VEGETATION DYNAMICS OF THE TALLGRASS PRAIRIE UNDER SHORT DURATION GRAZING

By

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CHAPTER I

INTRODUCTION

The use of sound grazing management practices can enhance the production of livestock from rangeland while maintaining or improving herbage production from that land. Anderson (1969) stated that proper grazing use is the most important and usually the least expensive way to achieve more production on rangeland. Without proper grazing use, the beneficial effects from almost any other range improvement practice can be nullified or severely reduced.

Grazing systems are one of the tools used by range managers to achieve proper grazing use. Recently, there has been much interest in a relatively new grazing system called short duration grazing (SDG). The concept of SDG was introduced into the United States from Rhodesia by Allan Savory. Savory (1978) claimed that current stocking levels on rangeland could be greatly increased (doubled or even tripled) while maintaining or improving range condition. These claims stemmed from years of observing wild herds of animals in Africa and the actual implementation of SDG systems in Rhodesia and South Africa. However, there is little scientific evidence available to either support or disprove these claims.

According to Heitschmidt et al. (1982b), increased herbage production, increased efficiency of harvest by the grazing animal, and increased forage quality might result in increases in carrying capacity under SDG. To further investigate the first two factors in the tallgrass prairie of Oklahoma, a study was initiated with the objective of monitoring a SDG system to determine if herbage production or harvest efficiency was affected by the timing and intensity of utilization by stocker cattle.

The following chapter of this thesis is written in a form for immediate submission for publication to the Journal of Range Management.

CHAPTER II

VEGETATION DYNAMICS OF THE TALLGRASS PRAIRIE UNDER SHORT DURATION GRAZING

Abstract

A simulated 8-pasture short duration grazing system was monitored in 1985 to determine if herbage production or harvest efficiency was affected by the timing and intensity of utilization by stocker cattle. Treatments consisted of 3 schedules of grazing under 2 stocking rates. Grazing schedule treatments were based on the number of rotation cycles completed in a 152 day grazing season with 2, 3, and 4-cycle treatments. Stocking rates consisted of 1.3 and 1.8 times the recommended normal. End of season standing crop was 4,360, 4,710, and 3,740 kg/ha for the 2, 3, and 4-cycle grazing schedule treatments, respectively, with a significant difference ($P < 0.10$) of 970 kg/ha between the 3 and 4-cycle treatments. Net accumulation rates ($\overline{X}$ = 34 kg/ha/day) were not significantly different ($P < 0.05$) among grazing schedules although they did follow the trend observed in end of season standing crop. Total herbage disappearance ($\overline{X}$ = 2,087 kg/ha) was similar among grazing schedules, but was 1,220 kg/ha greater ($P < 0.05$) under the heavy stocking rate than the light. When herbage disappearance was expressed on a per steer-day basis ($\overline{X}$ = 12 kg/steer day), no significant differences ($P < 0.05$) occurred between stocking rates indicating no increase in harvest efficiency at the higher stocking rate. It was

concluded that grazing pressures were probably not high enough in 1985 to increase harvest efficiency. Species composition did not change through the grazing season as a result of any of the treatments. Results indicate that the timing and frequency of utilization under short duration grazing may affect herbage productivity.

Introduction

Short duration grazing (SDG) is a multi-pasture, one-herd grazing system that involves rapid rotation of livestock. In theory, proper implementation of SDG on rangeland should allow large increases in stocking rates (Savory 1978).

Stocking rates may be increased if SDG brings about an increase in herbage production (Heitschmidt et al. 1982b). Short duration grazing has been observed to increase herbage production relative to ungrazed areas (Heitschmidt et al. 1982a) and continuous grazing (Jung et al. 1985). Tainton et al. (1977) observed a trend of increased herbage production as the grazing period decreased and the rest period increased. However, Ralphs et al. (1984) found that herbage production was not affected under four stocking rates on a SDG system. Because of the inconsistent results, more work is needed on the factors that affect herbage production under SDG before increased stocking rates are advocated based on increased herbage production alone.

