences, if valid, did not provide consistent evidence in favor of one treatment or the other, either at the beginning or end of the grazing season.

Therefore, it is concluded from these data that SDG offers no nutritional advantage for extending the season. However, this does not test the possibility that SDG might allow the animals to remain on a pasture longer without causing degradation of the plant community. Although not specifically tested, visual impressions were that, for the length of grazing seasons used in this study, the vegetation in CSLG was showing reduced vigor and plant cover in relation to SDG (see page 32).

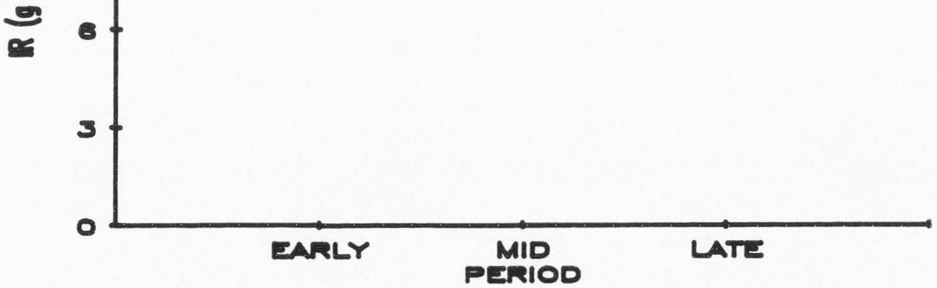

Figure 14. Comparison of method-by-time-of-sampling interaction means for ingestion rate (IR, g OM/ min) of heifers grazing crested wheatgrass under SDG and CSLG in 1984.

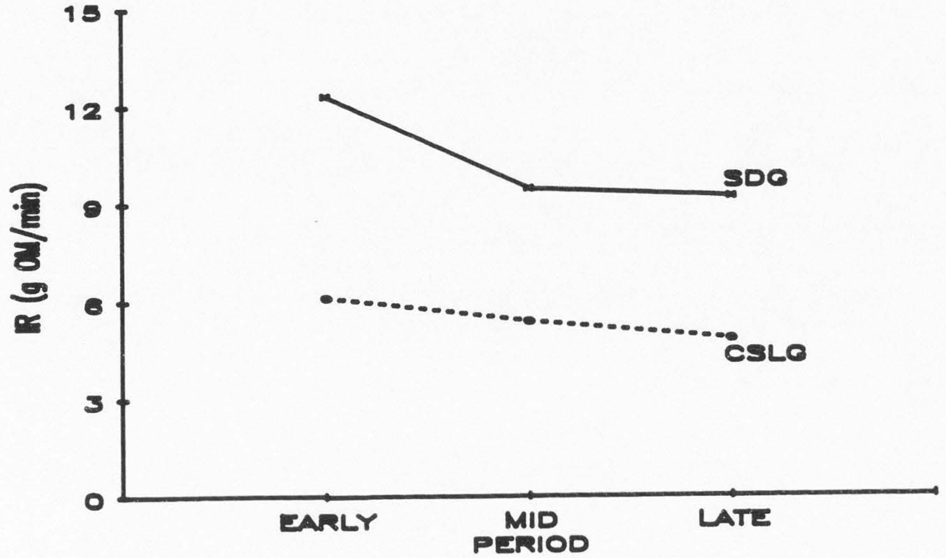

Figure 15. Comparison of method-by-time-of-sampling interaction means for ingestion rate (IR, g OM/ min) of heifers grazing crested wheatgrass under SDG and CSLG in 1985.

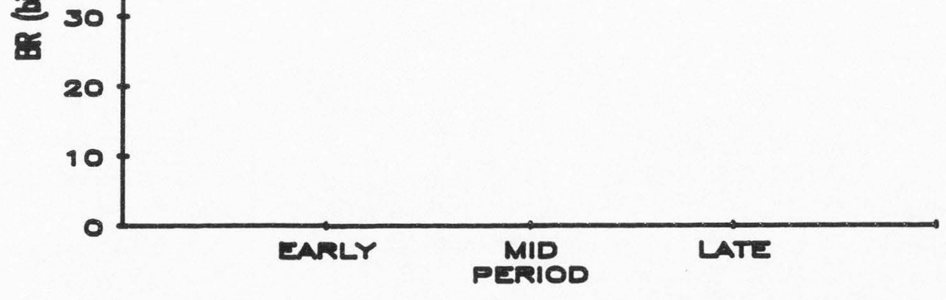

Figure 16. Comparison of method-by-time-of-sampling interaction means for biting rate (BR, bites/ min) of heifers grazing crested wheatgrass under SDG and CSLG in 1984.

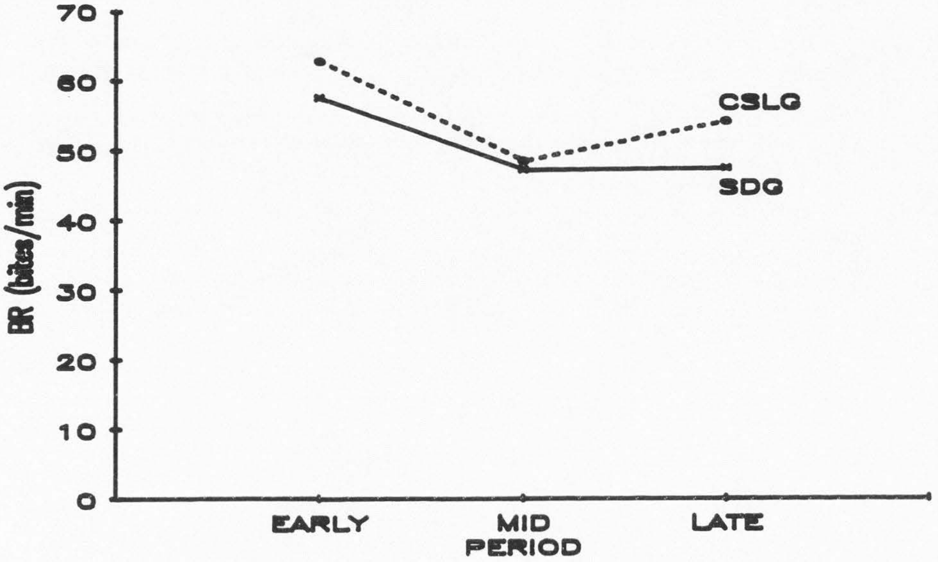

Figure 17. Comparison of method-by-time-of-sampling interaction means for biting rate (BR, bites/ min) of heifers grazing crested wheatgrass under SDG and CSLG in 1985.

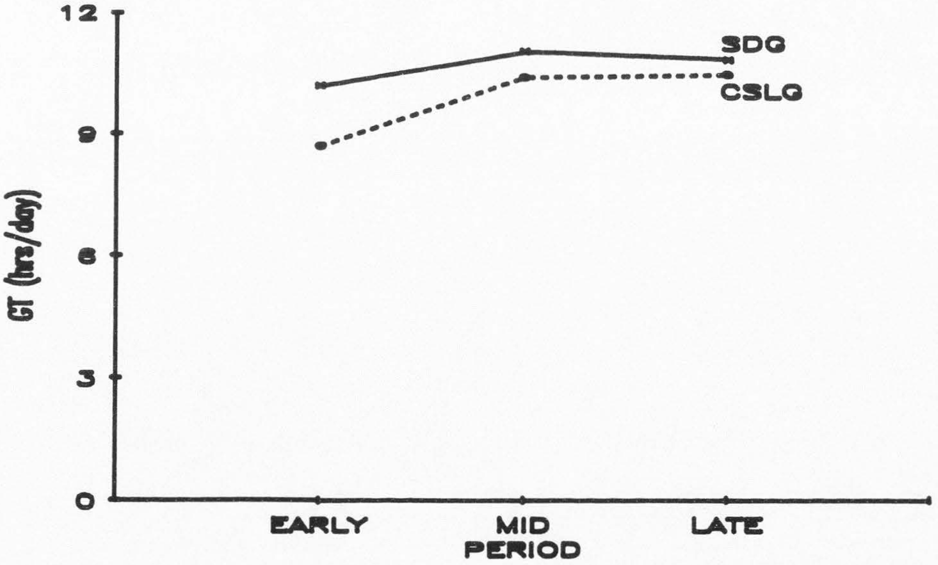

Figure 18. Comparison of method-by-time-of-sampling interaction means for grazing time (GT, hrs/ day) of heifers grazing crested wheatgrass under SDG and CSLG in 1984.

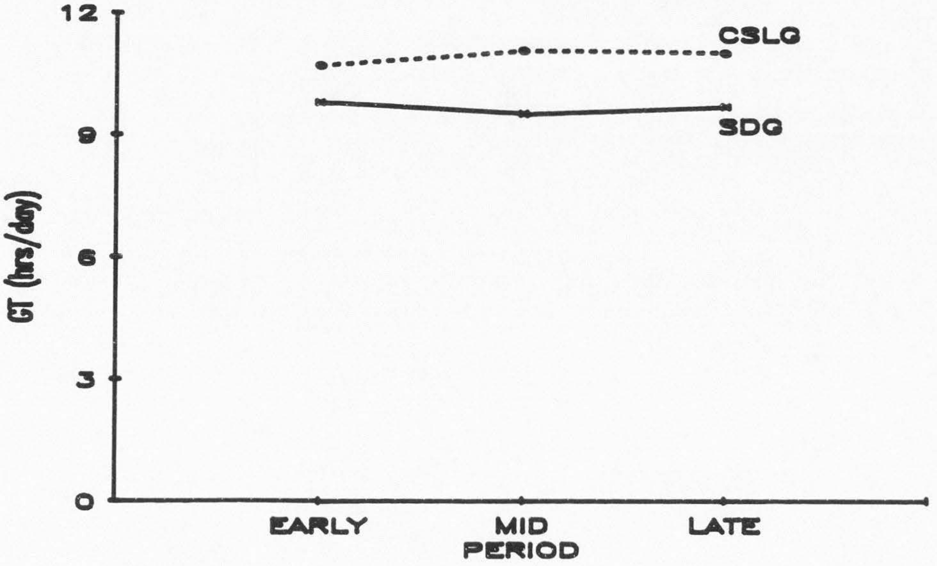

Figure 19. Comparison of method-by-time-of-sampling interaction means for grazing time (GT, hrs/ day) of heifers grazing crested wheatgrass under SDG and CSLG in 1985.

Daily Dynamics in SDG Paddocks

Diet Quality

In 1983, crude protein content and IVOMD both declined significantly from day one to day three (Figures 20 and 21, Appendix Tables 19 and 20). Because these declines were detected in the first year, it was decided to sample on a daily basis in the ensuing years, to get a better understanding of the dynamics of animal response to the rapid defoliation during the grazing of paddocks.

In 1984, crude protein and IVOMD did not change from day one to day two, but declined significantly by the third day (Figures 20 and 21, Appendix Tables 21 and 22). The paddock-by-cycle-by-day (PCD) interaction was significant for crude protein, indicating that variation in the daily response was significant among individual paddocks (Figure 22). The same differences in crude protein exist for all paddocks except two, paddocks one and seven on cycle two. In general, the trend of no change from day 1 to day 2, with a significant decline on day 3, held throughout the season. The PCD interaction was not significant for IVOMD, indicating that variations in daily responses between paddocks throughout the season could not be detected (Figure 23).

In 1985, crude protein and IVOMD both declined significantly from entry to the paddock to the first morning (day one), but did not change from day one to day two (Figures 20 and 21, Appendix Tables 23 and 24). The PCD interaction was significant for both crude protein and IVOMD (Figures 24 and 25). For CP, declines did not occur, or only occurred on the last day early in the season. After that,

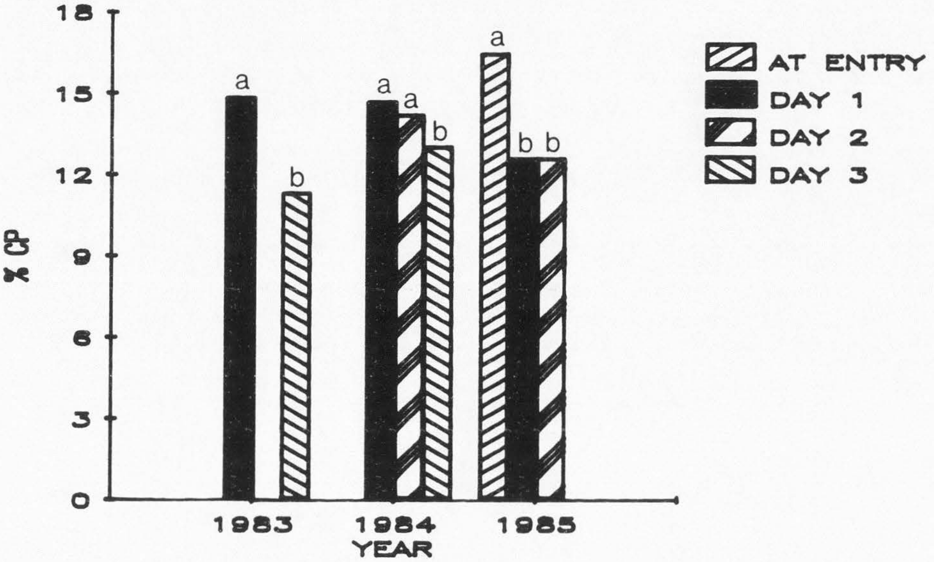

Figure 20. Comparison of mean daily changes in crude protein content of esophageal extrusa in SDG paddocks. Bars within years with different letters are significantly different ($P \leq .05$).

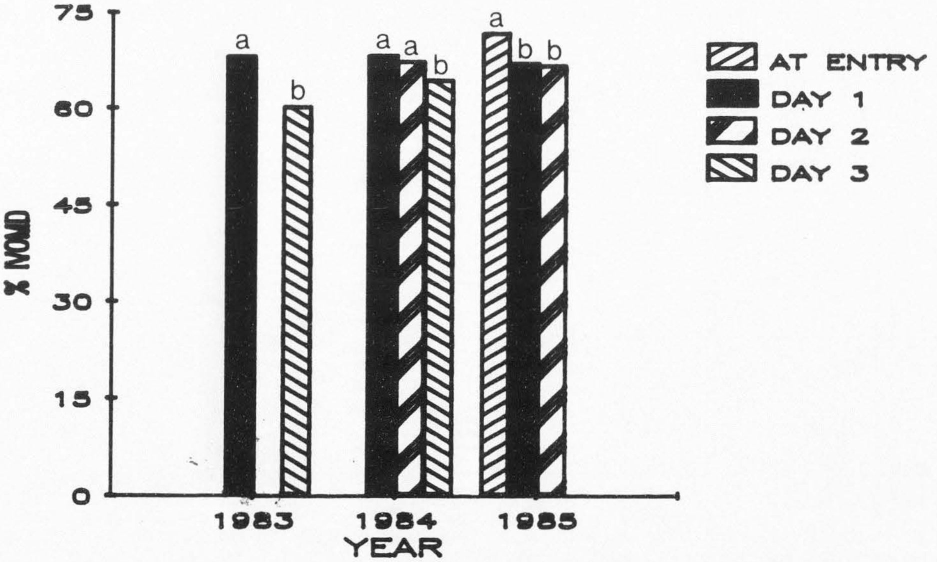

Figure 21. Comparison of mean daily changes in IVOMD of esophageal extrusa in SDG paddocks. Bars within years with different letters are significantly different ($P \leq .05$).

declines in crude protein generally followed the above pattern until the last paddock (Figure 24). Perhaps early in the season, when green plant material was all leaf, animals were capable of maintinaing diet quality longer. The seasonal response for IVOMD was similar, but more variable from paddock to paddock (Figure 25), with significant declines occurring between each sample in several cases.

