Journal of Range Management

Publication of the Society for Range Management

The Trail Boss

TABLE OF CONTENTS: Vol. 39, No. 6, November 1986

ARTICLES

Grazing Systems and Effects of Grazing

Forage Quality and Production and Animal Nutrition

Plant Establishment and Revegetation

Published bimonthly—January, March, May, July, September, November

INDIVIDUAL SUBSCRIPTION is by membership in the Society for Range Management.

LIBRARY or other INSTITUTIONAL SUBSCRIPTIONS on a calendar year basis are $56.00 for the United States postpaid and $66.00 for other countries, postpaid. Payment from outside the United States should be remitted in US dollars by international money order or draft on a New York bank.

BUSINESS CORRESPONDENCE, concerning subscriptions, advertising, reprints, back issues, and related matters, should be addressed to the Managing Editor, 2760 West Fifth Avenue, Denver, Colo. 80204.

EDITORIAL CORRESPONDENCE, concerning manuscripts or other editorial matters, should be addressed to the Editor, 2760 West Fifth Avenue, Denver, Colo. 80204.

INSTRUCTIONS FOR AUTHORS appear on the inside back cover of each issue. A Style Manual is also available from the Society for Range Management at the above address @$1.25 for single copies; $1.00 each for 2 or more.

THE JOURNAL OF RANGE MANAGEMENT (ISSN 0022-409X) is published six times yearly for $56.00 per year by the Society for Range Management, 2760 West Fifth Avenue, Denver, Colo. 80204. SECOND CLASS POSTAGE paid at Denver, Colo.

POSTMASTER: Return entire journal with address change—RETURN POSTAGE GUARANTEED—to Society for Range Management, 2760 West Fifth Avenue, Denver, Colo. 80204.

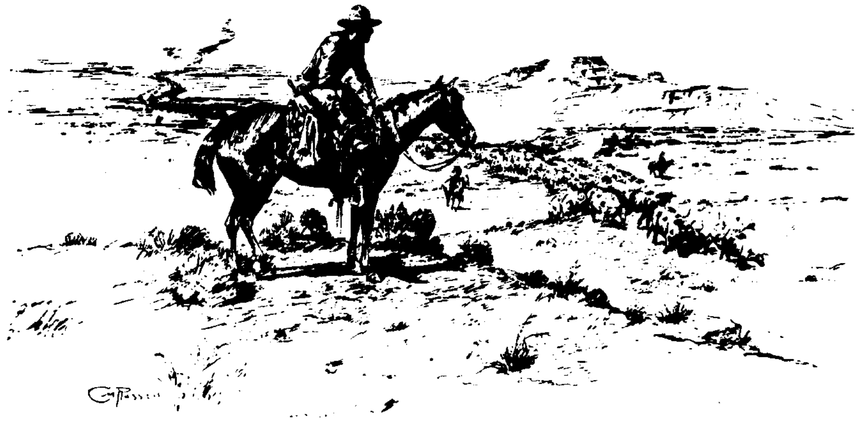
TECHNICAL NOTES

BOOK REVIEWS

MISCELLANEOUS

The **Journal of Range Management** serves as a forum for the presentation and discussion of facts, ideas, and philosophies pertaining to the study, management, and use of rangelands and their several resources. Accordingly, all material published herein is signed and reflects the individual views of the authors and is not necessarily an official position of the Society. Manuscripts from any source—nonmembers as well as members—are welcome and will be given every consideration by the editors. Submissions need not be of a technical nature, but should be germane to the broad field of range management. Editorial comment by an individual is also welcome and subject to acceptance by the editor, will be published as a "Viewpoint."

SOCIETY FOR RANGE MANAGEMENT



THE TRAIL BOSS

The **Society for Range Management**, founded in 1948 as the *American Society of Range Management*, is a nonprofit association incorporated under the laws of the State of Wyoming. It is recognized exempt from Federal income tax, as a scientific and educational organization, under the provisions of Section 501(c)(3) of the Internal Revenue Code, and also is classed as a public foundation as described in Section 509(a)(2) of the Code. The name of the Society was changed in 1971 by amendment of the Articles of Incorporation.

The objectives for which the corporation is established are:

—to develop an understanding of range ecosystems and of the principles applicable to the management of range resources;

—to assist all who work with range resources to keep abreast of new findings and techniques in the science and art of range management;

—to improve the effectiveness of range management to obtain from range resources the products and values necessary for man's welfare;

—to create a public appreciation of the economic and social benefits to be obtained from the range environment;

—to promote professional development of its members.

Membership in the Society for Range Management is open to anyone engaged in or interested in any aspect of the study, management, or use of rangelands. Please contact the Executive Vice-President for details.

Contribution Policy

The Society for Range Management may accept donations of real and/or personal property, subject to limitations imposed by State and Federal Law. All donations shall be subject to control by the Board of Directors and their discretion in utilization and application of said donations. However, consideration may be given to the donor's wishes concerning which particular fund account and/or accounts the contribution would be applied.

We recommend that donor consult Tax Advisors in regard to any tax consideration that may result from any donation. Donations may be made by bequests, legacies, devises or transfers from private individuals, partnerships, corporations, foundations, sections, organizations, estates, and trusts, or a memorial fund established as an expression of remembrance to members of real and/or personal property. Donations can be sent to the Society for Range Management, Executive Vice-President, 2760 West Fifth Avenue, Denver, Colorado 80204.

Cattle Responses to Continuous and Seasonal Grazing of California Annual Grassland

RAYMOND D. RATLIFF

Abstract

An 8-year (1961-1968) study at the San Joaquin Experimental Range, in the Sierra Nevada foothills in central California, compared continuous, repeated seasonal, and rotated seasonal grazing on native range, and continuous grazing on sulfur-fertilized range. Cow and calf weight responses showed continuous grazing of annual grassland range to be most productive for cow-calf production. At birth, no advantage of one grazing treatment over another was found among calf weights. At the start of the adequate green forage season, calves under both continuous grazing treatments (native and fertilized) averaged 15 kg heavier than calves under rotated seasonal grazing; calves on continuously grazed fertilized range averaged 12 kg heavier than calves under repeated seasonal grazing. At weaning, calves under continuous grazing treatments averaged 25 kg heavier than calves under seasonal grazing treatments. No advantage of one grazing treatment over another was found among mature cow weights.

Overstocking their rangeland was the reason Abram and Lot parted ways (Genesis 13:2-11). The concept of periodically resting the land was set forth by Moses (Exodus 23:10-11, Leviticus 25:1-7). Centuries later specialized grazing management or grazing systems (Range Term Glossary Committee 1974) were set forth to maintain and improve rangeland.

Most current grazing systems are designed for managing perennial grasslands. Their purpose is to improve range condition through better livestock distribution, improved plant vigor, greater seed production and seedling establishment, and breaks in habitual use patterns.

Such grazing systems may be of little value in managing annual grasslands. Annual plants grow, produce seed, and die in a single year. They need not accumulate food reserves or maintain vigor. Nevertheless, annual plants do respond to factors of seed germination and seedling establishment. And grazing management can affect annual grassland species composition, herbage yield, and livestock production.

Can better cow and calf production be obtained on annual grassland under continuous yearling grazing or under some form of grazing system? Cows kept all year in a single range unit at the San Joaquin Experimental Range, Madera County, California, had lower pregnancy and weaning percentages than cows moved to ungrazed units in August (Wagnon et al. 1959). Both groups received supplemental feeding. A third group of cows (moved but unsupplemented) had fewer stillbirths and otherwise did as well as the cows not moved. Interpreting responses of the cows not moved was, however, complicated by possible and unusual trace-element deficiencies. Their responses, therefore, were not attributed solely to grazing the same range unit yearlong. The question remained.

This paper reports cow and calf weight responses from an 8-year (1961–1968) study intended to answer that question. Herbage residue amounts and cow reproductive performance are also discussed.

Author is range scientist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, 2081 E. Sierra Ave., Fresno, Calif. 93710.

Many people were involved in this research. Specific recognition and thanks are due to: Stanley L. Anderson (range technician/herdsman), James L. Burns (maintenance foreman), C. Eugene Conrad (range scientist), Don A. Duncan (range scientist/project leader), Robert Flournoy (rancher/cooperator, Likely, California), Charles A. Graham (range scientist/superintendent), C. Dick Hansen (rancher/cooperator, Biola, California), Merton J. Reed (range scientist/project leader), Jack N. Reppert (range scientist), Stanley E. Westfall (range technician), and E. Joseph Woolfolk (division chief/assistant director).

Manuscript accepted 10 April 1986.

Methods

Experimental Area

The San Joaquin Experimental Range occupies about 1,862 ha of annual grass-oak woodland in the Sierra Nevada foothills. Elevations range from 213 to 518 m. Winters are relatively cool and wet. Summers are hot and dry.

Average (1934 to 1978) annual precipitation is 48.3 cm. December, January, and February are the wettest months with 8.6, 8.3, and 8.6 cm, respectively. July and August are the driest months with 2.5 mm. January is the coldest month with maximum and minimum temperatures averaging 11.8° C and 0.7° C, respectively. July is the hottest month with maximum and minimum temperatures averaging 36.7° C and 16.2° C, respectively.

Weather produces 3 characteristic forage seasons (Bentley and Talbot 1951). The "inadequate green" season begins after fall rains stimulate seed germination. During that forage season, environmental conditions usually limit plant growth. As a result, green forage is not of sufficient volume for cattle needs. Protein and energy supplements are usually necessary. The "adequate green" season begins in January or February when major grass species are 5 to 8 cm high. During that forage season, growth so accelerates that livestock cannot use all the herbage produced. The "dry" season begins when soil water becomes depleted in May or June. The annual plants produce seed and die. If it has cured well, dry season herbage may supply cattle with adequate protein and energy for several weeks.

Grazing Treatments

Historically, factors such as family tradition, ranch size, and available alternate forage have determined local practices. About half the operators (usually the larger ones) practiced a form of seasonal grazing. Cattle were taken to the higher mountains during the dry forage season. The home ranch was grazed continuously during the inadequate and adequate green forage seasons. Yearlong grazing, with some attempts at rotation, was the usual practice of small and part-time operators (Voorhies et al. 1942). Practices have changed little over the years.

This study compared continuous, repeated seasonal, and rotated seasonal grazing of native (unfertilized) range and continuous grazing of fertilized range. Elemental sulfur at 67 kg/ha was applied to fertilized areas every third year.

Under continuous grazing, cattle have access to all of their range all year. In this paper, the continuous grazing treatments are abbreviated to "cont-N" and "cont-F" for continuous grazing of native and fertilized range, respectively.

Under repeated seasonal grazing, cattle are on annual grassland range yearlong, but graze specifically restricted portions of their range during given forage seasons each year. Repeated seasonal grazing was studied by Wagnon et al. (1959) and Heady and Pitt (1979). Heady (1961) rotated the time (early, mid, late) of grazing during the growing season, but opened all areas to grazing during the dry and inadequate green forage seasons.

Under rotated seasonal grazing, cattle are on annual grassland range yearlong but graze specifically restricted portions of their range rotationally. The forage season of grazing is rotated among different portions of the range each year.

More efficient cattle production and better herbage production occur with moderate grazing than with close grazing on annual grassland (Bentley and Talbot 1951). Moderate grazing was therefore planned under all treatments.

Range Units

Swale, open-rolling, and rocky-brushy range site classes at the San Joaquin Experimental Range are described by Bentley and Talbot (1951) and Gaylord (1972). Productivity varies with site. Herbage production was therefore monitored for 2 years to determine and equalize grazing capacities.

The 4 treatments were then randomly assigned to 2 replications (blocks) of range units. One block of range units had about 26% open-rolling sites and 74% rocky-brushy sites. The other block of range units had about 89% rocky-brushy sites and 11% open-rolling sites. The 8 range units average 91 ha in size. Range units assigned seasonal treatments were partitioned into 3 subunits for grazing in the 3 forage seasons.

Supplemental Feeding

To properly maintain their animals, ranchers in the area supplement dry and/or inadequate green herbage (Voorhies et al. 1942). Therefore, when quality herbage was in short supply, 4.5 kg/head/day of high quality alfalfa *(Medicago sativa)* hay was fed in all treatments. Iodized salt was provided in the last half of the gestation to prevent goiter in new-born calves. Block salt was provided as needed.

The Cattle

A select herd of 99 yearling Hereford heifers was brought to the San Joaquin Experimental Range in April 1959. All were of good-to-choice feeder grades, weighed 204 to 227 kg, and were raised together. In November and December 1960, they had their first calves (Duncan and Reed 1973). In January 1961, balanced weight groups of 8 cows with calves were formed from the herd. The groups were randomly and permanently assigned to treatments and range units. The cows in the groups were called "testers." Their responses and those of their calves provided the measure of treatment effects. Other cows were put into and taken out of range units as needed to assure moderate use.

The breeding program was designed so that cows under all treatments would calve from late October to early December. Testers were culled if they twice failed to conceive and/or wean a calf, were sick for a protracted period, or, of course, died. To maintain a basic herd of 8 cows, culled testers were replaced.

At the change of forage seasons, cows were individually weighed following an overnight shrink. Calves were weighed within 24 hours of birth, when their dams were weighed, and at weaning.

Herbage Production and Residue

Herbage production by treatment was 3,100 kg/ha under cont-F, 2,390 kg/ha under cont-N, 2,240 kg/ha under repeated seasonal, and 2,460 kg/ha under rotated seasonal grazing (Caldwell et al. 1985; Caldwell, Menke and Duncan, unpublished manuscript).

At the start of the inadequate green forage season, 897 to 1,121 kg/ha of herbage residue was to remain in continuously grazed range units and subunits grazed in the adequate green and dry forage seasons. Estimates of herbage residues were made along random, permanent transects, and sampling was proportional to the amount of a site class in a range unit. The overall average therefore estimated amounts left in the range unit or subunit. Residual herbage on subunits grazed in the inadequate green forage season was assumed to equal the herbage production.

Analysis of Data

Differences in cattle responses among grazing treatments were of primary interest. Owing to variation in the quantity and quality of forage, variation in cattle responses from year to year was expected. Therefore, mature cow weights (at weaning in 1964) and average calf weights (over the 8 years) expressed long-term responses to treatment. The analysis of variance model to estimate differences between treatments was a randomized complete-block design, with 1 observation per cell. Calf weights analyzed were those at birth, at the start of the adequate green forage season, and at the start of the dry forage season (the usual weaning time). Mature cow weights were analyzed using their initial weights at the start of the study as a covariate. Determining 95% confidence intervals for pairwise differences among treatment means was by Tukey's "w-procedure" (Steel and Torrie 1960). In this paper, differences between treatments are expressed as $(\bar{X}1 - \bar{X}2) \pm w$, where w = Q (SE). Q comes from tables for the number of means compared and error degrees of freedom.

Results

Variation in the Green Forage Season

Starting dates for the adequate green forage season (Table 1) varied from 12 January to 20 February. On the average, they were similar to those reported for the experimental range by Bentley and Talbot (1951).

Table 1. Adequate green forage season at the San Joaquin Experimental Range, Madera County, California (1961-1968).

Year	Dates: Start	Dates: End	Length (days)
1961	Feb. 9	May 31	111
1962	Feb. 20	June 19	119
1963	Feb. 8	July 11	153
1964	Jan. 15	June 18	155
1965	Jan. 12	July 13	182
1966	Feb. 15	May 24	98
1967	Jan. 12	Aug. 4	204
1968	Feb. 7	May 24	107
Average	Feb. 1	June 22	141

Based on past ending dates (Bentley and Talbot 1951), the adequate green forage seasons in 1963, 1965, and 1967 ended later than usual. Those were 3 of 6 years from 1935 to 1978 in which April and May precipitation exceeded 10 cm and April, May, and June average maximum temperatures were below average. Late spring rains and low temperatures delayed the dry forage season.

Grazing Use and Herbage Residue

Based on the production estimates given earlier and leaving 1,121 kg/ha of residue, grazing potentials were 1.1, 1.8, 1.2, and 1.0 AUM/ha under cont-N, cont-F, rotated seasonal, and repeated seasonal grazing, respectively. Actual use by treatment was 1.1, 1.5, 0.8, and 0.7 AUM/ha, respectively.

Differences among years in residual herbage amounts relate to

Table 2. Estimated plant residue prior to fall germination by grazing treatment at the San Joaquin Experimental Range, Madera County, California (1961-1967).

Year	Grazing treatments: Continuous: Native	Continuous: Fertilized[2]	Seasonal[1]: Rotated	Seasonal[1]: Repeated	Average
	Kilograms per hectare				
1961	701	805	495	441	610
1962	432	459	414	440	436
1963	984	1132	833	887	959
1964	1542	1478	1301	1245	1392
1965	1340	2282	1490	1201	1578
1966	1124	1226	1391	1169	1228
1967	1997	2786	2072	1900	2189
Average	1160	1452	1142	1040	1199

[1]Residue in the inadequate green forage season subunits was not included.
[2]Fertilized with mineral sulfur every third year.

production and stocking. Average residue amounts range from 7% less to 30% more than planned (Table 2). Over all 7 years and all grazing treatments (excluding inadequate green forage season subunits), 7% more remained than planned. The lowest amount (-63%) occurred under rotated seasonal grazing in 1962. The highest amount (+148%) occurred under cont-F in 1967.

Residual herbage has little nutritional value after being leached by rain, and leaving an excess amount wastes resources. Under cont-N residual herbage averaged 39 kg/ha more than planned. Under cont-F an excess of 331 kg/ha remained. With additional cattle, another 0.3 AUM/ha/yr could have been obtained under the treatment. Including the inadequate green forage season subunits, residual amounts were 1,440 kg/ha (319 kg/ha extra) under repeated seasonal grazing and 1,581 kg/ha (460 kg/ha extra) under rotated seasonal grazing. Until the inadequate green forage season, a third of the production (one subunit) could not be used. It represents a loss of 0.3 AUM/ha/yr under repeated seasonal grazing and 0.4 AUM/ha/yr under rotated seasonal grazing.

Grazing use could probably have been heavier under all treatments during 1964, 1965, 1966, and 1967. Clawson et al. (1982) reported that 448 to 785 kg/ha of residual herbage (moderate use) produces the best cattle production on land like the San Joaquin Experimental Range. They also suggested minimum residual amounts of 448 kg/ha for lower or flat slopes, 672 kg/ha for average-gentle slopes, and 897 kg/ha for upper or steep slopes. Over the years studied, therefore, any difference among grazing treatments in residual herbage levels should have had minimal influence on cow and calf weight responses.

Relative contributions of plant species to the herbage produced may change, however, due to treatment. Moreover, differences in cow and calf responses may reflect such changes. Plant species responses to cont-N, cont-F, and the seasonal grazing treatments have been discussed (Caldwell et al. 1985; Caldwell, Menke and Duncan, unpublished manuscript).

Calf Response

Over all years and treatments, calf birth weights at the San Joaquin Experimental Range (Table 3) averaged 31.0 ± 0.8 kg. At the start of adequate green forage, calves averaged 94.8 ± 2.8 kg. At weaning, the average calf weight was 217.8 ± 4.3 kg.

Table 3. Calf birth weights, weights at the start of the adequate green and dry forage seasons, and rates of gain during the adequate green forage season (over all treatments) by crop year at the San Joaquin Experimental Range, Madera County, California.

Year	Calf weights			Green season gain per day
	Birth	Green season	Dry season	
	Kilograms			
1961	28.1[1]	82.9[1]	176.3	0.84
1962	28.3	96.4	201.0	0.87
1963	30.8	99.1	233.4	0.87
1964	31.8	87.3	214.6	0.81
1965	31.5	90.0	244.7	0.85
1966	31.1	106.1	219.3	1.15
1967	31.2	83.2	252.0	0.82
1968	30.4	95.2	189.8	0.88
Average	31.0	94.8	217.8	0.89

[1]For reader information; not used in analyses.

Calf weights at the start of the adequate green forage season reflect their ages more than inadequate green season forage quality. The calves were younger and weighed 90 kg or less when the adequate green forage season started in January. The calves were older and weighed over 90 kg when it started in February.

Variation in its length accounted for 90% (R = 0.95) of the variation in calf weight gains (Table 3) during the adequate green forage season. The longer that calves were on the range, the greater their final weights. Calf gains also reflected forage quality. Though the 1966 season was short (98 days), the adequate green forage was of high quality. Calves gains 1.2 kg per day that season, 0.27 kg per day more than in any other year.

Larger calves are commonly asserted to have greater vitality at birth and to be larger at weaning than smaller calves. For calf birth weights (Table 4), the 95% confidence interval for the difference between the continuous grazing treatments and repeated seasonal grazing was 2.4 ± 3.3 kg. The true difference is, therefore, between an advantage of 0.9 kg for repeated seasonal grazing and an advantage of 5.7 kg for continuous grazing. At those extremes, an advantage for repeated seasonal grazing would little affect future calf response, but an advantage for continuous grazing could affect future calf response.

Table 4. Calf birth weights and weights at the start of the adequate green and dry forage seasons by grazing treatment at the San Joaquin Experimental Range, Madera County, California.

Grazing treatment	Calf weights[1]		
	Birth	Green season	Dry season
	Kilograms		
Continuous			
Native	31.9a	100.4ab	229.0a
Fertilized[2]	31.9a	101.0a	227.8a
Seasonal			
Repeated	29.5a	88.6bc	205.2b
Rotated	29.7a	86.2c	202.2b
Tukey's "w"	3.3	12.2	18.6

[1]Within columns, treatment means followed by the same letter are not statistically different ($P<0.05$).
[2]Fertilized with mineral sulfur every third year.

Continued supplementation after parturition should tend to reduce treatment differences in calf weights. Nevertheless, at the start of the adequate green forage season, calves under continuous grazing weighed more than calves under seasonal grazing (Table 4). Calves were 14.2 ± 12.2 kg heavier under cont-N and 14.8 ± 12.2 kg heavier under cont-F than calves under rotated seasonal grazing. Also, calves under cont-F were 12.4 ± 12.2 kg heavier than calves under repeated seasonal grazing.

Treatment differences were amplified during the adequate green forage season. At the start of the dry forage season (the usual weaning time), calves under continuous grazing (Table 4) averaged 25 kg heavier than calves under seasonal grazing. Between cont-N and repeated and rotated seasonal grazing, the differences were 23.8 ± 18.6 kg and 26.8 ± 18.6 kg, respectively. Between cont-F and repeated and rotated seasonal grazing, the differences were 22.6 ± 18.6 kg and 25.6 ± 18.6 kg, respectively.

Similar results were reported by Duncan and Reed (1973). And continuous grazing gave better lamb weights and ewe performance than seasonal grazing of annual grassland (Heady 1961, Heady and Pitt 1979).

Cows under continuous grazing had the entire range unit for selecting forage. Those under seasonal grazing had one-third as much area. Consequently, although all cows received equal rations of hay, cows under continuous grazing had greater opportunity, after calving, to select diets conducive to high lactation rates. That may explain the heavier calves under continuous grazing at the start of the adequate green forage season.

Stocking rate differences during the adequate green forage season explain part of the difference in weaning weights between continuous and seasonal grazing treatments. Average stocking rates for cont-N and cont-F units were 2.3 and 1.9 ha/AUM, respectively. Average stocking rates for rotated and repeated seasonal subunits were 0.8 and 0.9 ha/AUM, respectively. Cows and calves under continuous grazing did not have to graze as closely as cows and calves under seasonal grazing. As a result, cows and calves under continuous grazing could be more selective in choos-

Table 5. Starting and mature tester cow weights and 95% confidence intervals for the mean cow weights at the start of the dry forage season (1961–1968) on the San Joaquin Experimental Range, Madera County, California.

Grazing treatment	Starting weight	Mature weight[1]	Confidence Interval[2]
	----------Kilograms----------		
Continuous			
Native	331.6	503.5a[3]	471.3 ± 34.2
Fertilized[4]	339.7	518.7a	492.8 ± 36.0
Seasonal			
Repeated	326.3	464.9a	441.3 ± 24.1
Rotated	336.8	459.4a	437.1 ± 21.1
Average	333.6	486.6	
Tuckey's "w"		146.4	

[1]At weaning of calves (18 June 1964) and adjusted for covariate effects of starting weights (10 Jan. 1961).
[2]For reader information. Cows without calves were not included. Confidence intervals for individual treatment means should not be used to assess treatment effects.
[3]Within column, values followed by the same letter are not statistically different ($P<0.05$).
[4]Fertilized with mineral sulfur every third year.

ing their diet (at least toward the end of the adequate green forage season).

Cow Responses

Weights of original tester cows that weaned calves in 1964 were used to estimate grazing treatment effects on the cows. Cow weights (taken on a specific date) summarize all influences from the start of the study. By 1965, many of the original testers in some range units had been replaced. Because their histories and those of the testers differed, replacement cow weights could not be used to reflect long-term treatment effects. Weights of all cows (replacements as well as testers) were used by Duncan and Reed (1973). The weights they reported therefore differ from those given here.

The 95% confidence interval for the difference in weights of mature cows (Table 5) under cont-F and those under rotated seasonal grazing, was 59.3 ± 146.4 kg. The true difference is, therefore, somewhere between an advantage of 87.1 kg for rotated seasonal grazing and an advantage of 205.7 kg for cont-F. Confidence intervals for other continuous and seasonal grazing comparisons may be similarly interpreted.

Ranchers commonly accept the premise that large cows produce large calves. Continuous grazing produced larger calves than seasonal grazing. Any true difference in cow weights is, therefore, likely an advantage for continuous grazing.

Fewer heifers may need be retained annually under rotated seasonal grazing. Over all years and grazing treatments, 34 (7.1% per year) of the original 64 cows were replaced. By treatment, replacements were 63% (cont-N), 56% (cont-F), 63% (repeated seasonal), and 31% (rotated seasonal). For all treatments, except rotated seasonal, 1 or more replacement cows were replaced.

The overall weaning rate was 0.88 calf/cow. Average weaning rates were 0.85 (cont-N), 0.87 (repeated seasonal), 0.90 (cont-F), and 0.90 (rotated seasonal).

The overall conception rate was 0.95 calf/cow. Conception by treatment averaged 0.91 (cont-N), 0.95 (repeated and rotated seasonal), and 0.98 (con-F). The overall weaning rate per pregnant cows was 0.93 calf/cow. Average weaning rates were 0.91 (repeated seasonal), 0.92 (cont-F), 0.94 (cont-N), and 0.95 (rotated seasonal).

Conclusions

For cow-calf operators dependent yearlong on annual grassland of the Sierra Nevada foothills, continuous grazing should be more productive than seasonal grazing. That conclusion is consistent with previous findings of livestock responses on annual grassland range. To maintain productivity of the resource base, stocking to obtain moderate use is recommended.

At the San Joaquin Experimental Range, calves on range grazed continuously were heavier at weaning than calves on range divided into seasonal units grazed repeatedly or in rotation. At a market price of $1.36/kg, (based on the 95% confidence interval), the return per calf under continuous grazing on native range would be between $11.15 and $61.74 more than per calf under rotated seasonal grazing. Whether differences of those sizes will induce cow-calf operators to change from seasonal to continuous grazing depends on cost-return relationships.

Literature Cited

Bentley, J.R., and M.W. Talbot. 1951. Efficient use of annual plants on cattle ranges in the California foothills. USDA, Washington, D.C. Circ. No. 870.

Caldwell, R.M., J.W. Menke, and D.A. Duncan. 1985. Effects of sulfur fertilization on productivity and botanical composition of California annual grassland. J. Range Manage. 38:108-113.

Clawson, J.W., N.K. McDougald, and D.A. Duncan. 1982. Guidelines for residue management on annual range. Cooperative Extension, Div. of Agr. Sci., Univ. Calif., Berkeley. Leafl. 21327.

Duncan, D.A., and M.J. Reed. 1973. Yearlong tops seasonal grazing in extended rangeland study. West. Livest. J. (Mt. Plains & Southwest Ed.) 51:32-48.

Gaylord, V.J. 1972. A method for the correlation of range sites with land association classes in the Sierra foothills. M.S. Thesis, California State Univ., Fresno.

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

Heady, H.F., and M.D. Pitt. 1979. Seasonal versus continuous grazing on annual vegetation of northern California. Rangelands 1:231-232.

Range Term Glossary Committee. 1974. A glossary of terms used in range management. 2nd ed. Soc. for Range Manage. Denver, Colo.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, Inc., New York.

Voorhies, E.C., L.A. Crawford, R.L. Adams, and G.A. Carpenter. 1942. Ranch organization and management in the granite area. p. 83-95. *In:* C.B. Hutchison and E.I. Kotok (eds.), The San Joaquin Experimental Range. Univ. Calif., Berkeley. Bull. 663.

Wagnon, K.A., H.R. Guilbert, and G.H. Hart. 1959. Beef cattle investigations on the San Joaquin Experimental Range. California Agr. Exp. Sta. Bull. 765.

Effects of Season and Stage of Rotation Cycle on Hydrologic Condition of Rangeland Under Intensive Rotation Grazing

S.D. WARREN, W.H. BLACKBURN, AND C.A. TAYLOR, JR.

Abstract

Infiltration rate and sediment production were measured over a 2-year period on an intensive rotationally grazed pasture. Measurements were taken prior to the movement of livestock onto the pasture, soon after their removal, and approximately midway through the subsequent rest period of each rotation through the system. Midgrass-dominated interspaces were characterized by significantly higher infiltration rates and lower sediment production than shortgrass-dominated interspaces. Infiltration rate declined and sediment production increased following the short-term intense grazing periods inherent in the rotational system. The detrimental effect was significant during periods of drought or winter dormancy, but not during periods of active growth. Soil characteristics relating to higher hydrologic condition were significantly more stable during the growing season, providing greater resistance to and resilience from the damaging impact of livestock activity.

Mismanagement of domestic livestock, especially through excessive stocking rates, has caused severe degradation of many of the world's rangelands (Bentley 1898, Box 1967, Dregne 1978). Moderate stocking rates which are designed to utilize approximately half of the current year's forage production are generally accepted as proper grazing management (Stoddard et al. 1975). However, even when "proper" stocking rates are achieved, livestock may selectively overutilize specific areas, certain forage species, or even individual plants. One tool to help prevent such uneven distribution of grazing is the implementation of rotational grazing systems. Additional goals of grazing systems include improvement or maintenance of the forage resource and increased animal production.

Over the last decade there has been a renewed interest in intensive rotation grazing, a concept which originated prior to the 19th century (Voisin 1959). Modern proponents of the system predict that, in addition to improved plant and animal production, the intense livestock activity associated with short-term, high stocking density will increase infiltration of rainfall into the soil and reduce erosion, even at stocking rates which double or triple the conventional moderate rates (Goodloe 1969, Savory 1978, Savory and Parsons 1980). Most scientific research with rotational grazing systems has shown that heavy stocking rates decrease infiltration rate and increase sediment production, regardless of the system used (Blackburn 1984; Gamougoun et al. 1984; McCalla et al. 1984a, 1984b; Pearson et al. 1975; Pluhar 1984; Smith 1980; Thurow 1985; Warren et al. 1986c; Weltz 1983). Even at moderate stocking rates, rotational grazing systems have no consistently significant hydrologic advantages over continuous grazing (Blackburn 1984; Blackburn et al. 1980; Knight 1980; Mbakaya 1985; McGinty et al. 1979; Skovlin et al. 1976; Wood 1980; Wood and Blackburn 1981a, 1981b; Wood et al. 1978).

Although the overall hydrologic impact has been evaluated for many rotational grazing systems, little is understood about the mode of action by which the watershed is impacted. The purpose of this investigation was to test the hypothesis of hydrologic improvement under intensive rotation grazing in relation to stage of the rotation cycle and seasonal variability.

Authors are presently environmental research scientist, USA-CERL, Environmental Division, P.O. Box 4005, Champaign, Ill. 61820, professor of watershed management, Department of Range Science, Texas A&M University, College Station 77843, and superintendent, Texas Agricultural Experiment Station, Sonora 76950. At the time of this research the senior author was graduate research assistant at Texas A&M University.

This study was a cooperative project between U.S. Department of Agriculture and Texas Agricultural Experiment Station. Financial support of the Soil Conservation Service RCA Special Study and a Science/Education Grant is acknowledged. Published with approval of the Director, Texas Agricultural Experiment Station as TA-20993.

Manuscript accepted 10 April 1986.

Study Area

Field research was conducted at the Texas Agricultural Research Station located on the Edwards Plateau near Sonora, Texas. In the fall of 1982, a 376-ha, 14-pasture intensive rotation grazing system was put into operation at the Station. Pastures ranged in size from 8 to 32 ha. The system was stocked with a single herd composed of a 1.63:1:1 ratio of cattle, sheep, and goats at a stocking rate of 8.1 ha/AU, which is the recommended moderate rate. The number of days of grazing per pasture per rotation cycle was dependent upon the condition of the forage resource within each pasture. During the spring and summer, the average rotation cycle was 56 days but slowed to 74 days during the winter dormant season.

A 32-ha pasture was used for this study. The pasture was in better condition than most others and was grazed at a heavier rate accordingly. During a typical 56-day rotational cycle, the pasture was grazed for 8 days, so that it was representative of a 7-pasture intensive rotation grazing system stocked at 4.8 ha/AU or 1.7x the recommended moderate rate. Stocking density while livestock were on the pasture was 0.68 ha/AU.

The physiognomy of the pasture was characterized by dense, scattered live oak (*Quercus virginiana* Mill.) mottes with grass interspaces. The midgrass component of the grass interspaces was dominated by sideoats grama (*Bouteloua curtipendula* (Michx.)) and Wright's threeawn (*Aristida wrightii* Nash). Other important midgrass included fall witchgrass (*Leptoloma cognatum* (Schult.) Chase), Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), and silver bluestem (*Bothriochloa saccharoides* (Swartz) Rydb.). The shortgrass interspaces were predominantly common curly mesquite (*Hilaria belangeri* (Steud.) Nash). Honey mesquite (*Prosopis glandulosa* Torr.) and ashe juniper (*Juniperus ashei* Buchholz), 2 woody species, were scattered through the grass interspaces in a savannah-like fashion. Prickly pear (*Opuntia* spp. Mill.) was also abundant.

Study sites were located on Kavett silty clay soils with slopes <3% and a depth of 250–500 mm overlying a fractured caliche layer and limestone substratum. The soils were of the clayey-skeletal, montmorillonitic, thermic family of Lithic Haplustolls, characterized by high shrink-swell capacity and high organic matter content. When undisturbed, they were well aggregated and had high rainfall infiltration capacity.

Therefore, dormant season, for purposes of this paper, refers to any extended period of vegetation dormancy, whether induced by cooler temperatures and shorter day length during the winter, or by extended drought, regardless of the time of year.