Stocking rates can also be increased if SDG increases harvest efficiency by the grazing animal (Heitschmidt et al. 1982b). Harvest efficiency has been shown to increase under SDG as stocking rates increased (Ralphs et al. 1984). Harvest efficiency is directly related to grazing pressure in that as grazing pressure increases, harvest efficiency increases (Stuth et al. 1981, Allison et al. 1983). However, grazing pressure is continuously changing during the growing season and adjustments must be made in stocking rate, stocking density, and/or the length of the grazing period to maintain optimum herbage allowances for increased harvest efficiency (Stuth et al. 1981). Because stocking rates, stocking density, and the length of the graze/rest periods can be adjusted, the grazing pressure in a SDG system can be more precisely controlled than in any other grazing system (Heitschmidt 1984). Thus, increased harvest efficiency is probably the principle factor by which stocking rates can be increased under SDG (Heitschmidt et al. 1982b, Walker 1984).

To further investigate the herbage production potential and harvest efficiency of SDG, a study was done with the objective of monitoring vegetation response, including standing crop dynamics, net accumulation rates, and utilization, under different grazing schedules and stocking rates.

Study Area

The study area was located on the Oklahoma State University Range Research Area approximately 21 km southwest of Stillwater, Oklahoma. The climate is continental with an average frost free growing period of 204 days extending from April to October. Average precipitation at Stillwater is 831 mm with 65% falling as rain from May to October. Mean temperature is 15° C with average minimum and maximum temperatures ranging from -4.3°C in January to 34°C in August (Myers 1982).

The soils found on the area are primarily of the Grainola-Lucien and Coyle-Lucien complexes, comprising approximately 60 and 35% of the area, respectively. The Grainola series has a loam surface and silty clay loam subsoil and is a member of the fine, mixed, thermic family of Vertic Haplustalfs. The Coyle series has a fine sandy loam surface and sandy clay loam subsoil and is a member of the fine-loamy, siliceous, thermic family of Udic Argiustolls. Scattered throughout both the Grainola and Coyle soils are shallow areas (0 to 43 cm in depth) comprised of the Lucien soil series. This series makes up less than 10% of the total area. It has a fine sandy loam surface and subsoil and is a member of the loamy, mixed, thermic, shallow family of Typic Haplustolls. Range site classification of the Grainola and Lucien soils is shallow prairie while the Coyle soil is loamy prairie.

The study area was established in 1984 on native tallgrass prairie. The area was dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), and switchgrass (*Panicum virgatum* L.), each comprising approximately 18% of the vegetation by weight in August 1984. Other important species included indiangrass (*Sorghastrum nutans* (L.) Nash), tall dropseed (*Sporobolus asper* (Michx.) Kunth), and western ragweed (*Ambrosia psilostachya* DC.).

Materials and Methods

Three grazing schedule (GRSC) treatments under 2 stocking rates (STRT) were investigated. Grazing schedule treatments were defined using a 152 day grazing season that ran from April 28 to September 27 in 1985. Treatments were based on the number of grazing cycles in an eight pasture rotation that could be completed during the designated grazing season with 2, 3, and 4-cycles being investigated. Within treatments, shorter graze/rest periods were used at the beginning of the grazing season when the vegetation was in a rapid growth stage and were gradually lengthened during the season as the vegetation matured (Table 1). Each treatment received 19 total days of grazing.

Stocking rate treatments were set at 1.3 (light) and 1.8 (heavy) times the Soil Conservation Service recommended rate for the range sites under study. Pasture size and animal number were varied to obtain these stocking rates. Three animals were run on 0.40 ha pastures to obtain the light stocking rate while 5 animals were run on 0.48 ha pastures to obtain the heavy stocking rate. Stocker steers and heifers with a starting weight of approximately 275 kg were used in the study.

Treatments were applied using a simulated 8-pasture SDG system. Pasture number 4 in the rotation was used to determine the mean system effect. Treatments were arranged in a randomized complete block design with 3 replications. Each block consisted of 7 treatment pastures, three 0.40 and three 0.48 ha in size, plus an ungrazed control pasture 0.20 ha in size.

Species composition by weight and total standing crop measurements were taken before and after each grazing period in a given pasture. The before and after sampling dates, however, did not fall on the same dates for all grazing schedule treatments because of differences in the length of the graze/rest periods. To allow direct comparison between treatments, five sampling dates were included at which time all pastures were sampled. These five dates were on May 1, June 9, July 16, August 22, and September 28 in 1985.

Species composition was estimated using the dry weight rank method described by Jones and Hargreaves (1979). Five vegetation categories (big bluestem, little bluestem, switchgrass, other grasses, and forbs) were separated based on relative importance and abundance on the study

Table 1. Days of grazing and rest per cycle for the 3 grazing schedule treatments.