When comparing across years, no significant differences were detected between days one and two in 1984 and 1985. Apparently, animals can attain a relatively high quality diet when they first enter a new paddock, as depicted at entry in 1985, but this response declines rapidly, within 18 to 20 hours. After that, the ensuing diet quality can be maintained for another day, as seen in both years data. However, when the animals were left in the paddocks for a third day, as in 1984, diet quality declined appreciably. This, also, may explain the difference in animal weight responses between years, with the SDG animals performing significantly better than CSLG in 1985 because they were moved before this decline in diet quality on the third day could occur.

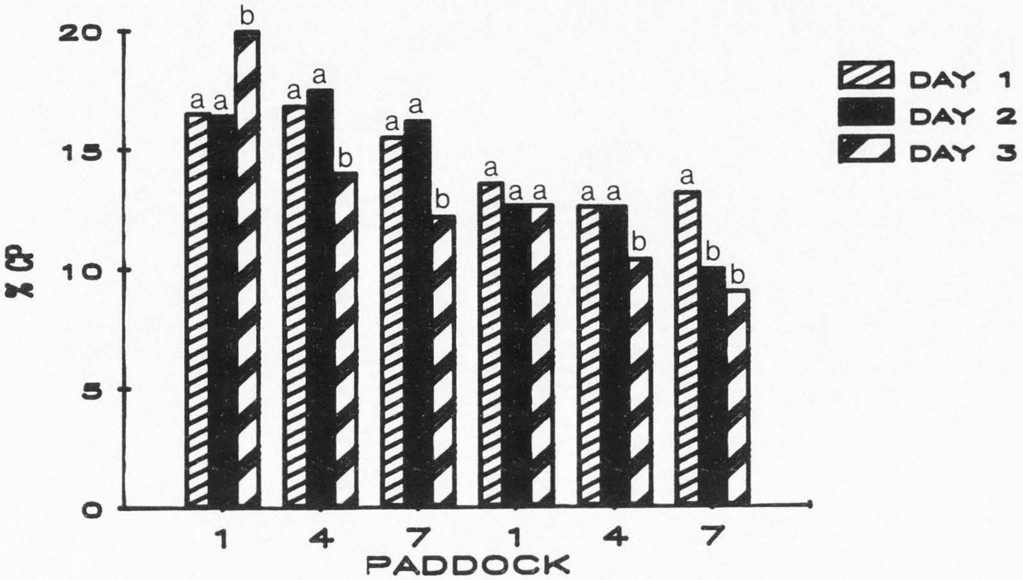

Figure 22. Comparison of daily changes in crude protein content (CP) of esophageal extrusa in individual SDG paddocks in 1984. Bars within paddocks with different letters are significantly different ($P \leq .05$).

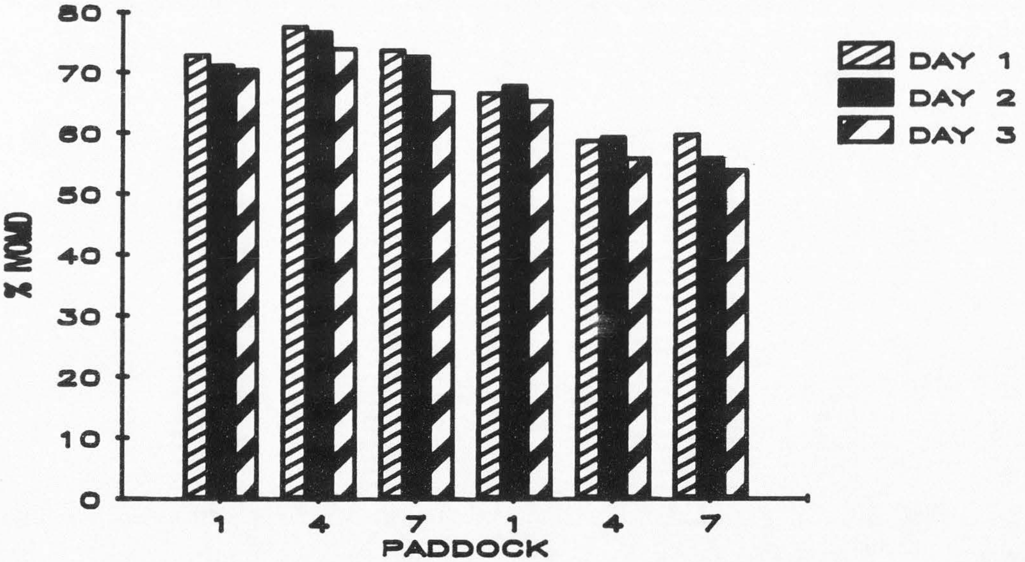

Figure 23. Comparison of daily changes in IVOMD of esophageal extrusa in individual SDG paddocks in 1984. Because the paddock by cycle by day interaction term was not significant, no statistical differences were detected between days within individual paddocks.

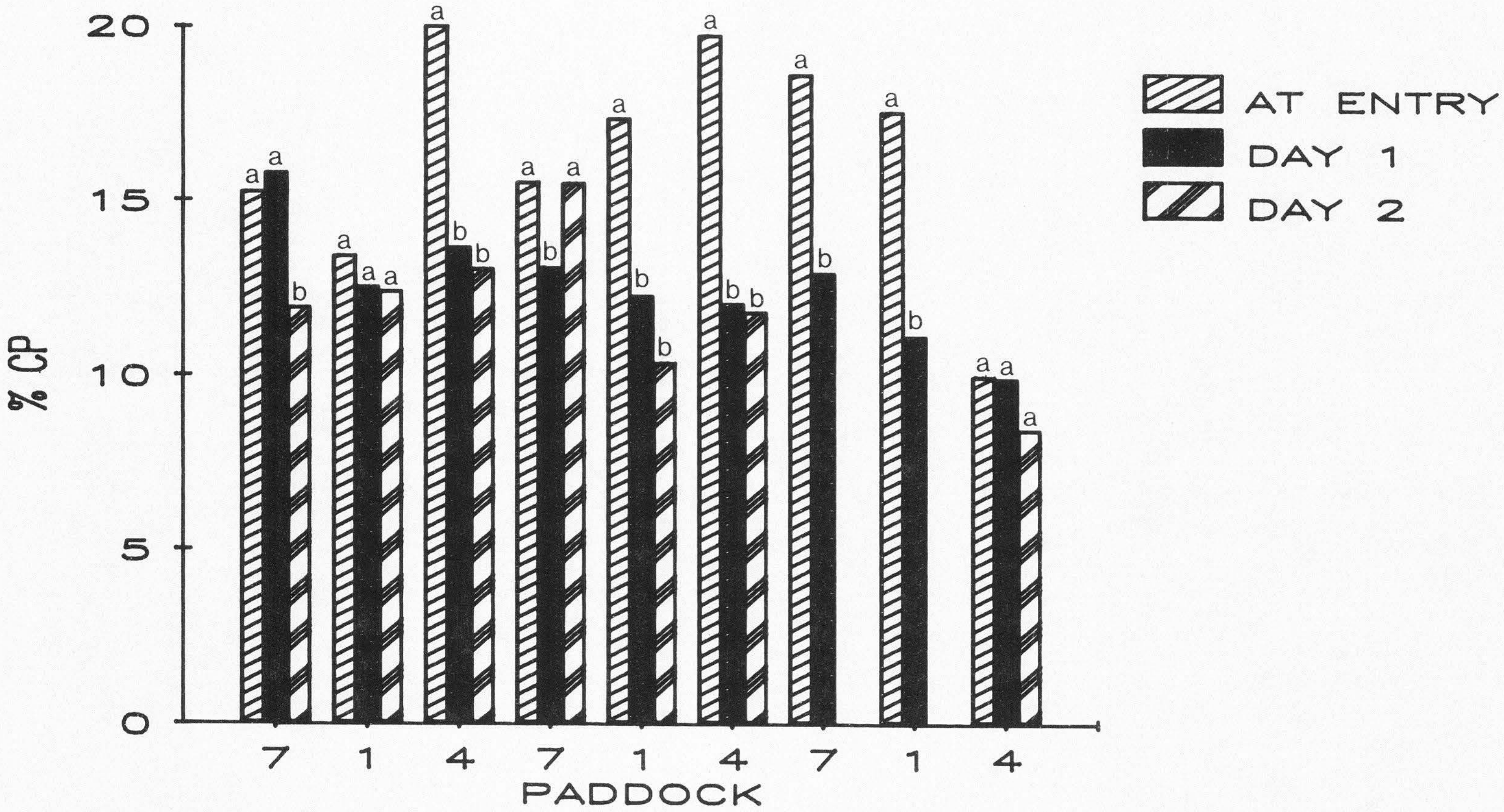

Figure 24. Comparison of daily changes in crude protein content (CP) of esophageal extrusa in individual SDG paddocks in 1985. Bars within paddocks with different letters are significantly different (P<.05).

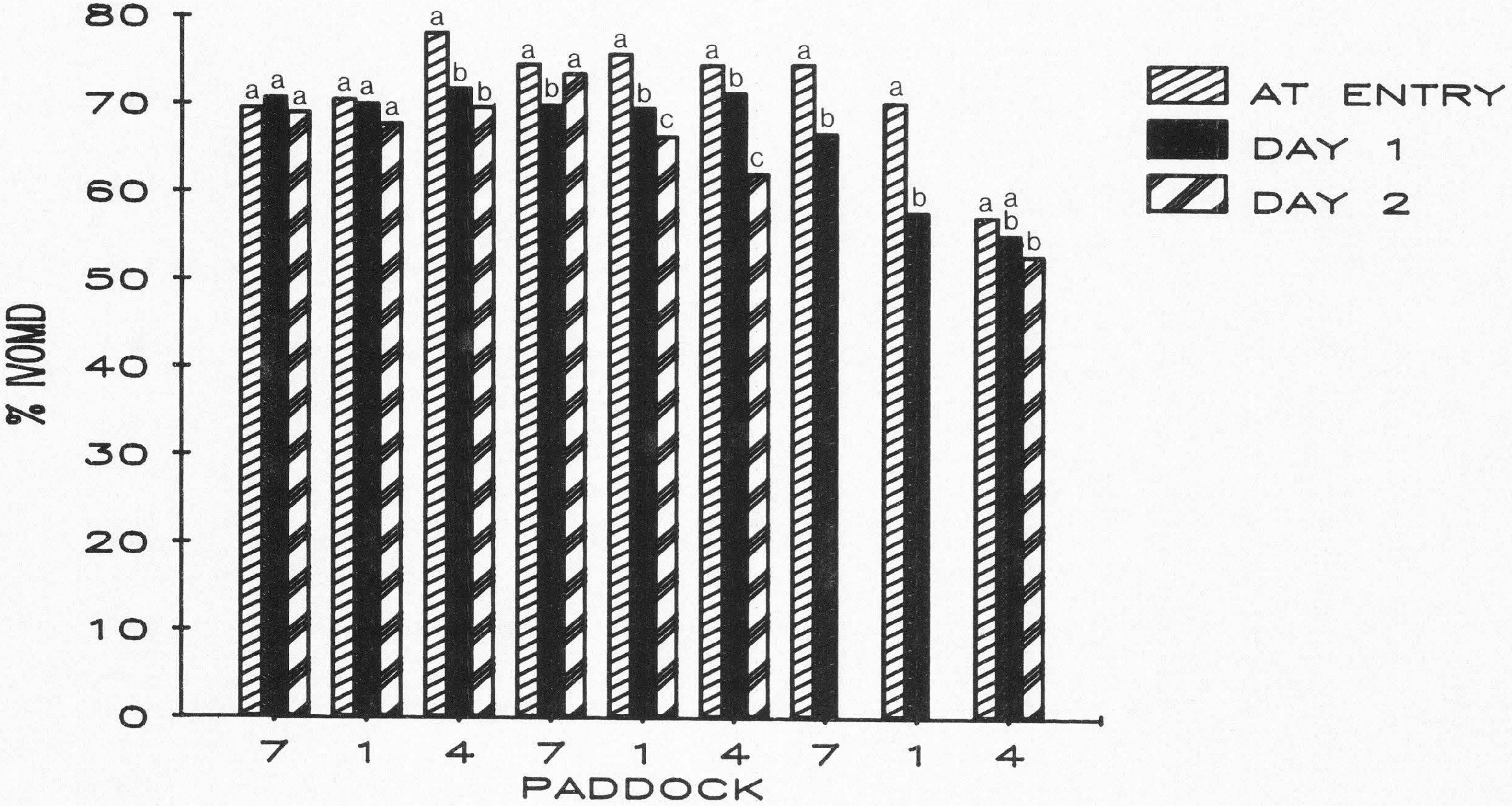

Figure 25. Comparison of daily changes in IVOMD of esophageal extrusa in individual SDG paddocks in 1985. Bars within paddocks with different letters are significantly different (P<.05).

Ingestive Behavior and Forage Intake

Ingestive Behavior in 1984. Ingestion rate and grazing time did not change (Figures 26 and 28, Appendix Tables 25 and 27), while biting rate increased from day 1 to day 2, and then remained the same on day 3 (Figure 27, Appendix Table 26). Animals apparently maintained ingestion rate as the paddock was defoliated by increasing biting rate. Because ingestion rate did not decline, animals did not have to increase their grazing time. Interestingly, the largest declines in biomass and plant height occurred on the last day in most paddocks (Figures 29 and 30), but the behavioral response of increased biting rate occurred between the first and second days.

PCD interactions were significant for ingestion rate and biting rate (Figures 31 and 32), but not grazing time. The PCD interaction for grazing time was not significant and is not presented. Significant changes in ingestion rates were found twice, in paddock four on both cycles. Therefore, ingestion rate significantly declined, as expected, in one paddock, but remained unchanged in the other two. Biting rate tended to remain unchanged early and late in the grazing season of 1984, but increased as days passed during the middle of the grazing season. These seasonal responses show no apparent relationship with seasonal dynamics of daily changes in biomass and plant height (Figures 29 and 30). The paddocks where ingestion rate was maintained through the three day period were not necessarily the same paddocks where biting rates increased, indicating that biting rate may not be the sole factor involved in the dynamics of daily ingestion rate. Apparently, there is no simple conclusion that biting rate is the lone variable that cattle use to offset

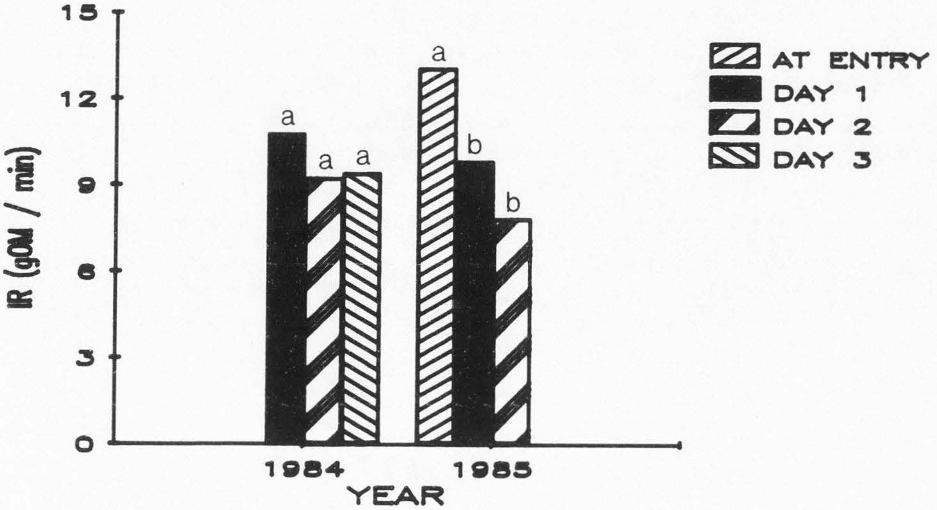

Figure 26. Comparison of mean daily changes in ingestion rates (IR, g OM/ min) of heifers grazing crested wheatgrass in SDG paddocks, 1984 and 1985. Bars with different letters within years are significantly different (P≤.05).