Methods

Beginning in the fall of 1982 when the intensive rotation grazing system was installed, and continuing until the fall of 1984, pastures were sampled immediately prior to the entry of livestock, soon after their removal, and approximately midway through the subsequent rest period of each rotation through the system. Two rotation cycles were omitted due to freezing temperatures which prevented rainfall simulation. Sixteen plots were sampled on each sample date at sites which were randomly located within the pasture. Half of the plots represented midgrass interspaces and half represented shortgrass interspaces.

A mobile, drip-type rainfall simulator (Blackburn et al. 1974) was used to determine infiltration rate and sediment production on variable area runoff plots. Plot size averaged approximately 0.4 m^2. In order to reduce variability attributable to antecedent soil water content, the plots were pre-wet by applying 105 area mm of water at a rate of 79 mm h^{-1} from a mist type nozzle located under a plastic cone 0.6 m above the soil. The plots were then covered with plastic tarps to prevent evaporation, and gravitational water was allowed to drain. After approximately 24 hours, when the soil had drained to near field capacity, simulated rainfall was applied at a rate of 203 mm h^{-1} for 30 minutes. The simulated raindrops were 2.5 mm in diameter. Drops falling 2.1 m reached 5.25 m/sec or 71% of the terminal velocity achieved by raindrops in an unlimited fall (Laws 1941). This application rate simulated a storm with a return period of about 120 years and was necessary to insure runoff from all plots. Runoff from each plot was regularly pumped into tared containers. At five minute intervals the runoff was weighed and mean infiltration rate (mm h^{-1}) was calculated by determining the difference between applied rainfall and the quantity of water running off the plot. At the end of each simulated rainfall event, runoff from the plot was thoroughly mixed and a 1-liter subsample was collected. The subsample was filtered through a tared Whatman #1 filter. Sediment remaining on the filter was oven-dried, weighed and converted to sediment production (kg ha^{-1}) based on the area and total runoff from each plot.

Immediately prior to each simulated rainfall event, soil bulk density and soil moisture content at a depth of 0–50 mm were determined adjacent to each runoff plot by the core method (Blake 1965) and gravimetric method (Roundy et al. 1983), respectively. Soil surface microrelief within each plot was measured with a 10-pin relief meter similar to the one described by Kincaid and Williams (1966). Following simulated rainfall, a composite surface soil sample was taken to a depth of 30 mm from within the plot and was used for analyses of soil organic matter content by the Walkley-Black method (Nelson and Sommers 1982) and aggregate stability by the wet-sieved method (Kemper 1965).

Percent aerial cover of midgrasses, shortgrasses, forbs, litter, rock, and bare ground was determined by ocular estimate for each runoff plot. Midgrass, shortgrass, and forb cover were combined to produce a single vegetative cover estimate. Litter cover was added to the vegetative cover total to produce a total organic cover estimate. Following rainfall simulation, grasses and forbs were clipped to a 10-mm stubble height and litter was hand collected from each plot. These samples were oven-dried and weighed. Grass and forb weights were combined to produce a standing crop value, and litter was added to calculate total above-ground herbaceous biomass.

Biomass variables and soil microrelief were highly skewed. Log_{10} transformations were performed to meet assumptions of normality. Analysis of variance based on a $3 \times 2 \times 2$ factorial design was used to determine if significant differences existed for dependent variables between stages of the rotation cycle (pre-graze, post-graze, mid-rest), seasons (growing, dormant), and grass types (midgrass, shortgrass). The error term in the analysis of variance consisted of the nested variation of the randomized sites within the factorial treatments (Snedecor and Cochran 1971). If differences were present, Duncan's multiple comparison test was used to separate the means (Steel and Torrie 1980). Simple correlation was computed for all combinations of dependent and independent variables. A significance level of 95% was used throughout.

Results and Discussion

The average growing season at the Station is 240 days and extends from March through October. Precipitation during 1983 (501 mm) was considerably below the long-term (1918–1984) average of 609 mm (Fig. 1). Drought conditions were even more severe the following year, with only 406 mm precipitation, from 10 January to 25 July 1984 there were no significant rainfall events (>10 mm). This resulted in a drought-induced extension of the dormant season well into the summer.

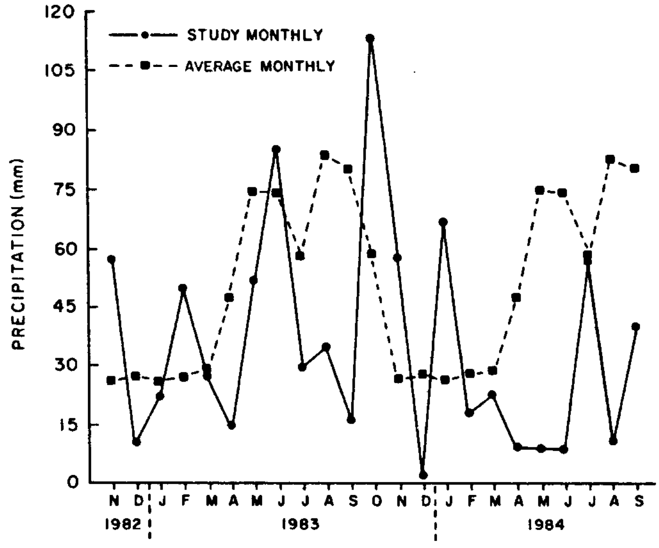


Fig. 1. *Long-term average monthly precipitation (1918–1984) and monthly precipitation during the study, near Sonora, Texas.*

Infiltration rate was significantly greater (162 vs. 121 mm h^{-1}) and sediment production significantly less (937 vs. 1,559 kg ha^{-1}) from plots located in midgrass interspaces than from plots representing shortgrass interspaces. Similar differences in hydrologic response due to grass type have been noted by Knight (1980); McCalla et al. 1984a, 1984b; Pluhar (1984); Thurow (1985); and Wood and Blackburn 1981a, 1981b. There was no significant interaction between grass type and other treatment factors. Therefore, grass types are combined for discussion of seasonal variability and stage of rotation cycle.

Seasonal Variability

Mean infiltration rate was significantly higher and sediment production was significantly lower during the growing season than during priods of dormancy (Fig. 2). Knight (1980), McCalla et al. (1984a), and Thurow (1985), also working at the Sonora station, reported similar seasonal variability for infiltration rate. Standing crop was the only vegetation or cover variable which varied significantly between seasons; it was greatest during the growing season (Table 1).

Most soil-related variables were significantly different between seasons (Table 1). Soil aggregate stability and soil organic matter were significantly higher and soil bulk density was significantly lower during the growing season, creating a more stable soil hydrologic condition. Soil aggregate stability and soil organic matter are highly autocorrelated by virtue of the fact that organic matter is a principal constituent in the binding of individual soil particles into soil aggregates. Soil organic matter content, in turn, is largely dependent on microbial decomposition of litter and humus. Soil microbes are most active during the growing season when soil moisture and soil temperature are favorable and litter is abundant. However, microbial activity may be limited by very high temperatures and low soil moisture conditions. During the summer drought of 1984, soil temperatures at a depth of 50 mm reached diurnal peaks approaching 37° C while soil moisture at that depth dropped as low as 2–3% on a dry weight basis. These conditions may have limited microbial activity and probably contributed to

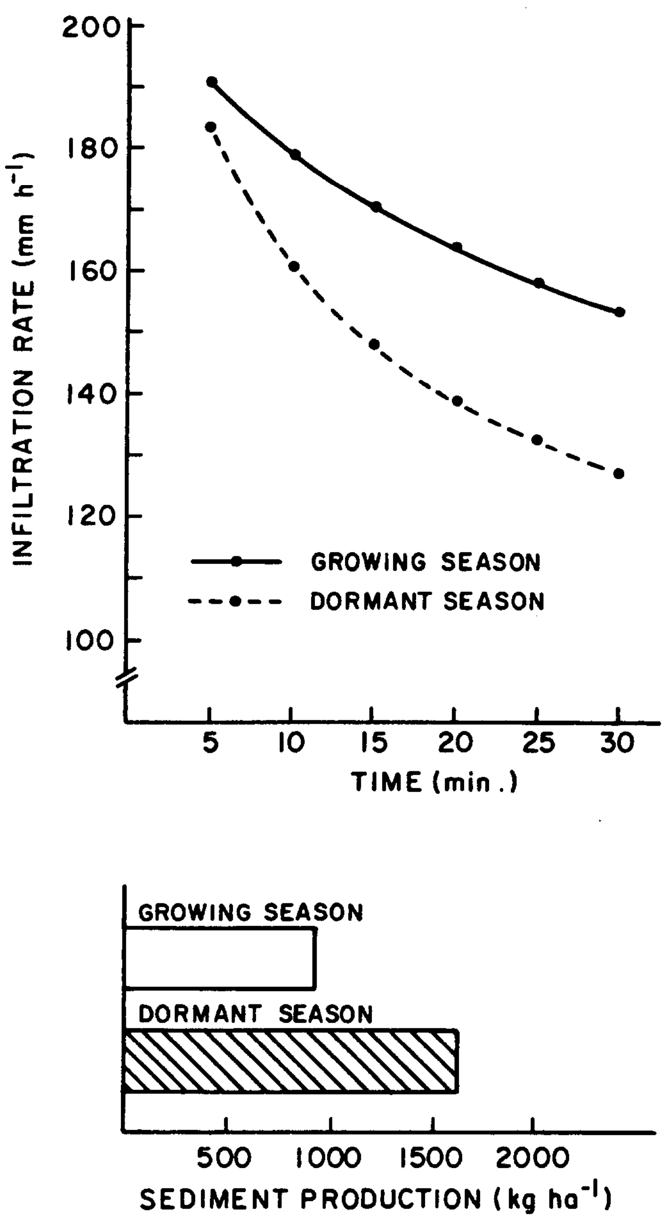


Fig. 2. *Mean infiltration rate after 30 minutes and sediment production during the growing and dormant seasons near Sonora, Texas. All means for infiltration rate at the same time interval and for sediment production are significantly different (P≤.05).*

the lower soil organic matter content and aggregate stability during the dormant season.

The degree of aggregation of soil particles is also positively related to soil bulk density. Porosity of the soil is generally enhanced and soil bulk density reduced as the degree of aggregation increases. Soil porosity during the growing season is also increased by the disruptive action of plant roots. In addition, most of the annual precipitation at the Sonora station falls during the growing season (Fig. 1). The shrinking and swelling of the predominant montmorillonitic clay soils, in response to wetting and drying, lightens the soil and decreases bulk density.

Vegetation variables were significantly correlated with infiltration rate and sediment production during the growing season and during periods of dormancy (Table 2). Grass and litter may intercept a significant portion of incident precipitation (Burgy and Pomeroy 1958, Corbett and Crouse 1968, McMillan and Burgy 1960) and thus reduce the impact of falling raindrops. Raindrops impinging directly on a bare soil surface may dislodge soil particles which may eventually clog soil pores or may be carried away by overland flow (Osborn 1954). Depending on plant morphology, much of the intercepted rainfall may be channeled to the base of the plant (Glover et al. 1962, Gwynne 1966) where plant roots and accumulated litter create a more porous soil characterized by high infiltration rates (Blackburn 1975, Ndawula-Senyimba et al. 1971, Wood and Blackburn 1981a).

Table 1. Mean vegetation and soil variables during the growing and dormant seasons, near Sonora, Texas.[1]

Variable	Growing season	Dormant season
Bare ground (%)	28.3a	30.3a
Litter cover (%)	20.5a	20.9a
Vegetation cover (%)	48.6a	46.5a
Total organic cover (%)	69.1a	67.4a
Standing crop (kg ha^{-1})	2311.5a	1967.7b
Litter accumulation (kg ha^{-1})	1242.6a	1205.5a
Total above ground herbaceous biomass (kg ha^{-1})	3548.9a	3157.1b
Microrelief (unitless)	1.15a	1.11a
Soil bulk density (Mg m^3)	0.77a	0.80b
Soil aggregate stability (%)	76.8a	62.2b
Soil organic matter content (%)	6.3a	5.8b

[1]Means followed by the same letter within a row are not significantly different (*P*≤.05).

Table 2. Simple correlation coefficients of vegetation and soil variables correlated with mean infiltration rate after 30 minutes and sediment production during the growing and dormant seasons, near Sonora, Texas.[1]

	Infiltration rate		Sediment production	
Independent variables	Growing season	Dormant season	Growing season	Dormant season
Bare ground	−.56	−.56	.53	.46
Litter cover	.28	.26	−.10 NS	−.09 NS
Vegetation cover	.37	.42	−.48	−.44
Total organic cover	.54	.57	−.52	−.45
Litter accumulation	.41	.40	−.22	−.19
Standing crop	.54	.47	−.39	−.36
Total above ground herbaceous biomass	.61	.58	−.41	−.36
Microrelief	.45	.40	−.30	−.19
Soil bulk density	−.17	−.36	.04 NS	.14
Soil aggregate stability	.14	.44	−.42	−.32
Soil organic matter content	.13	.26	−.27	−.17

[1]Correlation coefficients followed by NS are not significant (*P*≤.05).

Soil variables were also significantly correlated with soil hydrologic response (Table 2). Soil surface microrelief which results from small natural depressions, plant bases, and litter may slow overland flow, increase infiltration rate, and cause deposition of suspended soil particles. However, infiltration rates in depressions caused by cattle tracks may be severely reduced due to compaction (Kako and Toyoda 1981). Soil bulk density was more closely related to infiltration rate than to sediment production. In addition, the relationship was stronger during the dormant season than during periods of growth. Soil aggregate stability and soil organic matter content were also more strongly correlated with infiltration rate during the dormant season. However, these latter variables were more closely tied to sediment production during the growing season.

Stages of Rotation Cycle

Fluctuations between pre-graze and post-graze hydrologic condition were much more pronounced during dormant periods, regardless of the factors inducing the dormancy (Fig. 3). Overall,

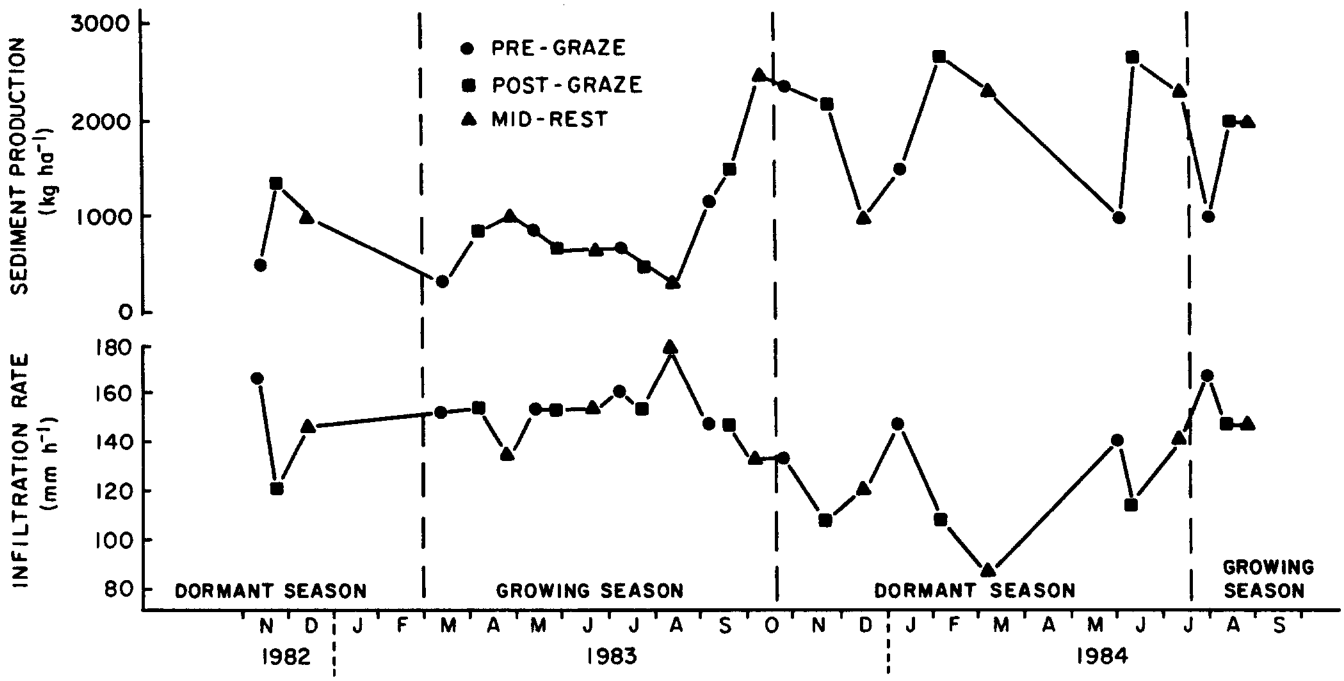


Fig. 3. *Mean infiltration rate after 30 minutes and sediment production as related to stage of rotation cycle and season near Sonora, Texas. Dormant season includes winter dormancy and drought-induced dormancy.*

during the growing season, mean terminal infiltration rate was somewhat higher before the movement of livestock onto the pasture than immediately after their removal, but the difference was not statistically significant (Table 3). During the dormant season, however, the decline in infiltration rate following grazing was significant. Despite the deleterious effect of trampling, some degree of hydrologic recovery did occur during the subsequent rest periods. By midway through the rest period, mean infiltration rate recovered to a level significantly greater than the post-graze condition, but remained significantly lower than the pre-graze condition.

Table 3. Mean infiltration rate after 30 minutes and sediment production at different stages of the short-duration grazing rotation cycle during the growing and dormant seasons near Sonora, Texas.[1]

	Infiltration rate (mm h-1)		Sediment production (kg ha-1)	
Stage of rotation cycle	Growing season	Dormant season	Growing season	Dormant season
Pre-Graze	159a	146a	744a	1241a
Post-Graze	153a	111c	964a	2017b
Mid-Rest	150a	124b	1074a	1640ab

[1]Means followed by the same letter within a column are not significantly different ($P \leq .05$).

Sediment production responded similarly to infiltration rate but in an inverse fashion (Table 3). The amount of sediment produced during simulated rainfall was greater following grazing than before grazing during both growing and dormant periods. However, as with infiltration rate, the negative impact of high intensity livestock activity was significant only during the dormant periods. Recovery of hydrologic condition in terms of sediment production was evident during the dormant season rest periods. The amount of sediment production declined by midway through the rest period to a level which was not statistically different from either the pre-graze or post-graze condition.

The augmented detrimental impact of intensive livestock activity during the dormant season is probably a reflection of overall lower hydrologic condition of the soil during that part of the year. Grazing animals not only remove protective biomass through grazing, but their trampling activity may reduce vegetative cover (Bryant et al. 1972, Edmond 1958, Plumb et al. 1984, Quinn and Hervey 1970, Witschi and Michalk 1979), destroy cryptogamic crusts which are essential to hydrologic stability (Brotherson and Rushforth 1983, Loope and Gifford 1972), compact the soil (Chandler 1940, Kako and Toyoda 1981, Knoll and Hopkins 1959, Lull 1959, Van Haveren 1983, Willatt and Pullar 1983, Warren et al. 1986b), decrease soil moisture (Chandler 1940, Edmond 1958, Knoll and Hopkins 1959), decrease soil organic matter content (Chandler 1940), reduce soil aggregate size (Chandler 1940, Warren et al. 1986b), reduce soil aggregate stability (Knoll and Hopkins 1959, Warren et al. 1986b), reduce soil hydraulic conductivity (Willatt and Pullar 1983), and reduce seedling emergence and establishment (Blom 1976, 1977). The ability of a watershed to withstand or recover from livestock impact is undoubtedly related to the hydrologic condition of the watershed at the time of the impact. During the growing season when soil moisture status, soil aggregate stabiity, soil organic matter content, soil bulk density, microbial activity, and above- and below-ground plant growth are near optimum levels, the potential of the soil to withstand livestock impact is high, as is the potential to recover following the removal of livestock. During periods of dormancy, however, the resistance to damage from grazing and for subsequent recovery after grazing is less than during the growing season.

Summary and Conclusions

Hydrologic response to an intensive rotation grazing system on silty clay soil, in terms of infiltration rate and sediment production, was different during the growing season than during periods of winter or drought-induced dormancy. Infiltration rate was significantly higher and sediment production was significantly lower during the growing season than during periods of dormancy. Greater vegetation standing crop and more stable soil physical characteristics during growth periods contributed to the differences. Mean infiltration rate was consistently lower and mean sediment production was consistently higher following grazing than before. The difference was significant during periods of dormancy but not during the growing season. Unfavorable growing conditions, reduced activity of soil organisms, and a decline in stability of soil physical properties during periods of dormancy contributed to the inability of the pasture to withstand intense livestock activity or to recover rapidly during the subsequent rest period.

In terms of hydrologic stability, operators of intensive rotation grazing systems should consider lower stocking rates and/or longer rest periods during winter dormancy or during periods of drought. Unfortunately, increasing the length of the rest period is a viable alternative only where the number of pastures is small (Warren et al. 1986a). Where the growing season is short and often unpredictable, as in most semiarid and arid regions, repeated intense trampling may lead to a long-term degradation of the soil resource.

Literature Cited

Bentley, H.L. 1898. Cattle ranges of the Southwest: A history of exhaustion of pasturage and suggestions for its restoration. USDA Farmers Bull. 72.

Blackburn, W.H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resources Res. 11:929-937.

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses, p. 927-983. *In:* Developing Strategies for Rangeland Management. Nat. Res. Council/ Nat. Acad. Sci. Westview Press, Boulder, Colo.

Blackburn, W.H., R.O. Meeuwig, and C.M. Skau. 1974. A mobile infiltrometer for use on rangeland. J. Range Manage. 27:322-323.

Blackburn, W.H., R.W. Knight, M.K. Wood, and L.B. Merrill. 1980. Watershed parameters as influenced by grazing, p. 552-572. *In:* Proc. of the Symp. on Watershed Manage. Amer. Soc. Civil Eng., Boise, Ida.

Blake, G.R. 1965. Bulk density, p. 374-390. *In:* C.A. Black (ed), Methods of Soil Analysis, Part I. Amer. Soc. Agron., Madison, Wis.

Blom, C.W.P.M. 1976. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. I. Soil compaction, soil moisture and seedling emergence. OEcol. Plant. 11:225-241.

Blom, C.W.P.M. 1977. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. II. Trampling and seedling estabishment. OEcol. Plant. 12:363-381.

Box, T.W. 1967. Range deterioration in west Texas. Southwestern Historical Quart. 9:37-45.

Brotherson, J.D., and S.R. Rushforth. 1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo National Monument, Arizona. Great Basin Natur. 43:73-78.

Bryant, H.T., R.E. Blaser, and J.R. Peterson. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a Meadowville loam. Agro. J. 64:331-334.

Burgy, R.H., and C.R. Pomeroy. 1958. Interception losses in grassy vegetation. Trans. Amer. Geophys. Union 29:1095-1100.

Chandler, R.F., Jr. 1965. The influence of grazing upon certain soil and climatic conditions in farm woodlands. J. Amer. Soc. Agron. 32:216-230.

Corbett, E.S., and R.P. Crouse. 1968. Rainfall interceptions by annual grass and chaparral...losses compared. USDA Forest Service Res. Pap. PSW-48.

Dregne, H.E. 1978. Desertification: Man's abuse of the land. J. Soil and Water Conserv. 33:11-14.

Edmond, D.B. 1958. The influence of treading on pasture: A preliminary study. N.Z. J. Agr. Res. 1:319-328.

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

Glover, P.E., J. Glover, and M.D. Gwynne. 1962. Light rainfall and plant survival in East Africa. II. Dry grassland vegetation. J. Ecol. 50:199-206.

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

Gwynne, M.D. 1966. Plant physiology and the future, p. 59-64. *In:* W. Davis and C.L. Skidmore (eds), Tropical pastures. Faber and Faber, London.

Kako, Y., and H. Toyoda. 1981. Soil conservation of sloping grassland. V. The infiltration capacity of water on sloping grasslands. (In Japanese). Bull. Nat. Grassl. Res. Inst. 18:127-136.

Kemper, W.D. 1965. Aggregate stability, p. 511-519. *In:* C.A. Black (ed), Methods of soil analysis, Part 1. Amer. Soc. Agron., Madison, Wis.

Kincaid, D.R., and G. Williams. 1966. Rainfall effects on soil surface characteristics following range improvement treatments. J. Range Manage. 19:346-351.

Knight, R.W. 1980. Hydrologic response of selected grazing systems on the Edwards Plateau. Ph.D. Diss., Texas A&M Univ., College Station.

Knoll, G., and H.H. Hopkins. 1959. The effects of grazing and trampling upon certain soil properties. Trans. Kansas Acad. Sci. 62:221-231.

Laws, J.O. 1941. Measurements of the fall-velocity of water-drops and raindrops. Trans. Amer. Geophy. Union 22:709-721.

Loope, W.L., and G.F. Gifford. 1972. Influence of soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. J. Soil and Water Conserv. 27:164-167.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA Misc. Pub. 768.

Mbakaya, D.S. 1985. Grazing systems effects on infiltration rates and sediment production of a bushed grassland, Buchuma, Kenya. M.S. Thesis, Texas A&M Univ., College Station.

McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984a. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:265-269.

McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984b. Effects of livestock grazing on sediment production, Edwards Plateau of Texas. J. Range Manage. 37:291-294.

McGinty, W.A., F.E. Smeins, and L.B. Merrill. 1979. Influence of soil, vegetation and grazing management on infiltration rate and sediment production of Edwards Plateau rangeland. J. Range Manage. 32:33-37.

McMillan, W.D., and R.H. Burgy. 1960. Interception loss from grass. J. Geophys. Res. 65:2389-2394.

Ndawula-Senyimba, M.S., V.C. Brink, and A. McLean. 1971. Moisture interception as a factor in the competitive ability of bluebunch wheatgrass. J. Range Manage. 24:198-200.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter, p. 539-579. *In:* A.L. Page (ed), Methods of Soil Analysis, Part 2. Amer. Soc. Agron., Madison, Wis.

Osborn, B. 1954. Soil splash by raindrop impact on bare soils. J. Soil and Water Conserv. 9:33-49.

Pearson, G.A., G.A. Jung, R.E. Fowler, and D.M. Mitchell. 1975. Effects of grazing on infiltration rates and waste water spray fields. Proc. Soil Sci. Soc. Amer. 29:954-957.

Pluhar, J.J. 1984. Hydrologic impacts of selected grazing systems on the Texas Rolling Plains. M.S. Thesis, Texas A&M Univ., College Station.

Quinn, J.A., and D.E. Hervey. 1970. Trampling losses and travel by cattle on sandhills range. J. Range Manage. 23:50-55.

Roundy, B.A., J.A. Young, G.J. Cluff, and R.A. Evans. 1983. Measurement of soil water on rangelands. USDA Agr. Res. Service, Agr. Res. Results, Western Ser. 31.

Savory, A. 1978. A holistic approach to ranch management using short duration grazing, p. 555-557. *In:* First Internat. Range Congr. Soc. Range Manage., Denver, Colo.

Savory, A., and S.D. Parsons. 1980. The Savory grazing method. Rangelands 2:234-237.

Skovlin, J.M., R.W. Harris, G.S. Strickler, and G.A. Garrison. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. USDA Forest Service Tech. Bull. 1531.

Smith, R.P. 1980. The influence of different grazing practices on infiltration rates and sediment production at Fort Stanton, New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces.

Snedecor, G.W., and W.C. Cochran. 1971. Statistical methods. Iowa State Univ. Press, Ames, Ia.

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

Stoddard, L.A., A.D. Smith, and T.W. Box. 1975. Range management. McGraw-Hill Book Co., New York.

Thurow, T.L. 1985. Hydrologic interrelationships with vegetation and soil as affected by selected livestock grazing systems and climate on the Edwards Plateau. Ph.D. Diss., Texas A&M Univ., College Station.

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

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

Warren, S.D., W.H. Blackburn, and C.A. Taylor, Jr. 1986a. Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing. J. Range Manage. 39: (In press).

Warren, S.D., M.B. Nevill, W.H. Blackburn, and N.E. Garza. 1986b. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Amer. J. 39: (In press).

Warren, S.D., T.L. Thurow, W.H. Blackburn, and N.E. Garza. 1986c. The influence of livestock trampling under short-duration grazing on soil hydrologic characteristics. J. Range Manage. 39:491-495.

Weltz, M. 1983. The influence of short duration and continuous grazing on infiltration rate and sediment yield in southcentral New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces.

Willatt, S.T., and D.M. Pullar. 1983. Changes in soil physical properties under grazed pastures. Aust. J. Soil Res. 22:343-348.

Witschi, P.A., and D.L. Michalk. 1979. The effect of sheep treading and grazing on pasture and soil characteristics of irrigated annual pastures. Aust. J. Agr. Res. 30:741-750.

Wood, M.K. 1980. Impacts of grazing systems on watershed values, p. 163-170. *In:* K.C. McDaniel and C. Alllison (eds), Grazing Management Systems for Southwest Rangelands. New Mexico State Univ., Las Cruces.

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

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

Wood, M.K., and W.H. Blackburn. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. J. Range Manage. 37:303-308.

Wood, M.K., W.H. Blackburn, F.E. Smeins, and W.A. McGinty. 1978. Hydrologic impacts of grazing systems, p. 288-291. *In:* Proceedings of the First Internat. Range Congr. Soc. Range Manage., Denver, Colo.

The Influence of Livestock Trampling under Intensive Rotation Grazing on Soil Hydrologic Characteristics

S.D. WARREN, T.L. THUROW, W.H. BLACKBURN, AND N.E. GARZA

Abstract

Infiltration rate decreased significantly and sediment production increased significantly on a site with a silty clay surface soil devoid of vegetation following periodic trampling typical of intensive rotation grazing systems. The deleterious impact of livestock trampling generally increased as stocking rate increased. Damage was augmented when the soil was moist at the time of trampling. Thirty days of rest were insufficient to allow hydrologic recovery. Soil bulk density, aggregate stability, aggregate size distribution and surface microrelief were related to the soil hydrologic response of the trampling treatments.

Many of the world's rangelands evolved in the presence and under the influence of grazing ungulates. However, the introduction and maintenance of domestic livestock on continuously or rotationally grazed pastures has the potential for altering botanical composition and cover (Ellison 1960) and soil physical properties (Klemmedson 1956, Reed and Peterson 1961). Modification of those parameters, either singly or in concert, may accelerate the natural erosion process and result in decreased on-site productivity, increased sediment production, and increased susceptibility of downstream flooding. As stocking rates of domestic livestock are increased under continuous year-long or season-long grazing, rainfall infiltration generally decreases while runoff and sediment loss increase (Alderfer and Robinson 1947, Rauzi and Hanson 1966, Rhoades et al. 1964). Heavy continuous grazing is generally detrimental to soil hydrologic characteristics, while the effects of moderate or light continuous grazing are significantly less deleterious and frequently not significantly different from each other (Blackburn 1984, Gifford and Hawkins 1978).

Supporters of intensive rotation grazing (IRG) systems such as the short-duration grazing method propose that heavy stocking rates under some forms of rotational grazing may be advantageous to the range ecosystem (Savory 1978, 1979). Under IRG, large numbers of livestock are concentrated on small areas for short periods of time, creating a "herd effect" or intensive trampling of the soil surface. Proponents of IRG contend that this "hoof action" will enhance infiltration of rainfall into the soil and reduce erosion, even when conventional stocking rates are doubled or tripled (Goodloe 1969, Savory 1983, Savory and Parsons 1980).

Previous reviews of the impacts of grazing systems on watershed characteristics have concluded that there are no consistently significant advantages to be accrued by implementing specialized grazing systems (Blackburn 1984, Gifford and Hawkins 1976, Shiflet and Heady 1971, Van Poollen and Lacey 1979). Heavy stocking rates are almost universally detrimental to rainfall infiltration and sediment loss, regardless of the grazing system in use (Blackburn 1984; Gamougoun et al. 1984; McCalla et al. 1984a, 1984b; Pluhar 1984; Smith 1980; Thurow 1987, Weltz 1983). Unfortunately, it is often unclear if the effects are caused by livestock hooves on the soil surface or by the removal of vegetation which would otherwise protect the soil from raindrop impact, increase soil porosity through root activity, and provide an organic substrate for soil arthropod and microbe activity.

Several studies have attempted to determine the impacts of livestock trampling in the absence of concomitant removal of vegetation, and have generally concluded that trampling compacts the soil, reduces rainfall infiltration rates, and increases soil erosion. Busby and Gifford (1981), Dadkhah and Gifford (1980), and Packer (1953) used mechanical trampling devices which imitated the compacting force of a livestock hoof but did not provide a rocking or churning effect caused by a hoof when walking. Bryant et al. (1972) used live animals, but neither they nor the former researchers related the degree of trampling disturbance to that which would occur in an intensive rotation grazing system. Edmond (1958, 1963, 1964) and Witschi and Michalk (1979) used sheep to reproduce the equivalent of a single day of grazing at several stocking rates. However, the studies were conducted on fertilized, irrigated pastures, a situation which is atypical of most of the world's rangelands. Albeit ungrazed, the ameliorating presence of live plant cover was present in all of the aforementioned studies.

The objective of this study was to evaluate the effect that livestock trampling has on infiltration rates and sediment production when a bare soil is subjected to trampling intensities incurred under

Authors are presently environmental research scientist, USA-CERL, Environmental Divison, P.O. Box 4005, Champaign, Ill. 61820; range research scientist, P.O. Box 2954, Mogadishu, Somalia; professor of watershed management, Department of Range Science, Texas A&M University, College Station 77843; and research associate, Texas Agricultural Experiment Station, Sonora 76950. At the time of research the principal and second authors were graduate research assistants, Texas A&M University.

This study was a cooperative project between U.S. Department of Agriculture and Texas Agricultural Experiment Station. Financial support of the Soil Conservation Service RCA Special Study and a Science/Education Grant is acknowledged.

Published with approval of the Director, Texas Agricultural Experiment Station as TA-20824.

Manuscript accepted 7 July 1986.

an intensive rotation grazing system, in order to test the hypothesized beneficial effects of the "herd effect" or "hoof action." The study was conducted on a bare soil to remove confounding effects due to variability in vegetative cover and botanical composition.