Grazing Schedule	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Mean	
	DG[1]	DR[2]	DG	DR	DG	DR	DG	DR	DG	DR
2-Cycle	6	42	13	91	--	--	--	--	10	67
3-Cycle	4	28	6	42	9	63	--	--	6	44
4-Cycle	3	21	4	28	5	35	7	49	5	33

[1]DG = Days of grazing per cycle.

[2]DR = Days of rest per cycle.

area. Fifty random measurements were taken per pasture per sample date using a 0.1 m^2 rectangular plot.

Current years' standing crop, both live and dead, was sampled by clipping 0.1 m^2 plots to ground level. Fifteen random samples were taken per pasture on each sampling date except on September 28 when 20 samples were taken. In addition, ten cages were placed in each pasture just prior to a grazing period. At the end of each grazing period, standing crop was sampled under the cages using 0.1 m^2 plots. Herbage samples were bagged and dried in a forced-air oven to a constant weight.

Net accumulation rate was calculated for each rest period by subtracting the standing crop at the beginning of the rest period from the standing crop at the end of the rest period and then dividing by the number of days in the period. These net accumulation rates were then weighted by the number of days in the rest period, summed, and divided by the total days of rest (133 days) for the grazing season to give an average net accumulation rate for each treatment.

Herbage disappearance was calculated for each grazing period by subtracting the uncaged standing crop from the caged standing crop at the end of the grazing period. Total herbage disappearance was then calculated for each treatment by summing the disappearance for each grazing period within that treatment. Herbage disappearance was also expressed on a per steer-day basis by dividing total herbage disappearance by the total number of steer-days/ha for each treatment. This was 143 steer-days/ha for the light stocking rate and 198 steer-days/ha for the heavy stocking rate treatments.

All data was analyzed using standard analysis of variance techniques for a randomized complete block design. Significant differences between means were separated using the least significant difference (LSD) method.

Results

Total Standing Crop

Precipitation for the period of October 1984 to September 1985 was 51% above normal and was well distributed. Because of the favorable moisture conditions, herbage production for the 1985 grazing season was well above normal with the largest ungrazed standing crop of 6,340 kg/ha measured on the September 28 sampling date. The largest standing crop for the 2 and 3-cycle GRSC treatments was measured on the July 16 sampling date while the largest standing crop for the 4-cycle treatment was measured on the August 22 sampling date (Table 2).

A significant difference ($P<0.05$) in standing crop was found between the 2 and 3-cycle grazing schedules on the June sampling date (Table 2). A GRSC X STRT interaction occurred on the July and August sampling dates which was attributed mainly to differences between the total days of grazing and the days of rest since the last grazing period for each treatment. A significant difference ($P<0.10$) was found among GRSC on the September date with a 970 kg/ha difference between the 3 and 4-cycle treatments. Dividing end of season standing crop by the largest ungrazed standing crop gave utilization estimates of 31, 26, and 41% for the 2, 3, and 4-cycle GRSC treatments, respectively. No differences were observed in standing crop between STRT treatments (Table 2).

Net Accumulation Rate

Average net accumulation rates were 34, 37, and 29 kg/ha/day for

Table 2. Total standing crop as influenced by grazing schedule (GRSC) and stocking rate (STRT) for five dates in 1985. Observed significance levels (OSL) are included for each date.

	Sampling Date														
	MAY 1			JUN 9			JUL 16			AUG 22			SEP 28		
	Stocking Rate			Stocking Rate			Stocking Rate			Stocking Rate			Stocking Rate		
Grazing Schedule	Light	Heavy	$\overline{X}$	Light	Heavy	$\overline{X}$	Light	Heavy	$\overline{X}$	Light	Heavy	$\overline{X}$	Light	Heavy	$\overline{X}$
	kg/ha														
2-Cycle	800	770	785	2260	2070	2165	5650	4480	5065	4460	3230	3845	4710	4010	4360
3-Cycle	740	900	820	2740	2810	2775	4340	5300	4820	4030	4210	4120	4990	4430	4710
4-Cycle	780	830	805	2370	2380	2375	3390	3550	3470	4460	5040	4750	3820	3660	3740
$\overline{X}$	770	830		2460	2420		4460	4440		4320	4160		4510	4030	
Source of Variation	OSL														
GRSC		0.788			0.028 (430)*			0.001			0.008			0.100 (740)+	
STRT		0.202			0.836			0.955			0.423			0.185	
GRSC X STRT		0.256			0.784			0.026 (1040)*			0.007 (1040)**			0.788	

+LSD(0.10)
*LSD(0.05)
**LSD(0.01)

the 2, 3, and 4-cycle GRSC treatments, respectively. Although not significantly different, net accumulation rates follow the trend observed in end of season standing crop. Net accumulation rates were similar between STRT treatments with an average of 34 kg/ha/day.