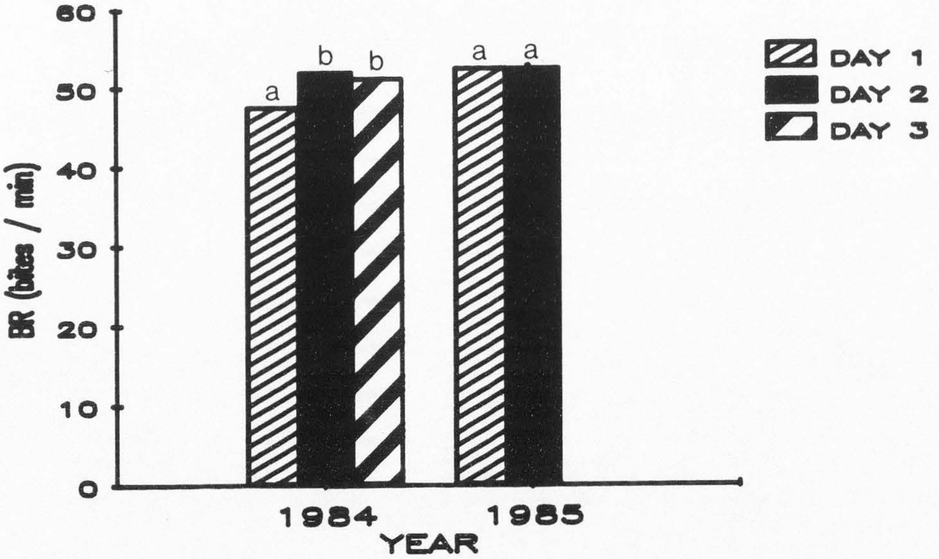

Figure 27. Comparison of mean daily changes in biting rates (BR, bites/ min) of heifers grazing crested wheatgrass in SDG paddocks, 1984 and 1985. Bars with different letters within years are significantly different (P≤.05).

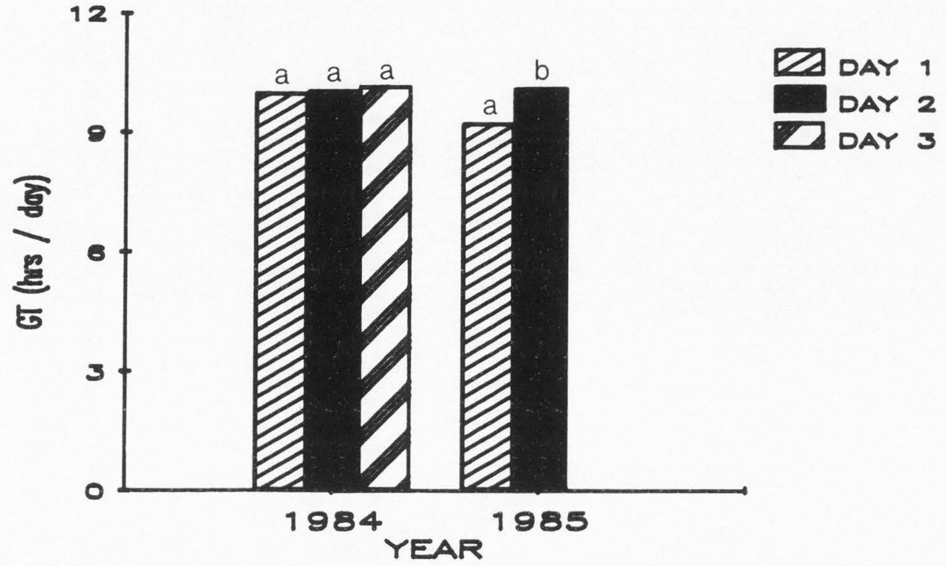

Figure 28. Comparison of mean daily changes in grazing time (GT, hrs/ day) of heifers grazing crested wheatgrass in SDG paddocks, 1984 and 1985. Bars with different letters within years are significantly different ($P \leq .05$).

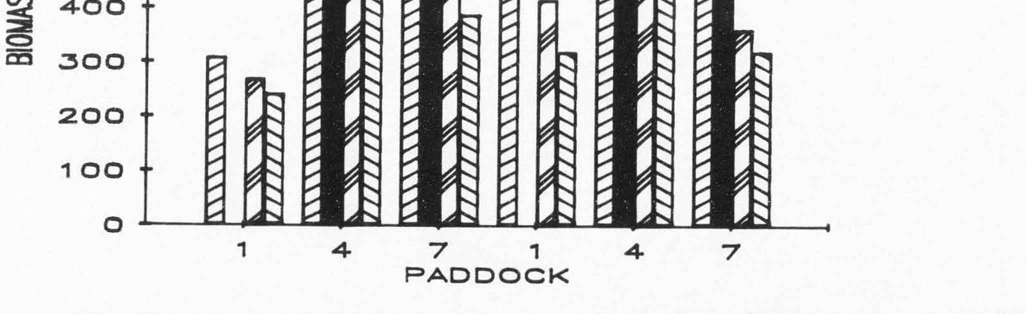

Figure 29. Aboveground herbage biomass dynamics (kg/ha) in individual SDG paddocks during 1984.

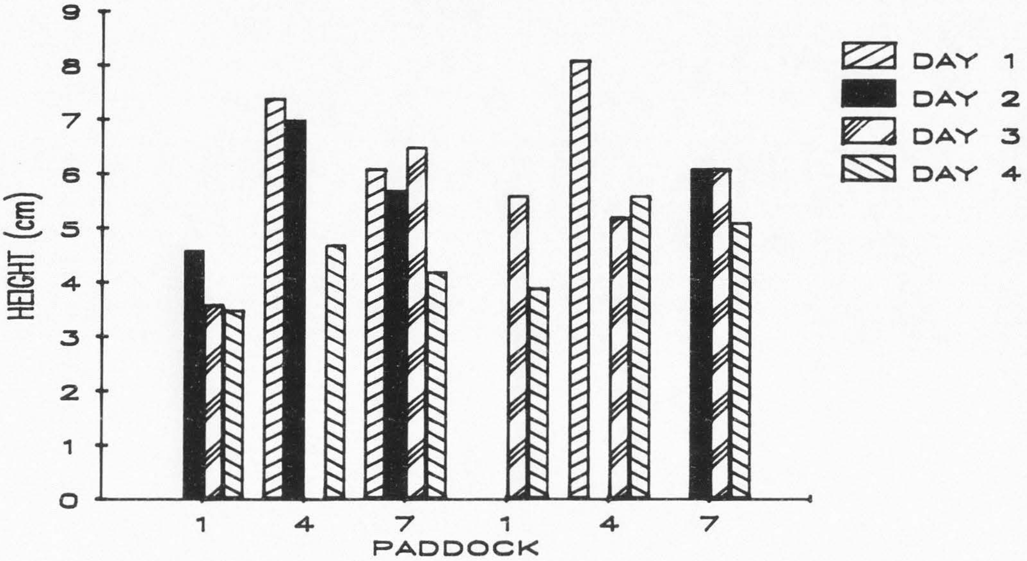

Figure 30. Dynamics of sward height (cm) in individual SDG paddocks during 1984.

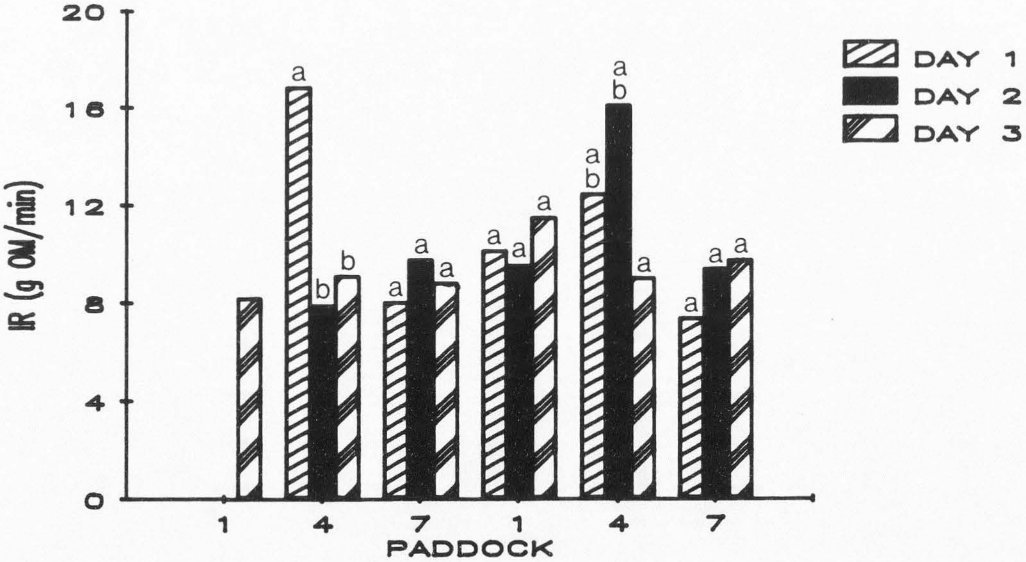

Figure 31. Comparison of daily changes in ingestion rate (IR) of heifers grazing crested wheatgrass in individual SDG paddocks in 1984. Bars within paddocks with different letters are significantly different ($P \leq .05$).

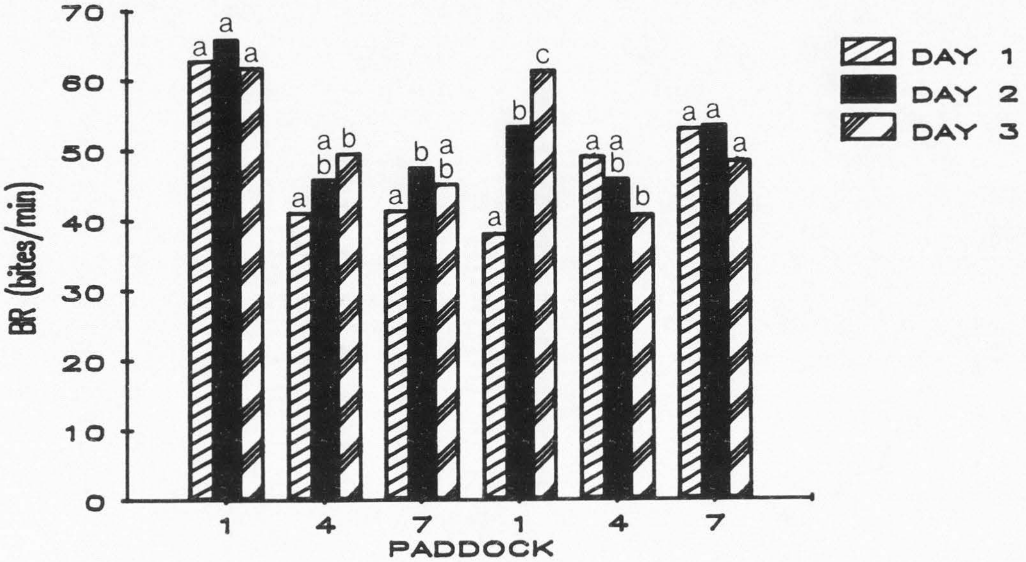

Figure 32. Comparison of daily changes in biting rate (BR) of heifers grazing crested wheatgrass in individual SDG paddocks in 1984. Bars within paddocks with different letters are significantly different ($P \leq .05$).

declines in bite size. This is supportive of Hodgson's (1985) statement that biting rate does not only compensate for declining bite size, but is also a direct result of changing sward structure. Therefore, dynamics of bite size and biting rate are not simply reciprocal, compensatory actions that maintain constant ingestion rate across variations in swards.

Ingestive Behavior in 1985. Ingestion rate declined significantly from sampling at entry to the paddock to the following morning (day 1), and subsequently remained unchanged (Figure 26, Appendix Table 28). Biting rate did not change between days 1 and 2 (the two consecutive morning samples) (Figure 27 Appendix Table 29). However, the largest declines in plant biomass and height typically occurred between days 1 and 2 (Figures 33 and 34), rather than between

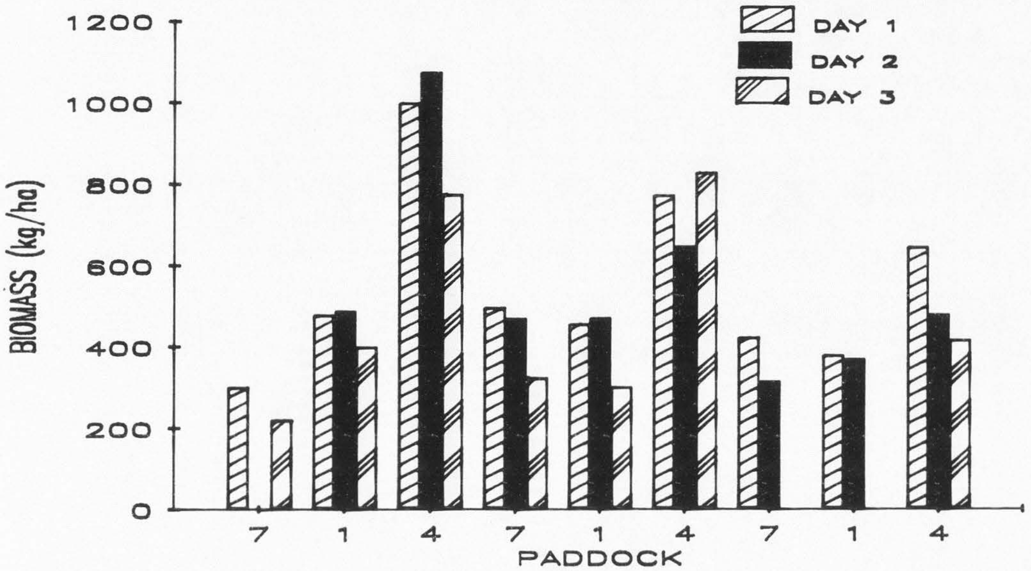

Figure 33. Aboveground herbage biomass dynamics (kg/ha) in individual SDG paddocks during 1985.