Study Area

Research was conducted at the Texas Agricultural Experiment Station near Sonora, Texas (31°N; 100°W). The study site had been protected from grazing and all other cultural activity for 7 years. The soil was a Kavett series (montmorillonitic, thermic, shallow Petrocalcic Calciustoll); all horizons above the root-restricting petrocalcic horizon at 25–50 cm depth were of silty clay texture. The solum was characterized by a high shrink-swell capacity and a relatively high organic matter content (>4%). Slopes were negligible (<3%). During previous years, the site supported a moderate cover of annual forbs. However, during the spring of 1984, the site was treated with 2,4-D. The herbicide, coupled with a severe summer drought, kept the site free from vegetation.

Methods

Trampling Rates

In order to accurately recreate the number of hoof impacts caused by a livestock herd per unit area per day, digital pedometers similar to those used by Walker et al. (1985) were placed on 5 Brangus heifers while they grazed with a livestock herd on a 32-ha pasture from a moderately stocked, 14-pasture intensive rotation grazing system at the Sonora Experiment Station. The pedometers were precalibrated and fastened to the foreleg metacarpus of each heifer with a plastic leg band. It was felt that distance measurements obtained from the pedometers might be inaccurate given the stride variability of any given animal when engaged in different activities such as traveling, foraging, or loafing (Anderson and Kothmann 1980, Walker et al. 1985). Therefore, the mean daily pedometer reading was multiplied by the number of heifers required to stock the intensive rotation system at a moderate rate and then divided by the area of the pasture. The resulting value was used to determine the necessary pedometer reading when recreating hoof impacts per unit area at the study site.

Four rates of trampling intensity were imposed on small paddocks (110 m^2) in a split-plot design at the study area. They included moderate (1x) (8.1 ha/AU/yr), double (2x) (4.1 ha/AU/yr), triple (3x) (2.7 ha/AU/yr), and no trampling (Ex). Each treatment was replicated 3 times. Treatments were repeated 5 times at 30-day intervals, commencing on 20 May and concluding on 20 September. At each sample date, prior to trampling, half of each paddock was wetted by sprinkling with approximately 10 mm of water in order to facilitate a comparison of the effect of trampling under both moist and dry conditions. Four heifers averaging 240 kg were used to create hoof impacts on the small paddocks. The heifers were forced to walk within the paddocks until the sum of their pedometer readings equaled the value that would be recorded by an entire herd at a given stocking rate on an equivalent area during a 4-day grazing period.

Infiltration and Sediment

Data on infiltration rate and sediment production were taken from each paddock at the first, third, and last trampling date. A mobile, drip-type rainfall simulator (Blackburn et al. 1974) was used to determine infiltration rate and sediment production from 0.5-m^2 plots before and after trampling at each sample date. Two replications of both dry- and moist-trampled plots were run in each paddock at each sample date. Simulated rainfall was applied at a rate of 203 mm h^{-1} for 45 minutes. The simulated raindrops were 2.5 mm in diameter. Drops falling 2.1 m reach 5.25 m/sec or 71% of the terminal velocity achieved by raindrops in an unlimited fall (Laws 1941). This application rate simulated a storm with a return period of 150 years and was necessary to insure runoff from all plots. Runoff from each plot was pumped regularly into tared holding bottles and weighed at 5-minute intervals throughout the simulated rainfall event. Weights were converted volume measurements, and infiltration rates (mm h^{-1}) were determined by calculating the difference between applied rainfall and runoff. At the termination of each simulated rainfall event, the runoff collected from each plot was thoroughly mixed and a 1-liter subsample was taken. The subsample was filtered through a tared #1 Whatman filter. The sediment retained by the filter was oven-dried, weighed, and converted to sediment yield (kg ha^{-1}) based on total runoff and plot size.

Soil Characteristics

Immediately prior to each simulated rainfall event, soil bulk

Table 1. Mean infiltration rate after 45 minutes and sediment production in relation to trampling intensity, soil water content at the time of trampling, and pre- or post-trample condition on the Edwards Plateau, Texas.[1]

	Infiltration Rate (mm h^{-1})					
	Trampled dry			Trampled moist		
Trampling intensity	Before trampling	After trampling	Mean	Before trampling	After trampling	Mean
0	166a (x)	166a (x)	166a	160a (x)	160a (x)	160a
1X	147b (x)	132b (x)	140b	133b (x)	130b (x)	133b
2X	137b (x)	106c (y)	121c	115bc(y)	83c (z)	99c
3X	134b (x)	101c (yz)	117c	109c (y)	82c (z)	96c
Mean	146 (x)	126 (yz)		129 (y)	114 (z)	
Overall Mean			136 (x)			122 (y)

	Sediment Production (kg ha^{-1})					
	Trampled dry			Trampled moist		
Trampling intensity	Before trampling	After trampling	Mean	Before trampling	After trampling	Mean
0	976a (x)	976a (x)	976a	2007a (x)	2007a (x)	2007a
1X	1829b (x)	3824b (y)	2827b	2998ab(xy)	2752a (xy)	2875a
2X	2272b (x)	4605b (y)	3438b	3542b (xy)	5048b (y)	4274b
3X	2211b (x)	7078c (y)	4788c	4057b (x)	7465c (y)	5861c
Mean	1804 (x)	4122 (z)		3141 (y)	4308 (z)	
Overall Mean			3078 (x)			3811 (y)

[1]Infiltration and sediment means followed by the same letter in a row (x, y, z) or in a column (a, b, c) are not significantly different at the 95% level of significance.

density and soil water content at a depth of 0–50 mm were determined adjacent to the runoff plot by the sand-funnel method (Blake 1965) and gravimetric method (Roundy et al. 1983), respectively. A composite soil sample of the surface 25 mm was collected from the area adjacent to each plot in order to determine aggregate size distribution by the dry sieving method (Kemper and Chepil 1965). The percentage weight of aggregates in size classes of 4.75–2.0, 2.0–1.0, 1.0–0.5, 0.5–0.21, and <.21 mm from an initial 100 g sample were incorporated into the mean-weight diameter equation (Youker and McGuinness 1956) to produce a single value which reflects relative aggregate size distribution. The larger the mean weight diameter value, the greater the proportion of larger aggregates.

Following each simulated rainfall event, soil surface microrelief within each plot was measured with a 10-pin relief meter similar to the one described by Kincaid and Williams (1966). A soil surface sample (0–50 mm) was taken from within each plot, air dried, ground through a 2-mm sieve, and analyzed for aggregate stability by the wet sieve method (Kemper 1965).

Prior to trampling at each date, two 1.0-kg soil samples were taken from both the dry and moist side of each paddock and soil moisture was determined gravimetrically (Roundy et al. 1983).

Analysis

Data were evaluated based on a split-plot design. In order to remove date-to-date variability and variability due to soil water content, while allowing for cumulative trampling effects, infiltration rates and sediment production from non-trampled paddocks at each date were adjusted to the overmean value for all dry, non-trampled paddocks. Infiltration rate and sediment production values for trampled paddocks were adjusted to the same degree as values for non-trampled paddocks at the respective dates. This provided a much clearer representation of treatment differences. Following adjustments, an analysis of variance was conducted to determine differences between moist and dry plots, trampling intensities, and pre- and post-trample conditions in terms of infiltration rate and sediment production. If differences were present, Duncan's multiple comparison test was used to separate the means (Steel and Torrie 1980).

Results and Discussion

Mean infiltration rates were determined after a period of 5, 10, 15, 20, 25, 30, 35, 40, and 45 minutes. Because of similarity of the data for the different time periods, only mean infiltration rate after 45 minutes will be discussed. Across all trampling intensities, mean infiltration rate was significantly higher and sediment production was significantly lower from plots which were trampled dry than from plots which were trampled moist (Table 1). This coincides with previous research which indicates that moist soils are often much more susceptible to compaction than dry soils (Edmond 1962, Lull 1959), especially at the very surface where a thin, impermeable layer may form (Beckmann and Smith 1974). Average soil water content in the surface 20 mm at the time of trampling in this study was 5.1 and 25.2% for the dry and moist plots, respectively. If the amount of water applied to the wetted plots had been increased, even greater disparity may have developed between dry and moist plots.

Infiltration rate was consistently higher and sediment production lower but not necessarily significantly higher or lower, before trampling than after regardless of soil moisture status at the time of trampling (Figs. 1 and 2). The difference between pre- and post-trample infiltration rate and sediment production was generally significant at the higher stocking rates (2x and 3x) but not under a moderate trampling regime (1x) (Table 1). This is consistent with Pluhar (1984), Warren et al. (1986a), and Weltz (1983), who demonstrated that infiltration rates were lower and sediment production was higher immediately following short-term high intensity grazing periods inherent in heavily stocked IRG systems. Pluhar

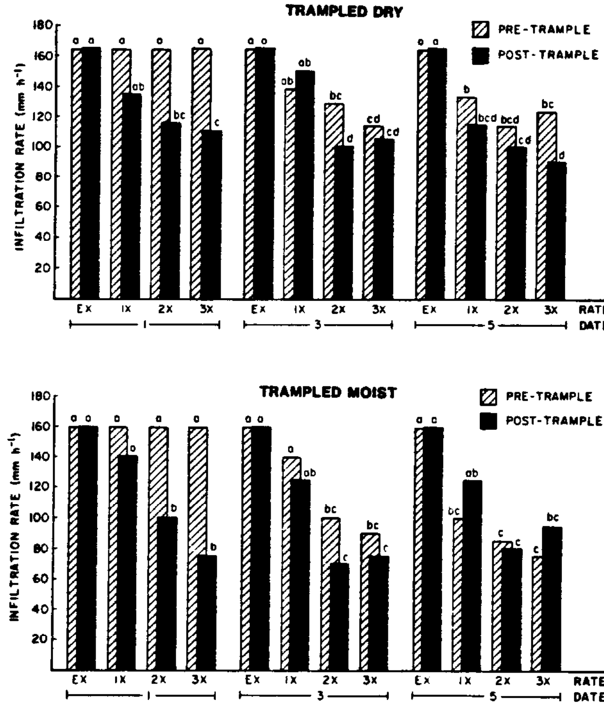


Fig. 1. *Mean infiltration rate after 45 minutes in relation to soil moisture at the time of trampling, pre- or post-trample condition, trampling rate, and sample date on the Edwards Plateau, Texas. (Means with the same letter within the same date and soil moisture status are not significantly different at the 95% level).*

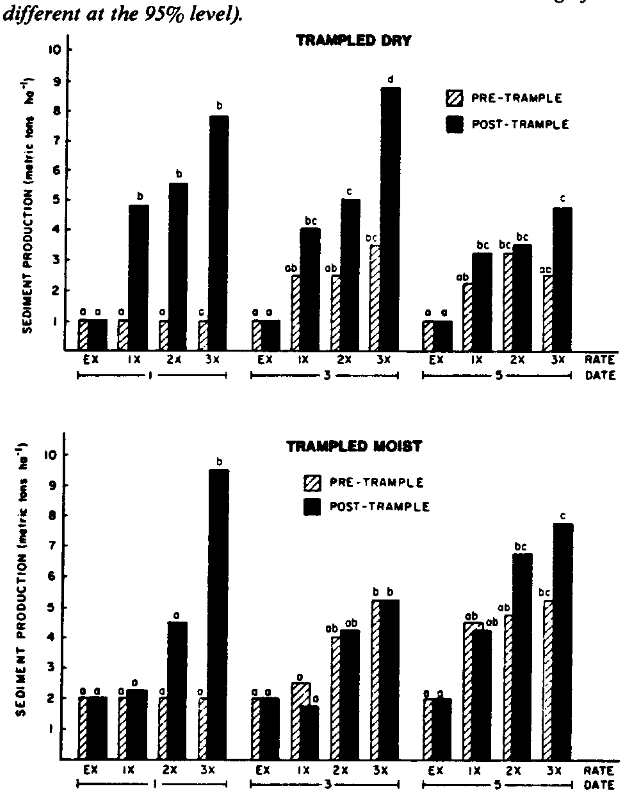


Fig. 2. *Mean sediment production in relation to soil moisture at the time of trampling, pre- or post-trample condition trampling rate, and sample date on the Edwards Plateau, Texas. (Means with the same letter within the same sample date and soil moisture status are not significantly different at the 95% level).*

(1984) and Weltz (1983) attributed the majority of the effect to the removal of standing vegetation. However, where vegetation is sparse, as in many semi-arid and arid regions, or where it is altogether absent as in this study, the effect of trampling must be attributed to changes in soil physical properties (Warren et al. 1986b).

Under both moist and dry soil conditions, trampling at a 1x stocking rate resulted in a significant decline in infiltration rate when compared to the untrampled paddocks (Table 1). A 2x or 3x stocking rate caused an additional significant decline. However, the 2x and 3x stocking rates were not significantly different from each other. Mean sediment production responded in a similar but inverse fashion as stocking rate increased (Table 1). However, unlike infiltration rate, the difference in sediment production between the 2x and 3x stocking rates was significant.

The reduction in hydrologic condition incurred by trampling at the high stocking rates under IRG did not appear to be cumulative. The decline in infiltration rate and increase in sediment production was apparently maximized by the third trampling date (Fig. 1 and 2). Some recovery of the soil appeared to occur during the 30-day rest periods as evidenced by higher pre-trample infiltration rates and lower pre-trample sediment production than the previous post-trample condition, even at the last sample date. Under the dry conditions encountered in this study, recovery was minimal and under no circumstances did infiltration rate or sediment production on the more heavily trampled paddocks recover to a level comparable to the trampling exclosures. The time required for significant recovery of soil hydrologic condition was not addressed by the experimental design and remains a viable research opportunity. Previous research on optimum rest periods for rotational grazing has dealt primarily with forage and animal response (Denny and Barnes 1977, Morley 1968, Noy-Meir 1976). Recovery of infiltration rates or sediment production following trampling has seldom been addressed and is easily confounded with recovery of vegetative cover. Recovery of the soil may be especially important in arid, semiarid, and disturbed or overgrazed temperate areas where vegetation is sparse.

Rate of trampling intensity, as well as many soil variables was significantly correlated with infiltration rate and sediment production (Table 2). Soil bulk density was the best predictor of infiltration rate and sediment production, regardless of soil moisture

Table 2. Simple correlation coefficients of variables correlated with mean infiltration rate after 45 minutes and sediment production on soil trampled dry and moist on the Edwards Plateau, Texas.[1]

	Infiltration Rate		Sediment Production	
Variable	Trampled dry	Trampled moist	Trampled dry	Trampled moist
Trample rate	-.45	-.40	.42	.40
Soil bulk density	-.55	-.64	.65	.64
Soil surface microrelief	.28	.41	-.30	-.34
Soil aggregate stability	.23	.39	-.14 NS	-.53
Aggregate size distribution	.09 NS	-.36	-.21	-.30

[1]Correlation coefficients followed by NS are not significant at the 95% level of significance.

condition at the time of trampling. It is well established that heavy stocking rates under continuous grazing lead to increased bulk density and, in turn, to reduced infiltration rates and increased sediment production (Alderfer and Robinson 1947, Knoll and Hopkins 1959, Rauzi and Hanson 1966). These results indicate that a similar response can be expected under IRG systems.

Soil surface microrelief was also significantly correlated to infiltration rate and sediment production (Table 2), although unrelated to trampling rate (Warren et al. 1986b). Natural undulations and depressions on the soil surface may slow overland flow allowing more water to infiltrate and causing deposition of suspended soil particles.

Size and stability of soil aggregates are generally closely related to soil hydrologic response (Free et al. 1940; Wood and Blackburn 1981a, 1981b). Interspaces between large aggregates increase the macroporosity of the soil which, in turn, enhances infiltration rate. As infiltration rate increases, less runoff is available to transport sediment. In addition, large aggregates are less likely to be transported by surface runoff water. Unstable aggregates, which are easily disrupted by raindrop impact, may clog soil pores causing a reduction in infiltration and an increase in sediment production. Both aggregate size distribution and aggregate stability were significantly correlated to soil hydrologic response in this study (Table 2). However, contrary to the predicted response, aggregate size distribution was negatively correlated to infiltration rate and positively correlated to sediment production on soil which was trampled while moist. This was caused by the formation of large, comparatively impermeable clods when the soil was compacted while moist (Warren et al. 1986b).

Literature Cited

Alderfer, R.B., and R.R. Robinson. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Amer. Soc. Agron. 39:948-958.

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

Beckmann, G.G., and K.J. Smith. 1974. Micromorphological changes in surface soils following wetting, drying and trampling, p. 832-845. *In:* G.K. Rutherford (ed), Soil Microscopy: Proceedings of the Fourth Internat., Working-meeting on Soil Micromorphology. The Limestone Press, Kingston, Ontario.

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses, p. 927-983. *In:* Developing Strategies for Rangeland Management. Nat. Res. Council/ Nat. Acad. Sci.. Westview Press, Boulder, Colo.

Blackburn, W.H., R.O. Meeuwig, and C.M. Skau. 1974. A mobile infiltrometer for use on rangeland. J. Range Manage. 27:322-323.

Blake, G.R. 1965. Bulk density, p. 374-390. *In:* C.A. Black (ed), Methods of Soil Analysis, Part I. Amer. Soc. Agron. Madison, Wis.

Bryant, H.T., R.E. Blaser, and J.R. Peterson. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a Meadowville loam. Agron. J. 64:331-334.

Busby, F.E., and G.F. Gifford. 1981. Effects of livestock grazing on infiltration and erosion rates measured on chained and unchained pinyon-juniper sites in southeastern Utah. J. Range Manage. 34:400-405.

Dadkhah, M., and G.F. Gifford. 1980. Influence of vegetation, rock cover and trampling on infiltration rates and sediment production. Water Resources Bull. 16:979-986.

Denny, R.P., and D.L. Barnes. 1977. Trials of multi-paddock grazing systems on veld. 3. A comparison of 6 grazing procedures at 2 stocking rates. Rhodesia J. Agr. Res. 15:129-142.

Edmond, D.B. 1958. The influence of treading on pasture: A preliminary study. N.Z. J. Agr. Res. 1:319-329.

Edmond, D.B. 1962. Effects of treading pasture in summer under different soil moisture levels. N.Z. J. Agr. Res. 5:389-395.

Edmond, D.B. 1963. Effects of treading perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures in winter and summer at two soil moisture levels. N.Z. J. Agr. Res. 6:265-276.

Edmond, D.B. 1964. Some effects of sheep treading on the growth of 10 pasture species. N.Z. J. Agr. Res. 7:1-16.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26:1-78.

Free, G.R., G.M. Browning, and G.W. Musgrave. 1940. Relative infiltration and related physical characteristics of certain soils. USDA Tech. Bull. 729.

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

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

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

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

Kemper, W.D. 1965. Aggregate stability, p. 511-519. *In:* C.A. Black (ed), Methods of Soil Analysis, Part 1. Amer. Soc. Agron., Madison, Wis.

Kemper, W.D., and W.S. Chepil. 1965. Size distribution of aggregates, p. 499-510. *In:* C.A. Black (ed), Methods of Soil Analysis, Part 1. Amer. Soc. Agron. Madison, Wis.

Kincaid, D.R., and G. Williams. 1966. Rainfall effects on soil surface characteristics following range improvement treatments. J. Range Manage. 19:346-351.

Klemmedson, J.O. 1956. Interrelations of vegetation, soils and range conditions induced by grazing. J. Range Manage. 9:134-138.

Knoll, G., and H.H. Hopkins. 1959. The effects of grazing and trampling upon certain soil properties. Trans. Kansas Acad. Sci. 62:221-231.

Laws, J.O. 1941. Measurements of the fall-velocity of water-drops and raindrops. Trans. Amer. Geophysical Union 22:709-721.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA Misc. Pub. 768.

McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984a. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:265-269.

McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984b. Effects of livestock grazing on sediment production, Edwards Plateau of Texas. J. Range Manage. 37:291-294.

Morley, F.H.W. 1968. Pasture growth curves and grazing management. Aust. J. Exp. Agr. and Anim. Husb. 8:40-45.

Noy-Meir, I. 1976. Rotational grazing in a continuously growing pasture: A simple model. Agr. Systems 1:87-112.

Packer, P.E. 1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. Forest. 51:28-31.

Pluhar, J.J. 1984. Hydrologic impacts of selected grazing systems on the Texas Rolling Plains. M.S. Thesis, Texas A&M Univ., College Station.

Rauzi, F. and C.L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Manage. 19:351-356.

Reed, M.J., and R.A. Peterson. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. USDA Tech. Bull. 1252.

Rhoades, E.D., L.F. Locke, H.M. Taylor, and E.H. McIlvain. 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. J. Range Manage. 17:185-190.

Roundy, B.A., J.A. Young, G.J. Cluff, and R.A. Evans. 1983. Measurement of soil water on rangelands. USDA Agr. Res. Service, Agr. Res. Results, Western Ser. 31.

Savory, A. 1978. A holistic approach to ranch management using short duration grazing, p. 555-557. *In:* Proceedings of the First Internat. Range. Cong., Soc. Range Manage., Denver, Colo.

Savory, A. 1979. Range management principles underlying short duration grazing, p. 375-379. *In:* Beef Cattle Science Handbook. Agriservices Foundation, Clovis, CA.

Savory A. 1983. The Savory grazing method or holistic resource management. Rangelands 5:155-159.

Savory, A., and S.D. Parsons. 1980. The Savory grazing method. Rangelands 2:234-237.

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

Smith, R.P. 1980. The influence of different grazing practices on infiltration rates and sediment production at Fort Stanton, New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces, NM.

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

Thurow, T.L. 1987. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas J. Range Manage. 40:(In press).

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

Walker, J.W., R.K. Heitschmidt, and S.L. Dowhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. J. Range Manage. 38:90-93.

Warren, S.D., W.H. Blackburn, and C.A. Taylor, Jr. 1986a. Effects of season and stage of rotation cycle on hydrologic condition of rangeland under intensive rotation grazing. J. Range Manage. 39:486-491.

Warren, S.D., M.B. Neville, W.H. Blackburn, and N.E. Garza. 1986b. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Amer. J. (50): (In press).

Weltz, M. 1983. The influence of short duration and continuous grazing on infiltration rate and sediment yield in southcentral New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces, NM.

Witschi, P.A., and D.L. Michalk. 1979. The effect of sheep treading and grazing on pasture and soil characteristics of irrigated annual pastures. Aust. J. Agr. Res. 30:741-750.

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

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

Youker, R.E., and J.L. McGuinness. 1956. A short method of obtaining mean weight-diameter values of aggregate analyses of soils. Soil Sci. 83:291-294.

Graduate Student Papers

Papers accepted for presentation by graduate students or recent graduates reporting graduate study research are eligible for a cash award contest to be held for the first time by SRM at the Idaho meeting. Papers will be evaluated as they are presented in their respective sessions by appointed judges, and winners selected according to cumulative scores by the judges.

Students interested in participating or inquiring about the contest should write: Pete W. Jacoby, Jr., Texas Agricultural Experiment Station, P.O. Box 1658, Vernon, TX 76384.

Disappearance of Forage Under Short Duration and Seasonlong Grazing

DONALD R. KIRBY, MARK F. PESSIN, AND GARY K. CLAMBEY

Abstract

A study was conducted in 1982 and 1983 at the Dickinson Experiment Station, North Dakota, in the mixed grass prairie to determine the effects of short duration grazing (SDG) and repeated seasonlong grazing (RSLG) by cattle on graminoid, forb, and half-shrub disappearance. Five range sites were delineated within each grazing treatment and evaluated for forage availability and disappearance. Graminoid disappearance was similar, regardless of grazing treatment, each year of the study. However, forb disappearance (i.e., utilization) increased three-fold in 1982 and more than two-fold in 1983 on the SDG treatment as compared to the RSLG treatment. Half-shrub availability and disappearance were negligible both years of the study. Spatial distribution of grazing among range sites on treatments must be evaluated with caution due to limitations in study design. Treatments were not equal-sized or replicated, and area, productivity potential, and distribution of range sites within treatments varied. Despite these limitations, no consistent pattern of site preference was discernible on either grazing treatment. In addition, a greater stocking rate (75%) and density (1400%) on the SDG treatment did not improve grazing distribution as measured by forage disappearance among the diverse range sites present.

Grazing management and systems have been the most important management practices implemented for improving rangelands (Kothmann 1980). Specialized systems such as short duration grazing have been hypothesized as contributing to range improvement by altering livestock distribution (Savory and Parsons 1980, Malecheck and Dwyer 1983). Defoliation patterns of native grass species by cattle have been reported for individual plants or plant parts under various grazing intensities (Gammon and Roberts 1978a, 1978b, 1978c; Hodgkinson 1980; Briske and Stuth 1982). Defoliation patterns among sites on grazed lands have generally emphasized specialized habitats or sites such as riparian (Johnson 1965, Bryant 1982, Gillen et al. 1985) and forested habitats (Hedrick et al. 1968, Miller and Krueger 1976, Roath and Krueger 1982, Gillen et al. 1984) or mountainous sites (Mueggler 1965, Cook 1966, Patton 1971). Information on the influence of grazing systems on cattle use among a variety of grassland plant communities (range sites) is lacking.

The objective of this study was to determine the effects of short duration (SDG) and repeated seasonlong cattle grazing (RSLG) on disappearance of plant classes and species on 5 range sites in the mixed grass prairie of western North Dakota.

Materials and Methods

The study was conducted on section 16 of the Dickinson Experiment Station approximately 35 km northwest of Dickinson, North Dakota. Average precipitation for the study area is 39 cm, with 80% received between April and September. Total precipitation was 64 and 39.5 cm in 1982 and 1983, respectively. Average daily temperature for the study area is 4° C, with a high of nearly 27° C in July and a low of −13° C in January. The growing season averages 120 days (USDA, SCS 1982). The taxa represented were typical of the mixed-grass prairie (Whitman and Wali 1975).

Five range sites, thin claypan (Tcp), shallow (Sh), sandy (Sa), silty (Si) and clayey (Cl) (USDA, SCS 1982), comprised nearly all of section 16. Average forage production is 780, 1,680, 2,352, 2,240 and 2,240 kg/ha for the Tcp, Sh, Sa, Si, and Cl sites, respectively. The Tcp site is gently sloping with deep soil, but root and moisture penetration is restricted by a subsoil natric horizon at a depth of approximately 8 cm. The Si site, located on the uplands, is composed of moderately deep to deep soils. Being on the uplands, the soils on this site are moderately well to well drained. Soils of the Sa site are moderately deep and well drained. This site is located on side slopes of uplands. The Sh range site is located on the uplands. Soils are shallow to moderately deep and well drained to excessively well drained. This site has very low available water capacity. The Cl range site is also located on uplands and is gently sloping. Soils on this site are moderately well drained to well drained. Total elevation difference between sites was approximately 35 m with slope varying from 0 to 10%. Range condition was high fair to low good on all sites at the initiation of the study. The study area (3 paddocks) under the SDG treatment was comprised of 34, 21, 8, 18, and 19%, respectively, of the Tcp, Sh, Sa, Si, and Cl range sites, while the RSLG treatment was comprised of 12, 32, 4, 20, and 32%, respectively, of the same sites.

Grazing Treatments

Section 16 was divided into 2 equal-sized grazing treatments in June 1981. Prior to this, the section was grazed seasonlong as part of a registered cattle operation. The western 130 ha were grazed continuously seasonlong. An 8-pasture, 1-herd short duration grazing system was implemented in the eastern 130 ha, with the 8 equal-sized paddocks radiating out from a central water and handling facility. The paddocks were managed on a 5-day graze and 35-day rest schedule throughout the grazing season on SDG paddocks. Each paddock in the SDG treatment was grazed 3 to 4 times per season depending upon the length of the grazing season. Stocking rate was 20 cow/calf pairs (0.67 AUM/ha) on the RSLG treatment, as recommended by SCS guidelines, and 35 cow/calf pairs (1.2 AUM/ha) on the SDG treatment. Grazing was initiated June 22 and 17 and terminated October 12 and 26 in 1982 and 1983, respectively, concluding 112 and 131 day grazing seasons.

Forage Production and Disappearance

The 5 range sites were delineated within each grazing treatment (3 adjacent paddocks on the SDG treatment) and 10 portable exclosures were randomly allocated at each site on both grazing treatments. Each range site was chosen between 200 to 600 m from a watering point. Availability of graminoids, forb, and half-shrub by class and species was estimated at the initiation and termination of grazing trials and every 40 days during the trials by clipping two 0.25-m^2 plots in each exclosure. Forage samples were oven-dried and availability reported on a dry weight basis. Exclosures were moved following each sampling. Forage disappearance was estimated by clipping 20 uncaged 0.25-m^2 plots on each site of each treatment. Each uncaged plot was "paired" with a caged plot following each availability estimate. The difference in dry weight between each caged and uncaged paired plot was summed and used to estimate percent forage disappearance.

T-tests were used to determine differences in total graminoid, forb, and half-shrub availability and disappearance between sim-

Authors are assistant professor and research assistant, Animal and Range Sciences Department; and assistant professor, Department of Botany, North Dakota State University, Fargo, 58105.

The authors gratefully acknowledge Mr. Tom Conlon, superintendent, Dickinson Experiment Station, and Mr. Clayton Haugse, chairman, Animal and Range Sciences Department, North Dakota University, for their assistance in this study.

Published with the approval of the Director, North Dakota Agricultural Experiment Station TA-1479.

Manuscript accepted 7 July 1986.

ilar range sites on the 2 grazing treatments (Steel and Torrie 1960).

Results

Precipitation for the 2 study years was highly variable. In 1982, 64 cm of precipitation were recorded for the year with almost 18 cm falling during May and early June and over 16 cm falling in late October and November. The following year, 1983, was near average with 39.5 cm of precipitation recorded for the year and only 12 cm falling during May and early June. Because of these differences, data for the 2 years were analyzed separately.

Availability and disappearance of the 3 classes of forage were summarized by year, site, and grazing treatment (Table 1). Comparison of forage availability on corresponding sites between the grazing treatments indicated similar availabilities with 3 exceptions. The Si site in 1982 and the Si and Cl sites in 1983 had significantly more forage available on the RSLG treatment than the SDG treatment.

Graminoid and total herbaceous availability increased on both grazing treatments from 1982 to 1983. Several conditions led to this increase. Despite receiving above-average growing season precipitation in 1982, spring growth on both treatments was retarded from the lack of soil moisture stored from a dry 1981 (21.5 cm precipitation). Following the growing season in 1982, over 16 cm precipitation was received between October and December and presumably stored in the soil. This previously stored soil moisture coupled with the near-average precipitation received in 1983 resulted in favorable growing conditions as evidenced by the increased graminoid availability in 1983 when compared to 1982 (Table 1).

In contrast, forb and half-shrub availability decreased from 1982 to 1983 on both grazing treatments. The timing of growing season precipitation may account for this. Plentiful May and June precipitation was received in 1982 resulting in strong growth of broad-leaved herbaceous plants. Early season precipitation fell sparingly in 1983. Broad-leaved herbaceous plants did not respond well to this delayed spring-summer precipitation (Table 1).

Mean graminoid disappearance (%) was similar, between the 2 grazing treatments, each year of the study (Table 1). However, percentage forb disappearance was three-fold higher in 1982 and more than two-fold higher in 1983 on the SDG when compared to the RSLG. Interestingly, despite the drop in forb production, percentage forb disappearance was similar on both grazing treatments from year to the next. Half-shrub production was negligible both years and does not warrant further discussion.

Total forage disappearance (%) was similar between the 2 grazing treatments each year, despite the SDG treatment being stocked at a 75% greater rate. The increased disappearance on both grazing treatments from 1982 to 1983 was a reflection of the decreased forb availability from one year to the next.

Of the 3 forage classes, graminoids were the major forage available and had the highest percentage disappearance (i.e., utilization) throughout the study period regardless of grazing treatment (Table 2). Graminoid availability increased on range sites from 1982 to 1983 over both grazing treatments, with the exception of the Tcp site on the RSLG treatment. Graminoids contributing significantly both years to forage on grazing treatments were the cool-season wheatgrasses (*Agropyron* spp.), needlegrasses (*Stipa* spp.), and sedges (*Carex* spp.), and the warm-season short grass blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud). In addition, cool-season short grasses, mainly junegrass (*Koeleria pyramidata* (Lam.) Beauv.), contributed greatly to production and disappearance in 1983.

Over the study period, significant differences were determined in availability of graminoids between similar range sites on the 2 grazing treatments (Table 2). In 1982 significantly more graminoids were available on the Si site of the RSLG treatment when compared to the same site on the SDG treatment. The Si and Cl sites on the RSLG treatment in 1983 were evaluated as having significantly greater graminoid availability when compared to the similar sites in the SDG treatment. These differences are a result of selection of sampling sites at the initiation of the trial and should not be attributed to grazing treatment.

Significant differences in graminoid disappearance were found between the 2 grazing treatments on most sites (Table 2). In 1982, graminoid disappearance was significantly higher on the Tcp and Si sites and significantly lower on the Sa site of the SDG treatment when compared to the RSLG treatment. The following year, 1983, graminoid disappearance was significantly higher on the Sa and Cl and significantly lower on the Sh and Si range sites of the SDG treatment when compared to the RSLG treatment.

Percentage graminoid disappearance also varied greatly each year between range sites within grazing treatments (Table 2). Graminoid disappearance during 1982 ranged from 22 to 50% among sites on the SDG treatment and 7 to 57% on the RSLG treatment. Only 1 site, the Tcp in the RSLG treatment, was determined as being nearly unutilized. Graminoid disappearance was only 7% on this site in 1982. During 1983 graminoid disappearance ranged

Table 1. Availability (kg/ha) and % disappearance in parentheses of forage on five range sites grazed under short duration (SDG) and repeated seasonlong (RSLG) grazing treatments on the Dickinson Experiment Station.[1]

Range Site	Plant Class							
	Graminoid		Forb		Half Shrub		Total	
	SDG	RSLG	SDG	RSLG	SDG	RSLG	SDG	RSLG
1982								
Tcp	582 (22a)	779 (7b)	370 (21a)	381 (6b)	179 (0)	66 (3)	1097 (18)	1226 (2)
Sh	657 (24)	530 (30)	620 (11)	576 (7)	77 (0)	159 (3)	1354 (17)	1265 (16)
Sa	1519 (29a)	1460 (57b)	491 (10a)	403 (2b)	211 (9a)	243 (1b)	2221 (23)	2106 (40)
Si	1305a(50a)	2382b(24b)	769 (4)	1094 (2)	134 (2)	26 (0)	2203a(31)	3502b(17)
Cl[2]	—	—	—	—	—	—	—	—
Mean[3]	725 (37)	1168 (36)	483 (18)	681 (6)	142 (1)	109 (5)	1350 (26)	1958 (24)
1983								
Tcp	595 (41)	747 (38)	172a(21)	470b(19)	64 (10)	31 (1)	831 (34)	1248 (30)
Sh	1218 (43a)	1637 (63b)	153 (11)	117 (3)	16 (0)	39 (0)	1387 (39)	1793 (58)
Sa	2035 (81a)	1815 (46b)	160 (11)	202 (2)	91 (17a)	104 (4b)	2286 (74)	2121 (40)
Si	1724a(32a)	2835b(61b)	250 (2)	218 (1)	61 (2)	32 (0)	2035a(27)	3085b(56)
Cl	1172a(74a)	2158b(36b)	182 (25a)	183 (6b)	19 (25)	14 (1)	1373a(67)	2355b(33)
Mean	998 (41)	1944 (41)	167 (17)	204 (7)	43 (9)	31 (1)	1208 (36)	2179 (37)

[1]Forage totals and means of availabilities and disappearance in the same row and range site followed by a different letter are significantly different ($P \leq 0.05$), t-test).
[2]Not sampled.
[3]Means were determined by multiplying the percentage of each range site on each grazing trial by the forage availability for each site and summing across sites. Means were not statistically analyzed.