Herbage Disappearance

Total herbage disappearance ($\overline{X}$ = 2,087 kg/ha) and herbage disappearance per steer-day ($\overline{X}$ = 12 kg/steer-day) were similar between GRSC treatments (Table 3). Total herbage disappearance was significantly higher ($P<0.05$) under the heavy stocking rate than the light with a difference of 1,220 kg/ha (Table 3). However, no significant difference occurred between stocking rates when herbage disappearance was expressed as kilograms per steer-day.

Species Composition

When the pastures were inventoried in August 1984, no significant differences in species composition were observed among the GRSC or STRT treatments. Species composition was monitored in all pastures at four points during the 1985 grazing season. Time of year or grazing treatment had no discernable influence on any of the vegetation categories. At the end of the grazing season on September 28, the effects of the grazing treatments on species composition would be expected to be of greatest magnitude because of differential use. However, no significant differences were observed as a result of the GRSC or STRT treatments (Table 4). Species composition was also monitored before and after each grazing period in 1985, but no significant species preference by the grazing animals was revealed.

Table 3. Total herbage disappearance and herbage disappearance per steer-day under 3 grazing schedules and 2 stocking rates in 1985.

Treatment	Total Herbage Disappearance	Herbage Disappearance per Steer-day
	----kg/ha----	-----kg/steer-day-----
GRSC		
2-cycle	1900 ± 280[1]	11 ± 1
3-cycle	2170 ± 320	13 ± 1
4-cycle	2190 ± 610	27 ± 3
LSD(0.05)	NS	NS
STRT		
Light	1480 ± 220	10 ± 2
Heavy	2700 ± 310	14 ± 2
LSD(0.05)	900	NS

[1]Standard error of the mean.

Table 4. End of season (September 28) species composition for five forage categories under 3 grazing schedules and 2 stocking rates in 1985.

Grazing Schedule	Species[1]														
	ANGE Stocking Rate			SCSC Stocking Rate			PAVI Stocking Rate			OGRAS Stocking Rate			FORB Stocking Rate		
	Light	Heavy	$\bar{X}$	Light	Heavy	$\bar{X}$	Light	Heavy	$\bar{X}$	Light	Heavy	$\bar{X}$	Light	Heavy	$\bar{X}$
	%														
2-Cycle	19	17	18	21	19	20	17	16	17	40	44	42	3	4	3
3-Cycle	22	23	23	24	13	19	15	21	18	36	42	39	2	1	2
4-Cycle	17	23	20	19	23	21	20	16	18	39	35	37	5	3	4
$\bar{X}$	19	21		22	18		17	18		39	41		3	3	

[1] ANGE = *Andropogon gerardii*
SCSC = *Schizachyrium scoparium*
PAVI = *Panicum virgatum*
OGRAS = Other grasses
FORB = Forbs

Although some species, such as big bluestem, were visually observed to be more highly utilized, all species were utilized to a similar degree so that no significant changes were measured from the beginning to the end of a grazing period.

Discussion

Total Standing Crop

The ungrazed herbage followed a typical growth pattern with rapid growth from May to the middle of July after which time the growth curve started to flatten. The 2 and 3-cycle GRSC treatments followed similar growth patterns with standing crop declining between the July and August sampling dates. The decline was a result of the final grazing period which was in August for both treatments. Although the net accumulation rates were slow at this time, standing crop did increase again by the end of the grazing season under both treatments partially as a result of unusually high soil moisture. The 4-cycle treatment had a slower net accumulation rate throughout the grazing season with the largest standing crop occurring later than for the 2 and 3-cycle treatments. The regrowth potential after the final grazing period was also more limited for the 4-cycle treatment because the final grazing period occurred later in the season when the herbage was more mature and accumulating at a slower rate. This difference among grazing schedules may partially explain the lower standing crop observed under the 4-cycle treatment at the end of the grazing season.