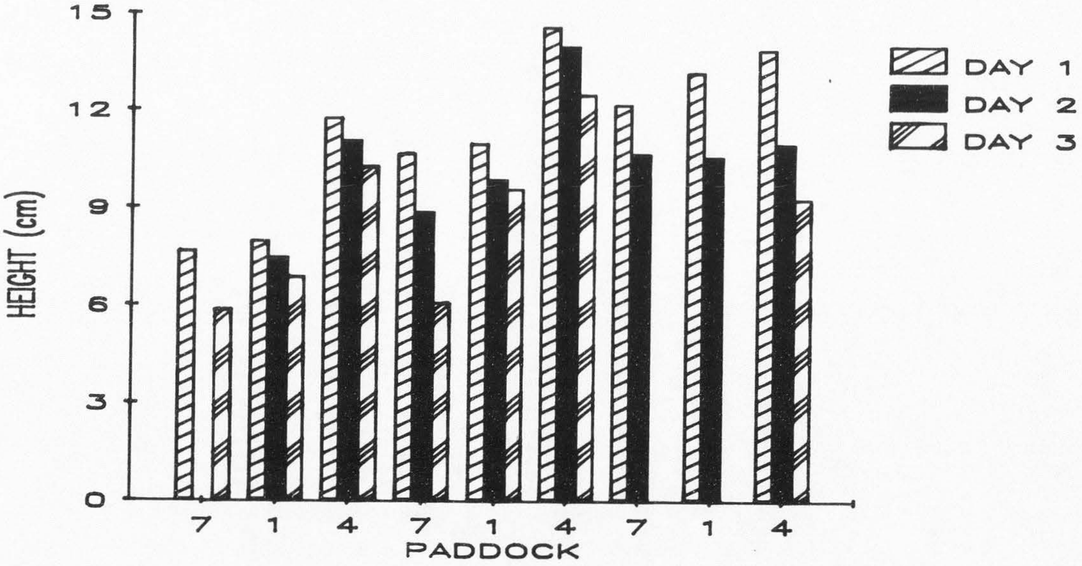

Figure 34. Dynamics of sward height (cm) in individual SDG paddocks during 1985.

entry and day 1. Grazing time increased significantly from the first day to the second day in the paddock (Figure 28, Appendix Table 30). In 1985, because animals did not increase biting rates, ingestion rates declined. However, as previously stated, ingestion rates remained constant in 1984, apparently due to increased biting rates. These contrasting results support the view that biting rate can be used to compensate for declining bite size to maintain a constant ingestion rate. This conclusion must be tempered by the previous argument that bite size and biting rate are not simply variables that respond reciprocally to variations in the sward. Regardless of whether biting rate is responding independent of bite size or not, these two variables do tend to compensate for each other by operating inversely as a sward changes, either due to plant maturity (Stobbs 1974b) or defoliation (Chacon and Stobbs 1976). In contrast to 1984, animals during 1985 increased grazing time, apparently to compensate for decreasing ingestion rate. It is interesting that animals used different components of ingestive behavior to compensate for apparent declines in bite size in each of the two years. This contrasts with Scarnecchia et al. (1985), who found that biting rate and grazing time increased simultaneously as the crested wheatgrass sward was defoliated. These compensatory increases also contrast with results reported by Jamieson and Hodgson (1979a). They found that biting rate and grazing time both declined as the sward was rapidly defoliated under strip grazing management.

PCD interactions were significant for biting rate (Figure 35) and grazing time (Figure 36), but not for ingestion rate in 1985. Except for unexplainable anomalies early in the season (the first two paddocks), biting rate remained unchanged for the remainder of the year (Figure 35). It can reasonably be concluded that biting rate was relatively unresponsive to daily changes in the sward throughout the season. Grazing time increased significantly in 10 of the 19 paddocks where two days of data were recorded, and remained unchanged in the other nine (Figure 36). Seven of these ten paddocks were in the last half of the grazing season. A corresponding seasonal trend in the magnitude of daily changes in biomass and plant height is not visually evident (Figures 33 and 34). Thus, seasonal differences in the presence of daily grazing time increases cannot be explained by similar seasonal trends in forage dynamics. Although grazing time changes within paddocks did not always occur, the increases were quite large when they did happen (0.6 to 2.1 hrs.). This translates into a 6 to 25 percent increase in daily grazing activity. Thus, the grazing time response was both qualitatively and quantitatively dynamic over the grazing season. Because the behavioral responses were so variable, both within and between years, it is evident that cattle were not using one component of ingestive behavior, either biting rate or grazing time, to compensate for declining bite size as the paddock was defoliated.

Forage Intake. As was the case when comparing SDG to CSLG (Figure 7) daily forage intake is a direct reflection of ingestion rate (Figure 37). Compensatory effects of increased grazing time in 1985 apparently had little effect on the decline in intake as ingestion rate declined. Once again, it appears that sward characteristics that affect ingestive behavior can have a direct effect on animal performance. Identification of these sward

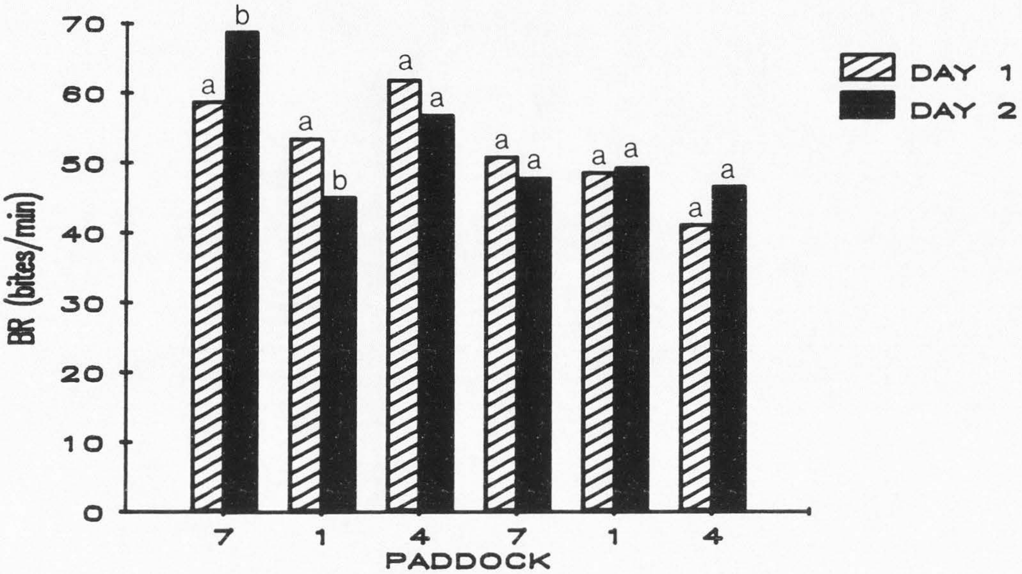

Figure 35. Comparison of daily changes in biting rate (BR) of heifers grazing crested wheatgrass in individual SDG paddocks in 1985. Bars within paddocks with different letters are significantly different ($P \leq .05$).

characteristics, and relating them to desired levels of ingestive behavior and intake should be useful in managing crested wheatgrass, particularly with SDG, to improve livestock performance. These relationships will be discussed, subsequently.

Intake values, where forage DM consumed is expressed as a percent of body weight, ranged from 1.9 to 2.6 percent. While calculated values for 1984 were comparable to NRC (1976) standards for the level of livestock performance observed, values for 1985 were low. Ingestion rates for days one and two in 1985 were both lower than for 1984, resulting in the lower calulated intake values. The differences between years are unexplainable. This may be an indication of limitations of using this method of measuring intake. However, it does not negate conclusions drawn on relative comparisons within years.

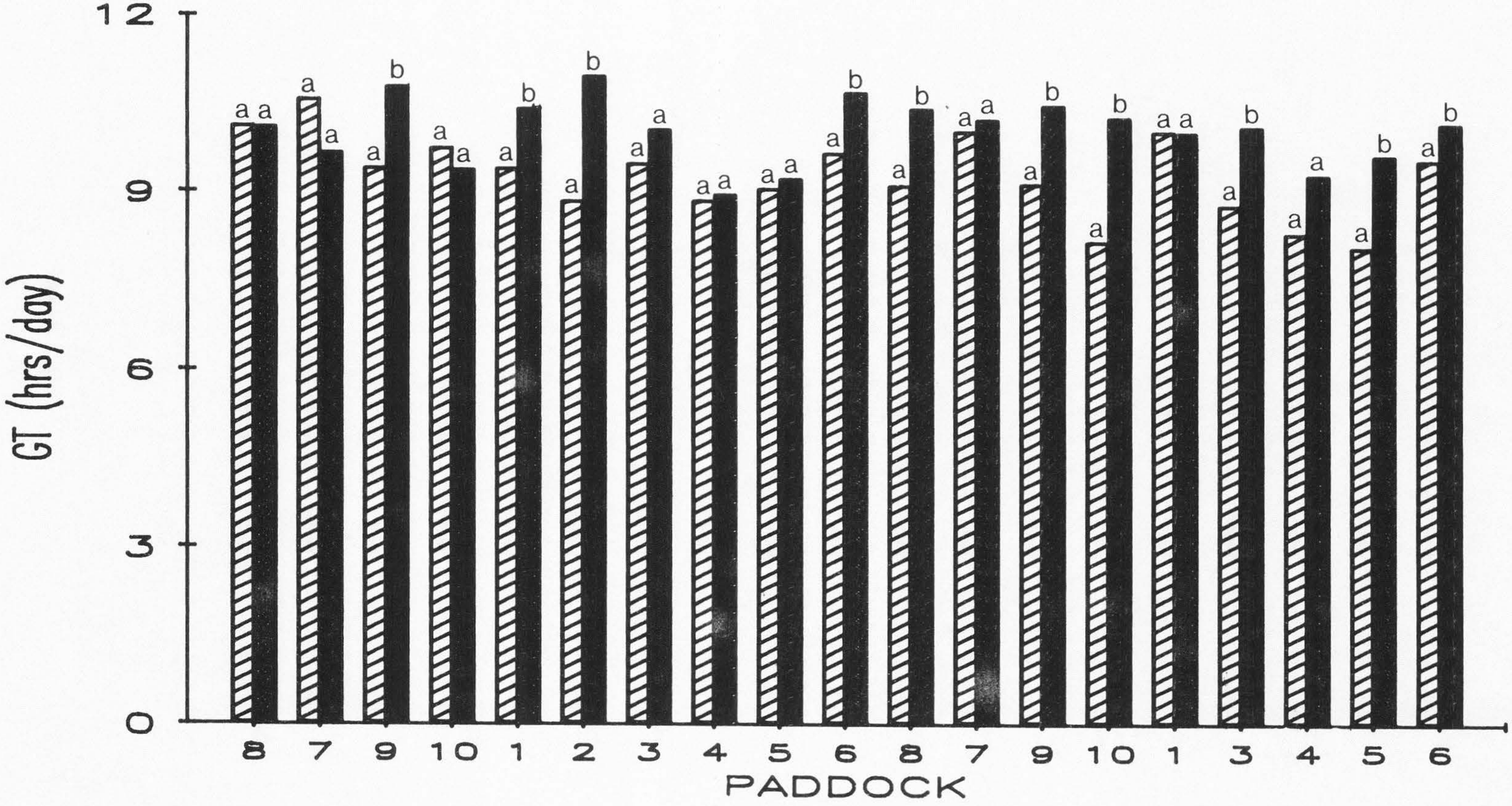

Figure 36. Comparison of daily changes in grazing time (GT) of heifers grazing crested wheatgrass in individual SDG paddocks in 1985. Bars within paddocks with different letters are significantly different (P<.05).

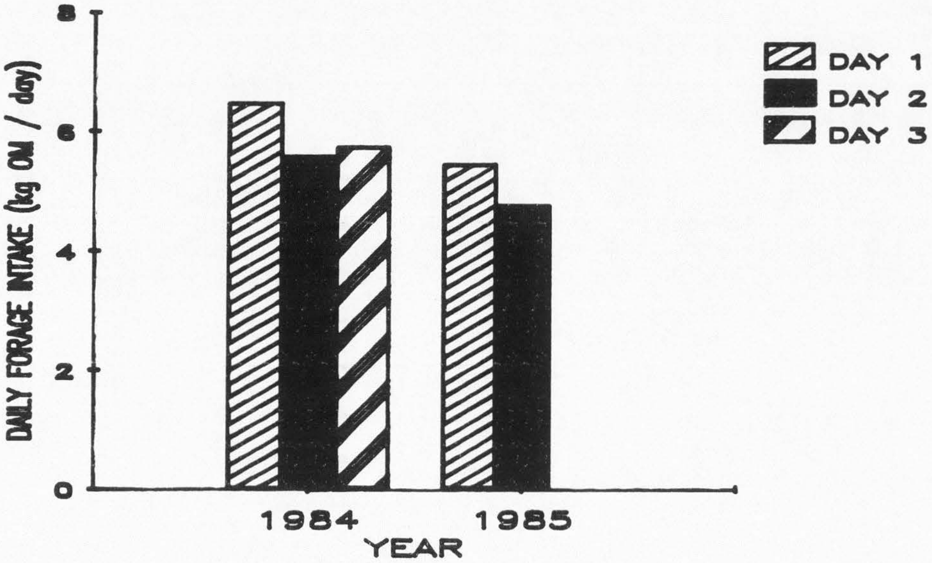

Figure 37. Daily forage intake (kg OM/ day) by heifers grazing crested wheatgrass in SDG paddocks, 1984 and 1985.

Foraging Behavior Model-Relations to Sward Characteristics

An exploratory model by Senft and Malechek (1985) indicated that forage biomass was a major constraint on forage intake, hence weight gains by cattle grazing intensively managed crested wheatgrass spring range. However, exact relationships among components of forage intake and crested wheatgrass sward characteristics are poorly understood. Thus, we do not know specifically how limited biomass availability affects forage intake. Intake has been found to be related to forage biomass by a Michaelis-Menton relationship (Allden and Whittaker 1970, Short 1985). Following this concept, Freer (1981) derived equations for intake, ingestion rate, and grazing time as functions of biomass, using Allden and Whittaker's data. A problem with this approach is that controls on intake and its components are not explicitly described. Biomass limits intake and ingestion rate only on the ascending portion of the curves. Above the saturation point, a second constraint or set of constraints takes over. A related problem with the Freer model is that it treats the "biomass-saturated" intake as a constant, but it actually varies under the second constraint (Senft and Malechek 1985). In a "multiple constraint" model, there are many controlling variables. But, under any particular set of circumstances, the single most limiting constraint controls intake.

Correlation of Sward to Behavioral Variables

Relationships between ingestive behavior and sward variables were analyzed first using simple correlation techniques (Table 6). These sward characteristics can be considered in three groups. The first

Table 6. Correlation coefficients (r) between ingestive behavior (ingestion rate (IR, g OM/min), biting rate (BR, bites/min), and grazing time (GT, hrs/day)) and several sward characteristics.

	IR	BR	GT
bulk density (gm/cm^3)	.51*	-.44*	-.79*
biomass (kg/ha)	.61*	-.31	-.66*
height (cm)	.19	-.55*	-.77*
crude protein (%)	.31	.51*	.31
IVOMD (%)	.16	.38*	.19
neutral detergent fiber (%)	-.38*	-.63*	-.20
acid detergent fiber (%)	-.31	-.22	.11
permanganate lignin (%)	-.13	.07	.07
cellulose (%)	-.33*	-.51*	-.25
hemicellulose (%)	-.30	-.73*	-.34

*significant at $P \leq .10$

group is sward physical structure, including sward bulk density, aboveground biomass, and plant height. The second group is positive nutritive characteristics, including crude protein and IVOMD. The third group contains fiber components (including neutral detergent fiber, acid detergent fiber, permanganate lignin, cellulose, and hemicellulose) that are typically considered as inversely related to forage quality.