Table 2. Availability (kg/ha) and % disappearance in parentheses by species of forage on five range sites for short duration (SDG) and repeated seasonlong (RSLG) grazing treatments on the Dickinson Experiment Station.

	Range Sites									
	Thin claypan		Shallow		Sandy		Silty		Clayey	
Plant class and species[1]	SDG	RSLG	SDG	RSLG	SDG	RSLG	SDG	RSLG	SDG	RSLG
	1982									
Grass and grass-like	582 (22)	779 (7)	657 (24)	530 (30)	1519 (29)	1460 (57)	1300 (50)	2382 (24)	—[3]	—
	±51[2]	±40	±43	±74	±65	±137	±65	±196		
Agropyron spp.	304 (29)	238 (0)	239 (14)	91 (0)	442 (93)	316 (0)	67(0)	777 (78)		
Stipa spp.	14 (0)	117 (73)	46 (67)	127 (94)	267 (58)	265 (48)	332 (49)	515 (60)		
Other cool-season grasses	57 (41)	62 (0)	87 (51)	97 (55)	61 (15)	94 (0)	172 (74)	231 (29)		
Carex spp.	46 (95)	20 (50)	69 (7)	6 (0)	264 (40)	329 (56)	367 (62)	293 (55)		
Bouteloua gracilis	132 (0)	249 (7)	185 (0)	120 (0)	446 (66)	456 (0)	335 (23)	547 (78)		
Other warm-season short grasses	29 (19)	93 (52)	31 (35)	89 (50)	39 (95)		27 (50)	19 (45)		
Forb	370 (21)	381 (6)	620 (11)	576 (7)	491 (10)	403 (2)	769 (4)	1094 (2)	—	—
	±114	±117	±168	±72	±103	±59	±61	±99		
Lotus purshianus	84 (26)	32 (11)	306 (8)	165 (10)	198 (8)	121 (0)	495 (3)	723 (2)		
Lepidium densiflorum	25 (42)	9 (9)	13 (61)	13 (0)	33 (0)	18 (0)	26 (15)	8 (23)		
Plantago eriopoda	56 (13)	39 (17)	61 (15)	14 (23)		18 (12)	45 (0)	75 (9)		
Aster ericoides	27 (50)	8 (0)	16 (31)	6 (0)	12 (14)	13 (8)				
Psoralea argophylla		18 (27)	26 (0)	33 (0)	36 (17)		90 (5)	41 (21)		
Sphaeralcea coccinea		7 (7)	29 (10)	22 (0)	8 (1)	6 (8)	51 (13)	37 (6)		
Melilotus officinalis		7 (65)	11 (24)	13 (46)		9 (71)		24 (25)		
Chenopodium album				99 (11)	19 (11)		25 (32)			
Other	178 (2)	261 (7)	158 (17)	211 (18)	185 (8)	218 (2)	37 (10)	186 (1)		
Half-shrub	179 (0)	66 (3)	77 (0)	159 (3)	211 (9)	243 (1)	134 (2)	25 (0)	—	—
	±31	±32	±16	±31	±52	±31	±42	±10		
Artemisia dracunculus	5 (0)		54 (0)	46 (0)	187 (9)	224 (1)	111 (2)	14 (0)		
Other	70 (0)	41 (2)	23 (0)	113 (4)	24 (7)	19 (0)	23 (0)	11 (0)		
	1983									
Grass and grass-like	595 (41)	747 (38)	1218 (43)	1637 (63)	2035 (81)	1815 (46)	1724 (32)	2835 (61)	1172 (74)	2158 (36)
	±86	±79	±79	±143	±106	±154	±117	±247	±75	±196
Agropyron spp.	135 (66)	138 (61)	16(100)	38 (66)	11(100)	166 (71)	469 (58)	699 (67)	329 (81)	622 (37)
Stipa spp.	14 (100)	18 (83)	249 (71)	342 (62)	448 (92)	367 (74)	230 (43)	260 (57)	141 (95)	204 (73)
Other cool-season grasses	146 (92)	157 (69)	78 (0)	232 (85)	190 (83)	286 (70)	234 (55)	456 (53)	307 (95)	485 (33)
Carex spp.	7 (0)	10 (80)	223 (0)	584 (39)	567 (77)	226 (92)	246 (0)	153 (71)	73 (93)	30 (43)
Warm-season grasses	293 (0)	424 (5)	652 (40)	441 (93)	819 (76)	270 (4)	545 (11)	1267 (59)	322 (32)	817 (28)
Forb	172 (21)	470 (19)	135 (11)	117 (3)	160 (11)	202 (2)	250 (2)	281 (1)	182 (25)	183 (6)
	±25	±101	±43	±36	±30	±68	±21	±41	±32	±25
Lotus purshianus		2 (50)			5 (35)	34 (20)	15 (17)	9 (14)	9 (50)	10 (21)
Plantago eriopoda	19 (38)	17 (31)		3 (0)		4 (0)	12 (24)	6 (0)	21 (13)	10 (28)
Psoralea argophylla		30 (10)	10 (30)	7 (10)	13 (0)	23 (0)	6 (0)	6 (0)	27 (21)	
Sphaeralcea coccinea				2 (0)		18 (15)	24 (15)	25 (22)	26 (33)	14 (26)
Melilotus officinalis		107 (43)								
Other	153 (22)	314 (5)	125 (10)	105 (4)	140 (10)	123 (2)	193 (5)	235 (17)	99 (24)	143 (14)
Half-shrub	64 (10)	31 (1)	16 (0)	39 (0)	91 (17)	104 (4)	61 (2)	32 (0)	19 (25)	14 (1)
	±9	±6	±6	±15	±32	±23	±23	±8	±5	±7
Artemisia dracunculus	33 (19)		15 (0)	17 (0)	79 (19)	97 (5)	51(3)	19 (0)	4 (49)	
Other	31 (6)	31 (4)	1 (0)	24 (0)	12 (0)	7 (0)	10 (0)	13 (0)	15 (25)	14 (1)

[1]Scientific names follow Great Plains Flora Association (1977) or more recent taxonomic considerations.
[2]Standard error of the mean.
[3]Not sampled.

from 32 to 81% among range sites on the SDG treatment and 36 to 63% on the RSLG treatment. In contrast to 1982, cattle utilized a more uniform amount of graminoid species on all sites over both grazing treatments in 1983.

Forb availability declined from 1982 to 1983 on all range sites in both grazing treatments (Table 2). No significant differences in total availability of forbs occurred in 1982 between similar range sites on the 2 grazing treatments. In 1983 only 1 site, the Tcp on the RSLG treatment, was found to have significantly more forb availability than the corresponding site in the SDG treatment. Forb availability was greatest both years on the Si range sites from both grazing treatments, despite these sites having the least diversity of forb species (26). The Sh sites in 1982 and the Tcp sites in 1983 on both treatments produced a significant quantity of forbs besides having the greatest diversity of forbs, 32 and 34 species, respectively.

Few individual forbs consistently contributed to herbaceous production on range sites. Only prairie bird's-foot trefoil (*Lotus purshianus* Clem. & Clem.), silver-leaf scurfpea (*Psoralea argophylla* Pursh), red false mallow (*Sphaeralcea coccinea* (Pursh) Rydb.), and alkali plantain (*Plantago eriopoda* Torr.) were present both years on the majority of sites for both treatments (Table 2). Peppergrass (*Lepidium densiflorum* Schrad.) and white aster (*Aster ericoides* L.) also contributed significantly to forb availability in 1982.

Total forb disappearance in both years was higher for each site in the SDG treatment when compared to the corresponding site in the RSLG treatment (Table 2). However, significantly higher disappearance of forbs on SDG sites occurred only on the Tcp and Sa range sites in 1982 and the Cl site in 1983. In 1982, total forb disappearance exceeded 10% on 3 of 4 range sites monitored on the SDG treatment, while no sites on the RSLG treatment exceeded 10% forb usage. Also in 1983, total forb disappearance exceeded

10% on 4 of 5 range sites examined on the SDG treatment, while only 1 site on the RSLG treatment exceeded 10% forb use.

Of the 27 forb species occurring in common on the corresponding range sites between grazing treatments in 1982, over 60% showed greater disappearance on the SDG treatment (Table 2). In comparing percentage disappearance of the 24 common forb species in 1983, 75% had higher percentage disappearance on the SDG treatment when compared to the RSLG treatment.

Half-shrub availability was limited on all sites and treatments in 1982 and less on all sites and treatments in 1983 when compared to 1982 (Table 2). No differences in availability of half-shrubs were determined in either year between range sites on the 2 grazing treatments. The Sa site both years produced the most half-shrubs, mainly green sage (*Artemisia dracunculus* L.), on the 2 grazing treatments.

Significant differences in disappearance of half-shrubs were determined both years only for the Sa site on grazing treatments (Table 2). More half-shrub disappearance, mainly green sage, occurred on the SDG treatment when compared to the RSLG treatment.

Discussion

Graminoids were the major forage available and had the greatest percentage disappearance (i.e., utilization) throughout the study regardless of grazing treatment. These results were not unexpected as cattle diets have generally been reported as being comprised mainly of graminoid species (Cook and Harris 1968, Rosiere et al. 1975, Allison et al. 1977, Kirby and Stuth 1982). The major graminoids available and contributing to livestock production were the wheatgrasses, needlegrasses, blue grama and other warm-season shortgrasses, and sedges.

Forbs and half-shrubs in addition to graminoids can be important contributors to cattle diets, especially early in the grazing season (Thetford et al. 1971, Buchanan et al. 1972, Allison and Kothmann 1979, Uresk and Paintner 1985). However, when dealing with forbs and half-shrubs at the species level in studies such as this, results are less conclusive because of annual variations in growth. In addition difficulties are also encountered in matching forb and half-shrub species composition in paired plots. These problems limit conclusions at the species level.

Forb diversity among range sites ranged from 26 to 34 species. Despite this diversity few individual species were grazed in quantity by cattle on either grazing treatment. Prairie bird's-foot trefoil, lamb's quarters (*Chenopodium album* L.), and yellow sweet clover (*Melilotus officinalis* (L.) Lam.) were the only forbs available in quantity and utilized consistently over the trial by cattle. Less consistently red false mallow, alkali plantain, and white aster were utilized by cattle on the grazing treatments.

Interpretation of grazing distribution among sites within and between treatments is made difficult by the study design. In the design grazing treatments were not replicated, pasture size and the percentages of high and low forage producing sites and their spatial relationship varied between treatments, and stocking rate and density also differed between treatments. Despite these limitations, spatial distribution of grazing requires discussion.

No consistent pattern of site preference was discernible from our data. Percentage graminoid and forb disappearance among sites within grazing treatments, and between similar sites across grazing treatments, showed no consistent trend. These results might not be unexpected as all study sites were dominated by graminoid species, easily accessible, and near watering points.

Increased stocking density has been associated with improved livestock grazing distribution in intensively managed grazing systems (Kothmann 1980). Despite the confounding of results by unequal pasture sizes, a greater stocking rate (75%) and density (1400%, 2.15 vs. 0.15 animals/ha) did not improve grazing distribution as measured by forage disappearance among the various range sites under our SDG treatment when compared to a conventional RSLG treatment. In 1982, grazing distribution among sites was more uniform on the SDG treatment when compared to the RSLG treatment. The reverse was observed in 1983. Stocking densities greater than were studied in our SDG design may improve distribution of grazing among diverse range sites. This will need further investigation.

Literature Cited

Allison, C.D., and M.M. Kothmann. 1979. Effect of level of stocking pressure on forage intake and diet quality of range cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 30:174-178.

Allison, C.D., R.D. Pieper, G.D. Donart, and J.D. Wallace. 1977. Fertilization influences cattle diets on blue grama range during drought. J. Range Manage. 30:177-180.

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

Bryant, L.D. 1982. Response of livestock to riparian zone exclusion. J. Range Manage. 35:780-785.

Buchanan, H., W.A. Laycock, and D.A. Price. 1972. Botanical and nutritive content of the summer diet of sheep on a tall forb range in southwestern Montana. J. Anim. Sci. 35:423-430.

Cook, C.W. 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manage. 19:200-204.

Cook, C.W., and L.E. Harris. 1968. Nutritive value of seasonal ranges. Utah Agr. Exp. Sta. Bull. 472.

Gammon, D.M., and B.R. Roberts. 1978a. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia. 1. Selectivity of grazing. Rhod. J. Agr. Res. 16:117-131.

Gammon, D.M., and B.R. Roberts. 1978b. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia. 2. Severity of defoliation. Rhod. J. Agr. Res. 16:133-145.

Gammon, D.M., and B.R. Roberts. 1978c. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia. 3. Frequency of defoliation. Rhod. J. Agr. Res. 16:147-164.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. J. Range Manage. 37:549-553.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1985. Cattle use of riparian meadows in the Blue Mountains of northeastern Oregon. J. Range Manage. 38:205-209.

Great Plains Flora Association. 1977. Atlas of the flora of the Great Plains. T.M. Barkley (ed.) Iowa State Univ. Press, Ames.

Hedrick, D.W., J.A. Young, J.A.B. McArthur, and R.F. Keniston. 1968. Effects of forest and grazing practices on mixed coniferous forests of northeastern Oregon. Oregon Agr. Exp. Sta. Tech. Bull. 103.

Hodgkinson, K.C. 1980. Frequency and extent of defoliation of herbaceous plants by sheep in a foothill range community in northern Utah. J. Range Manage. 33:164-169.

Johnson, W.M. 1965. Rotation, rest-rotation, and season-long grazing on mountain range in Wyoming. USDA Forest Serv. Res. Pap. RM-14.

Kirby, D.R., and J.W. Stuth. 1982. Botanical composition of cattle diets grazing brush managed pastures in east-central Texas. J. Range Manage. 35:434-436.

Kothmann, M.M. 1980. Evaluation of livestock needs on designing grazing systems for rangeland. Chap. 6 Part B. *In:* Digestive Physiology and Nutrition of Ruminants, D.C. Church (ed.), Vol. 3 O & B Books, Inc. Corvallis, Ore.

Malechek, J.C., and D.D. Dwyer. 1983. Short-duration grazing doubles your livestock? Utah Sci. 44:32-37.

Miller, R.F., and W.C. Krueger. 1976. Cattle use on summer foothill rangelands in northeastern Oregon. J. Range Manage. 29:367-371.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-257.

Patton, W.W. 1971. An analysis of cattle grazing on steep slopes. M.S. Thesis, Brigham Young Univ., Provo, Utah.

Roath, L.R., and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. J. Range Manage. 35:332-338.

Rosiere, R.E., R.F. Beck, and J.D. Wallace. 1975. Cattle diets on semiarid grassland: Botanical composition. J. Range Manage. 28:89-93.

Savory, A., and S. Parsons. 1980. The Savory grazing method. p. 215-221. *In:* Beef Cattle Science Handbook, M.E. Ensminger (ed.), Vol. 17.

Steel, R.D.G, and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, Inc. New York.

Thetford, F.O., R.D. Pieper, and A.B. Nelson. 1971. Botanical and chemical composition of cattle and sheep diets on pinyon-juniper grassland range. J. Range Manage. 24:425-431.

U.S.D.A., S.C.S. 1982. Soil survey of Dunn County, North Dakota.

Uresk, D.W., and W.W. Paintner. 1985. Cattle diets in a ponderosa pine forest in the northern Black Hills. J. Range Manage. 38:440-442.

Whitman, W.C., and M.K. Wali. 1975. Prairie: A multiple view. Univ. N.D. Press, Grand Forks.

Soil Hydrologic Response to Number of Pastures and Stocking Density under Intensive Rotation Grazing

S.D. WARREN, W.H. BLACKBURN, AND C.A. TAYLOR, JR.

Abstract

Infiltration rate and sediment production were measured for 2 years on 3 pastures from an intensive rotational grazing system. The pastures were 32, 24, and 16 ha in size. Stocking rate was held constant but stocking density at any given point in time varied due to pasture size. Stocking densities were 0.68, 0.51, and 0.32 ha/AU, respectively. Within the respective treatments, midgrass interspaces exhibited significantly higher infiltration rates and lower sediment production than shortgrass interspaces. Overall, the pasture grazed at the highest stocking density produced the lowest infiltration rates and the greatest sediment loss. However, there was no consistent trend in hydrologic responses over time and the differences appeared to be the result of random selection of a poorer condition site on 1 or 2 occasions rather than the result of stocking density. Regardless of whether the pasture grazed at the highest stocking density was in similar or poorer hydrologic condition in terms of treatment response, the data do not support the hypothesized beneficial hydrologic advantages of increased stocking density via manipulation of pasture size and numbers. Rest, rather than intensive livestock activity, appears to be the key to soil hydrologic stability. The potential for altering the length of the rest period is greatest where the number of pastures is small. Therefore, very little benefit in terms of soil hydrologic condition should be expected from large increases in the number of pastures within rotational grazing systems.

Rotational grazing of some form or another has been practiced for centuries. Transhumant or nomadic grazing is the most ancient and widely used form of rotational grazing. However, the most frequently addressed form of rotational grazing in current grazing management literature is intensive short-duration grazing. The principles of intensive rotation grazing were taught as early as the 1700's (Voisin 1959). Much of the revised interest in this system of management centers around proposed potential for significant increases in carrying capacity (Savory 1978, 1983).

The principal objective of most rotational grazing systems is to improve or maintain the vigor and production of the forage resource and/or improve animal production. One method of enhancing forage production is to increase available soil water through improved rainfall infiltration rate and reduced runoff loss. Some modern proponents of intensive rotational grazing have hypothesized that intense trampling activity associated with high stocking density will enhance rainfall infiltration and reduce erosion (Goodloe 1969, Office of Technology and Assessment 1982, Savory and Parsons 1980, Walter 1984).

Stocking density, which is a measure of grazing pressure at a given point in time, may be increased by adjusting stocking rates upward or by increasing the number of pastures within an existing rotation system. Both alternatives have been suggested (Goodloe 1969, Savory 1978, Savory and Parsons 1980). Heavy stocking rates under continuous grazing are almost universally deleterious to watershed condition, generally reducing rainfall infiltration rate and accelerating erosion (Alderfer and Robinson 1947, Blackburn 1984, Branson et al. 1981, Rauzi and Hanson 1966, Rhoades et al. 1964). Recent research has shown that the use of heavy stocking rates within rotational grazing systems is also detrimental to infiltration rate and sediment production, regardless of the system used (Gamougoun et al. 1984; McCalla et al. 1984a, 1984b; Pearson et al. 1975; Pluhar 1984; Smith 1980; Thurow 1985; Warren 1985; Weltz 1983). Some research has indicated that the incidence of heavily impacted trails may increase as the number of pastures is increased within an intensive rotational grazing system (Walker and Heitschmidt 1986). The effect that an increase in the number of pastures has on hydrologic parameters has not been addressed. The objective of this study was to evaluate infiltration rate and sediment production from pastures subjected to variable stocking density as affected by number of pastures rather than stocking rate.

Study Area

Field research was conducted during 1983 and 1984 at the Texas Agricultural Research Station near Sonora, Texas. The average growing season at the Station is 240 days and extends from March through October. Long-term average annual precipitation (1918–1984) is 609 mm. Annual precipitation for 1983 and 1984 was 108 and 203 mm below average, respectively.

The physiognomy of the area is characterized by dense mottes of live oak (*Quercus virginiana* Mill.) with grass interspaces. The midgrass component of the grass interspaces was dominated by sideoats grama (*Bouteloua curtipendula* (Michx.)) and Wright's threeawn (*Aristida wrightii* Nash). Fall witchgrass (*Leptoloma cognatum* (Schult.) Chase), Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), and silver bluestem (*Bothriochloa saccharoides* (Swartz) Rydb.) were of lesser importance. The shortgrass interspaces were predominantly common curly mesquite (*Hilaria belangeri* (Steud.) Nash). Honey mesquite (*Prosopis glandulosa* Torr.) and ashe juniper (*Juniperus ashei* Buccholz), 2 woody species, were scattered through the grass interspaces in a savanna-like fashion. Prickly pear (*Opuntia* spp. Mill.) was also abundant.

In the fall of 1982, a 376-ha 14-pasture intensive rotational grazing system was put into operation at the Station. Pastures ranged in size from 32 to 8 ha. The system was stocked with a single herd composed of a 1.63:1:1 ratio of cattle, sheep, and goats at a

Authors are presently rangeland watershed manager, USA-CERL, Environmental Division, P.O. Box 4005, Champaign, Ill. 61820; professor of watershed management, Department of Range Science, Texas A&M University, College Station 77843; and superintendent, Texas Agricultural Experiment Station, Sonora 76950. At the time of research, the senior author was graduate research assistant, Department of Range Science, Texas A&M University.

Published with approval of the Director, Texas Agricultural Experiment Station, as TA-20823.

Manuscript accepted 27 January 1986.

stocking rate of 8.1 ha/AU, which is the recommended moderate rate for the area. The number of days of grazing per pasture per rotation cycle was dependent upon the condition of the forage resource within each pasture. During the spring and summer months, the average rotation cycle was 56 days, but slowed to as much as 74 days during the winter dormant season.

Three pastures which were 16, 24, and 32 ha in size were used for this study. The 3 pastures had a similar history of moderate, discontinuous use and were in good range condition when the rotational grazing system was implemented. They were in better condition than most other pastures and were, therefore, grazed at a heavier rate, with the number of days grazing per cycle being proportional to the size of the pasture. For example, during a 56-day cycle the 32-ha pasture was grazed for 8 days while the 24-and 16-ha pastures were grazed for 6 and 4 days, respectively. The procedure maintained a constant year-long stocking rate of 4.8 ha/AU/yr, which is approximately 1.7x the recommended moderate rate. However, stocking density at any given point in time varied due to pasture size; the respective stocking densities for the 32-, 24-, and 16-ha pastures were 0.68, 0.51, and 0.34 ha/AU. This design effectively simulated 3 equally stocked 224-ha intensive rotational grazing systems, with the 32-, 24-, and 16-ha pastures representing 7-, 9-, and 14-pasture systems, respectively.

Research was conducted on Kavett silty clay soil with slopes <3% and a depth of 250–500 mm overlying a fractured caliche layer and limestone substratum. The soils are of the clayey-skeletal, montmorillonitic, thermic family of Lithic Haplustolls, characterized by high shrink-swell capacity and an organic matter content >6%. When undisturbed, they are well aggregated and have an average rainfall infiltration capacity exceeding 155 mm h^{-1}.

Methods

The pastures were sampled during 2 full rotation cycles for each of the first 2 summers following implementation of the grazing system. Each pasture was sampled 3 times per rotation cycle, once immediately prior to the introduction of livestock onto the pasture, again soon after their removal, and approximately midway through the subsequent rest period. Eight plots representing midgrass interspaces and eight representing shortgrass interspaces were sampled on each sample date at sites which were randomly selected within the appropriate pasture and soil type.

A mobile, drip-type rainfall simulator (Blackburn et al. 1974) was used to determine infiltration rate and sediment production on variable area runoff plots. Plot size averaged approximately 0.4 m^2. In order to reduce variability attributable to antecedent soil water content, the plots were pre-wet by applying 105 mm of water at a rate of 79 mm h^{-1} from a mist-type nozzle under a plastic cone 0.6 m above the soil. The plots were then covered with plastic tarps to prevent evaporation, and gravitational water was allowed to drain. After approximately 24 hours, when the soil had drained to near field capacity, simulated rainfall was applied at a rate of 203 mm h^{-1} for 30 minutes. The rainfall simulator produced drops 2.5 mm in diameter which reached 70% terminal velocity. This application rate simulated a storm with a return period of 120 years and was necessary to insure runoff from all plots. Runoff from each plot was regularly pumped into tared containers. At each 5-minute interval during the simulated rainfall event, the cumulative runoff was weighed and mean infiltration rate (mm h^{-1}) was calculated by determining the difference between applied rainfall and the quantity of water running off the plot.

At the end of each simulated rainfall event, runoff from the plot was thoroughly mixed and a 1-liter subsample was collected. The subsample was filtered through a tared Whatman #1 filter. Sediment remaining on the filter was oven-dried, weighed, and converted to sediment production (kg ha^{-1}) based on the area and total runoff from each plot.

Immediately prior to each simulated rainfall event, soil bulk density and soil moisture content at a depth of 0–30 mm were determined adjacent to each runoff plot by the core method (Blake 1965) and gravimetric method (Roundy et al. 1983), respectively. Soil surface microrelief within each plot was measured with a 10-pin relief meter similar to the one described by Kincaid and Williams (1966). Following simulated rainfall, a composite surface soil sample was taken to a depth of 30 mm from within the plot and was used for analyses of soil organic matter content by the Walkley-Black method (Nelson and Sommers 1982) and soil aggregate stability by the wet-sieve method (Kemper 1965).

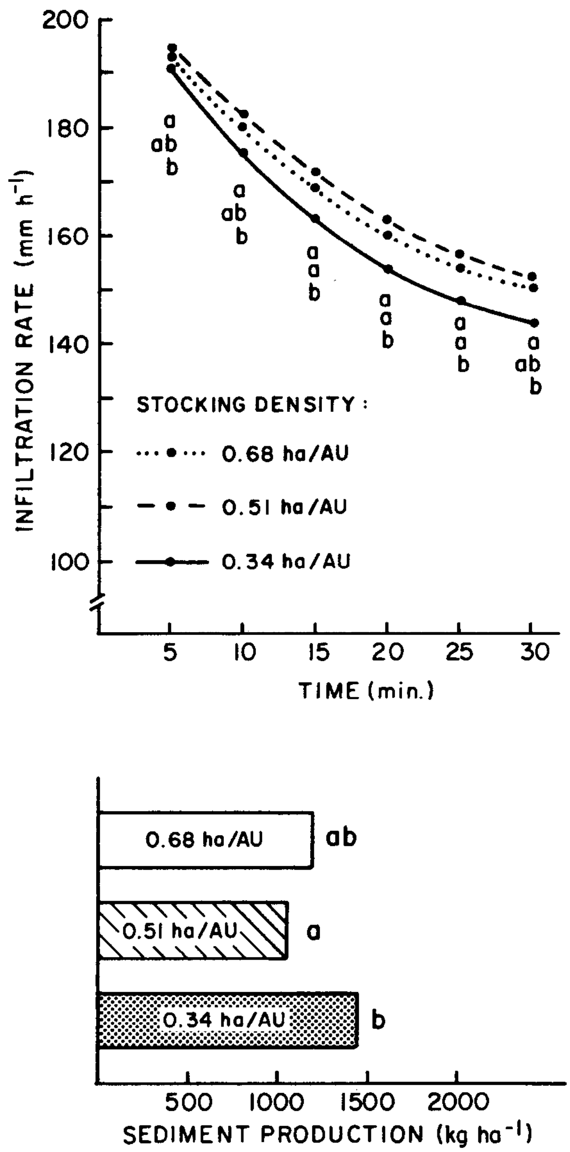


Fig. 1. *Mean infiltration rate and sediment production for pastures grazed at 3 stocking densities, Edwards Plateau, Texas. Infiltration means with the same letter for the same time increment or sediment production means with the same letter are not significantly different (α = .05).*

Percent aerial cover of midgrasses, shortgrasses, forbs, litter, rock, and bare ground was determined by ocular estimate for each rainfall plot. Midgrass, shortgrass, and forb cover were combined to produce a single vegetative cover estimate. Following rainfall simulation, grasses and forbs were clipped to a 10-mm stubble height and litter was hand collected from each plot. These samples were oven-dried and weighed. Grass and forb weights were combined to produce a vegetation biomass value.

Biomass variables and soil microrelief were highly skewed. Log_{10} transformations were performed to meet assumptions of normality. Analysis of variance, based on a 3 × 3 × 2 factorial design, was used to determine if significant differences existed for dependent variables between trampling intensities, stages of the rotation cycle, and grass types, respectively. The error term in the analysis of variance consisted of the nested variation of the randomized sites within the factorial treatments (Snedecor and Cochran 1967). If differences were present, Duncan's multiple comparison test was used to separate the means (Steel and Torrie 1980). Simple correlation coefficients were calculated for all dependent and independent variables. A 95% level of significance was used throughout.

Results and Discussion

Mean infiltration rate was significantly greater and the amount of sediment produced was significantly less from midgrass interspaces than from shortgrass interspaces. Similar differences in hydrologic response between midgrass and shortgrass interspaces have been noted by Knight (1980), McCalla et al. (1984a, 1984b), Pluhar (1984), Thurow (1985), and Wood and Blackburn (1981a, 1981b). Significant differences were also present between stages of the rotation sequence; infiltration rate was higher and sediment production lower prior to the movement of livestock onto a pasture than after their removal, but the magnitude of the difference was dependent on seasonal climatic conditions and is reported elsewhere (Warren et al. 1986a). There was no significant interaction between any of the main factors in terms of infiltration rate or sediment production. Therefore, grass types and stages of the rotation cycle were combined for analysis of variance for stocking density.

A significant difference in mean infiltration rate occurred at each 5-min increment of the simulated rainfall event between pastures representing variable stocking density (Fig. 1). The differences were not consistent, but as a general rule, the pasture which was grazed at the highest stocking density (0.34 ha/AU) had the lowest infiltration rate. After 30 min it was not significantly different from the pasture which was grazed at the lowest stocking density (0.68 ha/AU). The pasture which was grazed at an intermediate stocking density (0.51 ha/AU) had the highest infiltration rate, although it was not significantly different from the pasture grazed at the lowest stocking density. The same trend in hydrologic condition was true for sediment production (Fig. 1).

Logic would dictate that if stocking density were truly affecting hydrologic condition, then the pasture stocked at either the highest or lowest density would produce the highest infiltration rate and least amount of sediment. The pasture in best hydrologic condition would then be followed in sequence by the other 2 pastures, based on successively ascending or descending stocking density. Such was not the case in this study. Of the vegetation and soil variables measured, only bare ground, rock, and litter cover were significantly different between pastures (Table 1), but neither they nor other independent variables explained sufficient variability to be given much credence (Table 2). Therefore, the analysis of variance remained the best test of the study objectives.

In order to better understand the paradoxical results, an analysis of variance was conducted for each sample period. No consistent trend was evident and it appeared that the third and fourth sample periods in 1984 were disproportionately responsible for the overall significance of treatment differences (Fig. 2). In addition, the impact of stocking density should be most apparent in the immediate post-graze condition if high density trampling activity truly provides the hypothesized hydrologic benefits. Such a scenario would create a statistical interaction favoring the preferred stocking density during the immediate post-graze portion of the rotation cycle. No interaction between stocking density and stage of rotation cycle was found. It is, therefore, somewhat doubtful that

Table 1. Mean vegetation and soil variables within pastures representing 3 stocking densities on the Edwards Plateau, Texas.[1]

Variable	Stocking density 0.68 ha/AU	0.51 ha/AU	0.34 ha/AU
Bare ground (%)	27.1a	26.4a	31.5b
Rock cover (%)	2.3a	3.2b	2.7ab
Litter cover (%)	26.9a	28.0a	23.4b
Vegetation cover (%)	44.5a	41.8a	42.4a
Litter biomass (kg ha^{-1})	1758.1a	1739.7a	1637.4a
Vegetation biomass (ka ha^{-1})	2318.8a	2317.3a	2161.7a
Soil organic matter (%)	6.3a	6.5a	6.5a
Soil aggregate stability (%)	72.3a	69.6a	70.1a
Soil bulk density (Mg m^{-3})	0.74a	0.73a	0.73a
Microrelief (unitless)	1.1a	1.2a	1.1a

[1]Means followed by the same letter in a row are not significantly different at the 95% level of significance.

Table 2. Simple correlation coefficients of stocking density and vegetation and soil variables correlated with terminal infiltration rate and sediment production on the Edwards Plateau, Texas.[1]

Independent variables	Dependent Variables: Infiltration rate	Sediment production
Stocking density	.08 NS	-.08 NS
Bare ground	-.49	.49
Rock cover	-.13	.08 NS
Litter cover	.25	-.08 NS
Vegetative cover	.31	-.45
Litter biomass	.17	-.22
Vegetation biomass	.50	-.50
Soil organic matter content	.04 NS	-.18
Soil aggregate stability	.19	-.35
Soil bulk density	-.09	.03 NS
Microrelief	.48	-.33

[1]Correlation coefficients followed by NS are not significant at the 95% level of significance.

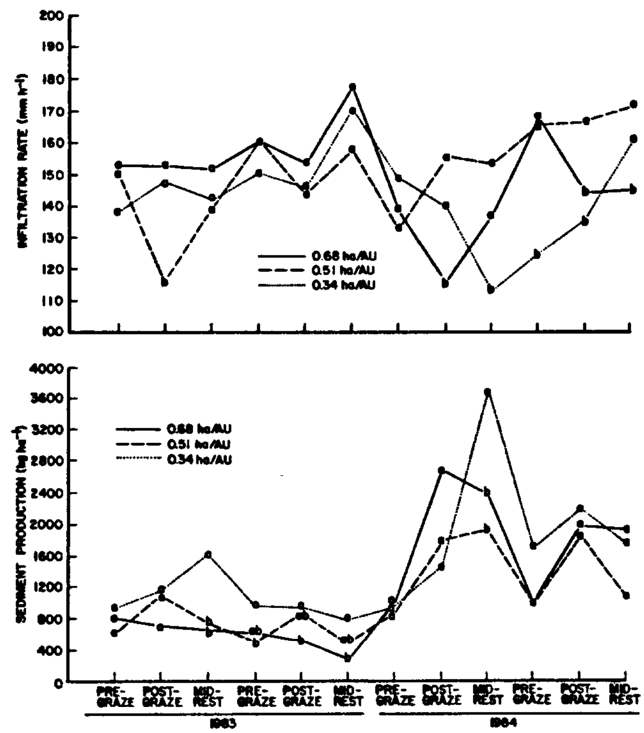


Fig. 2. *Mean infiltration rates and sediment production across time for pastures grazed at 3 stocking densities on the Edwards Plateau, Texas. Means for each sample date with the same letter are not significantly different (α = .05).*

stocking density was a major factor contributing to the differences detected between pastures. Rather, the random selection of a site with significantly poorer hydrologic condition on 1 or 2 occasions may have caused the paradoxical significance between pastures. The occurrence of significant spatial variability in hydrologic parameters on relatively uniform range sites is a common phenomenon (Devaurs and Gifford 1984, Gifford 1984). However, regardless of whether the pasture grazed at the highest stocking density was in poorer or similar hydrologic condition when compared to other pastures in terms of treatment response, these data do not support the hypothesized beneficial hydrologic advantages of increased stocking density via manipulation of pasture size and numbers.