According to Voisin (1959), grazing should be initiated at the point when the rate of herbage accumulation begins to decline. If the speed of rotation is too rapid and grazing is initiated before the optimum point of accumulation, total herbage will not accumulate to the point of the maximum absolute growth rate. Therefore, maximum total productivity will be decreased. This may also partially explain the lower productivity observed under the 4-cycle GRSC treatment. If grazing is delayed beyond the optimum point, the system becomes inefficient because the herbage is not growing at the maximum rate. Maximum total productivity will also not be reached in this situation although productivity will not be suppressed as much as when grazing is initiated too early.

One of the main objectives of SDG is to control the frequency and intensity of plant defoliation (Savory 1978, Kothmann 1980). The number of defoliations in a growing season can potentially affect plant productivity. Dwyer et al. (1963) found that intensity of clipping did not detrimentally affect production of native tallgrass species. However, as frequency of clipping increased from 1 to 4 times, herbage production decreased. Since plants under the 4-cycle treatment could have potentially been defoliated more times than under the other treatments, frequency of defoliation may also partially account for the decreased herbage production under the 4-cycle treatment.

Harvest Efficiency

Total herbage disappearance was higher under the heavy stocking rate which would be expected because of more total consumption by a larger number of grazing animals per hectare. However, disappearance expressed on a steer-day basis was similar between stocking rates which indicated no increase in harvest efficiency. These results differ from findings by Ralphs et al. (1984) in which total herbage disappearance was similar between stocking rate treatments. Therefore, as stocking rate increased, disappearance per animal-unit-day decreased and harvest efficiency increased (Ralphs et al. 1984).

Increases in harvest efficiency have been related to increases in grazing pressure (Stuth et al. 1981, Allison et al. 1983). Allison et al. (1983) found that as grazing pressure went from 50 to 10 kg/AUD, harvest efficiency increased from 53 to 99%, respectively. Grazing pressure on this study ranged from 30 kg/AUD on the 2-cycle heavy to 116 kg/AUD on the 4-cycle light treatment with an average across all treatments of 70 kg/AUD. Because of the above normal herbage production year, grazing pressures were probably too low for increased stocking rate to result in increased harvest efficiency.

Species Composition

Species composition was not affected by the grazing schedule or stocking rate treatments after one grazing season. Short-term changes in species composition are the result of selectivity by the grazing animal which may be manifest in the long term by the loss of highly preferred species. Although no short-term changes in species composition were detected, it is important to monitor composition over time becauase changes in herbage production, either up or down, can often be related to changes in species composition (Sims and Dwyer 1965). Changes in herbage production brought about by changes in species composition will lead to changes in the carrying capacity of the range.

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APPENDIXES

APPENDIX A

TABLES

Table A1. Calendar dates for each grazing period in 1985.

Grazing Period	Grazing Schedule					
	2-Cycle		3-Cycle		4-Cycle	
	On	Off	On	Off	On	Off
1	5-16	5-22	5-12	5-16	5-9	5-12
2	7-27	8-9	6-20	6-26	6-6	6-10
3	--	--	8-16	8-25	7-11	7-16
4	--	--	--	--	8-25	9-1

Table A2. Standing crop taken in August 1984 before treatments began, under 3 grazing schedules and 2 stocking rates.

Grazing Schedule	Stocking Rate		
	Light	Heavy	$\overline{X}$
	kg/ha		
2-Cycle	3850 ± 370[1]	4040 ± 190	3945 ± 190
3-Cycle	3940 ± 230	4080 ± 160	4010 ± 130
4-Cycle	3990 ± 100	4020 ± 270	4005 ± 130
$\overline{X}$	3930 ± 130	4050 ± 110	

[1]Standard error of the mean.

Table A3. Species composition for five vegetation categories and standing crop under ungrazed conditions for one date in 1984 and five dates in 1985.

Species[1]	1984 AUG 7	1985 MAY 1	1985 JUN 9	1985 JUL 16	1985 AUG 22	1985 SEP 28
	%					
ANGE	13 ± 2[2]	---	22 ± 2	21 ± 3	23 ± 6	21 ± 3
SCSC	19 ± 4	---	21 ± 4	22 ± 3	24 ± 4	23 ± 1
PAVI	13 ± 2	---	15 ± 3	19 ± 4	14 ± 2	15 ± 3
OGRAS	47 ± 3	---	35 ± 4	32 ± 2	36 ± 2	37 ± 3
FORB	9 ± 1	---	7 ± 2	7 ± 3	4 ± 1	5 ± 2
Standing Crop	kg/ha					
$\bar{X}$	3720 ± 360	850 ± 100	3250 ± 70	5000 ± 570	5750 ± 520	6340 ± 190

[1] ANGE = *Andropogon gerardii*
SCSC = *Schizachyrium scoparium*
PAVI = *Panicum virgatum*
OGRAS = Other grasses
FORB = Forbs

[2] Standard error of the mean.