Ingestion rate was positively correlated with physical characteristics, while biting rate and grazing time were negatively correlated. This indicates that as biomass became more available, ingestion rate increased, while biting rate and grazing time decreased. This agrees with previously reported results (Allden and Whittaker 1970, Freer 1981, Short 1985). Thus, ingestion rate can increase as more forage is available and accessible. Changes in ingestion rate were compensated for by inverse changes in biting rate or grazing time, as expected from results of Chacon and Stobbs

(1976). The negative correlation of biting rate and plant height agree with the conclusions of Hodgson (1985) that animals take more bites and spend less time manipulating forage as the sward becomes shorter. Correlation of ingestion rate with biomass was stronger than with sward bulk density. This is the opposite of the findings of Stobbs and Hutton (1974) and may be a reflection of the differences in structure of temperate and tropical grass swards.

As shown by herbage crude protein and IVOMD, increasing nutrient content and availability were positively related to all three behavioral responses. Correlations were only significant for biting rates, however. Increases in these nutrient characteristics is probably positively related to desirability, causing an animal to increase its rate of biting. They are also positively related to passage rate through the rumen, allowing increased intake, and thus, increased rate of biting.

Almost all fiber fractions were negatively correlated with ingestive behavior. However, few of the correlations were significant. As fiber content increases, the leaf:stem content is declining. This can be due either to selective defoliation of leaves, or increases of stem due to advancing maturity. This causes a decrease in accessibility of available leaf, resulting in reduction in ingestion rate and biting rate in an attempt to increase selectivity (Chacon and Stobbs 1976). Increasing fiber also makes the plant material tougher, causing prehension of bites to be more difficult. This effect can also cause a decline in rates of ingestion and biting. The relatively strong correlation of biting rate to hemicellulose content should be noted. Hemicellulose is a fiber matrix of branched-chain polysaccharides that bind the cellulose fibers of the cell wall together (Albersheim 1975). This provides structural rigidity to the plant cell walls (Albersheim 1975). The apparent effect of this binding is to increase the tensile strength of the plant material. Therefore, increased hemicellulose is probably related to increased "toughness", which causes an increase in the time and effort required to prehend a bite. Visual observations indicated that as the sward matured, the animals had to put a great deal more effort and time into tearing off individual bites. Increased fiber would also increase rumen retention time, causing a decline in forage intake, with resultant declines in ingestion rate and biting rate.

Model Development

Data collected in 1985 were used for model derivation. Piecewise linear functions were derived over the domain of points in which each characteristic was found to be correlated with ingestive behavior variables. Finally, slopes of linear functions were adjusted to optimize model performance in test runs with 1985 data. Data collected in 1984 were used for validation of the model. Performance criteria were accuracy of predictions of intake and ingestion rate.

Model Structure and Fit to Data

Ingestion rate was correlated with crested wheatgrass biomass ($r=0.61$, $P<.01$) up to about 550 Kg/ha (Figure 38). Model adjusting resulted in a steep slope in the biomass control function with the X-intercept at 180 Kg/ha. Forage crude protein (CP) content was identified as a second constraint (Figure 38). At availability levels

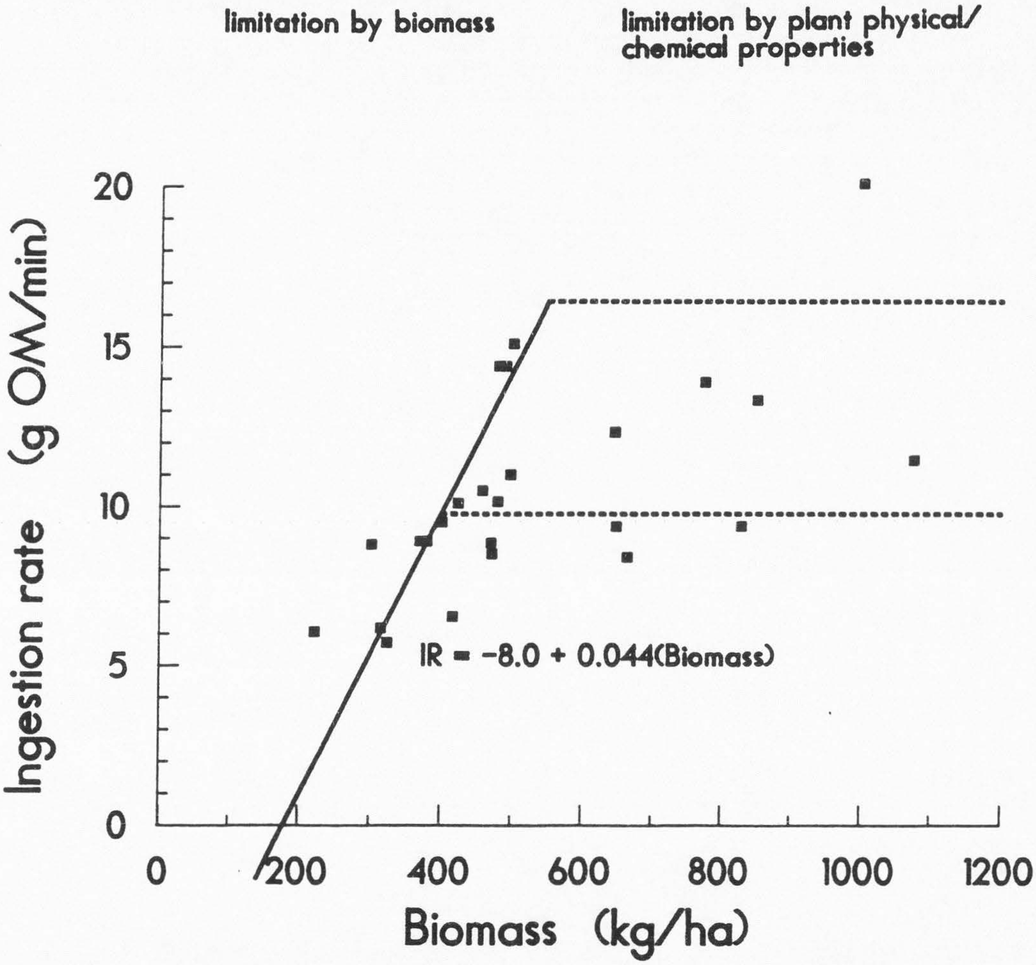

Figure 38. Observed ingestion rates (IR) as a function of crested wheatgrass biomass. Ingestion rate was limited by forage availability up to biomass levels of about 550 Kg/ha. Above that, ingestion rate was controlled by plant physical and chemical properties. The dashed lines represent two of an infinite set of possible levels of constraint by plant physical/chemical properties when biomass availability is not constraining.

above 550 Kg/ha, ingestion rate was positively correlated (r=0.76, P<.05) to forage crude protein content (Figure 39).

Forage crude protein content may have been an indicator of physical and chemical characteristics of forage that regulate ingestive behavior. There is probably not a direct relationship between ingestion rate and crude protein. There are several possible explanations for the biological meaning of the crude protein constraint on ingestion rate. It may be due to crude protein's relationship to (1) digestibility, (2) cell wall content, or (3) leafiness. First, digestibility was used as a similar constraint in earlier modelling efforts of intake on crested wheatgrass (Senft and Malechek 1985), and provided a similar relationship to intake. Second, as cell wall content increases, rate of passage through the rumen declines, thus decreasing intake. A positive correlation of crude protein to ingestion rate may indicate the effects of this relationship. Also, as cell wall content increases, ingestion rate may decline due to increased effort required to prehend bites. Third, because animals select leaves over stems, increasing leaf:stem ratio corresponds with increasing bite size (Chacon and Stobbs 1976), a component of ingestion rate. This increase in bite size, and thus ingestion rate, may be due to the ease of prehending bites in a leafy plant canopy. Ease of prehension can be related to two factors; lack of interference from undesired stems, and reduced effort required to tear off bites of leaves due to lower cell wall contents in leaves. The relative contribution of each of these possible explanations to the physical and/or chemical constraint on ingestion rate cannot be determined with the present model. However, regardless of the cause,

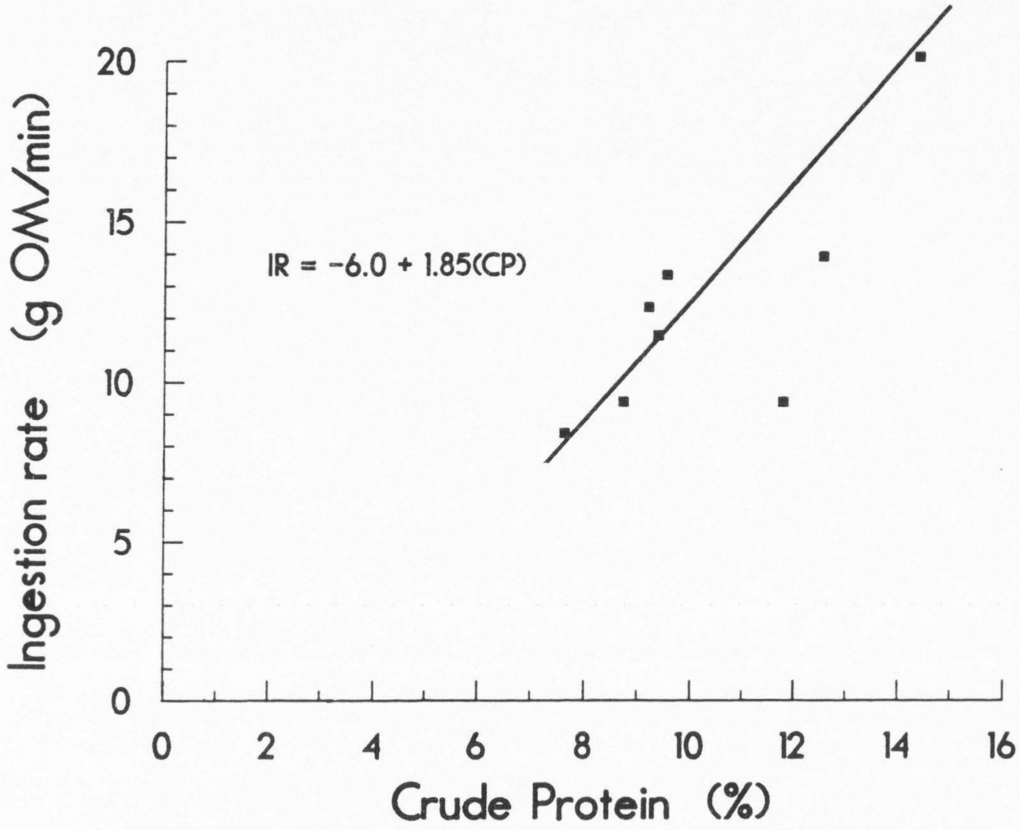

Figure 39. The relationship between ingestion rate (IR) and crude protein content for data points with biomass greater than 550 kg/ha.

it appears feasible to consider crude protein content as a viable indicator of this constraint.

Grazing time did not change significantly over the range of biomass availability encountered during the study in 1985 ($P<.05$). To approximate the exponential decline in grazing time at low biomass levels described by Freer (1981), data from Scarnecchia et al. (1985) were used to derive a function describing increases in grazing time as biomass declines to very low amounts. Above about 275 Kg/ha, grazing time was assumed to be 575.4 min/day (9.59 hr), the mean for the entire 1985 grazing season.

Validation

Internal verification with 1985 data indicated that predicted ingestion rates and forage intakes were reasonably close to observed values (Figure 40 and 41). Correlation coefficients were $r=0.82$ ($P<.001$) and $r=0.67$ ($P<.05$), respectively. The model tended to underestimate at low and high ingestion rates and overestimate at medium ingestion rates (Figure 40). The model used the sloping portion of the grazing time function only once. Otherwise, grazing time was "saturated" with available forage. Due to this lack of responsiveness, validations of grazing time were not done.

Although weaker, the correlation between predicted and observed ingestion rate for 1984 was statistically significant ($P<.01$, $r=0.50$) (Figure 40). Few observed intake data points were available for early 1984 because of a lack of reliable vibracorder data. Because of this small sample size, the correlation of predicted to observed intake was not statistically significant ($r=0.48$, $P>.20$) (Figure 41).

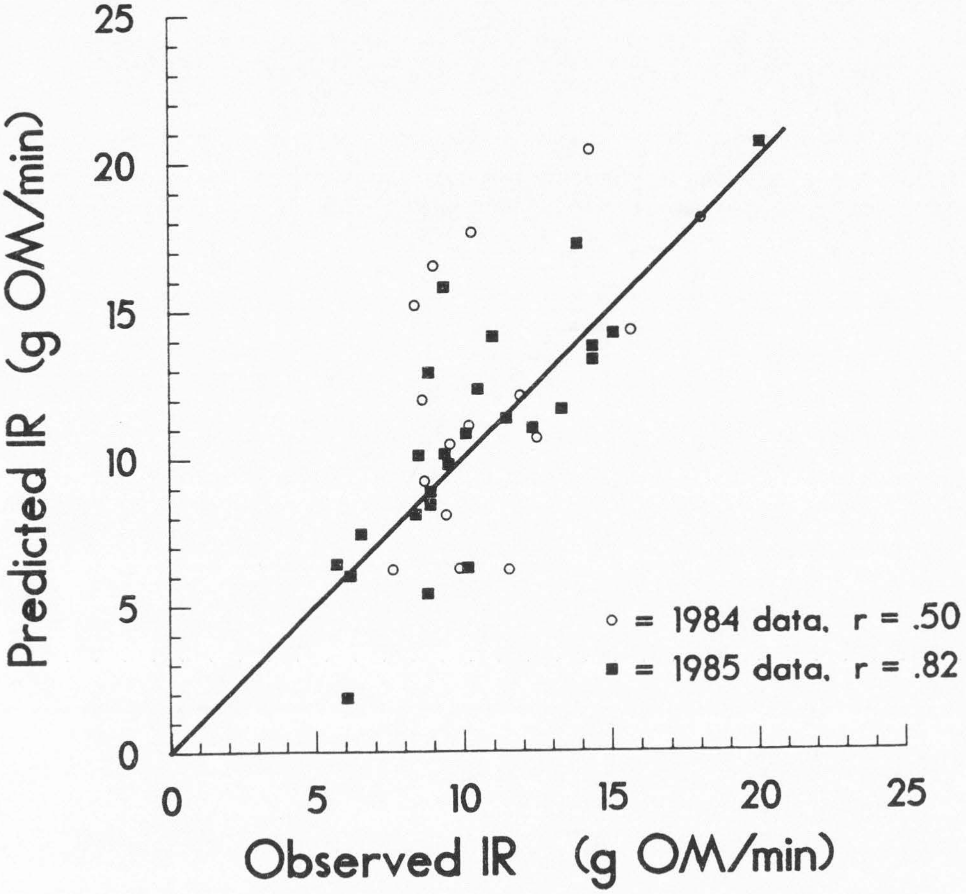

Figure 40. Validation of model predictions of ingestion rate (IR) against observed data from 1984 and 1985.