It is true that subdividing pastures of an existing rotational grazing system will result in increased stocking density per pasture during the grazed portion of the rotation cycle. However, one must also consider the length of the period during which grazing occurs. When the number of pastures is increased, the length of the grazing period per pasture must be reduced proportionately in order to avoid overgrazing. The stocking rate or total number of animal unit days (AUD) per unit area remains the same, regardless of the number of pastures. For example, 47 animal units were present on the Sonora grazing system at all times. Under a 56-day rotation cycle, the smallest pasture (16 ha) was grazed for 4 days per cycle giving a total of 11.75 AUD/ha:

$$(47 \text{ AU} \times 4 \text{ days}) \div 16 \text{ ha} = 11.75 \text{ AUD/ha}.$$

The largest pasture (32 ha) was impacted to the same degree after a typical 8-day grazing period:

$$(47 \text{ AU} \times 8 \text{ days}) \div 32 \text{ ha} = 11.75 \text{ AUD/ha}.$$

The principal difference was the number of days over which the impact occurred. The difference of 4 days in this study is probably insignificant in terms of a 56-day rotation cycle. Indeed, the results of this study indicate that, at best, manipulation of stocking density by increasing the number of pastures within an intensive rotational system will do little to modify the hydrologic effects of intensive trampling. Pluhar (1984), likewise, detected no difference in the post-graze hydrologic condition of pastures which represented 14-and 42-pasture rotational grazing systems of equal size, stocked at the same rate, and grazed with a rotation cycle of equal length.

Perhaps of greater importance than the length of the grazing period, is the length of the rest period. Infiltration rate is generally lower and sediment production higher following short periods of intensive grazing associated with rotational grazing system (Pluhar 1984, Smith 1980, Warren 1985, Weltz 1983, Wood and Blackburn 1981a, 1981b). The impact is especially acute during dry or dormant seasons and increases as stocking rate increases (Warren et al. 1986b). In order to avoid long-term progressive degradation, rest periods must be of sufficient length to allow full recovery of the soil hydrologic condition prior to the reoccurrence of livestock impact. It seems logical that any increase in stocking rate must, therefore, be accompanied by an increase in the length of the rest period in order to compensate for the greater impact. Rest should also be increased during seasons of maximum livestock impact (i.e., drought or winter dormancy). In addition, the necessary length of the rest period may be longer in semiarid and arid regions than in more mesic regions.

The potential for increasing the length of the rest period through manipulation of the number of pastures is minimal where the number of pastures is already large. By definition, short-duration grazing systems have a stocking density index >2 (Society for Range Management 1974). This requires that the land area available to livestock at any point in time must be less than 50% of the total land area in the grazing system. For a 1-herd system, the minimum number of pastures to meet the criterion is 3. The greatest potential for altering the number of rested days occurs where the number of pastures is small. For the 56-day rotation cycle at the

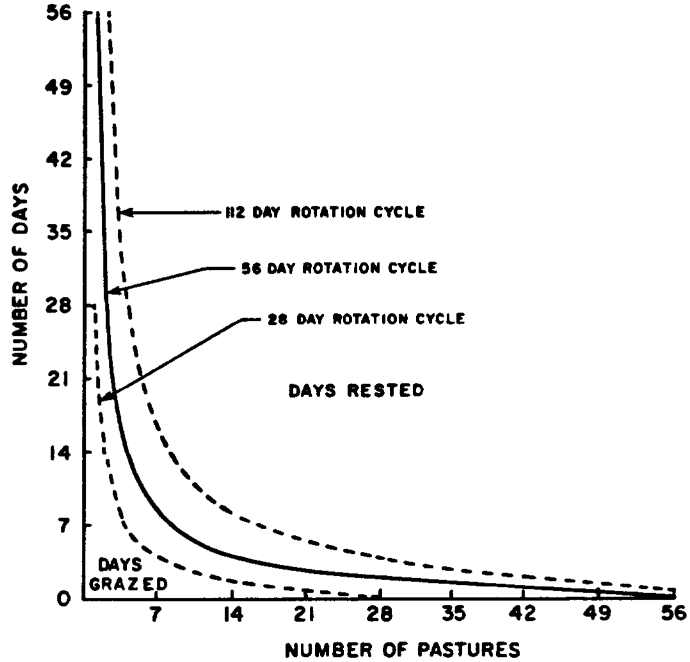


Fig. 3. *Days rested (area above line) and days grazed (area below line) as a function of pasture number in a rotational grazing system and to the length of the rotation cycle.*

Sonora Station, the maximum potential occurs between 3 and 8 pastures (Fig. 3). Three pastures is the necessary minimum to be classified as a short-duration grazing system, and 7.5 days is the point of inflection on the curve, beyond which the potential for increasing the length of the rest period is minimized. This supports the conclusion that differences in infiltration rate and sediment production between pastures representing 7-, 9-, and 14-pasture short-duration grazing systems in this study were not attributable to stocking density.

Significant alterations in the length of the rotation cycle have little effect on the number of pastures that can be added before reaching the point of inflection. For 28- and 112-day rotation cycles, the point of inflection is reached at 5 and 12 pastures, respectively (Fig. 3). Therefore, regardless of the length of the rotation cycle, altering the number of pastures in an intensive rotational grazing system will probably have little effect on soil hydrologic condition, except where only a few pastures are present.

Literature Cited

Alderfer, R.B., and R.R. Robinson. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Amer. Soc. Agron. 39:948-958.

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses, p. 927-983. *In:* Developing Strategies for Rangeland Management. Nat. Res. Counc.-/Nat. Acad. of Sci. Westview Press, Boulder, Colo.

Blackburn, W.H., R.O. Meeuwig, and C.M. Skau. 1974. A mobile infiltrometer for use on rangeland. J. Range Manage. 27:322-323.

Blake, G.R. 1965. Bulk density, p. 374-390. *In:* C.A. Black (ed), Methods of Soil Analysis, Part I. Amer. Soc. Agron., Madison, Wis.

Branson, F.A., G.F. Gifford, K.G. Renard, and R.F. Hadley. 1981. Rangeland hydrology. Range Sci. Ser. No. 1. Kendall/Hunt Pub. Co., Dubuque, Ia.

Devaurs, M., and G.F. Gifford. 1984. Variability of infiltration within large runoff plots on rangelands. J. Range Manage. 37:523-528.

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

Gifford, G.F. 1984. Vegetation allocation for meeting site requirements, p. 35-116. *In:* Developing Strategies for Rangeland Management. Nat. Res.

Counc./Nat. Acad. of Sci. Westview Press, Boulder, Colo.
Goodloe, S. 1969. Short duration grazing in Rhodesia. J. Range Manage. 22:369-373.
Kemper, W.D. 1965. Aggregate stability, p. 511-519. *In:* C.A. Black (ed), Methods of Soil Analysis, Part I. Amer. Soc. Agron., Madison, Wis.
Kincaid, D.R., and G. Williams. 1966. Rainfall effect on soil surface characteristics following range improvement treatments. J. Range Manage. 19:346-351.
Knight. R.W. 1980. Hydrologic response of selected grazing systems on the Edwards Plateau. Ph.D. Diss., Texas A&M Univ., College Station.
McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984a. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:265-269.
McCalla, G.R., W.H. Blackburn, and L.B. Merrill. 1984b. Effects of livestock grazing on sediment production, Edwards Plateau of Texas. J. Range Manage. 37:291-294.
Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter, p. 539-579. *In:* A.L. Page (ed), Methods of Soil Analysis, Part 2. Amer. Soc. Agron. Madison, Wis.
Office of Technology Assessment. 1982. Impacts of technology on U.S. cropland and rangeland productivity. Congress of the United States, Washington, D.C.
Pearson, G.A., G.A. Jung, R.E. Fowler, and D.M. Mitchell. 1975. Effects of grazing on infiltration rates and waste water spray fields. Proc. Soil Sci. Soc. Amer. 29:954-957.
Pluhar, J.J. 1984. Hydrologic impacts of selected grazing systems on the Texas Rolling Plains. M.S. Thesis, Texas A&M Univ., College Station.
Rauzi, F., and C.L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Manage. 19:351-356.
Rhoades, E.D., L.F. Locke, H.M. Taylor, and E.H. McIlvain. 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. J. Range Manage. 17:185-190.
Roundy, B.A., J.A. Young, G.J. Cluff, and R.A. Evans. 1983. Measurement of soil water on rangelands. USDA Agr. Res. Serv. Agr. Res. Results, Western Ser.
Savory, A. 1978. A holistic approach to ranch management using short duration grazing, p. 555-557. *In:* Proc. of the 1st Internat. Range Cong., Soc. Range Manage., Denver, Colo.
Savory, A. 1983. The Savory grazing method or holistic resource management. Rangelands 5:155-159.
Savory, A., and S.D. Parsons. 1980. The Savory grazing method. Rangelands 2:234-237.
Smith, R.P. 1980. The influence of different grazing practices on infiltration rates and sediment production at Fort Stanton, New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces.
Snedecor, G.W., and W.C. Cochran. 1967. Statistical methods. Iowa State Univ. Press, Ames.
Society for Range Management, Range Term Glossary Committee. 1974. A glossary of terms used in range management. Denver, Colo.
Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Book Co., New York.
Thurow, T.L. 1985. Hydrologic interrelationships with vegetation and soil as affected by selected livestock grazing systems and climate on the Edwards Plateau. Ph.D. Diss., Texas A&M Univ., College Station.
Voisin, A. 1959. Grass productivity. Philosophical Library, Inc. New York.
Walker, J.W., and R.K. Heitschmidt. 1986. Effect of various grazing treatments on type and density of cattle trails. J. Range Manage. 39:
Walter, J. 1984. Rangeland revolutionary: An interview with Allan Savory. J. Soil and Water Conserv. 29:235-240.
Warren, S.D., W.H. Blackburn, and C.A. Taylor, Jr. 1986a. Effects of season and stage of rotation cycle on hydrologic condition of rangeland under intensive rotation grazing. J. Range Manage. 39:486-491.
Warren, S.D., T.L. Thurow, W.H. Blackburn, and N.E. Garza. 1986b. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. J. Range Manage 39:491-495.
Weltz, M. 1983. The influence of short duration and continuous grazing on infiltration rate and sediment yield in southcentral New Mexico. M.S. Thesis, New Mexico State Univ., Las Cruces.
Wood, M.K., and W.H. Blackburn. 1981a. Grazing systems: Their influence on infiltration rates in the Rolling Plains of Texas. J. Range Manage. 34:331-335.
Wood, M.K., and W.H. Blackburn. 1981b. Sediment production as influenced by livestock grazing in the Texas Rolling Plains. J. Range Manage. 34:228-231.

Third International Rangeland Congress To Be Held in New Delhi, India, in 1988

Plans for the 3rd IRC are being reorganized with excellent support from the Government of India. The meeting date has been postponed one year to allow mailing of the first notice well in advance of the Congress. The date is expected to be in the month of November, 1988.

Look for more details concerning the 3rd IRC in upcoming issues of *Rangelands*. Please pass this information on rescheduling of the meeting to universities and all others interested in rangeland management.

Hydrologic Characteristics of Vegetation Types as Affected by Livestock Grazing Systems, Edwards Plateau, Texas

T.L. THUROW, W.H. BLACKBURN, C.A. TAYLOR, JR.

Abstract

Infiltration rate and sediment production were assessed in oak, bunchgrass and sodgrass vegetation types in moderate continuous (MCG), heavy continuous (HCG), and intensive rotation (short-duration, SDG) grazing systems and in a livestock exclosure (LEX). Infiltration rate was related to the total organic cover and bulk density characteristics of the site (R^2 = .86). The amount of cover was more important than type, indicating that protection of soil structure from direct raindrop impact was the primary function of cover on infiltration. The SDG and HCG pastures had lower total organic cover with correspondingly lower infiltration rates compared to the MCG and LEX pastures. Bulk density, an indicator of soil structure, was significantly lower in oak mottes than in the grass interspace, but there was no significant difference between pastures. Sediment production was related to the total aboveground biomass and the bunchgrass cover of the site (R^2 = .79). Obstruction to overland sediment transport and protection from the disaggregating effect of direct raindrop impact were the primary functions of the total aboveground biomass and bunchgrass cover. Total aboveground biomass was greatest in the oak motte and least in the sodgrass interspace, consequently the sodgrass interspace had the greatest amount of sediment production and the oak mottes had the least sediment production. Midgrass cover and total aboveground biomass in the MCG and LEX pastures was significantly greater than in the SDG and HCG pastures; thus sediment production from the MCG and LEX pastures was significantly lower than from the SDG and HCG pastures.

The hydrologic condition of a range site is the result of complex interactions of soil and vegetation factors. Infiltration rate and sediment production integrate these factors and are good indicators of hydrologic condition. The type of livestock grazing system and stocking rate differentially impact soil structure and vegetation growth in different plant communities. Successional trends in plant communities were directly proportional to grazing intensity, with the most severe changes occurring under heavy grazing (Ellison 1960). Palatable species decline as grazing pressure increases and are replaced by shrubs or other vegetation which are less preferred by livestock and more resistant to grazing (Dyksterhuis 1949). Perennial bunchgrasses are especially important indicators of rangeland condition in the Edwards Plateau of Texas. Many bunchgrass species are palatable and nutritious for livestock and provide good soil stabilization. However, many bunchgrasses have aboveground apical meristems and are not tolerant of repeated heavy grazing. Rich and Reynolds (1963) found that perennial bunchgrass basal cover was reduced by heavy grazing but was unaffected by moderate grazing. Rhoades et al. (1964), Sharp et al. (1964) and Dunford and Weitzman (1955) found that heavily grazed pastures were dominated by sod-forming grasses whereas bunchgrasses dominated moderate and non-grazed pastures.

The authors are presently range research scientist, P.O. Box 2954, Mogadishu, Somalia; professor of watershed management, Department of Range Science, Texas A&M University, College Station 77843; and superintendent of the Texas Agricultural Experiment Station at Sonora 76950. Send reprint requests to second author. At the time of research, the senior author was graduate research assistant, Department of Range Science, Texas A&M University.

The authors would like to thank the personnel of the Texas Agricultural Research Station at Sonora and Ronnie Anson for their help during this study. This study was a cooperative project between U.S. Department of Agriculture and Texas Agricultural Experiment Station. Financial support of the Soil Conservation Service RCA Special Study and a Science/Education Grant is acknowledged.

Published with the approval of the Director, Texas Agricultural Experiment Station as TA - 20746.

Manuscript accepted 29 May 1986.

Infiltration rates are generally observed to be highest under trees and shrubs, followed in decreasing order by bunchgrasses and sodgrasses (Smith and Leopold 1941, Woodward 1943, Reed and Peterson 1961, Box 1961, Blackburn 1975, Wood and Blackburn 1981, Knight et al. 1984). Each life form responds differently to grazing pressure and range improvement practices. The extent to which these rangeland uses alter the vegetation composition is a prime factor determining the effects on the soil structure and hydrologic condition of the site.

The objective of this research was to study oak, bunchgrass, and sodgrass plant communities to determine how their infiltration rate and sediment production differ from each other. Also, the infiltration rate and sediment production of each of the 3 plant communities was studied to determine how the effects of livestock grazing systems differ for each plant community under moderate continuous, heavy continuous, and intensive rotation grazing systems and livestock.

Study Area

The study was conducted during May, 1984, at the Texas Agricultural Experiment Station located about 56 km south of Sonora, in Sutton and Edwards Counties, Texas (31° N; 100° W). The rolling stony hill topography that characterizes the station is typical of the Edwards Plateau. The average growing season on the station is 240 days. Precipitation is highly variable within a year and in annual amount (range, 1918–1984, varies from 156 mm to 1,054 mm; median of 438 mm). Most precipitation results from intense, short duration thunderstorms.

The vegetation types of the study site can be characterized as being dominated by either oak mottes, bunchgrass, or sodgrass. Oak mottes dominated 27% of the land area of the study site and were composed primarily of live oak (*Quercus virginiana* Mill.). Bunchgrasses dominated 30% of the study site with the primary species being sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.), and threeawn (*Aristida* spp.). Sodgrasses, primarily curlymesquite (*Hilaria belangeri* (Steud.) Nash), dominated 43% of the study site.

Methods

The infiltration rate and sediment production of oak motte, bunchgrass, and sodgrass vegetation types were determined in 4 different treatment pastures. The study pastures were adjacent to each other and were selected for this study because they had similar soils (Tarrent silty clays averaging 273 mm depth and overlying an undulating fractured caliche), similar slope (1–2%), and the same past grazing history (grazed at a moderate continuous rate of 8.1 ha/au/yr from 1949–1978). Three grazing regimes were established in 1978: moderate continuous grazing (MCG) stocked at 8.1 ha/au/yr; heavy continuous grazing (HCG) stocked at 4.6 ha/au/yr; and a high-intensity low frequency (HILF) system (8–1; 17:119 day) stocked at 8.1 ha/au/yr. In January, 1980, the HILF pasture was changed to an intensive rotation (short duration grazing, SDG) system (14-1; 4:50 day) and stocked at 4.6 ha/au/yr, and a livestock exclosure (LEX) was established. The stocking ratio for the grazed pastures was 50:25:25 cattle, sheep, and goats.

The study site not only had similar grazing history, soil, and vegetation prior to study initiation in 1978, but were similar hydrologically. Infiltration rate and sediment production of the site prior to this study was similar within vegetation type. Pretreatment infiltration rates averaged 22 cm h^{-1} for the oak mottes, 19.8 cm h^{-1} for the bunchgrasses, and 13.8 h^{-1} for the sodgrasses. Sediment production pretreatment averaged 5 kg ha^{-1} from oak mottes, 15 kg ha^{-1} from bunchgrasses, and 18.7 kg ha^{-1} from sodgrass sites (Knight 1980, Knight et al. 1984).

Eight 0.5-m^2 randomly located runoff plots in each vegetation type and each pasture were sampled. Oak trees were cut by hand and carefully removed from the study plot area to facilitate equipment access. Plots were pre-wet by applying 100 liters of water via a mist-type nozzle over a 1.1-m^2 circular area. The plots were then covered with plastic and allowed to drain to field capacity. This procedure removed the variability that would have resulted from antecedent moisture conditions and allows direct comparison of all sites. Infiltration rates and sediment production were determined using a drip-type rainfall simulator (Blackburn et al. 1974). The simulated raindrops were 2.5 mm in diameter. Drops falling 2.1 m reach 5.25 m/sec or 71% of the terminal velocity achieved by raindrops in an unlimited fall (Laws 1941). The simulated rainfall was applied at a rate of 203 mm h^{-1} for 50 minutes, which represents a storm return period of about 150 yr. This admittedly high rate was chosen to ensure that all plots would reach terminal infiltration rate. This criterion was desirable so that the rates could be compared between plant communities and grazing treatments. Runoff was continuously collected from each plot and was recorded by weight at 5-minute intervals. Infiltration rates were determined by calculating the difference between the applied volume of simulated rainfall and the runoff. A 1-liter subsample of the thoroughly mixed runoff was taken at the conclusion of the sample period. Each subsample was filtered through a tared #1 Whatman filter. Sediment remaining on the filter was oven-dried, weighed, and converted to sediment production (kg ha^{-1}) based on the area and total runoff from each plot and used as an index of sheet erosion.

The percentage and type of foliar cover in each plot was determined by ocular estimate. Standing grass and standing forbs were clipped and litter was collected from each plot, separately dried at 60° C for 48 h, weighed, and converted to kg ha^{-1}.

Soil cores were taken at the 0–30 mm and 50–80 mm depths adjacent to each plot prior to the initiation of the simulated rainfall. Soil bulk density was determined by the core method (Black 1965). Soil moisture content was determined by the gravimetric method (Gardner 1964).

A soil sample of the surface 50 mm was taken from each plot after the simulated rainfall test. Organic matter content was determined by the Walkley-Black method (Walkley and Black 1934), aggregate stability by the weight sieve method (Kemper and Koch 1965) and soil texture by the hydrometer method (Bouyoucos 1962).

Data normality was determined by tests for skewness and kurtosis. Values for sediment production were skewed and were therefore transformed using a $\log_{10}$ transformation. Differences between treatments were determined by analysis of variance. The error term in the analysis of variance consisted of the nested variation of the randomized sites within the treatments (Snedecor and Cochran 1971). Treatment means were separated by Duncan's new multiple range test (Duncan 1955). Significance levels were used to determine the degree of linear association of the measured variables, and forward stepwise multiple regression analysis (Draper and Smith 1981) was used to identify the set of variables that most influenced infiltration rate and sediment production.

Results and Discussion

Infiltration rates were greatest at the first 5 min reading for each vegetation type, and then declined in subsequent readings until a terminal infiltration rate was reduced. The shape of the mean infiltration rate curve for each of the vegetation types is shown in Figure 1. Mean infiltration rates for each of the 5 min sample

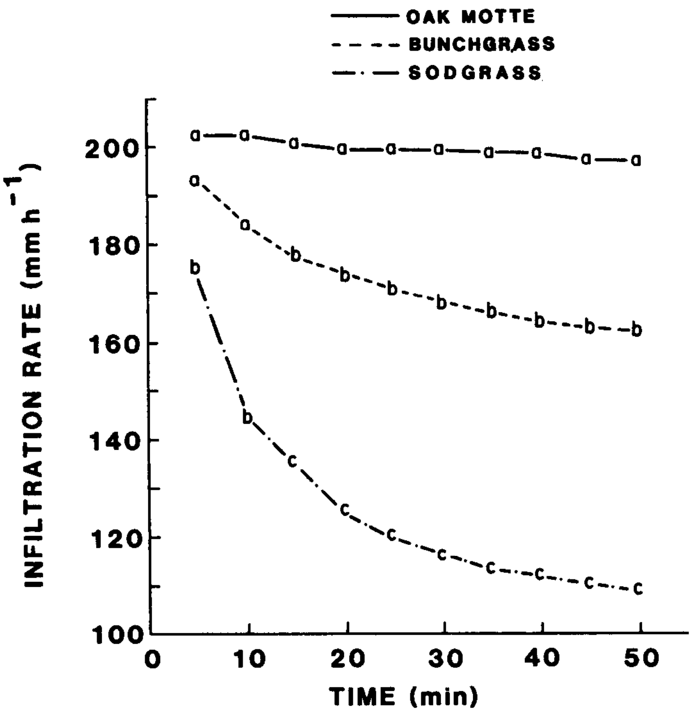


Fig. 1. *Mean infiltration rate for the 3 vegetation types across the 50 min simulated rainfall application, Edwards Plateau, Texas. Means with the same letter for the same time period are not significantly different (P≤.05).*

periods showed similar trends when correlated with other measured variables, but mean infiltration rates from measurements taken after 50 min always showed the greatest correlations. Therefore, in the following text, only mean infiltration rates after 50 min will be discussed.

Stepwise regression analysis was used to identify the set of measured variables that most effectively predicted infiltration rate. The following model (R^2 = .86) was developed:

$$\text{Mean infiltration rate after 50 min} = 9.32 + 0.16\,(\text{Total organic cover}) - 8.57\,(\text{Bulk density 0–30 mm}).$$

Total organic cover was the variable most strongly correlated with infiltration rate (R^2 = .80) (Fig. 2). The total organic cover under oak mottes was consistently higher than in the grass interspace, and bunchgrass sites were significantly greater than the sodgrass sites. There was no difference between grazing treatment pastures in total organic cover in oak mottes due to the great accumulation of oak leaf litter. The bunchgrass and sodgrass vegetation types had less total organic cover in the HCG and SDG systems than in the MCG and LEX pastures.

The second most important variable of the infiltration rate multiple regression model was the bulk density of the soil surface (R^2 = 0.61). Bulk density did not differ among grazing treatments. The surface bulk densities of the bunchgrass vegetation type (0.93 Mg m^{-3}) and sodgrass vegetation type (0.92 MG m^{-3}) were not significantly different, but both were significantly greater than the oak motte surface bulk density (0.69 Mg m^{-3}). Bulk density was negatively related to aggregate stability (R^2 = .59), soil organic matter content (R^2 = 0.61) and clay soil texture (R^2 = .40) indicating that the bulk density measurement integrates several aspects of soil structure. Aggregate stability and soil organic matter did not differ among grazing treatments but did differ among vegetation types. Aggregate stability was significantly greater in the oak mottes (86.0%) than on either bunchgrass (77.4%) or sodgrass (73.2%) sites. Likewise, soil organic matter was significantly greater in the

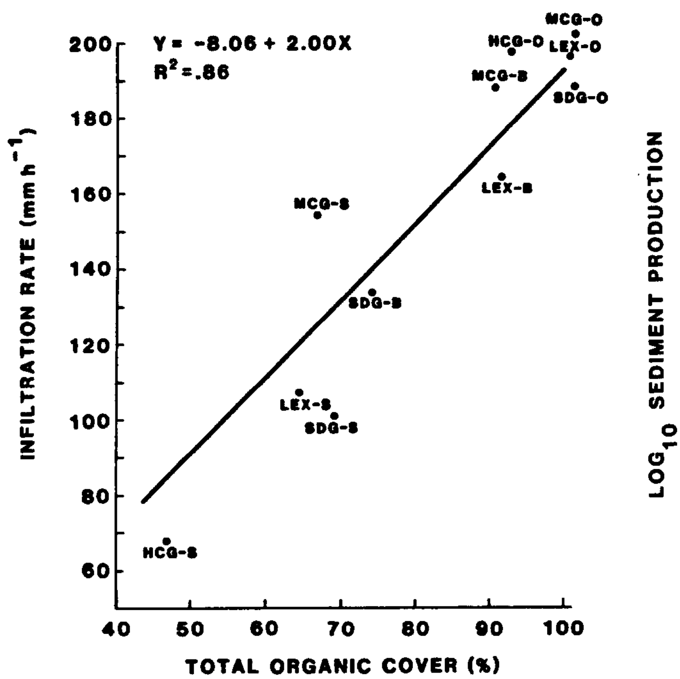


Fig. 2. *Relationship of infiltration rate with total organic cover (%) for heavy continuous (HCG), short-duration (SDG), moderate continuous (MCG) and livestock exclosure (LEX) pastures, Edwards Plateau, Texas. (0 = oak motte, B = bunchgrass, S = sodgrass).*

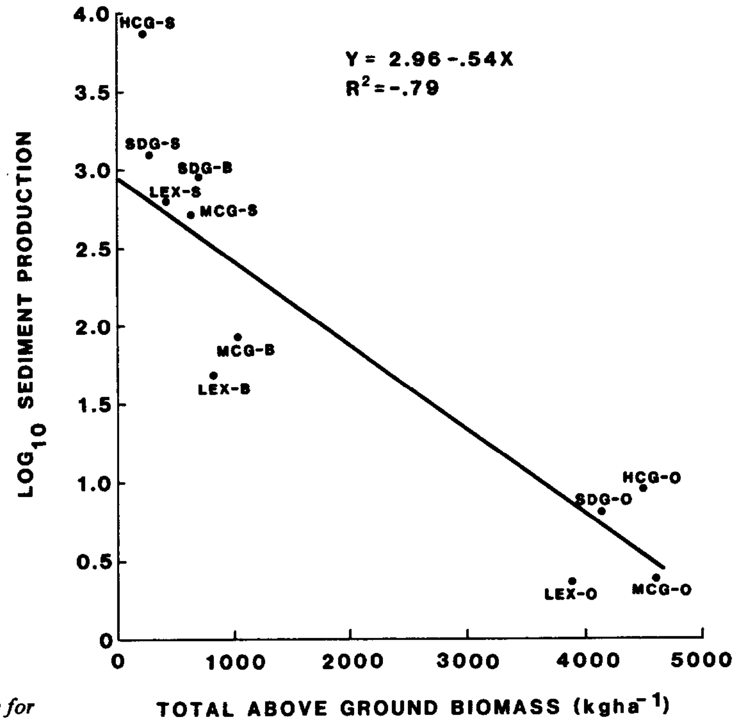


Fig. 3. *Relationship of the Log_{10} sediment production with total aboveground biomass (kg ha^{-1}), for heavy continuous (HCG), short-duration (SDG), moderate continuous (MCG), and livestock exclosure (LEX) pastures, Edwards Plateau, Texas. (0 = oak motte, B = bunchgrass, S = sodgrass).*

oak mottes (11.2%) than in either the bunchgrass (5.5%) or sodgrass (5.6%) sites.

Both variables in the infiltration rate equation are related to the integrity of the surface soil pore structure. The linear relationship of total organic matter with infiltration rate shows that the type of organic cover is not as important as the amount. The primary role of cover from an infiltration standpoint is that it decreases the kinetic energy of the raindrops before they strike the soil. This protects the pore integrity of the surface structure by dissipating the raindrop impact velocity, thus reducing the disaggregating potential of the rain. Thus, pores are less likely to be clogged by disaggregated soil particles. Bulk density is also a measurement of soil structure, giving an indication of the volume of passages available into which water may pass.

The following model (R^2 = .79) was developed to determine the set of variables that would be most effective for predicting sediment production:

Mean sediment production after 50 min = 5.15 + 0.03 (Total aboveground biomass) −0.01 (Bunchgrass Cover)

Total aboveground biomass was the variable most strongly correlated with sediment production (R^2 = .65) (Fig. 3). Total aboveground biomass and bunchgrass cover were not strongly correlated (R^2 = .31), because the total aboveground biomass estimate was strongly influenced by leaf litter in the oak mottes.

Bunchgrass cover was the second most important variable of the sediment production model (R^2 = −.63). There was a significant difference in bunchgrass cover (primarily composed of Texas wintergrass) under the oak mottes, with the LEX (34%) and MCG (20%) pastures having significantly greater bunchgrass cover than either the SDG (7%) or HCG (4%) pastures. This same pattern was found in the bunchgrass interspace with the MCG (68%) and LEX (58%) pastures having significantly greater cover than the SDG (32%) pasture. There was no bunchgrass interspace in the HCG pasture.

Total aboveground biomass protects the soil surface from the disaggregating affects of direct raindrop impact. Both total aboveground biomass and bunchgrass cover also serve as barriers to sediment transport by causing overland flow to move in a slower, more torturous path. Thus, the obstruction provided by the bunch growth form and litter is an important determinant of sediment loss. The negative relationship of bunchgrass cover with sediment loss contrasts with the sodgrass growth form which does not provide a large obstruction barrier and thus has a poor, negative relationship to sediment production (R^2 = −.34).

The differences in infiltration rate and sediment production between treatment pastures are shown in Figures 4 and 5. These

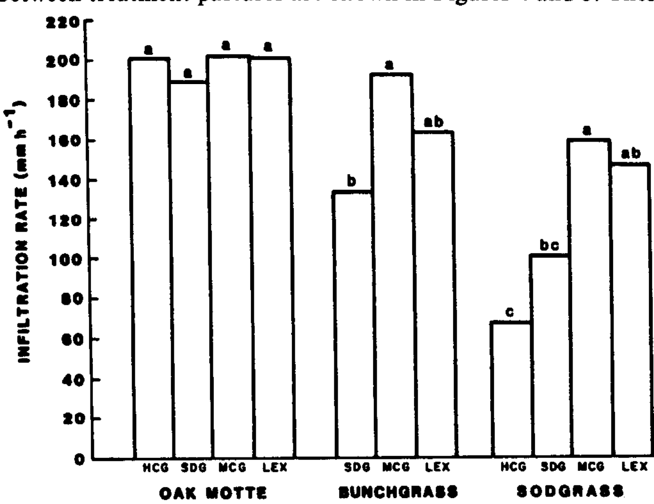


Fig. 4. *Mean infiltration rate (mm h^{-1}) for heavy continuous (HCG), short-duration (SDG), moderate continuous (MCG), and livestock exclosure (LEX) treatments and vegetation types, Edwards Plateau, Texas. Means with the same letter in each vegetation type are not significantly different ($P \leq .05$).*

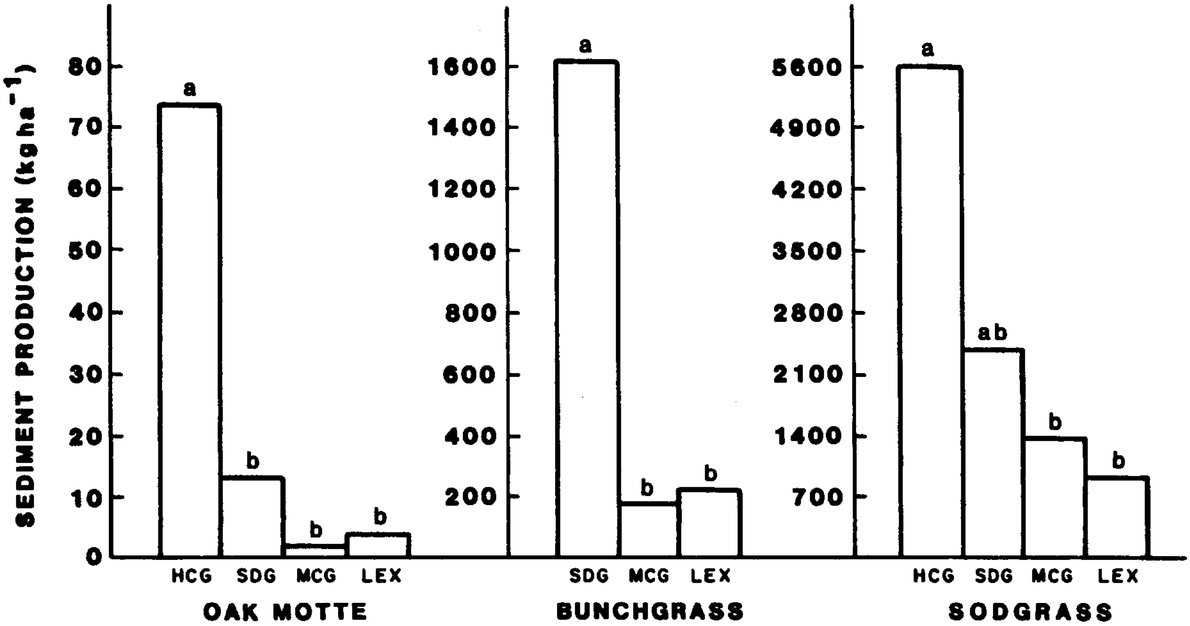


Fig. 5. *Mean sediment production (mm h^{-1})* for heavy continuous (HCG), short-duration (SDG), moderate continuous (MCG), and livestock exclosure (LEX) treatments and vegetation types, Edwards Plateau, Texas (Note that sediment production scale changes). Means with the same letter in each vegetation type are not significantly different (*P≤.05).*

patterns can be explained by the relationship of factors that characterize each pasture as expressed in the 2 regression models described above. An exception to the sediment regression model exists for the significantly greater sediment production from the HCG oak mottes compared to the oak motte sediment production of other treatments. The sediment yield from the HCG oak mottes was 12 times greater than sediment yield from the oak mottes in the other pastures even though oak motte infiltration rates on all 4 treatments were similar. This may be a result of the heavy sheet erosion that has been occurring in the grass interspace of the HCG pasture since that system was established in 1978. Based on runoff data from 3 (1.8 m by 22.1 m) natural runoff plots in each of the HCG, MCG and SDG pastures, the natural runoff from the HCG pasture averaged an annual sediment loss of 700 kg ha^{-1} compared to 250 kg ha^{-1} for the MCG and 563 kg ha^{-1} for the SDG pastures. Sediment suspended in grass-interspace-overland flow would be dropped when the runoff encounters the oak motte soils whose structure can accommodate a water infiltration rate in excess of most natural runoff events. Such overland flow events are essentially limited to the grass interspace since the much greater infiltration rate of the oak mottes would rarely be exceeded by natural precipitation events. Consequently, soil and nutrients eroded from the grass interspace are deposited in the oak mottes. This increased deposition of sediment in the HCG oak mottes over the past 6 years probably accounts for the greater sediment production. This pattern of soil erosion in the grass interspace and sediment deposition in oak mottes has led to oak mottes being visibly mounded in pastures on the Edwards Plateau that have been heavily grazed for many decades.