Table A4. Mean grazing pressure by grazing schedule, stocking rate treatment combination for each grazing period in 1985.

Grazing Period	Grazing Schedule					
	2-Cycle		3-Cycle		4-Cycle	
	Stocking Rate		Stocking Rate		Stocking Rate	
	Light	Heavy	Light	Heavy	Light	Heavy
	kg/AUD					
1	49 ± 3[1]	30 ± 1	67 ± 0	51 ± 2	43 ± 4	103 ± 6
2	54 ± 4	31 ± 3	91 ± 6	63 ± 2	94 ± 9	78 ± 5
3	--	--	77 ± 6	55 ± 2	116 ± 11	88 ± 6
4	--	--	--	--	99 ± 3	72 ± 2

[1]Standard error of the mean.

APPENDIX B

CONTROLLING VARIATION IN GRAZING STUDIES: SUBSAMPLING VS. REPLICATION

APPENDIX

CONTROLLING VARIATION IN GRAZING STUDIES: SUBSAMPLING VS. REPLICATION

Introduction

The variation that makes up experimental error comes from two main sources. First, there is the inherent variability that exists in the experimental material to which treatments are applied. Second, there is the variation which results from any lack in uniformity in the physical conduct of the experiment (Steel and Torrie 1980).

Grazing studies designed to measure vegetation parameters have always been restrained by the inherently large variation in native plant communities. One has little control over the species present, the proportions of these species, or their dispersal throughout the site. Differences in soils, topography, and climate, which affect the production potential of different areas, also contribute to the variability in the native plant communities.

There are two main ways of reducing or controlling this source of variability in the experimental error. The first is through the experimental design and the second is through the choice of size and shape of experimental units (Steel and Torrie 1980). The randomized complete block design has been widely used in grazing studies for controlling variation. The greater efficiency of this design is accomplished by the use of blocks where each block contains all treatments. Blocks are laid out such that the variation within a block is less than the variation between blocks. The variation between blocks is then arithmetically removed from the experimental error. Furthermore, the shape of individual experimental units should be long and narrow and the block approximately square (Steel and Torrie 1980). This is to achieve maximum variation among blocks and minimum variation among experimental units within the blocks.

Kempthorne (1952) has shown that as the size of experimental units decrease, statistical efficiency increases. However, the minimum size of the experimental unit in grazing studies is limited. The unit must be of sufficient size to permit normal behavior patterns and also provide an adequate nutritional diet for the grazing animals (Hilmon et al. 1963, Reed and Skovlin 1963). Therefore, some statistical efficiency is sacrificed to meet the needs of the grazing animal.

Since the experimental unit required for grazing studies is large, subsampling within the unit is usually warranted. Subsampling can cause increases in the experimental error because plot to plot variation within an experimental unit is added to the variation between units. In vegetation studies, the plot to plot variation, or subsample error, is a measure of the homogeneity of the vegetation within the experimental unit (Steel and Torrie 1980). The less homogeneous the vegetation within the unit, the less precise the estimated experimental unit mean and the larger the subsample error. As the subsample area increases (number and/or size of subsample increases) and approaches the experimental unit area, the smaller the subsample error becomes and the more precise the estimate of the experimental unit mean.

Thus, it is advantageous to take as many subsamples as possible to get the most precise estimate of the experimental unit mean. The number of subsamples taken, however, will usually be constrained by cost and time considerations. Because of these constraints, one would like to optimally allocate resources between experimental units (replications) and subsampling units so as to minimize the variance of a treatment mean.