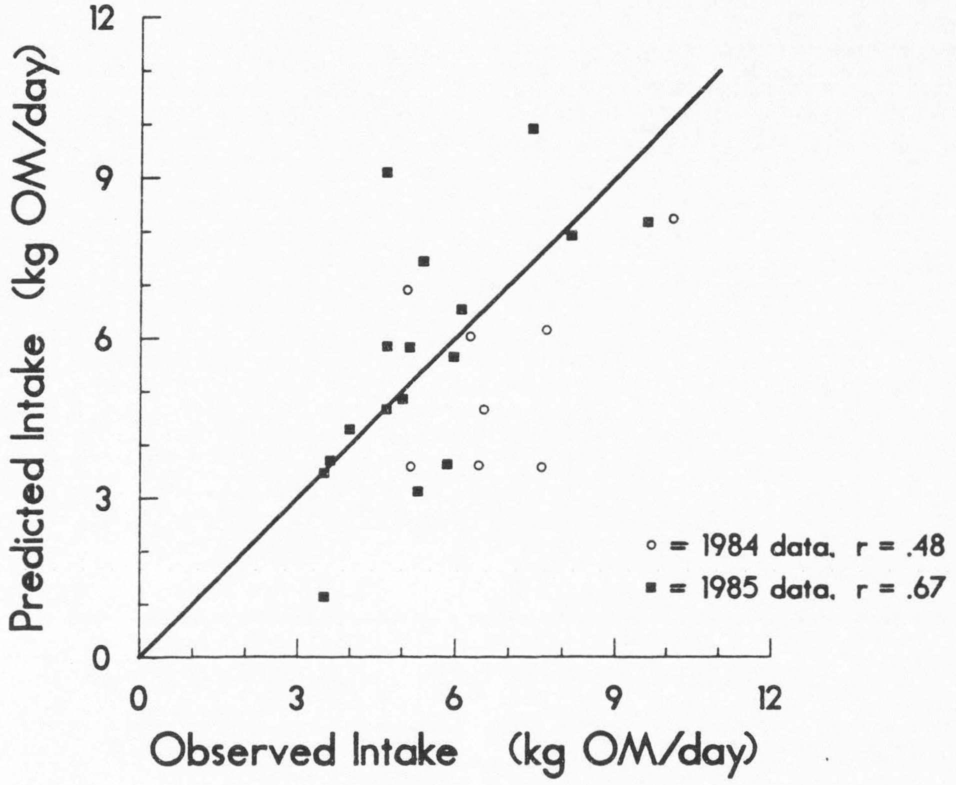

Figure 41. Validation of model predictions of total daily forage intake against calculated intake data from 1984 and 1985.

Although these correlations are not strong, significant correlations for a preliminary model of this nature with few variables is a positive indication of its value.

Plots of predicted to observed data for ingestion rate and intake in CSLG are presented in Figures 42 and 43. Predicted values were fairly close to observed data for 1984. However, the model severely overpredicted both ingestion rate and intake for 1985 data. It appears that the relationship between predicted and observed 1985 data points on the ingestion rate scatter plot (Figure 42) intercepts the origin, but is much steeper than the slope of a one to one relationship between predictions and observations. Due to a lack of data, it is difficult to make stronger conclusions concerning the ability of the model to predict ingestive behavior and forage intake in CSLG. However, it is evident that the relationships are at least qualitatively similar.

Model Behavior

With 1985 data, the model used the biomass equation to predict ingestion rate 14 of 25 times, indicating that biomass was limiting ingestion rate 56 percent of the time. The biomass equation was used for 50 percent of the 1984 observations. Both constraints, biomass availability and crude protein content, appear to regulate intake equally under the conditions of this study. This supports the previous hypothesis that biomass availability limits intake in short duration grazing (Senft and Malechek 1985).

The high X-intercept in the ingestion rate vs. biomass relationship should be noted. A large proportion of herbage remaining

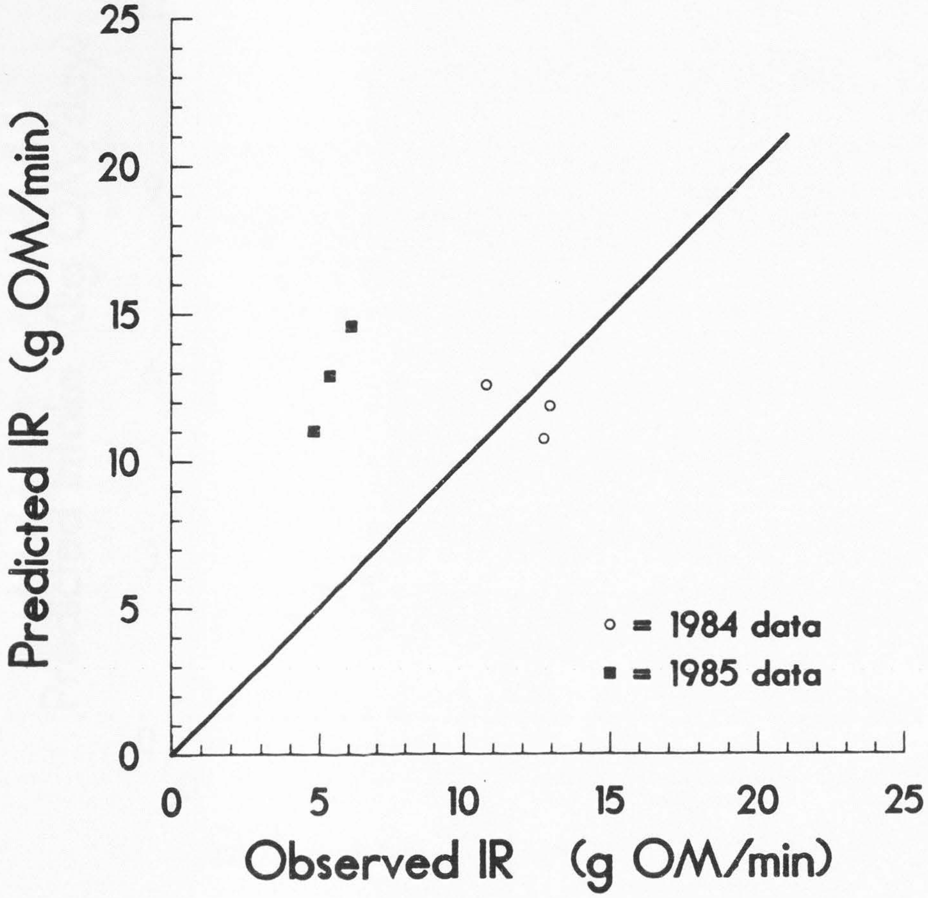

Figure 42. Validation of model predictions of ingestion rate (IR) against observed data from CSLG, 1984 and 1985.

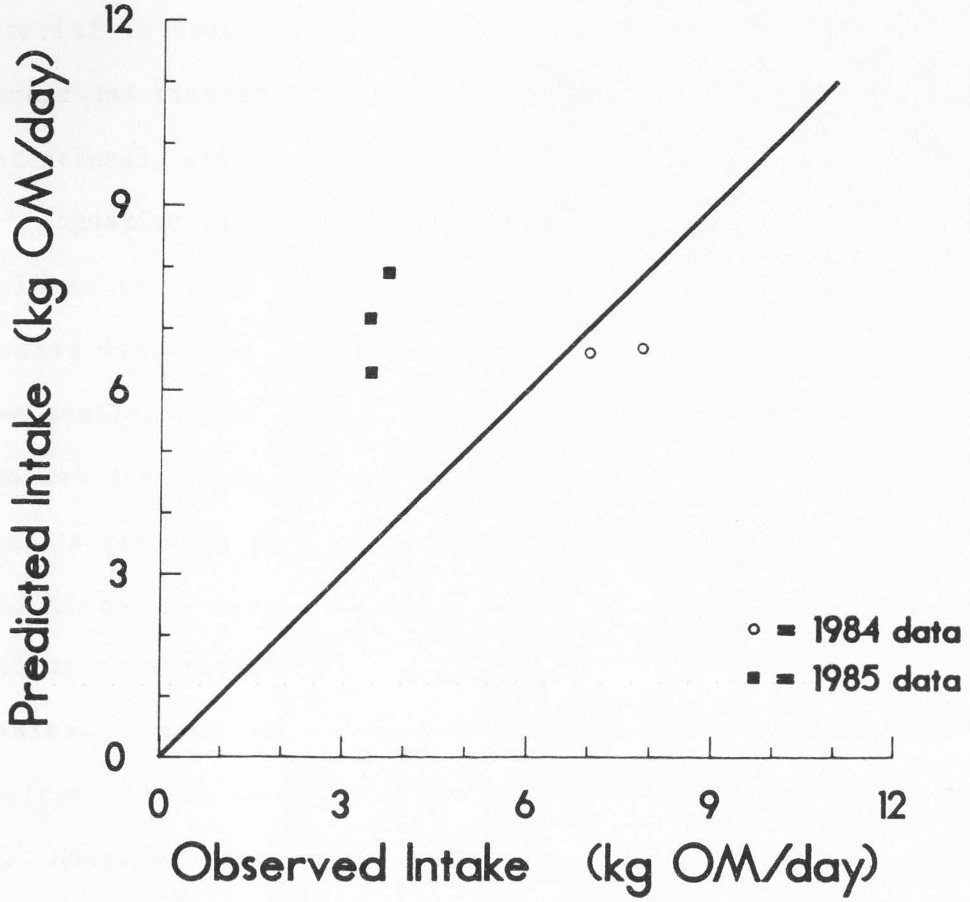

Figure 43. Validation of model predictions of total daily forage intake against calculated intake data from CSLG, 1984 and 1985.

when biomass approached 180 Kg/ha was in "wolf plants". Wolf plants contain large amounts of stems and standing dead biomass, and are not readily accepted by cattle (Norton et al. 1983). This suggests that during the growing season, cattle may perceive only live or green material as being available forage. Thus, measurements of total aboveground biomass may over-estimate the amount of available herbage that actually affects ingestion rate and intake.

Ingestion rate and forage intake rapidly declined as biomass was depleted or crude protein declined (Figure 44). This response to biomass depletion agrees with the results of Freer (1981). Because time available for grazing was apparently fairly constant, ingestion rate was the primary determinant of forage intake. Sensitivity of the animal's response to changing sward characteristics means that forage conditions in many real-life situations could limit an animal's ability to satisfy its intake requirements during a normal day of grazing. Under short-duration grazing, this was expressed as declining intake with each successive day spent in a paddock (Figure 37). Compared to rapid declines in ingestion rate, there was little compensatory increase in grazing time. Not surprisingly, this agrees with results discussed previously concerning ingestive behavioral response between treatments and between days in SDG paddocks.

An important emergent property of the multiple constraint model is that biomass saturation levels for ingestion rate and intake were not constants (Figure 44). Instead, they varied with level of plant maturity and state of defoliation, and thus with crude protein content (see dotted lines on Figure 38). This complex behavior implies that

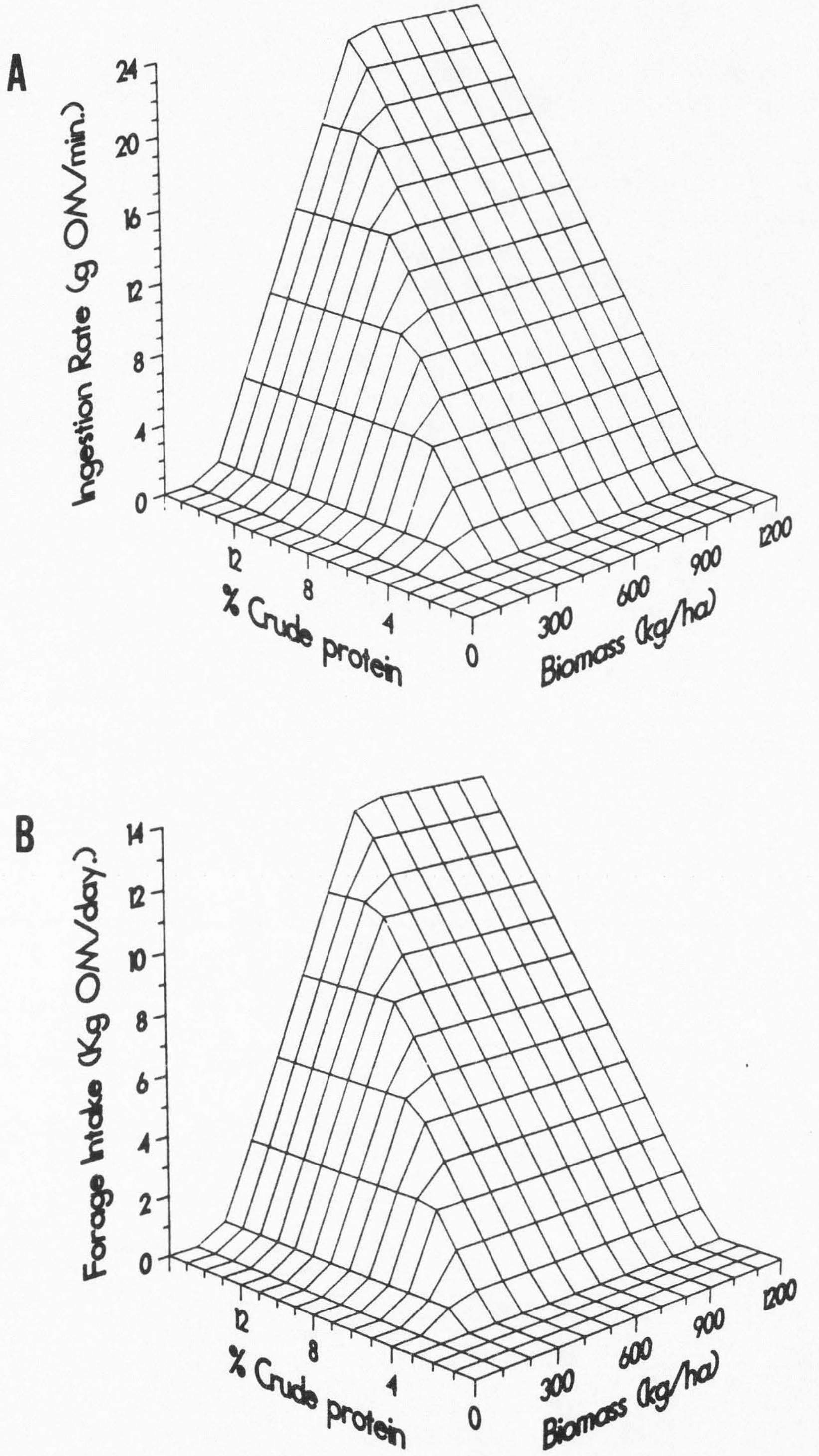

Figure 44. Ingestion rate (A) or forage intake (B) as a function of available biomass and forage crude protein content. These are only two of several possible constraints on intake by heifers grazing crested wheatgrass pastures.

a single critical biomass level cannot be determined and used solely as criteria for putting animals on or removing them from pastures. The apparent threshold of 550 Kg/ha evident in Figure 38 was a season-long average. Consideration would also have to be given to other constraints on ingestive behavior.

Model Limitations

This model represents a first step toward a process-oriented view of forage intake on rangelands. As such, it has many limitations.

First, the model only describes two constraints on intake; available biomass and herbage crude protein content. In other vegetation types, and in mature crested wheatgrass stands, sward leaf:stem ratios and other characteristics may present additional constraints. Also, at very high crude protein contents, animals' physiological processes may present an additional constraint, limiting the highest predicted ingestion rates and intakes depicted in Figure 44.