Oak mottes had a significantly higher sand content (27.2%) than the bunchgrass (19.5%) or sodgrass (18.1%) sites. In a random sample of 100 soil cores on the treatment pastures it was established that sand content was strongly correlated negatively with soil depth (R^2 = –0.85). An explanation for oak mottes being generally associated with the shallower, sandy textured soils may be related to competition during seedling establishment. On the deeper clay sites grasses would have access to the volume of water stored above the fractured caliche layer and thus could effectively compete against oak seedling establishment. However, on shallow sites, competition during seedling establishment would be lower. If the oak seedling roots could penetrate the fractured caliche and tap a deeper water source it would then be relatively free from grass competition for water. Once the oak is established, the affects of the greater litter deposition would increase the organic matter content of the soil and would aid aggregate stability and decrease bulk density. The enhancement of these soil structure factors could also be aided by microclimate factors which could aid microorganism activity. Such changes that aid soil structure development would aid the ability of the oak motte to retain water and nutrients eroding from the grass interspace. The large amounts of leaf litter and the cool-season bunchgrasses which are associated with the oak mottes provide effective barriers that slow overland flow and cause sediment deposition.

Literature Cited

Black, C.A. (ed.). 1965. Methods of soil analysis. Amer. Soc. Agron. Series No. 9, Madison, Wis.

Blackburn, W.H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resour. Res. 11:929-937.

Blackburn, W.H., R.O. Meeuwig, and C.M. Skau. 1974. A mobile infiltrometer for use on rangeland. J. Range Manage. 27:322-323.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. Agron. J. 54:464-465.

Box, T.W. 1961. Relationships between plants and soils of 4 range plant communities with south Texas. Ecology 42:794-810.

Draper, N.R., and H. Smith. 1981. Applied regression analysis. John Wiley and Sons, Inc., New York, NY.

Duncan, D.B. 1955. Multiple range and multiple F test. Biom. 11:1-42.

Dunford, E.G., and S. Weitzman. 1955. Managing forests to control soil erosion. p. 235-247. *In:* Water, USDA Yearbook, 1955.

Dyksterhuis, E.J. 1949. Condition and management of rangeland based on quantitative ecology. J. Range Manage. 2:104-115.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26:1-78.

Gardner, W.H. 1965. Water content, p. 82-125. *In:* C.A. Black (ed.) Methods of soil analysis (Part 1). Amer. Soc. Agron. Agron. Ser. No. 9, Madison, Wis.

Kemper, W.D., and E.J. Koch. 1965. Aggregate stability of soils from the western portions of the U.S. and Canada. USDA Tech. Bull. 1355.

Knight, R.W. 1980. Hydrologic response of selected grazing systems on the Edwards Plateau. Ph.D. Diss., Texas A&M Univ., College Station.

Knight, R.W., W.H. Blackburn, and L.B. Merrill. 1984. Characteristics of oak mottes, Edwards Plateau, Texas. J. Range Manage. 37:534-537.

Laws, J.O. 1941. Measurements of the fall-velocity of water-drops and raindrops. Trans. Amer. Geophys. Union 22:709-721.

Reed, M.J., and R.A. Peterson. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. USDA Tech. Bull. 1252.

Rhoades, E.D., L.F. Locke, H.M. Taylor, and E.H. McIlvain. 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. J. Range Manage. 17:185-190.

Rich, R.L., and H.G. Reynolds. 1963. Grazing in relation to erosion on some chaparral watersheds of central Arizona. J. Range Manage. 16:322-326.

Sharp, A.L., L.J. Bond, J.W. Neuberger, A.R. Kuhlman, and J.K. Lewis. 1964. Runoff as affected by intensity of grazing on rangeland. J. Soil Water Conserv. 19:103-106.

Smith, H.L., and L.R. Leopold. 1941. Infiltration studies in the Pecos-River Watershed, New Mexico and Texas. Soil Sci. 53:195-204.

Snedecor, G.W., and W.G. Cochran. 1971. Statistical methods. Iowa State University Press, Ames.

Walkley, A., and A.I. Black. 1934. An examination of the Deqtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Wood, M.K., and W.H. Blackburn. 1981. Grazing systems: Their influence on infiltration rates in the rolling plains of Texas. J. Range Manage. 34:331-335.

Woodward, L. 1943. Infiltration capacities on some plant-soil complexes on Utah range watershed lands. Trans. of Amer. Geophys. Union. 24:468-475.

Botanical Composition and Diet Quality of Cattle Under a Short Duration Grazing System

DONALD R. KIRBY AND MARK PARMAN

Abstract

A study was conducted in 1981 and 1982 at the Dickinson Experiment Station Ranch Headquarters in the mixed grass prairie of western North Dakota to determine seasonal and daily cattle diets under a short duration grazing system. Significant seasonal decreases in crude protein (CP) and in vitro digestible organic matter (IVDOM) were determined both years of the study. Dietary CP did not meet lactating and/or dry, pregnant cow requirements throughout the grazing season either year. In 1981, no seasonal difference in dietary CP and IVDOM was determined between the initiation and termination of grazing on individual paddocks. Only one significant difference occurred in 1982 when dietary CP decreased significantly between the first and last day of grazing individual paddocks in fall. Grass dominated cattle diets both years of the study. The major grasses selected were western wheatgrass *(Agropyron smithii)*, needle-and-thread *(Stipa comata)*, and blue grama *(Bouteloua gracilis)*. Cattle showed no consistent seasonal trend in grass or browse selection, while forbs decreased in diets as the grazing season advanced. Selection of forage species and plant classes by cattle while they occupied a paddock varied little during seasonal collection periods throughout the study.

Specialized grazing systems have not consistently been successful in meeting the nutrient intake requirements of grazing livestock (Lewis 1969, Launchbaugh et al. 1978). Short duration grazing systems (SDG), have been suggested as being able to increase carrying capacity while maintaining or improving individual livestock performance (Savory 1978). It has been suggested that SDG will enhance the dietary quality of grazing livestock by decreasing the maturity of available forage while consistently providing an adequate quantity of forage (Kothmann 1980, Heitschmidt et al. 1982a). However, little information is available to substantiate the enhancement of livestock diets or performance through the use of SDG (Heitschmidt et al. 1982b). An understanding of the effects of SDG on seasonal diets and diets selected within the occupation of individual paddocks is essential prior to applying this intensive grazing method.

The objectives of this study were to examine the botanical composition and evaluate the nutritive content of cattle diets seasonally and within the occupation period of paddocks under an SDG system in the mixed grass prairie of western North Dakota.

Materials and Methods

The study was conducted during the 1981 and 1982 grazing seasons on the Dickinson Experiment Station Ranch Headquarters (T. 143 N., R. 96 W.), located approximately 35 km northwest of Dickinson, North Dakota. Annual average precipitation is 39 cm with 80% received during the growing season, May to September. In 1981 and 1982, 20 and 66 cm of precipitation were received, respectively. Average daily temperature is 4° C, with a monthly high of 27° C in July and low of −13° C in January. Average length of the growing season is 120 days (USDA 1982). Vegetation is typical mixed grass prairie of the Northern Great Plains as described by Whitman and Wali (1975).

The SDG system was implemented by subdividing 130 ha into 8 equal sized paddocks radiating from a central watering facility. Paddocks were maintained on a 5:35 day graze: rest sequence and grazed with 35 cow-calf pairs each year. Grazing seasons were 25 June to 2 September and 22 June to 12 October for 1981 and 1982, respectively. Stocking rates were .64 (moderate) and .98 (heavy) AUM's/ha for 1981 and 1982, respectively.

Five range sites, thin claypan, shallow, sandy, silty, and clayey, comprised 50, 32, 3, 8 and 7%, respectively, of the SDG treatment. Production and disappearance of current year's forage was estimated seasonally by clipping 20 paired, caged and uncaged, 0.25-m^2 quadrats on each range site. Caged and uncaged quadrats were clipped each 40 days following the completed rotation of the cattle herd through paddocks. Grass, forb, and total herbaceous production for each year was determined by multiplying the percentage of each range site by the averaged grass, forb, and total herbaceous production estimated for that site and summing across sites. Forage disappearance was estimated as the difference in dry weight between paired, caged and uncaged quadrats and averaged by year as described for forage production determinations.

Four to 6 esophageally fistulated cows were utilized to collect diet samples from 3 adjacent paddocks. Cows were fasted overnight, then consecutive 1 hr diet collections were made at dawn. Diet samples were collected prior to each of these paddocks being grazed by the cattle herd and immediately following the 5-day occupation of these same paddocks. Collections were made at

Authors are assistant professor and research assistant, Animal and Range Sciences Department, North Dakota State University, Fargo 58105.

The authors gratefully acknowledge Mr. Tom Conlon, Superintendent, Dickinson Experiment Station, for his assistance in this study.

This article is published with the approval of the Director North Dakota Agricultural Experiment Station as Journal Article 1440.

Manuscript accepted 19 March 1986.

approximately 40-day intervals corresponding with seasons and the rotation cycle. Seasons were designated early summer, summer, early fall, and fall and corresponded to late-June through mid-July, mid-July through mid-August, mid-August through mid-September, and mid-September through early-October collection periods, respectively.

Dietary samples from each cow and collection were thoroughly mixed and subsamples removed and frozen. Samples were then lyophilized and nutrition samples ground to pass a 1-mm screen.

Nutrient analyses included crude protein (CP) determined by the micro-Kjeldahl method (AOAC 1970), and in vitro digestible organic matter (IVDOM) determined by the procedures described by Tilley and Terry (1963) and Van Soest and Wine (1967).

Botanical composition of diets followed the microscopic analysis technique described by Kothmann (1968). Plant fragments were identified within 20 randomly selected microplots. Data were recorded by class and species of ingested plant.

Data from diets were analyzed as a split-plot design with year as the main plot and daily or seasonal collection periods as subplot treatments. Duncan's multiple range test was used to compare differences among means following analysis of variance (Steel and Torrie 1960).

Results and Discussion

In 1981, precipitation at the Dickinson Experiment Station Ranch Headquarters was 55% of the long-time average (39 cm). Resultant graminoid, forb, and total herbaceous production averaged 615, 144, and 759 kg/ha, respectively. This led to a shortened grazing season of 2½ months. Herbaceous disappearance was 55%. Greater-than-average precipitation was received in 1982 (66 cm) resulting in estimated production of 725, 483, and 1,208 kg/ha of grass, forb, and total herbaceous production, respectively. The grazing season was terminated after 4 months with herbaceous disappearance estimated to be 41%.

Seasonal percentages of CP and IVDOM differed in diets selected between the 2 years of the study (Table 1). With one exception: % CP and IVDOM were less within each similar season of 1981 when compared to 1982. Since the first year of the study was conducted under severe drought conditions, less forage, especially green, growing forage was available for cattle to graze. Consequently, cattle were forced to select more mature forage which probably contributed to the decreased nutrient percentages found in 1981 diets. In addition, herbaceous utilization was greater in 1981. A decrease in herbage allowance has been reported to reduce diet quality (Allison and Kothman 1979, Taylor et al. 1980).

Early summer and summer CP content of diets in 1981 were significantly greater than those selected in early fall (Table 1). Percentage CP in diets did not meet lactating cow requirements (9.2%) (NRC 1984) in summer and early fall although dry, pregnant cow requirements (5.9%) were met throughout the grazing season. Early summer dietary IVDOM in 1981 was significantly greater than that determined for summer or early fall. Only early summer diets exceeded 50% IVDOM.

During 1982, % CP and IVDOM content of diets selected by cows decreased from early summer through fall (Table 1). Mean % CP was significantly less in early fall and fall diets when compared to early summer diets. Summer % CP content in cattle diets was also significantly greater than fall dietary CP. Beginning in early summer, % IVDOM in forage selected by cows decreased significantly with each succeeding season. Early summer and summer dietary CP exceeded lactating cow requirements, while all seasonal diets selected in 1982 exceeded dry, pregnant cow requirements for CP. Diets selected throughout the 1982 grazing season exceeded 50% IVDOM.

Few differences were found in the nutritive content of cattle diets collected at the beginning and end of a 5-day occupation period of selected research paddocks (Table 1). Over the 1981 grazing period, no differences in any season were determined for either dietary CP or IVDOM between the initiation and termination of grazing on paddocks. Two differences were noted in 1982. Early summer % IVDOM and fall % CP were greater in diets selected on the first day when compared to the last day of paddock occupation. The difference found for early summer % IVDOM is probably of litle biological importance since values at this season were high. However, the difference determined for CP between first and last day diet collections on grazed paddocks in fall may be critical in cattle herd maintenance. Decreased dietary quality under intensive rotational grazing during some portion of the grazing period is in agreement with results reported by Heady (1961), Barnes (1977), and Sharrow (1983). Under the conditions of this study, a shortening of occupation periods or allowing access to a greater number of paddocks after forage maturation may help maintain dietary quality through improved selectivity at or near the level required by grazing livestock.

Over both years of the study, grass dominated cattle diets in all seasons (Table 2). However, several differences in diet selectivity were noted between years. In 1981, a drought year, a higher percentage of grass was found in cattle diets during the early summer and summer following movement into a fresh paddock than in 1982. In addition, the browse component of before grazed diets in fall 1981

Table 1. Crude protein (%) and in vitro digestible organic matter (%) content of cattle diets selected over a 5-day occupation of paddocks under a short duration grazing system at the Dickinson Experiment Station Ranch Headquarters.

Year	Collection period	Season: Early summer	Summer	Early fall	Fall
		crude protein			
1981	before	9.4±.21[1]bc[2]	8.5±.19d	6.9±.23e	
	after	8.7±.21cd	8.5±.25d	—	—
	average[3]	9.1±.16c	8.5±.15d	6.9±.23e	—
1982	before	11.5±.79a	10.0±.57bc	8.2±.28de	6.9±.13e
	after	10.6±.44ab	8.9±.52cd	7.6±.24e	5.6±.22f
	average	11.1±.47ab	9.5±.40c	8.0±.20de	6.3±.20ef
		in vitro digestible organic matter			
1981	before	60±.99cd	47±.86f	43±1.16f	—
	after	59±.71d	45±.73f	—	—
	average	60±.61cd	46±.58f	43±1.16f	—
1982	before	72±1.78a	63±1.16cd	59±.94e	52±.71f
	after	65±1.53bc	61±.75de	59±.64e	51±1.0f
	average	69±1.32ab	62±.75cde	59±.59e	52±.62f

[1]Standard error.
[2]Means within nutrients followed by a different letter differ at the 0.05 level.
[3]Averages are over 5-day collection periods within seasons.

Table 2. Botanical composition (%) of cattle diets selected over 5-day occupations of paddocks under a short duration grazing system at the Dickinson Experiment Station Ranch Headquarters.

Forage class and species	Before Grazing				After Grazing			
	Early summer	Summer	Early fall	Fall	Early summer	Summer	Early fall	Fall
					1981			
Grass	91±1.13[1]ab[2]	94±1.99a	85±3.14bc	—	83±1.10c	90±1.63ab	—	—
Agropyron smithii	32	31	23	—	32	25	—	—
Stipa comata	14	7	1	—	13	7	—	—
Total cool-season	64	43	24	—	58	38	—	—
Bouteloua gracilis	21	43	56	—	21	44	—	—
Total warm-season	27	51	61	—	25	52	—	—
Forb	6±.69ef	2±.54e	1±.45e	—	16±1.14hi	5±.73e	—	—
Browse	3±.77kl	4±1.51kl	14±2.69m	—	1±.21k	5±2.31l	—	—
					1982			
Grass	72±2.68d	82±2.13c	87±1.41bc	87±1.65bc	75±2.04d	85±3.14bc	84±.81bc	89±1.22ab
Agropyron smithii	48	44	10	11	44	34	11	13
Stipa comata	2	7	3	3	4	8	4	2
Total cool-season	60	61	29	29	58	54	25	25
Bouteloua gracilis	9	16	49	47	13	23	47	52
Total warm-season	12	21	58	58	17	31	59	64
Forb	24±3.19j	14±2.41gh	9±.79fg	9±.85fg	20±1.58ij	14±2.69gh	10±.93fg	5±.55ef
Browse	4±1.46kl	4±.51kl	4±1.03kl	4±.87kl	5±1.08l	1±.45k	6±1.30l	6±1.67l

[1]Standard error.
[2]Means of plant classes followed by a different letter differ at the 0.05 level.

was greater than that determined for the comparable season in 1982. Conversely, forb availability and selection by cattle prior to paddocks being grazed was greater in all seasons of 1982, a wet year, when compared to 1981.

Seasonal diets in 1981 ranged from 85 to 94% grasses (Table 2). Selection of grass by cattle was significantly greater in summer when compared to the early fall grazing period. Western wheatgrass (*Agropyron smithii* Rydb.), needle-and-thread (*Stipa comata* Trin. & Rupr.), total cool-season grasses, and forbs decreased in diets from early summer through early fall. Blue grama (*Bouteloua gracilis* H.B.K. Lag. ex. Steud.) and total warm-season grasses increased in diets as the grazing season progressed. Browse significantly increased in early fall cattle diets when compared to early summer and summer diets. The significant decrease in grass and increase in browse in 1981 cattle diets as the grazing season progressed is probably in response to the drought conditions since the limited amounts of grass available during the latter part of the grazing season were well cured while the previously unutilized browse component provided an alternative forage source of high nutrient quality. Shifts in cattle diets towards browse in fall have also been reported by Roath and Krueger (1982) and Kirby and Stuth (1982b).

In 1982, grasses again dominated the composition of seasonal cattle diets ranging from 72 to 87% of the diet (Table 2). Selection for grass was significantly less in early summer when compared to the latter seasons. Again western wheatgrass, needle-and-thread, and cool-season grasses decreased while blue grama and total warm-season grasses increased in diets as the grazing season advanced. Selection for forbs was significantly greater in early summer when compared to the following seasons. Browse was selected in low amounts throughout 1982.

Selection among forage classes varied with time spent in paddocks both years of the study (Table 2). During 1981, grass selection by cattle decreased over the 5-day occupation of paddocks in early summer, while forb selection increased during the same period. Browse selection showed no trend for the drought-shortened 1981 grazing season.

Diet selection of plant classes with seasons and occupation periods was more constant in 1982 than 1981 (Table 2). No differences in seasonal grass selectivity over the 5-day cattle occupation of paddocks were determined in 1982. Selection of grass during occupations varied only 2 to 3 percentage points in each of the seasonal collection periods. In addition, no differences were detected for forb or browse composition in diets between the initiation and termination of grazing on paddocks in 1982.

Summary and Conclusions

Extremes in precipitation received during the study led to a variation in plant classes and species available as forage. Grasses and forbs had a more limited availability and greater utilization in 1981 when compared to 1982. Consequently, nutritional and botanical compositions of forage selected by cattle varied significantly between years and seasons.

Crude protein content of diets did not meet lactating cow requirements in early fall or fall either year of the study. However, CP did meet dry, pregnant cow requirements throughout seasonal diet collections both years of the study. A decline in dietary CP with advanced maturity and reduced availability of forage is in agreement with many grazing studies (Streeter et al. 1968, Obioha et al. 1970, Scales et al. 1974, Allison and Kothmann 1979, Kirby and Stuth 1982a, Yates and Wallace 1982). Earlier weaning of calves and/or supplementation of cows or calves in fall should help mitigate this nutritional deficiency in late season forage on seasonally grazed ranges.

Diets selected at the initiation and termination of grazing on paddocks generally decreased in CP and IVDOM. In late fall 1982, a significant decrease in dietary CP below the requirement needed for dry, pregnant cow was determined between the beginning and final day of paddock occupation. This may be critical in cow herd maintenance prior to winter. Despite not being statistically significant, the general decrease in diet quality during a paddock occupation might be of biological significance. A rapidly fluctuating and decreasing nutrient and forage supply should lead to less than optimum dietary selectivity, hence livestock productivity. Possibly a shortening of the occupation period after forage maturation or access to multiple paddocks may maintain dietary quality at or above levels required by grazing cattle without further managerial inputs. A reduction in stocking rate, supplementation, early calf weaning, etc., however, may be necessary to maintain or improve livestock performance after forage maturation.

Botanically, grasses dominated the composition of diets both years of the study. Major grasses selected were western wheatgrass and blue grama with needle-and-thead less consistently selected. Despite some selection of forbs and browse, these plant classes were not observed as being consistently utilized under our short duration grazing system. This suggests that an alternate class of livestock may also need to be stocked in this region regardless of management system to make efficient use of these classes of forage.

Literature Cited

Allison, C.D., and M.M. Kothmann. 1979. Effect of level of stocking pressure on forage intake and diet quality of range cattle. Amer. Soc. Anim. Sci., West. Sec., Proc. 30:174-178.

A.O.A.C. 1970. Official methods of analysis. (11th ed.) Ass. of Off. Agr. Chem., Washington, D.C.

Barnes, D.L. 1977. An analysis of rotational grazing on veld. Rhodesia Agr. J. 74:147-151.

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

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

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

Kirby, D.R., and J.W. Stuth. 1982a. Brush management influences the nutritive content of cattle diets in east-central Texas. J. Range Manage. 35:431-434.

Kirby, D.R., and J.W. Stuth. 1982b. Botanical composition of cattle diets grazing brush managed pastures in east-central Texas. J. Range Manage. 35:434-436.

Kothmann, M.M. 1968. The botanical composition and nutrient content of the diet of sheep grazing poor condition pasture compared to good condition pasture. Ph.D. Diss. Texas A&M Univ., College Station, Texas.

Kothmann, M.M. 1980. Consideration of livestock needs in designing grazing systems for rangelands, p. 78-90. *In:* D.C. Church (ed.), Digestive Physiology and Nutrition of Ruminants; Vol. 3. Practical Nutrition. O & M Books. Corvallis, Ore.

Launchbaugh, John L., Clenton E. Owensby, Frank L. Schwartz, and Larry R. Corah. 1978. Grazing management to meet nutritional and functional needs of livestock, p. 541-546. *In:* D.N. Hyder (ed.), Proc. 1st Internat. Range Cong., Soc. Range Manage. Pub. Denver, Colo.

Lewis, James K. 1969. Range management viewed in an ecosystem framework, p. 97-187. *In:* G.M. Van Dyne (ed.) The Ecosystem Concept In Natural Resource Management, Academic Press. New York.

N.R.C. 1984. Nutrient requirements of domestic animals; No. 6. Nutrient requirements of beef cattle. Nat. Acad. Sci. Washington, D.C.

Obioha, F.C., D.C. Clanton, L.R. Rittenhouse, and C.L. Streeter. 1970. Sources of variation in chemical composition of forage ingested by esophageal fistulated cattle. J. Range Manage. 23:133-135.

Roath, L.R., and W.C. Krueger. 1982. Cattle grazing influence on a mountain riparian zone. J. Range Manage. 35:100-103.

Savory, A. 1978. A holistic approach to ranch management using short duration grazing, p. 555-557. *In:* D.N. Hyder (ed.), Proc. 1st Internat. Range. Cong., Soc. Range Manage. Pub. Denver, Colo.

Scales, G.H., A.H. Denham, C.L. Streeter, and G.M. Ward. 1974. Winter supplementation of beef calves on Sandhill range. J. Anim. Sci. 38:442-448.

Sharrow, S.H. 1983. Forage standing crop and animal diets under rotational vs. continuous grazing. J. Range Manage. 36:447-450.

Steel, R.D.G., and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, Inc. New York.

Streeter, C.L., D.C. Clanton, and O.E. Hoehne. 1968. Influence of advance in season on nutritive value of forage consumed by cattle grazing western Nebraska native range. Nebraska Agr. Exp. Sta. Bull. 227.

Taylor, Charles A., M.M. Kothmann, L.B. Merrill, and Doak Elledge. 1980. Diet selection by cattle under high-intensity low-frequency, short duration, and Merrill grazing systems. J. Range Manage. 33:428-434.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Brit. Grassld. Soc. 18:104-111.

U.S.D.A., S.C.S. 1982. Soil Survey of Dunn County, North Dakota.

Van Soest, P.J., and R.H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determinations of plant cell-wall constituents. J. Ass. Off. Agr. Chem. 50:50-55.

Whitman, W.C., and M.K. Wali. 1975. Prairie: A multiple view. Univ. N.D. Press, Grand Forks.

Yates, D.A., and J.D. Wallace. 1978. Cattle diets on irrigated pasture. J. Range Manage. 31:213-215.

Effect of Time of Grazing in First Crop Year on Subsequent Productivity of Russian Wildrye

N.W. HOLT, T. LAWRENCE, AND M.R. KILCHER

Abstract

Russian wildrye (*Elymus junceus* Fisch.) is an important rangeland grass. It is slow to establish and could be damaged by grazing too soon after seeding. To test this hypothesis the effect of date of first grazing on the productivity of a newly established Russian wildrye pasture was determined for the first crop year, that is, the year after establishment, and 3 subsequent years at Swift Current, Saskatchewan. In the first crop year the grazing days per hectare with yearling steers was 134 days and 138 kg/ha total liveweight gain was obtained for a grazing period beginning on 15 June. When grazing was started 1 May or 1 August, carrying capacity was not different but beef production was 60 and 84 kg/ha, respectively. In the second year, when all pastures were grazed continuously from 4 May, the greatest number of days grazing were obtained when grazing had been delayed until 1 August the previous year. However, date of first grazing in the first production year did not affect liveweight gain in the second year nor liveweight gain or grazing days in the subsequent 2 years of grazing with steers. It was concluded that grazing of newly established Russian wildrye pastures should be delayed in the first crop year until the plants are fully headed (about mid-June).

Russian wildrye (RWR) (*Elymus junceus* Fisch.) is an important pasture grass for the semiarid prairies of the Northern Great Plains (Heinrichs et al. 1976, Smoliak and Slen 1974, Berdahl and Barker 1984). While the variety Swift has better establishment vigor than older varieties (Lawrence 1979), *Elymus* species tend to develop more slowly than other grasses (Lawrence and Kilcher 1972). In eastern Montana RWR and Altai wild rye (*Elymus angustus* Trin.) produced the least forage of 7 grass species in the first year after seeding, the first crop year, but were among the species which produced the most forage in the second year after seeding (White and Wight 1981). White and Wight reported the highest dry matter yield of RWR from the July harvest in the first crop year and from a June harvest in the second year after establishment. In a simulated grazing study at Swift Current, Saskatchewan, Leyshon (1983) compared the effects of 6 different harvest dates of RWR (25 May to 29 July) in the first crop year (1977) on productivity in 4 subsequent years when harvests were taken whenever 10 cm of grass were available. Leyshon found that highest yields in the first crop year were obtained with a July harvest. However, in the 3 following years, the greatest yield of forage was obtained when the first crop year harvest was delayed at least until mid-June. Leyshon concluded that RWR should not be grazed in the first crop year until the time of flower (mid to late June).

The objective of this study was to test, under grazing conditions, the hypothesis that delayed harvest of RWR in the first crop year would increase productivity in the second and subsequent years, especially if defoliation was continuous as with grazing animals.

Materials and Methods

This grazing test was conducted at Swift Current, Saskatchewan, on a Swinton loam soil (aridic haploborall). In May of 1980 12 paddocks (previously fallowed) of 1.62 ha each were sown to 'Swift' RWR at 90-cm row spacings. No fertilizer was applied during the course of the trial. Available soil phosphorus was 7.2 ppm (0–15 cm) and available soil nitrogen was judged to be adequate. A good stand was obtained and the treatments were assigned to the pastures in a randomized complete block design for 4 replicates. The three 1981 treatments were: grazing to commence 1 May; 15 June (early flower); and 1 August (mature seed). Three yearling Hereford steers (275 kg average weight) were used to graze each paddock each year. In 1981 a put-and-take system was used for the May treatment but other pastures were grazed continuously. From 1981 to 1984, all pastures were grazed continuously from the same date in early May (when 10 cm of forage was available). Animals were removed when grass was grazed to 3 cm or when animals showed no weight gain over the 2-week period since the previous weighing. Cattle were weighed after 16 hours off feed and water. Days of grazing and cattle weight changes were used to compare treatments. Data were analyzed for each year. The mean square for the interaction of treatment and replicate was used to test the significance of the treatment effects and to determine a least significant difference (LSD).

Authors are forage agronomist, grass breeder and range scientist (retired), respectively, Agriculture Canada, Research Station, Swift Current, Saskatchewan. S9H 3X2.

The authors wish to express their appreciation to Mr. Helmut Peters for technical assistance and supervision of the research.

Manuscript accepted 6 March 1986.

Results and Discussion

With the exception of 1982, yearly precipitation for the years 1980 to 1984 was below the long-term average 359 mm for the Swift Current area. In 1 year, 1984, April– August precipitation was below the long-term average of 209 mm.

A delayed start to grazing RWR in 1981, the first crop year, did not increase the total grazing days per hectare (Table 1). In 1982, when all pastures were grazed from 4 May, the delayed grazing in 1981 increased the total animal days of grazing per hectare in 1982. In 1983 and 1984, there were no differences among the treatments for animal grazing days.

Table 1. Effect of date of first grazing in the first crop year on the carrying capacity of Russian wildrye pastures in the first crop and subsequent years.

Date grazing commenced 1981	1981	1982	1983	1984	Total
	animal days/ha				
May 1	122	240	253	184	799
June 15	134	297	253	210	894
August 1	127	329	253	178	887
LSD (P=.05)	NS[1]	66	NS	NS	NS

[1]NS = not significant at $P = 0.05$.

In 1981, postponement of grazing until 15 June produced the highest average daily gain and total weight gain by the steers (Table 2). A further delay in date of first grazing did not result in further gains; in fact, as the grass matured and quality declined (Lawrence and Troelsen 1964), average daily gain decreased. Lowest productivity was obtained when grazing started on 1 May. Date of first use in 1981 did not affect average daily gain for the years 1982 to 1984. Although beef production in 1982 was numerically greatest for those pastures where grazing was delayed in 1981, the differences among treatments were not significantly different at P = 0.05. Leyshon (1985) found forage yields to be higher in the year after a delayed harvest of the first crop. He reported on effects of delayed harvest in a period of slightly below normal annual precipitation. In this study precipitation in 1982 for April–August may have

Table 2. Effect of date of first grazing on the productivity of Russian wildrye pastures.

Date grazing commenced 1981	Lightweight gain				Beef production				
	1981	1982	1983	1984	1981	1982	1983	1984	Total
	kg/day				kg/ha				
May 1	0.50	0.90	0.63	0.61	60	214	159	109	542
June 15	1.05	0.86	0.62	0.62	138	246	157	132	673
August 1	0.65	0.71	0.61	0.65	84	233	156	117	590
LSD (P=.05)	0.21	NS[1]	NS	NS	49	NS	NS	NS	62

[1]NS = not significant at $P = 0.05$.

helped the RWR pastures recover from early grazing in 1981. Total production over the 4 years was significantly favored by delayed grazing in first crop year.

Beef production per hectare was much greater in the second year after establishment than in the first. This has also been reported for dry matter (White and Wight 1981, Leyshon 1983). In our study, productivity declined in 1983 and 1984 due to a lack of precipitation.

It is a temptation for producers to graze a new seeding of RWR early in the first crop year so as to begin to obtain some return for the costs of establishment. Although RWR has been promoted for early season use, this experiment demonstrated that in the first crop year, productivity will be greater if the date of first grazing is delayed until mid June. The benefits of allowing the new plants to develop may be carried over into the second and later years.

Literature Cited

Berdahl, J.D., and R.E. Barker. 1984. Selection for improved seedling vigor in Russian wild ryegrass. Can. J. Plant Sci. 64:131-138.

Heinrichs, D.H., R.W. Lodge, and M.R. Kilcher. 1976. Russian wild ryegrass and Altai wild ryegrass for early summer pasture. Can. J. Plant Sci. 56:287-291.

Lawrence, T. 1979. Swift Russian wild ryegrass. Can. J. Plant Sci. 59:515-518.

Lawrence, T., and M.R. Kilcher. 1972. Emergence, seedling growth, and yield of Altai wild ryegrass and other grasses as influenced by soil temperature and fertility. Can. J. Plant Sci. 52:795-800.

Lawrence, T., and J.E. Troelsen. 1964. An evaluation of 15 grass species as forage crops for southwestern Saskatchewan. Can. J. Plant Sci. 44:301-310.