Methods

To determine the optimum number of subsamples per experimental unit, Kempthorne (1952) gives the equation:

$$s = \sqrt{\frac{CS^2}{C_s S_e^2}} \qquad (1)$$

where: s = optimum number of subsamples per experimental unit

C = cost of installing, maintaining, and operating an experimental unit excluding sampling unit costs

C_s = cost of measuring a sampling unit throughout the life of the study

S^2 = mean square (MS) for subsampling

$S_e^2 = \frac{\text{MS for error - MS for subsampling}}{s'}$

s' = original number of samples per experimental unit

To determine the optimum number of replications, Kempthorne (1952) gives the equation:

$$r = \frac{C_o}{C + \sqrt{CC_s \frac{S^2}{S_e^2}}} \qquad (2)$$

where: r = optimum number of replications

C_o = total cost per treatment

C, C_s, S^2, and S_e^2 = same as in equation 1

The optimum allocation of resources for the present study was based on S^2 and S_e^2 values from the five complete sampling dates in 1985 and cost values estimated for the sample and experimental units (pastures) used. The estimated cost of measuring one sampling unit over the five year life of the study was \$15/sampling unit (Table B1). The estimated cost of installing, maintaining, and operating one experimental unit over the life of the study was \$253/experimental unit (Table B2). The total cost per treatment was calculated using the equation:

$$C = r(C + sC_s) \quad (3)$$

where: C = total cost per treatment

r = number of replications in the original study (3)

s = number of subsamples per experimental unit in the original study (15)

C and C_s = same as in equation 1

The total cost per treatment in this study was \$1434 (\$1659 in September when 20 subsamples were taken).

Results

As the optimum number of subsamples increases, the optimum number of replications decreases (Table B3). For the May and June dates, allocation of current sampling was very near optimum. However, for the July and September dates, optimum allocation would have been one more replication and about five less subsamples per pasture.

The allocation of available resources between subsamples and

Table B1. Inputs used to estimate cost of measuring one sampling unit for the short duration grazing study in 1985.

Input	Estimated amount of input
Clipping 0.1 m^2 plot (min/plot)	3
Sorting, weighing, etc. (min/plot)	1
Number of plots clipped in one year	9
Life of study (years)	5
Labor cost per man-hour	$5.00

Table B2. Inputs used to estimate cost of installing, maintaining, and operating one experimental unit for the short duration grazing study in 1985.

Input	Estimated amount of input
Miles of fence	2.6
Cost per mile of fence	$1000
Number of experimental units	21
Time to put cattle on and off pastures per grazing period (hours)	4
Number of men required to put cattle on and off pastures	3
Grazing periods per year	9
Life of study	5
Labor cost per man-hour	$5.00

Table B3. Optimum allocation of subsamples and replications using 1985 data from the short duration grazing study.

Date	Optimum subsamples/ experimental unit	Optimum replications
May 1	15	3
Jun 9	14	3
Jul 16	9	4
Aug 22	50	2
Sep 28	10	4

Table B4. Within and between pasture variation values for the short duration grazing study in 1985.

Date	Within pasture variation (S^2)	Between pasture variation (S_e^2)
May 1	58,700.300	4,358.921
Jun 9	709,945.150	63,921.604
Jul 16	1,196,694.392	243,462.226
Aug 22	2,218,673.280	14,942.433
Sep 28	2,268,075.169	384,505.818

replications depends on the magnitude of the difference between the within and between pasture variation. When the within pasture variation is large in comparison to the between pasture variation, it is more advantageous to allocate resources to more subsamples per pasture. This was the case for the August date (Table B4) in which optimum allocation would have been 50 subsamples per pasture (Table B3). In this example, the within and between pasture variation was influenced not only by the homogeneity of the vegetation, but also by the amount of standing crop at any one time, the uniformity of forage utilization, and the accumulated days of grazing in a pasture at the time of sampling. These variables caused shifts in the between and within pasture variance structures which led to the shifts in the optimum allocation of resources.

One must remember that these results do not guarantee differences between treatments will be detected with any degree of statistical certainty. With the given variance structures and costs, however, this is the optimum allocation of resources between subsamples and replications.

In most grazing studies, the number of replications is limited by land availability. The cost of adding another experimental unit becomes very high, especially when land costs are considered. When a very large experimental unit cost is used in equation 1, the optimum number of subsamples becomes very large. This number may even approach the point where the whole experimental unit would be sampled.

In summary, when constrained by number of replications, it is best to take as many subsamples as possible. This would give the best estimate of the subsampling error, and therefore, the best estimate of the experimental error. The number of subsamples that one is able to take, however, will still be constrained by cost, time, sampling impact on the experimental unit, and other factors.

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