Second, the model only considers two components of intake; ingestion rate and daily grazing time. Ingestion rate can be further separated into biting rate and bite size. These were not considered in this study due to the lack of accurate bite size data. However, these factors may help to further define animal response to changing sward conditions, and may help explain why crude protein is the second constraint on ingestion rate.

Third, the generality of these relationships to other vegetation types or other classes of livestock needs to be tested. On these low productivity monocultures, intake is apparently very sensitive to biomass availability. However, on diverse native systems of similar productivity where stocking rates are lower, intake may be buffered by opportunity to consume less palatable species or to use less attractive vegetation types when preferred forage items become limiting (Senft 1986). Therefore, the point at which the biomass-ingestion rate relationship saturates and crude protein becomes the constraint may change. Also, in more complex vegetation types, sward leaf:stem ratios, or other constraints, may be present.

Use of the model to design management strategies for crested wheatgrass stands is premature, since the model is based on data from only one site and two years of collection. Several potential constraints were not fully evaluated. Estimates of biomass and crude protein levels to manage for should only be considered after further knowledge has been gained.

Nonetheless, the multiple constraint model suggests some principles of livestock:forage interaction on crested wheatgrass pastures. Most interesting is the sensitivity of forage intake to management. While the potential for expression of the constraints exists under all grazing management strategies, this relationship is more likely to be expressed under intensive grazing systems, such as short duration grazing, on seeded monocultures.

Management Guidelines for SDG Paddock Grazing Periods

Diet quality, ingestive behavior, and forage intake all changed rapidly as paddocks were grazed under the conditions specific to this study. Diet quality and ingestion rate both declined within the first few hours in a paddock, but then remained constant into the second day of grazing. However, significant declines were again experienced on the third day in 1984. Therefore, livestock should be moved among paddocks at least every two days during the rapid growth stage of crested wheatgrass. Improved animal performance in 1985, when grazing periods were reduced to two days rather than three, support this conclusion. However, this is confounded with the possibility of cumulative effects on the vegetation from previous years grazing.

An ideal situation would be to use computer simulation models to determine levels of forage characteristics to manage for to meet desired levels of animal performance. Meeting or exceeding these desired levels could be used as determinants of animal turn-on and turn-off for individual paddocks. However, due to the previously discussed limitations of the model, this is currently unadvisable. Perhaps, as more data of a similar nature become available, the model can undergo further development and testing, thus becoming capable of use as such a planning tool.

These management guidelines are based on animal responses, and intended to provide improved animal performance. They are not based on plant response and resultant effects on range condition. Other components of UAES 780 will be more capable of providing management guidelines for plant response.

CONCLUSIONS

Conclusions concerning each objective of this study are:

SDG versus CSLG

In terms of animal performance, weight gains were significantly greater in CSLG during the latter half of 1983, no differences were detected 1984, and the SDG animals gained significantly more throughout 1985. Conclusions that a trend in favor of SDG was developing over the three year period are confounded by several factors, including cumulative grazing management effects, site differences, and changes in grazing management.

Diet quality was the same in both treatments throughout the study. However, ingestion rate was significantly higher and grazing time was significantly less in SDG in 1985, providing evidence for the differences in animal performance.

Implications for Extending the Season of Nutritious Forage

No evidence was found in either diet quality or ingestive behavior that supported the hypothesis that the season of nutritious forage could be extended by using SDG instead of CSLG. However, this does not exclude or consider the possibility that SDG will allow the present level of use and livestock performance to be sustained over the long term without degradation to the plant community compared to CSLG.

Daily Dynamics of Diets in SDG Paddocks

Diet quality significantly and rapidly decreased over successive days in all three years as the paddocks were defoliated. Ingestion rate declined significantly in 1985, but not in 1984. Significant increases in biting rate in 1984 indicated that animals may have been compensating for declining bite size with increased biting rate, thus maintaining constant ingestion rate. Biting rate did not change in 1985, thus the decline in ingestion rate. Grazing time did not change in 1984, but increased significantly in 1985. Evidently, when ingestion rate did decline, grazing time increased to compensate. When responses in individual paddocks were considered, these responses were not constant in all cases, even within years. The resulting conclusion is that the responses of these ingestive behavior variables to changing sward conditions is complex and intertwined, and no simple decision rule based on only one variable is being used by the cattle. The resultant effect was a decline in daily forage intake as the paddock was defoliated.

Relationships between Ingestive Behavior and Sward Characteristics

A model was developed that predicted ingestion rate and grazing time from available biomass and herbage crude protein content. Forage intake was calculated as the product of ingestion rate and grazing time. The model indicated that as a sward matures or is defoliated, declines in biomass and herbage crude protein content translate into rapid declines in ingestion rate, and thus, forage intake. Rather than a conclusive statement on the nature of these relationships, the model provides a hypothesis of the relationships that appeared to exist during this study. As such, this hypothesis should be subjected to further testing to ascertain its validity and to provide more detail. Thus a better mechanistic understanding of animal response at the plant/animal interface will result.

Management Guidelines for SDG Paddock Grazing Periods

Because of the rapid declines in diet quality and ingestion rate, it is recommended that paddocks be grazed for two or less days during the active growth period of crested wheatgrass. Improved livestock performance in 1985, when these guidelines were followed, support this recommendation. Use of the model developed in this study to identify sward characteristics to monitor as a management planning tool is not recommended at this time, because of its preliminary and hypothetical nature.

Recommendations for Future Research

Determination of relationships between sward and diet characteristics needs further consideration. Controlled "plot size" studies need to be carried out in which sward conditions are carefully developed, controlled, and measured. Because bite size appears to be a critical variable, it needs to be quantified, in addition to the ingestive behavior variables considered in this study. This approach should allow improved control over variability in sward characteristics, as well as improved detail in understanding interactions of components of the plant/animal interface, thus helping to determine the mechanisms of diet selection by cattle.

Further studies need to be conducted concerning the implications of different stocking rates, stocking densities, and grazing periods to provide further knowledge concerning these important variables of SDG. Possibly these could also be done in plot size studies. The current grazing cell could be used to condition livestock to the high stocking density and rapid movements among paddocks, but groups of animals could be moved to plots with the desired stocking variables at the times chosen for sampling. This would allow the testing of several stocking variable treatments at once, as well as use of plots as replicates, overcoming the problem of lack of replication in the grazing cell.

Recommendations for Range Management

Although SDG provided significant improvement in livestock performance, which may translate into substantial economic gain (Table 4), caution should be applied in recommending the wholesale use of SDG on crested wheatgrass ranges. Conception rates of heifers subjected to SDG have been lower than for the heifers used in CSLG during this study. Although these differences in conception rates are currently unexplainable, this study indicates that plane of nutrition was not the cause. Perhaps behavioral problems due to social stress played a role. Despite the adequate plane of nutrition for animal growth found in this study, until these reduced conception rates are understood and can be overcome, use of SDG with reproductive livestock cannot be recommended.

Livestock response appears to be very sensitive to the rapid changes in sward condition as SDG paddocks are defoliated, thus making proper rate of rotation through paddocks critical to successful improvement of livestock performance. We currently do not have the knowledge to make precise recommendations concerning management of SDG. Also, unless a manager is dedicated to careful monitoring and planning, livestock performance could be seriously and quickly impacted, even with proven management guidelines.

Caution must be taken in providing recommendations for range management from this study, due to certain limitations of the study design. The SDG grazing cell and CSLG pasture were small relative to areas of rangeland typically managed as a unit. Therefore, these scale of size differences may have affected such factors as livestock distribution, and thus modified overall response to the grazing methods. However, the ability to more closely follow effects of defoliation on both animal and plant responses was facilitated by the size of the experimental range units.

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APPENDIX

Table 7. Analysis of variance comparing crude protein content between grazing methods in 1983.

Source	df	MS	F	p
method	1	42.348152	2.428	NS
time	4	26.362448	1.000	NS
method X time	4	17.438534	1.256	NS
error	35	13.878912		

Table 8. Analysis of variance comparing IVOMD between grazing methods in 1983.

Source	df	MS	F	p
method	1	11.241846	0.144	NS
time	4	237.802714	1.000	NS
method X time	4	77.993665	1.256	NS
error	35	43.167445		

Table 9. Analysis of variance comparing crude protein content between grazing methods in 1984.

Source	df	MS	F	p
method	1	.546111	0.029	NS
time	2	251.285555	13.535	NS
method X time	2	18.564962	4.972	.01
error	64	3.733829		

Table 10. Analysis of variance comparing IVOMD between grazing methods in 1984.

Source	df	MS	F	p
method	1	2.715715	0.018	NS
time	2	1608.198631	10.684	<.05
method X time	2	150.517466	12.806	.000
error	64	11.753548		

Table 11. Analysis of variance comparing crude protein content between grazing methods in 1985.

Source	df	MS	F	p
method	1	5.734047	4.14	NS
time	2	13.416326	9.69	NS
method X time	2	1.385156	0.127	NS
error	130	10.939912		

Table 12. Analysis of variance comparing IVOMD between grazing methods in 1985.

Source	df	MS	F	p
method	1	11.673667	1.53	NS
time	2	274.882222	35.99	.05
method X time	2	7.637280	0.263	NS
error	130	29.019223		

Table 13. Analysis of variance comparing ingestion rate between grazing methods in 1984.

Source	df	MS	F	p
method	1	81.764926	10.423	.10
time	2	22.498670	2.868	NS
method X time	2	7.844519	1.344	NS
error	45	5.834645		

Table 14. Analysis of variance comparing ingestion rate between grazing methods in 1985.

Source	df	MS	F	p
method	1	169.243243	52.309	<.025
time	2	14.553704	4.492	NS
method X time	2	3.235457	0.189	NS
error	88	17.105910		

Table 15. Analysis of variance comparing biting rate between grazing methods in 1984.

Source	df	MS	F	p
method	1	767.686618	0.928	NS
time	2	678.372627	0.828	NS
method X time	2	827.054190	7.403	.001
error	201	111.713491		

Table 16. Analysis of variance comparing biting rate between grazing methods in 1985.

Source	df	MS	F	p
method	1	378.403382	8.914	<.10
time	2	1164.102349	27.42	<.05
method X time	2	42.451858	0.583	NS
error	212	72.827191		

Table 17. Analysis of variance comparing grazing time between grazing methods in 1984.

Source	df	MS	F	p
method	1	47.665550	6.72	NS
time	2	41.928334	5.91	NS
method X time	2	7.095590	2.83	NS
error	280	2.511199		

Table 18. Analysis of variance comparing grazing time between grazing methods in 1985.

Source	df	MS	F	p
method	1	121.755746	32.98	<.05
time	2	0.190631	0.178	NS
method X time	2	3.691761	3.442	.033
error	354	1.072666		

Table 19. Analysis of variance for daily changes within SDG paddocks; the dependent variable is crude protein in 1983.

Source	df	MS	F	p
paddock	2	11.868621	0.392	NS
animal	6	30.268162	-----	--
cycle	1	20.979142	1.650	NS
paddock X cycle	2	11.802455	0.928	NS
cycle X animal	5	12.717939	-----	--
day	1	63.852858	28.702	.000
paddock X day	2	14.691635	6.604	.024
cycle X day	1	1.519781	0.683	NS
paddock X cycle X day	2	6.604511	2.969	.117
error	7	2.224718	-----	--

Table 20. Analysis of variance for daily changes within SDG paddocks; the dependent variable is IVOMD in 1983.

Source	df	MS	F	p
paddock	2	78.297120	2.028	NS
animal	6	38.605027	-----	--
cycle	1	299.205032	9.652	.027
paddock X cycle	2	35.647809	1.150	NS
cycle X animal	5	30.999774	-----	--
day	1	317.431794	5.232	.056
paddock X day	2	0.892689	0.015	NS
cycle X day	1	25.074068	0.413	NS
paddock X cycle X day	2	57.231192	0.943	NS
error	7	60.675974	-----	--

Table 21. Analysis of variance for daily changes within SDG paddocks; the dependent variable is crude protein in 1984.

Source	df	MS	F	p
paddock	2	39.628136	6.262	.014
animal	12	6.328287	-----	--
cycle	1	310.221580	112.501	.000
paddock X cycle	2	0.877087	0.318	NS
cycle X animal	10	2.757494	-----	--
day	2	17.646698	8.463	.001
paddock X day	4	17.721544	8.498	.000
cycle X day	2	5.704534	2.736	.077
paddock X cycle X day	4	7.145708	3.427	.017
error	40	2.085269	-----	--

Table 22. Analysis of variance for daily changes within SDG paddocks; the dependent variable is IVOMD in 1984.

Source	df	MS	F	p
paddock	2	163.901686	24.034	.000
animal	12	6.819551	-----	--
cycle	1	2639.373883	239.567	.000
paddock X cycle	2	253.109259	22.974	.000
cycle X animal	10	11.017255	-----	--
day	2	96.518418	10.554	.000
paddock X day	4	11.153708	1.220	NS
cycle X day	2	1.440879	0.158	NS
paddock X cycle X day	4	6.541917	0.715	NS
error	40	9.144961	-----	--

Table 23. Analysis of variance for daily changes within SDG paddocks; the dependent variable is crude protein in 1985.

Source	df	MS	F	p
paddock	2	32.064829	5.730	.018
animal	12	5.595564	-----	--
cycle	2	19.025909	8.486	.002
paddock X cycle	4	33.504200	14.944	.000
cycle X animal	24	2.242027	-----	--
day	2	200.700637	83.274	.000
paddock X day	4	9.891879	4.104	.005
cycle X day	4	6.316995	2.621	.043
paddock X cycle X day	6	35.418520	14.696	.000
error	61	2.410128	-----	--

Table 24. Analysis of variance for daily changes within SDG paddocks; the dependent variable is IVOMD in 1985.

Source	df	MS	F	p
paddock	2	275.281446	35.956	.000
animal	12	7.655987	-----	--
cycle	2	252.732557	69.483	.000
paddock X cycle	2	249.060573	68.474	.000
cycle X animal	24	3.337311	-----	--
day	2	274.237140	47.654	.000
paddock X day	4	59.329580	10.310	.000
cycle X day	4	40.467778	7.032	.000
paddock X cycle X day	6	40.257361	6.994	.000
error	61	5.754719	-----	--

Table 25. Analysis of variance for daily changes within SDG paddocks; the dependent variable is ingestion rate in 1984.

Source	df	MS	F	p
paddock	2	39.465018	7.629	.008
animal	11	5.173274	-----	--
cycle	1	14.946724	4.203	.080
paddock X cycle	2	5.641275	1.586	NS
cycle X animal	7	3.556231	-----	--
day	2	7.232617	1.097	NS
paddock X day	4	27.692788	4.199	.012
cycle X day	2	26.547654	4.026	.033
paddock X cycle X day	2	26.863107	4.074	.032
error	21	6.594520	-----	--

Table 26. Analysis of variance for daily changes within SDG paddocks; the dependent variable is biting rate in 1984.

Source	df	MS	F	p
paddock	2	2567.346003	36.150	.000
cycle	1	220.149860	3.100	.080
day	2	366.591280	5.162	.006
paddock X cycle	2	1703.244008	23.983	.000
paddock X day	4	226.932124	3.195	.014
cycle X day	2	0.973804	0.014	NS
paddock X cycle X day	4	592.956688	8.349	.000
error	227	71.018451	-----	--

Table 27. Analysis of variance for daily changes within SDG paddocks; the dependent variable is grazing time in 1984.