Leyshon, A.J. 1983. Effect on the subsequent productivity of newly seeded pastures of time and intensity of first use. p. 51-56. *In:* 1982 Research Hi-Lites, Research Station, Swift Current, Saskatchewan.

Smoliak, S., and S.B. Slen. 1974. Beef production on native range, crested wheatgrass and Russian wild rye pastures. J. Range Manage. 27:433-436.

White, L.M., and J.R. Wight. 1981. Seasonal dry matter yield and digestibility of seven grass species, alfalfa, and cicer milkvetch in eastern Montana. Agron. J. 73:457-462.

Vegetal Change in the Absence of Livestock Grazing, Mountain Brush Zone, Utah

DENNIS D. AUSTIN, PHILIP J. URNESS, AND ROBERT A. RIGGS

Abstract

Canopy cover of vegetation dominated by Gambel oak was determined in 1983 in adjacent canyons characterized by different grazing histories. Results were compared with data collected in 1935, and the methods replicated those used in the earlier study. Vegetal changes since 1935 in Red Butte Canyon where livestock grazing had been excluded since 1905 were small compared with those of Emigration Canyon where heavy grazing continued into the 1930's, but was gradually phased out and discontinued in 1957. Large differences in vegetal cover between the 2 canyons reported in 1935 were mostly eliminated by 1983.

Selective foraging by livestock is an important factor determining the composition of plant communities, and directly affects associated animal communities. Livestock select palatable forage and thereby give a growth advantage to less palatable, ungrazed plants. On many mule deer winter ranges in the Intermountain Region livestock grazing shifted presettlement, grass-dominated communities to shrublands (Stewart 1941, Reynolds 1960, Christensen and Johnson 1964, Hull and Hull 1974, Harniss and Wright 1982). Mule deer herds responded to the increase in available winter forage and numbers significantly increased (Hancock 1981).

Authors are wildlife biologist, associate professor, and research assistant, Department of Range Science, UMC 52, Utah State University, Logan 84322.

This paper is a contribution of Utah State Division of Wildlife Resources, Federal Aid Project W-105-R.

Manuscript accepted 9 June 1986.

However, due to erosion problems often associated with excessive livestock grazing and increased emphasis on watershed and recreation values, livestock grazing on many Intermountain winter ranges has been decreased or eliminated (Stewart 1936, Stoddart and Smith 1955). On those ranges where previously heavy livestock grazing was eliminated, secondary succession, accelerated by deer use in winter, would be expected to slowly alter plant communities toward more grasses and forbs and fewer desirable shrubs (Rogers 1982). Consequently reductions in numbers of mule deer may be predicted.

The mountain brush zone found throughout the Intermountain Area commonly occurs as transition range between sagebrush foothills and coniferous forest. Open stands of deciduous trees, with abundant grass and forb understory having high nutritive value, make the zone valuable and attractive for grazing. Consequently many areas were highly impacted by livestock before grazing was curtailed. However, little is known about post-grazing succession. This study reports changes in vegetal composition from 2 areas previously grazed by livestock, but receiving no livestock use in several decades.

Study Areas

Red Butte and Emigration Canyons, lying directly east of Salt Lake City, Utah, are typical drainages within the mountain brush zone. They have a general east-west orientation and are parallel and adjacent. Their mouths are at about 1,520 m elevation with the canyons rising to over 1,830 m. Vegetation is dominated by Gambel oak (*Quercus gambelii* Nutt.) throughout. Yearly precipitation increases from about 55 cm at the lower elevations to over 90 cm near the head of the canyons (Bond 1979). Both canyons contain small permanent streams with Red Butte draining about 65 km^2 and Emigration 104 km^2.

The canyons, with Emigration being grazed by livestock until 1957 and Red Butte ungrazed since 1905, were originally selected for study because of their comparability in position, physiography and previous historical use (Evans 1936, Cottam and Evans 1945). Both canyons were privately owned and grazed by livestock for about 40 years (1848–1888). Between 1888–1909 Red Butte Canyon was purchased by the U.S. government. Livestock grazing subsequently was reduced due to erosion problems and essentially eliminated by 1905 with no livestock grazing permitted since then. Emigration Canyon remained in private ownership until portions were purchased by the Salt Lake City municipality for watershed protection beginning about 1935, and land usage gradually came under control of the Public Utilities office. Prior to 1935 livestock grazing was heavy (Evans 1936) and, based upon early settlement descriptions of the vegetation, caused considerable vegetal change (Cottam and Evans 1945). From 1935–56 Emigration Canyon was lightly grazed with a band of about 1,000 sheep in spring and fall. From 1957–83 livestock grazing was not allowed (Pers. comm. LeRoy Hooton,Jr., Public Utilities Director, September 1984).

Methods

The methods described by Cottam and Evans (1945) were followed. This involved establishing 4 nonpermanent transects in each canyon. Transects were located using topographic maps along the canyon road, and altitudinal elevations of the transects' mid points were 1,520, 1,630, 1,710, and 1,770 m for transects numbered 1, 2, 3, 4, respectively. The center of each transect was the stream bottom nearest the elevation-road intersection. Each transect consisted of 40 evenly spaced plots lying in a line perpendicular to the main drainage with 20 plots on each side of the canyon. Plots were separated by 60 m, determined by pacing, except for the first plot of each half transect, which was 30 m from the stream bottom. Plots were circular and contained 9.29 m^2.

Vegetal data were obtained using the point-observation-plot method (Stewart and Hutchings 1936). This method consisted of estimating plant cover by species to the nearest .023 m^2 (.25 ft^2). Our data collection period, mostly in July, 1983, corresponded closely to that of Cottam and Evans (1945). Data as reported by Cottam and Evans (1945) and detailed by Evans (1936) were converted to mean percentages for direct comparison with our 1983 data. Data were analyzed by standard *t*-test of the means.

Results and Discussion

Cottam and Evans (1945) reported that in 1935 total canopy cover in Red Butte Canyon was about double that of Emigration Canyon. Although neither original data nor statistical tests are available for individual transects, 3 of their 4 transects, paired by elevation between canyons, showed large, probably significant, differences (Fig. 1). Mean canopy cover over the 4 transects was significantly different ($P<.10$). However, in 1983 no significant differences ($P<.10$) in mean cover or between paired transects remained, and indeed, Emigration Canyon had slightly more cover than Red Butte. Combined north and south slopes showed the same trends.

Perennial grasses, represented primarily by bluebunch wheatgrass (*Agropyron spicatum* Pursh), showed a difference in 1935 between canyons. However, by 1983 with grazing exclusion no difference remained, as cover significantly increased in Emigration Canyon (Table 1). Annual cheatgrass (*Bromus tectorum* L.) did not significantly increase in either canyon. All other unlisted grasses combined, mostly annuals including rattlesnake brome (*Bromus brizaeformis* Fisch. and Mey.) and Japanese brome (*Bromus japonicus* Thumb.), increased in both canyons, as did total grasses.

Canopy cover of total forbs, 3 of 4 important forbs, and all other unlisted forbs combined, were different between canyons in 1935 (Table 1). In 1983 no differences between canyons were found. Total forb cover showed no change in Red Butte Canyon, but increased in Emigration.

Total shrub cover and most of the important shrub species were not different between canyons in both 1935 and 1983 (Table 1). The differences that were found in 1935 with big sagebrush (*Artemisia tridentata* Nutt.) and myrtle pachistima (*Pachistima myrsinites* Pursh) remained in 1983. Changes in cover within canyons between 1935–83 were more important. Total shrubs and all other, unlisted shrubs combined showed no change in Red Butte Canyon,

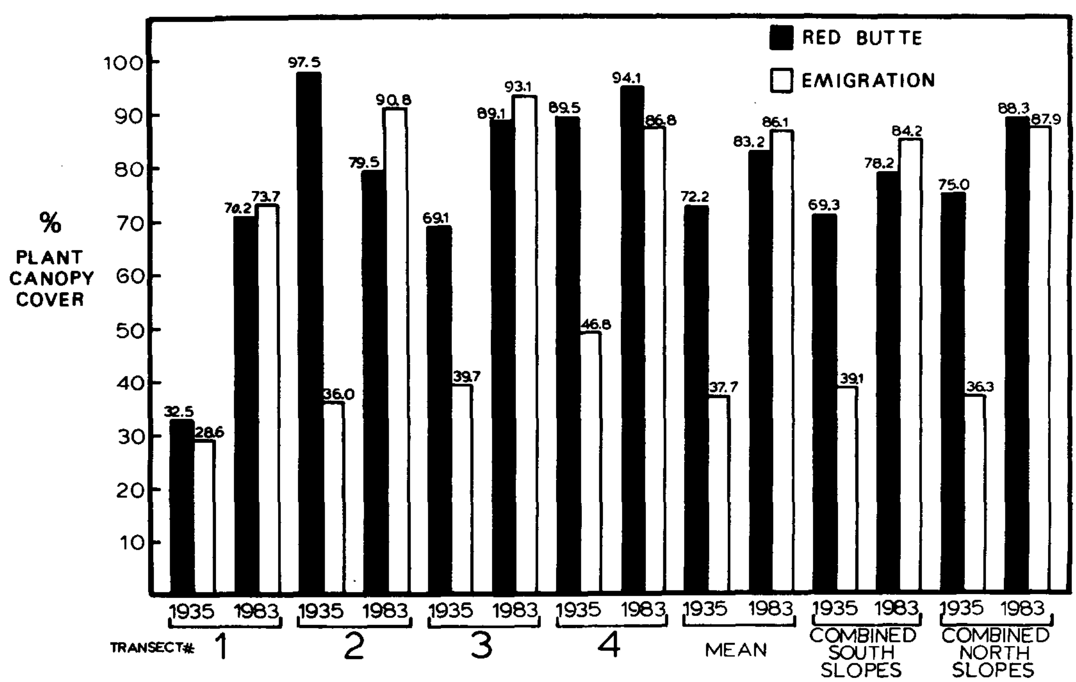


Fig. 1. *Comparison of total plant canopy cover of Red Butte and Emigration Canyons, 1935, 1983.*

Table 1. Mean percent plant canopy cover of important (minimum mean cover=0.05%) species in Red Butte and Emigration Canyons, 1935, 1983[1].

	Red Butte		Emigration	
Species	1935	1983	1935	1983
Grasses				
Agropyron spicatum	1.1^{a}	1.7^{a}	0.1^{b}	1.4^{a}
Bromus tectorum	3.9^{a}	8.1^{a}	2.5^{a}	2.7^{a}
All others	1.4^{a}	9.3^{b}	0.7^{a}	11.0^{b}
Sub total	6.4^{a}	19.1^{b}	3.3^{a}	15.1^{b}
Forbs				
Aster spp.	1.2^{a}	0.5^{ab}	0.2^{b}	0.5^{ab}
Balsamorhiza sagittata	4.5^{a}	2.4^{b}	0.9^{b}	1.0^{b}
Lathyrus spp.	1.3^{a}	0.8^{a}	0.7^{a}	1.2^{a}
Wyethia amplexicaulis	5.5^{a}	3.3^{ab}	1.4^{b}	4.3^{a}
All others	12.9^{a}	11.6^{a}	6.4^{b}	9.7^{a}
Sub total	25.4^{a}	18.6^{a}	9.6^{b}	16.6^{a}
Shrubs				
Amelanchier alnifolia	1.9^{a}	0.5^{a}	0.9^{a}	1.2^{a}
Artemisia tridentata	0.2^{a}	0.2^{a}	2.6^{b}	2.8^{b}
Mahonia repens	0.6^{a}	0.5^{a}	0.7^{ab}	1.3^{b}
Pachistima myrsinites	1.6^{a}	3.0^{a}	0.2^{b}	0.1^{b}
Physocarpus malvaceus	4.0^{a}	4.2^{a}	1.0^{b}	4.5^{a}
Prunus virginiana	1.1^{a}	1.3^{a}	1.7^{a}	1.8^{a}
Quercus gambelii	22.5^{ab}	27.9^{a}	12.8^{b}	27.2^{a}
Rosa woodsii	2.9^{a}	0.2^{c}	0.8^{b}	1.3^{ab}
Symphoricarpos oreophilus	2.0^{a}	1.6^{a}	2.1^{a}	8.1^{a}
All others	3.6^{ab}	5.9^{ab}	1.9^{b}	5.9^{a}
Sub total	40.4^{ab}	45.5^{a}	24.8^{b}	54.5^{a}
Total	72.2^{a}	83.2^{a}	37.7^{b}	86.1^{a}

[1]Figures with any common letter across lines are *not* different ($P < .10$).

but increased in Emigration. The dominant species, Gambel oak, along with ninebark (*Physocarpus malvaceus* Green) did not significantly increase in Red Butte Canyon, but more than doubled in Emigration, suggesting heavy livestock use reduced cover prior to the 1935 survey. The rate of cover increase of Gambel oak was near the 4% per year rate suggested by Christensen (1949) in Emigration Canyon. Contrary to our findings, Nixon (1967) reported Gamble oak decreased over a 10-year period in grazing exclosure, but suggested the decrease was due to invading big-tooth maple (*Acer grandidentatum* Nutt.), which was uncommon in our study area.

Thomas (1970) reported on 2 exclosures in the mountain brush zone following 10 and 37 years of grazing protection. His results paralleled our findings, and he concluded that following protection from grazing, vegetation change slowly progressed toward improvement in range condition and forage species abundance and composition.

For a variety of proposed reasons, plant communities often respond differently following livestock exclusion (Costello and Turner 1941, Sanders and Voth 1983, West et al. 1984). However, from the available literature (Table 2) it appears perennial grasses and total vegetation generally increased. The response of perennial forbs and shrubs varied by habitat. In our study of the mountain brush zone many native plant species increased after livestock grazing was eliminated in Emigration Canyon (Table 1). A similar increase was likely to have occurred in Red Butte Canyon between 1905–35.

In both 1935 and 1983 winter moisture was adequate to recharge the soil moisture profile, and consequently early season growth of perennial plants would be expected to be similar between years. Nonetheless it should be noted that 25 comparable Utah weather stations between 1,500–1,800 m recorded 47.9 cm of mean precipitation in 1983 and 24.2 cm in 1935. However, Cottam and Evans (1945) indicated surveys were completed for several summers beginning in 1935, but because vegetal conditions were essentially the same between years, they published only the 1935 data. The difference in precipitation would more likely have affected cover differences in annual plants, as possibly reflected in our values for grasses.

The influence of wild ungulate populations on vegetation should not be ignored in interpreting results on areas protected from domestic grazers. Smith (1949) compared adjacent ranges at the lower elevational extent of the mountain brush zone used by mule deer during winter in northern Utah. One range was heavily grazed by livestock in spring and summer, while the second had been protected from livestock during the previous 11 years. Perennial forbs and grasses were more abundant on the range protected from livestock, but shrubs, primarily big sagebrush, were much less abundant due to heavy deer browsing. The trend of decreasing shrubs on range protected from livestock grazing continued through 1982 (Urness and Austin[1]). Riordan (1970), Thomas (1970) and McKean and Bartmann (1971) reported similar results. In our study area, deer use as determined from transects within the

[1]Manuscript in preparation titled "Reponse of deer winter range to elimination of livestock in northern Utah.".

Table 2. Vegetal response from livestock grazing exclusion at a number of rangeland locations.

Reference	Habitat	Years of Exclusion	Yearly Precipitation (cm)	Vegetal Response: Shrubs	Perennial Forbs	Perennial Grasses	Annual Grasses	Total Vegetation
Costello and Turner 1941	Shortgrass	Variable	—	Decrease	Increase	Increase	—	Increase
	Ponderosa pine	Variable	—	Increase	No change	Increase	—	Increase
	Sagebrush	Variable	—	Decrease	Increase	Increase	—	Increase
	Aspen-grass	Variable	—	No change	Decrease	Increase	—	Increase
	Pinyon-juniper	Variable	—	Increase	Increase	Increase	—	Increase
	Mountain grassland	Variable	—	Increase	Increase	Increase	—	Increase
Gardner 1950	Grassland-desert	30	43	Increase	No change	Increase	No change	Increase
Robertson 1971	Sagebrush-grass	30	—	Increase	Increase	Increase	Increase	Increase
McLean and Tisdale 1972	Fescue grassland	21-29	—	—	Decrease	Increase	—	Increase
	Ponderosa pine	20-35	—	Decrease	Decrease	Increase	—	Increase
Smith and Schmutz 1975	Grassland-desert	28	38-41	Increase	Decrease	Increase	—	Increase
Rice and Westoby 1978	Semi-desert shrub	15	15-40	No change	No change	No change	Variable	No change
Anderson and Holte 1981	Sagebrush-grass semi-desert	25	21	Increase	—	Increase	—	Increase
Kleiner 1983	Grassland-desert	10	22	Increase	Decrease	Decrease	No change	Increase
Sanders and Voth 1983	Sagebrush-grass	46	40–50	Variable	Variable	Variable	Variable	No change
West et al. 1984	Sagebrush-grass semi desert	13	29–41	—	No change	No change	Increase	No change

study areas and adjacent canyons collected by the Utah Division of Wildlife Resources (1960–83), indicated a mean overwinter impact of about 50–80 deer-days/ha/year, and mean utilization on Gambel oak of about 25–30%. This level of use did not control the spread of Gambel oak, which increased significantly in Emigration Canyon, and probably was not effective in decreasing other browse species (Table 1).

In conclusion, plant cover responses due to decreased grazing (1935–56) followed by grazing exclusion (1957–83) in the Gambel oak community are summarized as (1) vegetation recovery resulted in greater total plant cover, and (2) cover of all classes of vegetation including Gambel oak increased. In comparison plant cover response (1935–83) due to grazing exclusion beginning in 1905 showed little significant change.

Literature Cited

Anderson, J.E., and K.E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. J. Range Manage. 34:25-29.

Bond, H.W. 1979. Nutrient concentration patterns in a stream draining a montane ecosystem in Utah. Ecology 60:1184-1196.

Christensen, E.M. 1949. The ecology and geographic distribution of oak brush *(Quercus gambelii)* in Utah. Thesis, Univ. of Utah, Salt Lake City.

Christensen, E.M., and H.B. Johnson. 1964. Presettlement vegetation and vegetational change in 3 valleys in central Utah. Brigham Young Univ. Sci. Bull. Biol. Series IV(4):1-15.

Costello, D.F., and G.T. Turner. 1941. Vegetation changes folowing exclusion of livestock from grazed ranges. J. Forest. 39:310-315.

Cottam, W.P., and F.R. Evans. 1945. A comparative study of the vegetation of grazed and ungrazed canyons of the Wasatch Range, Utah. Ecology 26:171-181.

Evans, F.R. 1936. A comparative study of the vegetation of a grazed and ungrazed canyon of the Wasatch Range. Thesis, Univ. of Utah, Salt Lake City.

Gardner, J.L. 1950. Effects of 30 years of protection from grazing in desert grassland. Ecology 31:44-50.

Hancock, N.V. 1981. Mule deer management in Utah—past and present p. 1-25. Mule Deer Workshop. Utah Coop. Wildl. Res. Unit, Utah State Univ.

Harniss, R.O., and H.A. Wright. 1982. Summer grazing of sagebrush-grass range by sheep. J. Range Manage. 35:13-17.

Hull, A.C., Jr., and M.K. Hull. 1974. Presettlement vegetation of Cache Valley, Utah and Idaho. J. Range Manage. 27:27-29.

Kleiner, E.F. 1983. Successional trends in an ungrazed, arid grassland over a decade. J. Range Manage. 36:114-118.

McKean, W.T., and R.W. Bartmann. 1971. Deer-livestock relations on a pinyon-juniper range in northwestern Colorado. Colorado Div. Game, Fish and Parks. Proj. W101R, Job 1, Final Report.

McLean, A., and E.W. Tisdale. 1972. Recovery rate of depleted range sites under protection from grazing. J. Range Manage. 25:178-184.

Nixon, E.S., 1967. A comparative study of the mountain brush vegetation in Utah. Great Basin Natur. 27:59-66.

Reynolds, T.A. 1960. The mule deer. Utah State Dep. Fish and Game Pub. 60-4.

Rice, B., and M. Westoby. 1978. Vegetative responses of some Great Basin shrub communities protected against jackrabbits or domestic stock. J. Range Manage. 31:28-34.

Riordan, L.E. 1970. Differences in range vegetation resulting from grazing by deer, cattle and sheep. Proc. Soc. Amer. Forest. 57:147-151.

Robertson, J.H. 1971. Changes on a sagebrush-grass range in Nevada ungrazed for 30 years. J. Range Manage. 24:397-400.

Rogers, G.F. 1982. A photograph history of vegetation change in the central Great Basin desert. Univ. of Utah Press, Salt Lake City.

Sanders, K.D., and A.S. Voth. 1983. Ecological changes of grazed and ungrazed plant communities. p. 176-179. *In:* Managing Intermountain Rangelands-Improvement of Range and Wildlife Habitats. U.S. Forest Serv. Gen. Tech. Rep. INT-157.

Smith, A.D. 1949. Effects of mule deer and livestock upon a foothill range in northern Utah. J. Wildl. Manage. 13:21-23.

Smith, D.A., and E.M. Schmutz. 1975. Vegetative changes on protected versus grazed desert grassland ranges in Arizona. J. Range Manage. 28:453-458.

Stewart, G. 1936. History of range use. p. 119-133. *In:* USDA Forest Serv., The Western Range. 94th Congr. 2nd Session. Senate Document 199.

Stewart, G. 1941. Historic records bearing on agricultural and grazing ecology in Utah. Ecology 39:362-375.

Stewart, G, and S.S. Hutchings. 1936. The point-observation-plot (square feet density) method of vegetation survey. J. Amer. Soc. Agron. 28:714-722.

Stoddart, L.A., and A.D. Smith. 1955. Range management. 2nd Edition. McGraw-Hill Co.

Thomas, J.W. 1970. A comparison of vegetation changes in a mountain brush type after grazing and protection from grazing during 37 years. M.S. Thesis. Brigham Young Univ. Provo, Utah.

West, N.E., F.D. Provenza, P.S. Johnson, and M.K. Owens. 1984. Vegetation change after 13 years of livestock grazing exclusion on sagebrush semidesert in west central Utah. J. Range Manage. 37:262-264.

Effect of Season and Regrazing on Diet Quality of Burned Florida Range

K.R. LONG, R.S. KALMBACHER, AND F.G. MARTIN

Abstract

Diet crude protein and in vitro organic matter digestibility (IVOMD) of diets of esophageally fistulated steers were compared for a pasture grazed June to September ("summer" pasture) and again in January to March ("winter-regraze") with a pasture grazed in "winter-only". The longevity of improvement in diet quality due to burning also was measured. Grass and forb yields were determined before and after grazing. Dietary crude protein and IVOMD were greater ($P<0.05$) on the summer (8.4% and 47%) as compared to the winter-only pasture (6.7% and 32%) in both years. Diet protein concentration of the winter-regraze pasture (7.6%) was not different ($P>0.05$) from summer or winter-only diets in both years. IVOMD in diets from the winter-regraze (36%) was intermediate and significantly different from the summer and winter-only pasture in the first year. Diet IVOMD in the second year was not different ($P>0.05$) on the winter-regraze (34%) and winter-only (32%) pastures. Diet quality was not different ($P>0.05$) in summer (8.2% protein, 46% IVOMD) beginning 4 months after a burn as compared to forage quality in summer 16 months after the burn (8.5%, 47%, respectively). Compared to grazing in winter only, grazing in summer may improve digestibility of forage from range when that range is regrazed the following winter, but protein and energy of the summer range will be deficient for lactating cows.

Ranching has been a cow-calf industry in Florida where cattlemen have been limited by infertile, sandy soils, wide variations in rainfall and temperature, and a poor annual distribution of low quality forage from extensively managed subtropical pastures. Although weaning weight, production/cow, and production/ha increase with intensification (Peacock et al. 1974), dollar returns/cow can decrease (Anderson and Hipp 1973). Many Florida ranchers have found that the greater cost of increased calf production from fertilized, introduced forages can be offset with low cost of range.

Some nutritional deficiencies of Southeastern U.S. range have been recognized. A seasonal decline (April to December) in nutritive value 44 to 32% TDN, respectively) was accompanied by declining forage intake and cow weights in Georgia (Hale et al. 1962). Range forage in Georgia may vary from 4 to 8% crude protein and 25 to 45% digestibility as determined by in vitro procedures on hand-collected samples (Lewis et al. 1975).

There are few methods for improving the quality of range forage. Perhaps diet quality could be improved through control of grazing time. Many ranchers utilize their fertilized pastures during summer while deferring use of native pastures until winter when plants are often senescent and forage quality is low. It has been shown that crude protein and IVOMD (in vitro organic matter digestibility) in creeping bluestem *(Schizachyrium stoloniferum)* in winter were improved by clipping (Kalmbacher et al. 1981, Kalmbacher et al 1985) or grazing (Kalmbacher and Martin 1986) during the growing season. It was our hypothesis that summer grazing of native pastures would result in higher quality forage for winter grazing.

Authors are former graduate assistant, Department of Agronomy, University of Florida, Gainesville 32611; agronomist, Ona Agricultural Research Center, Ona, Florida 33865; and statistician, Department of Statistics, University of Florida, Gainesville 32611.

This is Florida Agr. Exp. Sta. Pap. No. 5818.
Manuscript accepted 22 May 1986.

Materials and Methods

The study was conducted at the University of Florida's Ona Agricultural Research Center in south-central Florida. The study area has been described (Kalmbacher et al. 1984). Two 8.1 ha native pastures were grazed (Fig. 1). One was grazed during summer and will be referred to as 'summer' pasture, then regrazed in the winter, when referred to as 'winter-regraze' pasture. The second pasture was grazed in 'winter-only' and will be referred to as such. The summer pasture was first grazed from 16 June to 26 Aug. 1980. During this time 101 diets were sampled from 4 esophageally fistulated Brahman-cross steers (325 kg). Forage was collected from 5 fistulated steers on the winter pastures between 12 Jan. and 15 Mar. 1981, when a total of 111 and 108 diet samples were collected from the winter-regraze and winter-only pastures, respectively. Collections on summer pasture in the second year were made from 9 June to 15 Sept. 1981, when 89 diets were sampled. The winter pastures were grazed from 3 Jan. to 16 Mar. 1982, when 81 and 75 diets were sampled.

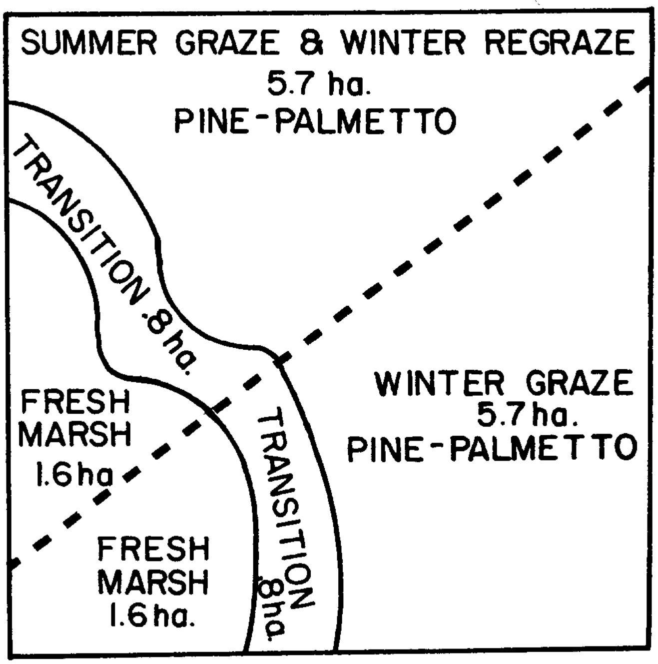


Fig. 1. *Pasture layout of grazing study area. Ona, Florida. 1980–82.*

Esophageally fistulated steers were allowed a 2-week adjustment on the study pasture prior to collection. Animals were coralled at night to aid in capture at 0800 hr, to insure appetite, and to minimize regurgitation during collection. A 1.0- to 1.5-kg sample of ingested forage was usually obtained once per day in 15 to 20 minutes in screen-bottom collection bags. The fistulated steers were herded back to the pen, collection bags removed, cannulae replaced, and steers fed 0.5 or 1.0 kg/steer (summer or winter, respectively) of mixed grain. Minerals and water were provided *ad libitum*. Animals were released after collections but penned and fed the same amounts in evening.

Diets collected by steers were spread on screen frames, dried at 50° C for 24 hours, and ground (0.5-mm mesh). Samples were analyzed for crude protein (Gallaher et al. 1976, Isaac and Johnson 1976) and IVOMD (Moore and Mott 1974, 1976).

Nonfistulated steers were used during collection periods to assure uniform grazing and provide additional grazing pressure. Stocking rates in 1980 and 1981 (including nonfistulated steers) for summer and winter pastures were 55 and 53 animal unit grazing days/ha, respectively. Stocking rates for these respective pastures in 1981–82 were 59 and 40 animal unit grazing days/ha.

Data analysis used the general linear model (GLM) procedure of the statistical analysis system (SAS) (Helwig and Council 1979). Replications were the 4 or 5 esophageally fistulated steers.

Eighteen permanent transects were established in the 16.2-ha study area to determine range yield. Three transects were located at random in each of 3 range sites of each pasture (Fig. 1). Transects were 215 m long on pine-palmetto sites, 36 m on fresh marsh sites, and 90 m on transition sites. Within each transect on pine-palmetto, transition, and fresh marshes, 66, 45, and 12, 0.25 m^2 quadrats were clipped. Forage was cut near the soil surface or water level in the marsh, and vegetation was sorted into creeping bluestem, *Andropogon* spp., carpet grasses (*Axonopus* spp), maidencane *(Panicum hemitomon),* "other grasses", and forbs. Forage was dried (50° C) for 48 to 72 hr, and reweighed for yield determination. This was done in January 1980, and then pastures were back-fire burned in February. Pastures were resampled prior to grazing in June 1980 and January 1981, and after grazing in August 1980 and March 1981.

Results and Discussion

Season Effects

Crude protein and IVOMD

There was a significant ($P<0.05$) decline in diet crude protein and IVOMD from summer to winter-only pastures in both years (Table 1). Year had no significant effect on either crude protein or IVOMD and differences among seasons and all pastures were consistent both years. Protein in winter diets (avg. 6.7%) was about 1.6 percentage units lower than it was in summer (avg. 8.3%). There was an average 14.7 unit decline in diet IVOMD. Differences in diet quality were largely due to weathering and aging, and an increase in diet shrub content (Kalmbacher et al. 1984). Shrubs that constituted a large portion of the winter diet contained more crude protein than grass but were lower in IVOMD (Long 1983).

Table 1. Diet crude protein and IVOMD of five esophageally fistulated steers grazing two range pastures; one in summer and again in winter, and the other in winter-only. Ona, Florida 1980-1982.

	Forage Quality Index			
	CP	IVOMD	CP	IVOMD
	1980-81		1981-82	
	%			
Pasture-season				
Summer	8.2 a[1]	46.4 a	8.5 a	47.1 a
Winter-regraze	7.5 ab	35.9 b	7.6 ab	34.3 b
Winter-only	6.8 b	32.2 c	6.6 b	32.1 b

[1]Means within a column followed by the same letter are not different (Duncan's MRT, $P<0.05$).

Regrazing Effects

Crude protein

Crude protein content of diets were not different ($P>0.05$) between the summer and winter-regraze pastures (Table 1). There may be 2 reasons for this observation. First, cattle were able to select a relatively good diet from the poor forage that was available during winter. Selection included shrubs which were fairly high in crude protein in mid-winter and also spring growth of high protein forbs. Secondly, grasses, except maidencane, carried- over from September to December maintained protein contents similar to that in summer (Long 1983). Most of the forage available in winter was carried-over because there were little regrowth between September and December (Fig. 2).

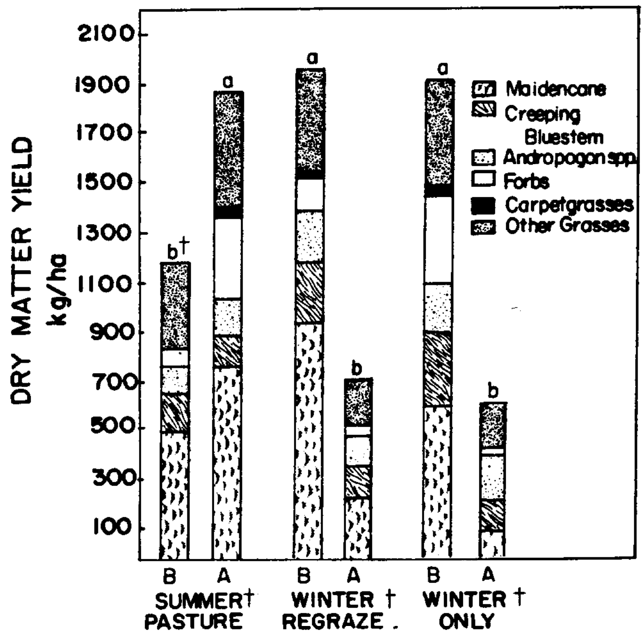


Fig. 2. *Species composition of available forage before (B) and after (A) grazing. Ona, Florida. 1980–1981. Difference in pasture yield before and after grazing significant ($P<0.05$).*

Diet crude protein was 0.7 to 1.0 percentage units higher on the winter-regraze as compared to the winter-only pasture in 1981 and 1982, respectively (Table 1). This slight improvement was brought about by younger, less weathered regrowth on the winter- regraze pasture. These differences in crude protein between winter-regraze and winter-only pastures were not significant ($P>0.05$). The amount of forage on offer was similar in these 2 pastures (Fig. 2), and botanical composition of the winter diets was not different ($P>0.05$) (Kalmbacher et al. 1984).

IVOMD

The difference in diet IVOMD between summer and winter-regraze pastures was significant ($P>0.05$) in both years (avg. 11.7 percentage units) (Table 1). Diet IVOMD was also different between diets from the winter-regraze and winter-only pasture (avg. 5.0 percentage units) in 1981, but not different in 1982. Comparison of the changes in percentage units indicates that seasonal effects had a greater influence on diet IVOMD than regrazing effects.

The decline in diet IVOMD from summer to the 2 winter-grazed pastures was due more to differences in age of forage carried over from summer than changes in diet composition, which have been mentioned. Forage was 4 to 7 months old on the summer, 3 to 11 months old on the winter-regraze, and 11 to 13 months old on the winter-only pasture in the first year. Regrowth during summer and between October and December on the winter-regraze pasture was probably lower in lignin (ADL) and acid detergent fiber (ADF) fractions than forage on the winter-only pasture. The relationship between ADL and ADF with IVOMD has been observed in creeping bluestem of different maturities (Kalmbacher et al. 1981).