Source	df	MS	F	p
paddock	8	32.397543	14.688	.000
animal	3	32.951429	14.939	.000
paddock X animal	24	2.205725	-----	--
cycle	1	65.581308	28.444	.000
paddock X cycle	7	20.136187	8.733	.000
cycle X animal plus pad. X cycle X anim.	17	2.305647	-----	--
day	2	0.214315	0.119	NS
paddock X day	16	3.633355	2.025	.023
cycle X day	2	3.068497	1.710	NS
paddock X cycle X day	12	2.138457	1.192	NS
error	70	1.794414	-----	--

Table 28. Analysis of variance for daily changes within SDG paddocks; the dependent variable is ingestion rate in 1985.

Source	df	MS	F	p
paddock	2	48.983810	5.967	<.05
animal	4	53.806586	6.554	.012
paddock X animal	8	8.209497	-----	--
cycle	2	53.017138	10.176	.005
paddock X cycle	4	4.481194	0.860	NS
cycle X animal plus pad. X cycle X anim.	18	5.207222	-----	--
day	2	87.826483	14.234	.000
paddock X day	4	9.038701	1.465	NS
cycle X day	4	9.838700	1.595	NS
paddock X cycle X day	6	3.288506	0.533	NS
error	26	6.170045	-----	--

Table 29. Analysis of variance for daily changes within SDG paddocks; the dependent variable is biting rate in 1985.

Source	df	MS	F	p
paddock	2	1273.164557	24.735	.000
cycle	1	3219.033179	62.539	.000
day	1	0.059516	0.001	NS
paddock X cycle	2	249.509371	4.847	.009
paddock X day	2	145.430299	2.825	.063
cycle X day	1	123.825809	2.406	NS
paddock X cycle X day	2	438.465440	8.518	.000
error	124	51.472623	-----	--

Table 30. Analysis of variance for daily changes within SDG paddocks; the dependent variable is grazing time in 1985.

Source	df	MS	F	p
paddock	9	2.967496	7.298	.000
animal	3	14.229850	34.995	.000
paddock X animal	27	0.406620	-----	--
cycle	1	1.424831	3.450	<.10
paddock X cycle	8	0.119630	0.291	NS
cycle X animal plus pad. X cycle X anim.	27	0.412963	-----	--
day	1	26.025184	52.966	.000
paddock X day	9	1.323365	2.693	.011
cycle X day	1	4.541305	9.242	.004
paddock X cycle X day	8	1.114991	2.269	.036
error	55	0.491353	-----	--

Table 31. Detailed grazing control chart for 1983, providing the grazing prescription and resultant animal unit days of use for each paddock.

Cycle	Paddock	Date in	grazing days	wt.(kg)	AUE	Anim. nos.	AUDs
1	1	5/6	2	264	.67	86	115.2
	2	8	3.5	267	.68	86	204.7
	3	12	3	270	.69	86	178.0
	4	15	3	274	.69	89	184.2
	5	18	3	277	.70	92	193.2
	6	21	3	280	.70	92	193.2
	7	24	3	283	.71	92	195.7
	8	27	3	287	.72	92	198.7
	9	30	2	290	.72	92	132.5
	10	6/1	2	294	.73	92	134.3
1	Subtotal		27.5				1729.7
2	1	6/3	3	294	.73	92	201.5
	2	6	3	296	.73	92	201.5
	3	9	3	297	.74	92	204.2
	4	12	3.5	299	.74	92	238.3
	5	15	3.5	301	.74	92	238.3
	6	18	3	302	.74	92	204.2
	7	21	3	304	.75	92	207.0
	8	24	2	306	.75	92	138.0
	9	27	2	307	.75	92	138.0
	10	29	2	309	.76	92	139.8
2	Subtotal		28				1910.8
3	1	7/1	1.5	309	.76	92	104.9
	TOTAL		57				3745.4
							44.58 AUD/ha
							0.67 ha/AUM
	CSLG	5/6	27.5	259	.695	31	592.5
		6/3	29.5	294	.755	31	690.4
			57				1282.9
							45.82 AUD/ha
							0.66 ha/AUM

Table 32. Detailed grazing control chart for 1984, providing the grazing prescription and resultant animal unit days of use for each paddock.

Cycle	Paddock	Date in	grazing days	wt.(kg)	AUE	Anim. nos.	AUDs
1	10	5/6	2	232	.60	94	112.8
	1	8	3	235	.61	94	172.0
	2	11	3	240	.62	94	174.8
	3	14	3	244	.63	94	177.7
	4	17	3	249	.64	94	180.5
	5	20	3	254	.65	94	183.3
	6	23	3	258	.65	94	183.3
	7	26	3	263	.66	94	186.1
	8	29	3	267	.67	94	188.9
	9	6/1	3	272	.68	94	191.8
1	Subtotal		29				1751.2
2	10	6/4	3	277	.69	94	194.6
	1	7	3	280	.70	94	197.4
	2	10	3	281	.70	94	197.4
	3	13	3	283	.70	94	197.4
	4	16	3	286	.71	94	200.2
	5	19	3	288	.71	94	200.2
	6	22	2	290	.71	94	133.5
	7	24	3	291	.72	94	203.0
	8	27	2	294	.72	94	135.4
	9	29	3	297	.73	94	205.9
2	Subtotal		28				1865.0
	TOTAL		57				3616.2
							43.05 AUD/ha
							0.70 ha/AUM
	CSLG	5/6	29	235	.655	31	588.8
		6/4	28	282	.715	31	620.6
			57				1209.5
							43.20 AUD/ha
							0.69 ha/AUM

Table 33. Detailed grazing control chart for 1985, providing the grazing prescription and resultant animal unit days of use for each paddock.

Cycle	Paddock	Date in	grazing days	wt.(kg)	AUE	Anim. nos.	AUDs
1	8	4/22	2	254	.65	95	123.5
	7	24	2	256	.65	95	123.5
	9	26	2	259	.66	95	125.4
	10	28	2	261	.66	95	125.4
	1	30	2	263	.66	95	125.4
	2	5/2	2	266	.67	95	127.3
	3	4	2	268	.67	95	127.3
	4	6	2	271	.68	95	129.2
	5	8	2	273	.68	95	129.2
	6	10	2	275	.69	95	130.5
1	Subtotal		20				1266.7
2	8	5/12	2	278	.69	95	131.5
	7	14	2	280	.70	95	132.2
	9	16	2	282	.70	95	132.9
	10	19	2	285	.71	95	134.0
	1	20	2	287	.71	95	134.7
	2	22	2	290	.71	95	135.8
	3	24	2	292	.72	95	136.5
	4	26	3	295	.72	95	206.3
	5	29	2	296	.73	95	137.9
	6	31	2	298	.73	95	138.6
	Subtotal		21				1420.4
3	8	6/2	1	299	.73	95	69.4
	7	3	1	300	.73	95	69.6
	9	4	1	301	.73	95	69.8
	10	5	1	302	.74	95	70.0
	1	6	1	303	.74	95	70.2
	2	7	1	303	.74	95	70.2
	3	8	1	304	.74	95	70.3
	4	9	2	306	.74	95	141.3
	5	11	1	307	.75	95	70.8
	6	12	1	309	.75	95	71.2
	Subtotal		11				772.8
	TOTAL		52				3459.9
							41.19 AUD/ha
							0.73 ha/AUM
	CSLG	4/22	32	257	.68	32	696.3
		5/24	20	290	.725	32	464.0
			52				1160.3
							41.44 AUD/ha
							0.72 ha/AUM

Table 34. Daily means for ingestive behavior and sward characteristics in 1984. Included are: ingestion rate (IR, g OM/min), biting rate (BR, bites/min), grazing time (GT, hrs/day), aboveground biomass (BIO, kg/ha), plant height (HT, cm), crude protein (CP, %), IVOMD (%), neutral detergent fiber (NDF, %), acid detergent fiber (ADF, %), permanganate lignin (PML, %), cellulose (CELL, %), and hemicellulose (HCL, %).

date	pad	IR	BR	GT	BIO	HT	CP	IVOMD	NDF	ADF	PML	CELL	HCL
5/08	1.1	0.00	62.97	0.00	301	4.6	16.62	70.76	48.62	26.13	2.47	18.46	22.49
5/13	14	12.72	59.84	0.00	422	0.0	17.19	65.26	57.23	31.69	3.32	23.19	25.54
5/17	4.1	0.00	0.00	0.00	821	7.4	14.99	60.63	60.25	32.63	2.38	23.81	27.62
5/18	4.1	18.07	43.04	0.00	770	7.0	13.00	59.19	59.81	33.12	3.11	24.77	26.69
5/19	4.1	9.03	47.89	0.00	552	0.0	13.01	61.33	58.63	31.49	2.73	24.39	27.14
5/20	4.1	10.32	50.93	0.00	577	4.7	13.83	65.03	58.30	30.24	2.17	22.88	28.06
5/26	7.1	0.00	0.00	0.00	683	6.1	12.13	66.13	58.33	29.91	2.61	23.09	28.42
5/27	7.1	8.39	41.51	0.00	606	5.7	11.45	59.58	61.35	32.49	2.93	24.79	28.86
5/28	7.1	10.20	47.65	0.00	635	6.5	9.24	59.76	61.75	34.28	3.66	25.68	27.47
5/29	7.1	8.70	45.31	0.00	388	4.2	10.74	63.08	60.35	31.66	2.13	23.70	28.69
6/07	1.2	11.92	46.90	0.00	453	0.0	11.94	64.27	61.12	32.51	3.62	24.37	28.61
6/09	1.2	9.56	53.45	10.92	416	5.6	10.32	59.42	61.59	34.64	4.34	25.77	26.95
6/10	1.2	11.52	61.45	11.00	320	3.9	9.51	61.78	61.16	33.98	4.51	25.52	27.18
6/11	14	12.93	58.28	10.12	447	0.0	11.95	61.55	62.33	32.69	3.59	25.37	29.64
6/16	4.2	14.34	57.43	0.00	785	8.1	14.26	59.52	63.29	33.87	4.52	26.35	29.42
6/17	4.2	12.49	49.16	10.25	730	0.0	9.01	56.40	63.61	35.22	4.85	26.96	28.39
6/18	4.2	15.70	45.98	10.71	525	5.2	10.97	58.79	64.42	34.73	4.20	26.93	29.69
6/19	4.2	8.64	40.87	9.80	450	5.6	11.23	57.09	62.73	34.45	4.38	26.62	28.28
6/24	7.2	0.00	54.01	0.00	544	0.0	10.57	58.82	63.59	34.88	4.43	26.60	28.71
6/25	7.2	7.61	53.10	11.29	562	6.1	6.61	54.77	63.91	36.13	5.10	27.35	27.78
6/26	7.2	9.43	53.54	11.53	362	6.1	8.32	57.13	64.73	36.32	5.16	27.50	28.41
6/27	7.2	9.87	48.48	10.86	321	5.1	7.69	60.29	63.10	35.02	4.84	26.10	28.08
6/27	14	10.76	60.70	10.85	575	0.0	10.04	60.52	63.30	34.46	3.74	26.22	28.84

Table 35. Daily means for ingestive behavior and sward characteristics in 1985. Included are: ingestion rate (IR, g OM/min), biting rate (BR, bites/min), grazing time (GT, hrs/day), aboveground biomass (BIO, kg/ha), plant height (HT, cm), crude protein (CP, %), IVOMD (%), neutral detergent fiber (NDF, %), acid detergent fiber (ADF, %), permanganate lignin (PML, %), cellulose (CELL, %), and hemicellulose (HCL, %).

date	pad	IR	BR	GT	BIO	HT	CP	IVOMD	NDF	ADF	PML	CELL	HCL
4/24	7.1	15.10	65.20	10.58	500	7.7	15.42	62.73	56.85	33.15	4.49	24.41	23.70
4/26	7.1	6.05	68.80	9.68	222	5.9	11.26	55.44	61.10	38.25	6.02	27.97	22.85
4/29	14	6.10	62.70	10.16	508	8.8	12.50	61.81	58.97	33.85	4.70	25.10	25.12
4/30	1.1	14.40	72.90	0.00	480	8.0	12.82	62.93	53.93	32.16	4.98	23.01	21.77
5/01	1.1	14.40	61.90	9.41	490	7.5	12.22	60.32	60.74	35.33	4.97	26.38	25.41
5/02	1.1	9.50	56.90	10.43	401	6.9	12.65	62.01	58.47	34.32	4.66	25.10	24.15
5/06	4.1	20.10	51.30	0.00	1000	11.8	14.38	62.12	58.42	33.09	4.12	24.80	25.33
5/07	4.1	11.45	48.80	8.87	1075	11.1	9.38	54.85	61.80	35.60	5.37	27.58	26.20
5/08	4.1	13.90	49.50	8.88	775	10.3	12.55	59.89	62.60	35.05	4.36	27.59	27.55
5/14	7.2	11.00	62.70	0.00	498	10.7	15.70	67.43	56.80	30.90	3.91	23.66	25.90
5/15	7.2	8.85	53.60	10.13	471	8.9	12.25	61.66	59.95	34.71	4.36	25.93	25.24
5/16	7.2	5.72	45.20	10.51	325	6.1	13.92	61.67	59.70	33.34	4.58	25.59	26.36
5/20	1.2	10.50	60.20	0.00	458	11.0	11.27	61.33	62.79	35.31	4.32	26.96	27.48
5/21	1.2	8.50	51.00	10.06	472	9.9	8.71	58.79	61.29	34.57	4.18	26.52	26.72
5/22	1.2	8.80	47.90	10.04	302	9.6	11.83	63.72	62.49	34.54	4.19	25.35	27.95
5/22	14	5.35	48.50	10.66	470	9.4	13.00	57.85	65.50	36.53	3.89	28.92	28.97
5/26	4.2	13.34	42.90	0.00	850	14.6	9.54	57.53	62.63	34.81	4.68	27.02	27.82
5/27	4.2	9.37	41.30	8.33	648	14.0	11.78	61.49	60.25	32.65	4.16	25.75	27.60
5/28	4.2	9.38	46.80	8.35	828	12.5	8.73	58.38	60.93	33.28	4.50	26.37	27.65
5/29	4.2	8.40	43.40	9.31	664	11.1	7.62	57.09	63.90	35.46	4.54	27.98	28.44
6/03	7.3	10.10	50.00	0.00	424	12.2	13.65	63.59	64.97	34.13	3.59	26.50	30.84

Table 35. (continued)

date	pad	IR	BR	GT	BIO	HT	CP	IVOMD	NDF	ADF	PML	CELL	HCL
6/04	7.3	6.17	50.40	9.45	316	10.7	13.04	64.92	62.94	34.00	3.91	26.03	28.94
6/06	1.3	8.90	53.80	0.00	380	13.2	12.13	61.67	63.36	34.50	4.52	26.92	28.86
6/07	1.3	8.90	48.20	9.37	370	10.6	10.98	56.52	67.18	35.46	4.47	27.85	31.72
6/09	4.3	12.34	47.80	0.00	645	13.9	9.20	54.95	66.47	36.57	4.98	28.39	29.90
6/10	4.3	10.15	46.40	9.59	480	11.0	6.64	51.93	67.02	38.08	6.23	30.42	28.94
6/11	4.3	6.53	41.60	10.15	417	9.3	7.27	52.55	67.48	38.19	5.81	29.14	29.29
6/12	14	4.80	54.10	11.93	428	10.2	10.10	55.93	67.85	36.92	4.14	29.26	30.93

VITA

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