Seasonal Trends

Diet crude protein of the 2 winter pastures started and continued in the same order of magnitude (Fig.3). Diet IVOMD from these 2 pastures started about 35%, but IVOMD on the winter-only pasture declined, while the winter-regraze remained rather constant.

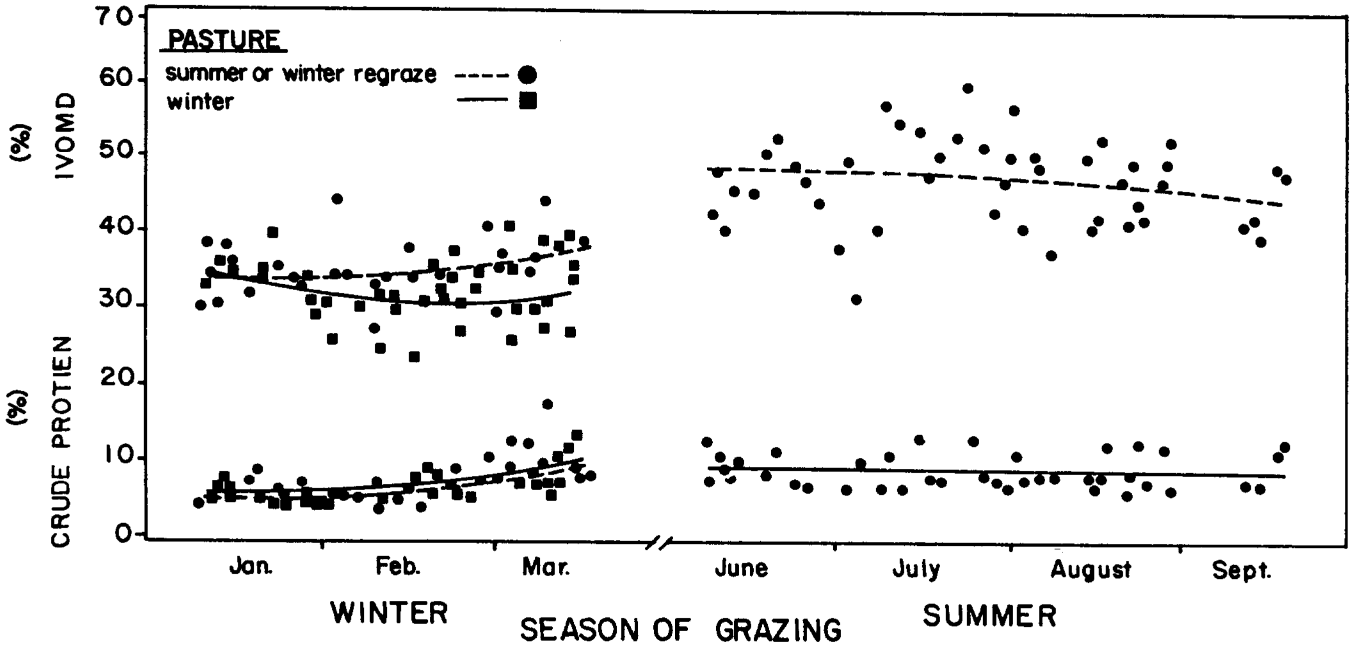


Fig. 3. *Crude protein content and in vitro organic matter digestibility (IVOMD) in diets of 5 esophageally steers grazing range in summer, regrazing the summer pasture in winter, and winter only. Values represent averages of diets over steers on that collection date. Ona, Florida. 1980–81 and 1981–82.*

The reason for apparent differences in IVOMD is not known, and there is no statistical method for establishing differences in the slopes of the lines. Each point in Figure 3 was an average of the respective quality index for the fistulated steers, and curves were empirically determined (Reimsch 1967). Variation in diet IVOMD seemed to be less early in winter but increased when all steers grazed better quality spring growth as well as older winter forage.

Longevity of Burning Effects

Diet protein and IVOMD from the 1980 summer pasture represented diet quality 4 to 7 months after a burn, while in 1981 they represented the diet 16 to 19 months after a burn. The similarity in quality of summer diets of 1980 and 1981 indicated that cattle selected a diet that was not different (P>0.05) in protein and digestibility in summer regardless of whether or not the range had been burned the previous winter. Crude protein IVOMD of hand-clipped creeping bluestem and other forages declined 4 to 6 months after a February burn (Kalmbacher et al. 1985, Hilmon and Lewis 1962, Lewis et al. 1975), which indicates that the advantage due to burning was already lost during the first summer. It had been a concern that diet quality would decline 1 or more years after a burn, but animal selectivity can apparently overcome quality losses demonstrated in clipping studies.

Pasture Yield

There was less (P<0.05) forage at the beginning of summer than there was at the end (Fig. 2), which indicated diet quality was not limited by amount or kind of forage. Winter-regraze pasture yield (2,010 kg/ha) was not different (P>0.05) from winter-only yield (1,920 kg/ha) even though the winter-regraze pasture had been formerly grazed from June to September. About 65% of the grass and forbs (1,300 kg/ha) were eaten or lost during the winter grazing period (Fig. 2).

Weathering and trampling losses were visually estimated to be 70%, thus 30% of the 1,300 kg/ha utilized. On wiregrass *Aristida stricta)* range, which yielded 2,600 kg/ha and was stocked at 35 animal unit grazing days/ha, about 40% utilization was measured (Lewis and McCormick 1971).

It is estimated that cattle (avg. 430 kg), which were stocked at 45 and 53 animal unit grazing days/ha, consumed about 8.6 and 6.4 kg/head/day of grass and forb dry matter on winter-regraze and winter-only pastures, respectively. This was about 1.7 to 2.0% of body weight not considering shrub consumption, which was 21 and 29% of diet dry matter in the winter regraze and winter only pastures, respectively (Kalmbacher et al. 1984). Forage intake on wiregrass range in Georgia varied from about 1.5 to 2.3% of body weight (Hale et al. 1962).20

Study Implications

As compared to grazing in winter only, regrazing a pasture in winter did not improved diet protein significantly in either year, but IVOMD was improved in 1 year. Because this was a minor improvement in quality, it is doubtful that it would be important in reducing supplementation needs. Cattle may be at the maximum of intake because of limitations in rumen capacity, yet their diets may still be deficient in protein and energy (National Research Council 1984). The most pressing problem with this range does not appear to be production but forage quality.

Most range research in the Southeast has been conducted on wiregrass range, a connotation which implies a poor condition class with 25% or less of the yield of forage coming from higher yielding bluestems, etc. (Yarlett 1974). Range in this study was in good condition, with 50% or more of the forage from grasses like creeping and chalky bluestems. Fostering such grasses may provide cattlemen with more forage (Yarlett 1965), but there doesn't appear to be an improvement in diet quality as a result of the change in botanical composition.

These data demonstrate a strong need to introduce forages on Florida range with better nutritional potential. Even when range should have been high in quality 4 to 7 months after a burn, average diet crude protein and energy would not be adequate for lactating cows (National Research Council 1984). Winter range, regardless of grazing history, would not maintain a cow in any physiological condition without supplementation.

Literature Cited

Anderson, C.L., and T.S. Hipp. 1973. Requirements and returns for 1,000-cow beef herds on flatwoods soils in Florida. Florida Agr. Ext. Cir. 385.

Gallaher, R.N., C.O. Weldon, and R.C. Boswell. 1976. A semi-automated procedure for total nitrogen in plant and soil samples. Soil Sci. Soc. Amer. Proc. 40:887-889.

Hale, O.M., R.H. Hughes, and F.E. Knox. 1962. Forage intake by cattle grazing wiregrass. J. Range Manage. 15:6-19.

Helwig, J.T., and K.A. Council. 1979. S.A.S. users guide. SAS Institute. Raleigh, N.C.

Hilmon, J.B., and C.E. Lewis. 1962. Effect of burning on south Florida range. USDA Forest Serv., Southeast Forest Exp. Sta. Pap. 146.

Isaac, R.A., and W.C. Johnson. 1976. Determination of total nitrogen in plant tissues using a block digester. J. Ass. Off. Anal. Chem. 69:98-101.

Kalmbacher, R.S., K.R. Long, M.K. Johnson, and F.G. Martin. 1984. Botanical composition of the diets of esophageal fistulated steers grazing south Florida rangeland. J. Range Manage. 37:334-340.

Kalmbacher, R.S., F.G. Martin, and W.D. Pitman. 1986. Effect of grazing stubble height and season on establishment, persistence and quality of creeping bluestem. J. Range Manage. 39:223-227.

Kalmbacher, R.S., F.G. Martin, and J.M.S. Andrade. 1981. Yield and quality of creeping bluestem as affected by time of cutting. J. Range Manage. 34:471-474.

Kalmbacher, R.S., F.G. Martin, W.S. Terry, D.H. Hunter, and L.D. White. 1985. Effects of clipping on burned and unburned creeping bluestem. J. Range Manage. 38:531-535.

Lewis, C.E., R.S. Lowery, W.G. Monson, and F.E. Knox. 1975. Seasonal trends in nutrients and cattle digestibility of forage on pine-wiregrass range. J. Anim. Sci. 41:208-212.

Lewis, C.E., and W.C. McCormick. 1971. Supplementing pine-wiregrass range with improved pasture in south Georgia. J. Range Manage. 24:334-339.

Long, K.R. 1983. Evaluation of Florida native range using esophageal fistulated steers. M.S. Thesis. University of Florida, Gainesville.

Moore, J.E., and G.O. Mott. 1974. Recovery of residual organic matter from in vitro digestion samples. J. Dairy Sci. 57:1258-1259.

Moore, J.E., and G.O. Mott. 1976. Fermentation tubes for in vitro digestion of forages. J. Dairy Sci. 59:167-169.

National Research Council. 1984. Nurient requirements of domestic animals. No. 1. Nutrient requirements of beef cattle. Sixth revised ed. Nat. Acad. Sci., Nat. Res. Council. Washington, D.C.

Peacock, F.M., R.E.L. Greene, E.M. Hodges, W.G. Kirk, and M. Koger. 1974. Forage systems as related to the economics of beef production in south-central Florida. Proc. Soil and Crop Sci. Soc. Fla. 34:148-151.

Reimsch, C.H. 1967. Smoothing by spline functions. Numerische Mathematick. 10:177-183.

Yarlett, L.L. 1965. Control of saw palmetto and recovery of native grasses. J. Range Manage. 18:344-345.

Yarlett, L.L. 1974. Important native grasses for range conservation in Florida. USDA, SCS. Gainesville, Florida.

Nutritive Quality of Ceanothus Shrubs in California Mixed Conifer Forest

JOHN G. KIE

Abstract

Mule deer *(Odocoileus hemionus)* in the Sierra Nevada rely heavily on mountain whitethorn (*Ceanothus cordulatus,* Kell.) and deerbrush (*C. integerrimus,* H&A) as summer forage. In this study, mountain whitethorn leaves, deerbrush leaves, and deerbush twigs were collected from shrubs growing in full sun every 2 weeks during summer, and from shrubs growing under a range of overstory crown closures during late summer-early fall. Samples were analyzed for calcium, phosphorus, crude protein, in vitro digestible dry matter (IVDDM), gross energy, digestible energy, and sequential fibers. Summer samples of all 3 forages had adequate concentrations of calcium, apparently adequate concentrations of crude protein, and inadequate concentrations of digestible energy and phosphorus for growth and development in deer. IVDDM values were lower than expected based on fiber content alone, suggesting high concentrations of digestion-inhibiting compounds. In general, forage quality declined as summer progressed. Crown closure and shrub age had only minor effects on forage quality, but significant annual differences were found in several variables in both species. Under conditions common to the southern Sierra Nevada, annual differences in precipitation may have been more important than available light in determining forage quality. Forage deficiencies in late summer may have a substantial adverse affect on newly weaned fawns. Marginal forage quality with respect to certain nutrients suggests the need to further explore deer nutritional ecology on summer and other seasonal ranges in the Sierra Nevada.

Author is research wildlife biologist and project leader, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Avenue, Fresno Calif. 93710.

The author thanks Gary Eberlein, Steve Myler, Patricia Page, Jeannette Peyton, Scott Willems, and Joy Winckel for field and lab assistance, and Chuck Evans for statistical and computer assistance. Advice on the manuscript was provided by Susan Conard, Thomas Hanley, and Robert Powers.

Manuscript accepted 22 May 1986.

Deerbrush (*Ceanothus integerrimus,* H&A) and mountain whitethorn (*C. cordulatus,* Kell.) are important forage species for mule deer *(Odocoileus hemionus)* on migratory and summer ranges in the Sierra Nevada of California. They frequently are the most abundant species present in deer diets (Hagen 1953), and are also used by cattle grazing on summer allotments.

These shrubs become established following wildfire, prescribed burning, or logging. As forest trees become reestablished, they shade out deerbrush and whitethorn shrubs (Tappeiner 1980), thereby reducing potential forage for deer. Although aspects of forage quality were investigated as early as the 1930's (Cronemiller 1953), advances in analytical techniques (Goering and Van Soest 1970) as well as evidence of the effects of shade on forage quality in other forest browse species (Blair et al. 1983) justified further study. The purpose of this research was to compare the nutritional quality of deerbrush and mountain whitethorn shrubs (1) growing in full sun during the summer growing season, and (2) growing under a range of overstory crown closures in late summer-early fall.

Materials and Methods

Study Area

The study area was on the southeast flank of Dinkey Mountain, in the Sierra National Forest east of Fesno, California (37° 00′ N, 119° 08′ W) in the southern Sierra Nevada. Four sampling sites were located at about 1,700 m elevation in second-growth Sierra Nevada mixed conifer forest. The sites were on Shaver series soils (Pachic Ultic Haploxerolls) characterized by gentle to moderately steep slopes. The sites were within 5 km of each other and represented the upper elevational range of deerbrush and the lower elevational range for mountain whitethorn in the southern Sierra Nevada. Overstory tree species included white fir (*Abies concolor,* Gord. & Glend.), ponderosa pine (*Pinus ponerosa,* Doug.), sugar pine (*P. lambertiana,* Doug.), and incense cedar (*Libocedrus decurrens,* Torr.). The area was used by the North Kings deer herd primarily during spring (May–June) and fall (October–November) migration each year. Cattle had access to the sites from July to September.

Collection of Forage Samples

Four composite forage samples were collected every 2 weeks during summer 1983, on a separate site for each species. Sampling began on 1 June and continued through 8 September, prior to leaf abscision, in the deciduous deerbrush. Sampling of evergreen mountain whitethorn continued through 6 October. Each sample consisted of material taken from at least 4 individual shrubs growing in full sun.

Because both leaves and twigs of deerbrush are readily eaten by cattle and deer, current season's growth of both were collected, but were analyzed separately. Although whitethorn leaves are persistent, abundant new growth is available beginning in early June, and the new twig and leaf material is highly palatable. However, whitethorn twigs soon become spinescent, providing a mechanical defense to browsing by cattle. Mule deer consume whitethorn throughout the summer by picking individual leaves. Therefore, only the leaves of mountain whitethorn were collected for analysis. During the first and second collection periods, whitethorn samples contained undifferentiated new growth, in addition to leaves from the previous year.

To assess the effects of overstory crown closure on forage quality, samples were taken from 30 deerbrush shrubs in September (12 in 1982 and 18 in 1983), and 30 mountain whitethorn shrubs in October (10 each in 1981, 1982, and 1983) growing under a range of crown closures. These samples were collected in conjunction with a study on the influence of shrub volume and crown closure on annual production (Kie 1985). Crown closure of overstory trees was obtained by taking a photographic slide with a 35-mm camera and a 28-mm wide-angle lens (75° field of view), held 1.5 m above the ground, pointing directly upward over each shrub sampled. The resulting slide was projected on a grid of 150 points and the percentage of points intersecting tree boles, branches, or crown was recorded as overstory crown closure. The largest basal stem of each shrub was sectioned for age determination.

Nutrient and Digestibility Analyses

All samples were oven dried at 55–60° C. Crude protein and gross energy were determined by Kjeldahl and bomb calorimetric procedures, respectively. Calcium and phosphorus analyses were performed through atomic absorption spectrophotometry. Forty-eight hour in vitro digestible dry matter (IVDDM) was determined according to the method of Tilley and Terry (1963), using rumen inocula from cows maintained on hay diets. Results are similar to those obtained in vivo or in vitro with inocula from wild ruminants (Welch et al. 1983). Sequential detergent fiber analyses (Goering and Van Soest 1970) included neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and acid insoluble ash (AIA). IVDDM and fiber analyses were performed by Wildlife Habitat Management Services at Washington State University. All results were reported on a dry weight basis.

Digestible energy was estimated from gross energy and IVDDM values with the equation developed by Robbins et al. (1975:74) for white-tailed deer *(O. virginianus).* Expected IVDDM was also calculated based on fiber content of phenolic-free forages, using the equation of Mould and Robbins (1982:27) for white-tailed deer. Nutrient concentrations were compared to recommended standards developed for penned white-tailed deer and domestic cattle.

Statistical Analysis

Analysis of covariance was used with the dependent variables measured from samples collected each fall. Unlike the summer composite samples, each fall sample represented material from a

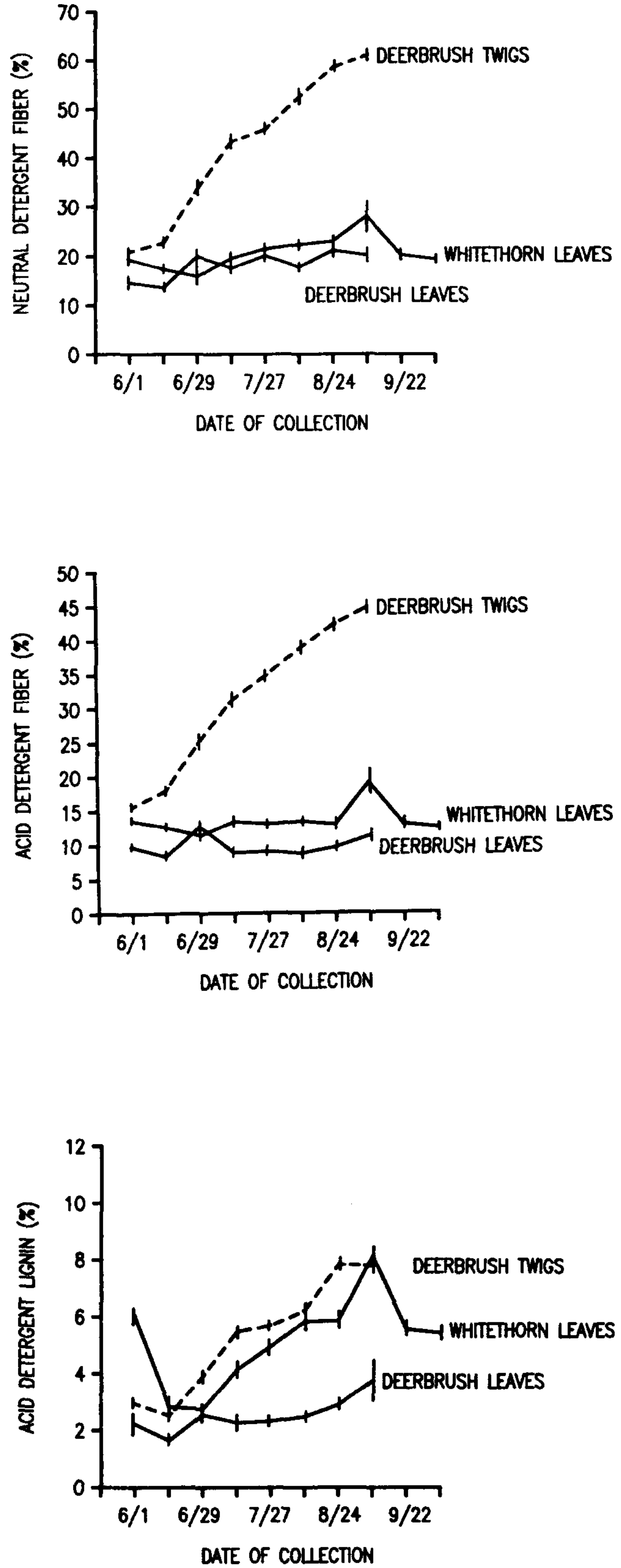


Fig. 1. *Neutral detergent fiber, acid detergent fiber, and acid detergent lignin in whitethorn leaves, deerbrush leaves, and deerbrush twigs. (Vertical lines are ± 1 standard error).*

single shrub. The model treated each dependent variable separately and examined the effects of overstory crown closure and shrub age as covariates, and the effects of year of collection as a main factor. Simple correlation coefficients were calculated for the independent-dependent variable combinations determined to be significantly ($P<0.05$) related by the analyses of covariance.

Results and Discussion

Biweekly Summer Samples

NDF, or cell wall constituents, and ADF values were slightly higher in whitethorn leaves than in deebrush leaves, and concentrations in both species increased slightly over the summer (Fig. 1). NDF and ADF in deerbrush twigs were higher than in either of the leaf forages and increased more rapidly as the growing season progressed. The ADL values were higher in whitethorn leaves and deerbrush twigs than in deebrush leaves (Fig. 1). ADL declined in whitethorn leaves from early to mid-June, when current year's growth began to make up an increasing proportion of the sample. Subsequently, ADL values in all 3 forages increased over the summer.

Mean IVDDM values ranged from 19 to 40% for whitethorn leaves and from 47 to 64% in deerbrush leaves, the levels declining slightly over the summer (Fig. 2). The decline was sharper in deerbrush twigs, ranging from 64% early in the season to 16% by early September. Although IVDDM values were low compared to

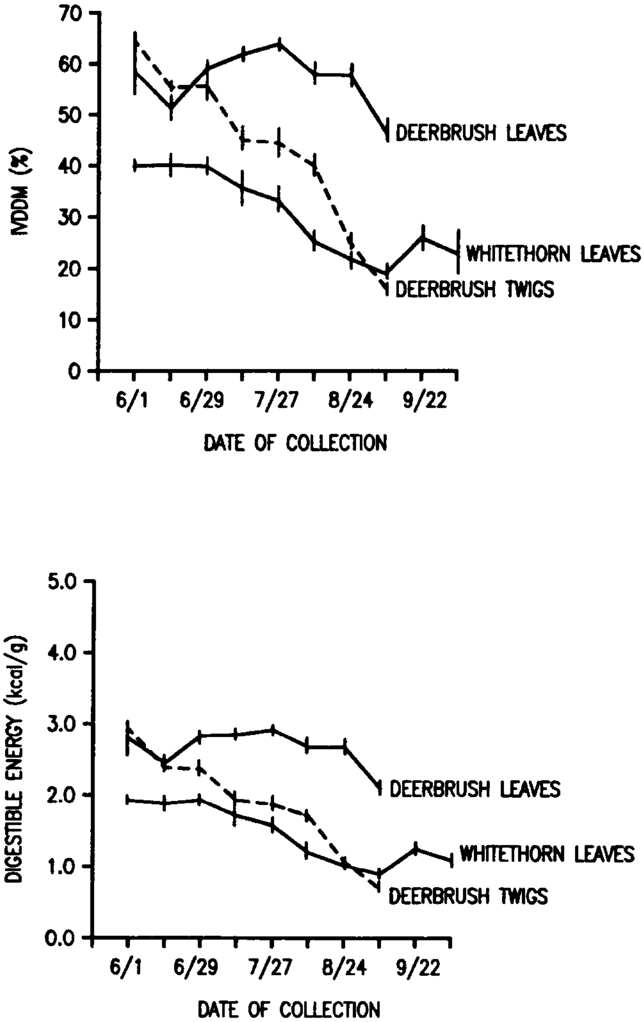


Fig. 2. *In vitro digestible dry matter (IVDDM) and digestible energy in whitethorn leaves, deerbrush leaves, and deerbrush twigs. (Vertical lines are ± 1 standard error).*

high-quality herbaceous forage, they were similar to values reported for other forest shrub species (Hanley and McKendrick 1983, Leslie et al. 1984).

Observed IVDDM values were lower than expected based on fiber content of forages relatively free of digestion-inhibiting phenolic compounds (Mould and Robbins 1982). Expected IVDDM values ranged from 62 to 78% for whitethorn leaves, 73 to 80% for deerbrush leaves, and 57 to 78% for deerbrush twigs. Soluble phenolics, a broad class of secondary plant compounds, suppress the digestion of neutral detergent solubles, thereby lowering IVDDM values (Mould and Robbins 1982). Some forest shrubs in southeast Alaska exhibited IVDDM values as low as two-thirds of that expected based on fiber content, suggesting high concentrations of digestion inhibitors (Hanley and McKendrick 1983).

Cronemiller (1953) reported high concentrations of saponin in deerbrush in early fall, suggesting this as a cause for decreased palatability and occasional nervous system disorders in cattle. Conversely, Countryman (1982) found acetone solvent extractives averaged only 7.7% in mountain whitethorn foliage. This value was comparable to acetone-extracted total phenolics for most forages categorized as low-phenolic by Mould and Robbins (1982).

Gross energy remained constant throughout the summer at 4.6 to 5.0 kcal/g in whitethorn and deerbrush leaves and 4.3 to 4.6 kcal/g in deerbrush twigs. Because IVDDM declined during the summer, digestible energy, estimated from gross energy and IVDDM, declined also. At digestible energy concentrations below 2.17 kcal/g, total energy intake by white-tailed deer is constrained by the physical capacity of their digestive systems (Ammann et al. 1973). The NRC (1976) recommended standard for lactating beef cattle is 2.3 kcal/g of digestible energy (based on the requirement of 1.9 kcal/g of metabolizable energy, plus the energy used in urine and methane production). Digestible energy values were below these standards season-long in whitethorn leaves, after early September in deerbrush leaves, and after early July in deerbrush twigs (Fig. 2). In addition, concentrations of oils, such as those found at low levels in whitethorn leaves by Countryman (1982), can inflate the estimation of digestible energy because of their high gross energy content.

Crude protein concentrations were highest in deerbrush leaves and twigs and declined during the summer (Fig. 3). Crude protein

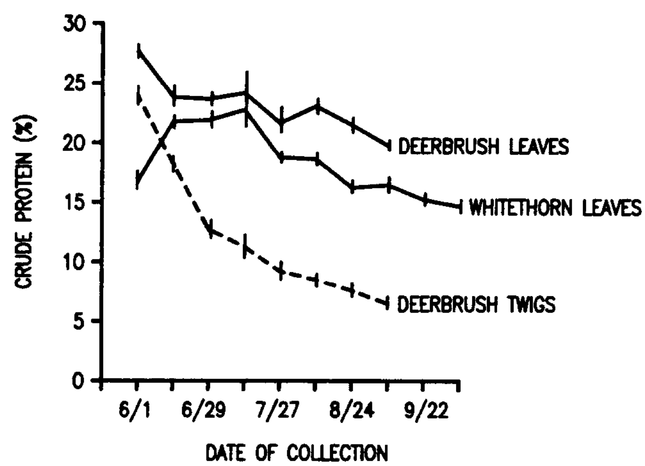


Fig. 3. *Crude protein in whitethorn leaves, deerbrush leaves, and deerbrush twigs. (Vertical lines are ± 1 standard error).*

in whitethorn leaves increased with the addition of new growth in mid-June, and then also declined. Although crude protein concentrations as low as 9% are sufficient for maintenance in adult white-tailed deer, the requirement for maximum growth ranges from 13 to 16% for adults and up to 20% for weaned fawns (French et al. 1956, McEwen et al. 1957, Ullrey et al. 1967). The NRC (1976) crude protein standard for lactating cattle is 9.2% (the digestible protein standard is 5.4%). Crude protein concentrations in both

Table 1. Means and standard errors (SE) for nutrient variables in whitethorn leaves (n = 30) collected during fall 1981, 1982, and 1983, and in deerbrush leaves (n = 30) and deerbrush twigs (n = 30) collected during fall 1982 and 1983.

Variable		Whitethorn Leaves Mean (SE)	Deerbrush Leaves Mean (SE)	Deerbrush Twigs Mean (SE)
Neutral detergent fiber (%)	1981:	27.90 (0.80)	—	—
	1982:	28.34 (1.61)	33.66 (1.92)	65.48*(2.25)
	1983:	25.49 (2.24)	29.38 (1.39)	53.17*(1.05)
Acid detergent fiber (%)	1981:	14.11 (0.50)	-	—
	1982:	16.95 (1.13)	19.85*(1.71)	48.42*(2.02)
	1983:	14.59 (1.50)	14.65*(0.89)	38.95*(0.88)
Acid detergent lignin (%)	1981:	7.95*(0.48)	—	—
	1982:	9.49*(0.91)	10.31*(1.38)	15.63*(1.57)
	1983:	6.27*(0.50)	5.90*(0.66)	8.45*(0.29)
IVDDM (%)	1981:	36.82*(0.91)	—	—
	1982:	29.06*(1.54)	53.93*(3.64)	33.49 (1.70)
	1983:	35.03*(1.27)	63.60*(1.38)	35.14 (1.40)
Digestible energy (kcal/g)	1981:	1.86*(0.05)	—	—
	1982:	1.44*(0.08)	2.42*(0.18)	1.48 (0.08)
	1983:	1.73*(0.07)	2.93*(0.06)	1.56 (0.06)
Crude protein (%)	1981:	13.18 (0.33)	—	—
	1982:	14.12 (0.18)	18.15*(0.43)	8.22*(0.34)
	1983:	13.62 (0.33)	16.92*(0.30)	7.77*(0.23)
Calcium (%)	1981:	1.08 (0.10)	—	—
	1982:	1.13 (0.04)	3.66*(0.47)	1.27*(0.10)
	1983:	1.01 (0.05)	2.33*(0.10)	1.07*(0.05)
Phosphorus (%)	1981:	0.14*(0.01)	—	—
	1982:	0.17*(0.01)	0.18 (0.01)	0.16*(0.01)
	1983:	0.17*(0.01)	0.19 (0.01)	0.12*(0.01)

*Significant (P<0.05) difference with respect to year of collection (after adjustment for overstory crown closure and shrub age).

leaf forages were well above these levels.

Crude protein concentrations were known to be high in both deerbrush and whitethorn leaves (Hagen 1953). However, phenolic compounds can greatly lower protein digestibility (Mould and Robbins 1982). Furthermore, only about 60 to 80% of total plant nitrogen (the basis on which crude protein is calculated) is tied up as true protein (Van Soest 1982). Powers (personal communication) found true protein (based on trichloroacetic acid soluble nitrogen) in 3 samples of deerbrush leaves collected in early summer averaged only 80% of crude protein. As with digestible energy values, additional research is needed on digestible protein content in shrubs over a range of sites (Hanley and McKendrick 1985).

Calcium values in all 3 forages were high and increased in both whitethorn and deerbrush leaves during the summer (Fig. 4). Calcium requirements for optimum growth and antler development in white-tailed deer were estimated at 0.64% (McEwen et al. 1957). A concentration of 0.40% was considered adequate for normal development of fawns (Ullrey et al. 1973). The recommended standard for lactating beef cows is 0.28% calcium (NRC 1976). All 3 forages exceeded these standards by wide margins.

Phosphorus values began at moderate levels but declined steadily as the summer progressed (Fig. 4). Phosphorus requirements for optimum growth and antler development in white-tailed deer may range as high as 0.56% (McEwen et al. 1957). Dietary concentrations of 0.26% phosphorus were considered adequate for weaned fawns (Ullrey et al. 1975). The NRC (1976) recommended standard for lactating cattle is 0.28% phosphorus. By late July, phosphorus concentrations in whitethorn leaves, deerbrush leaves, and deerbrush twigs had all dropped below these levels. As a result of high calcium and low phosphorus concentrations, high calcium:-phosphorus ratios may further exacerbate phosphorus deficiencies.

The pattern of phosphorus deficiency and excess calcium was reported earlier for deerbrush (Cronemiller 1953), and was also

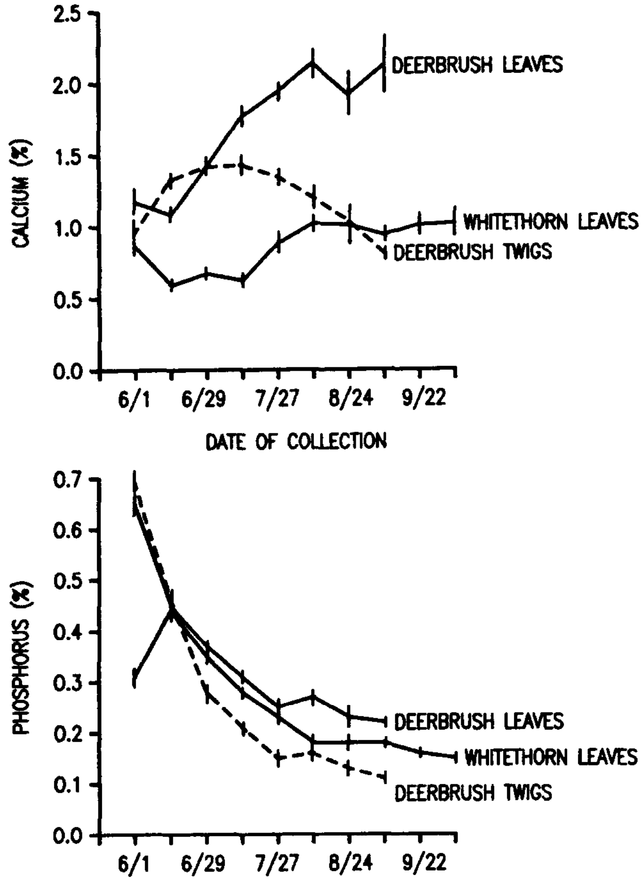


Fig. 4. *Calcium and phosphorus in whitethorn leaves, deerbrush leaves, and deerbrush twigs. (Vertical lines are ± 1 standard error).*

found in forest shrubs in southeast Alaska (Hanley and McKendrick 1983). Seasonally low phosphorus values were also reported for forest shrubs eaten by deer in Washington (Leslie et al. 1984).

Late Summer-Early Fall Samples

In whitethorn leaves, significant ($P<0.05$) yearly differences were found in ADL, IVDDM, digestible energy, and phosphorus (Table 1). The 1982 samples were characterized by high ADL, low IVDDM, and low digestible energy. Heavy spring snowfall remained on the study area late into summer 1982, delaying plant growth for several weeks. The 1982 samples were higher in ADL and lower in IVDDM, contrary to what would be expected from samples collected at an earlier phenological stage. This suggests a complex interaction between weather conditions and changes in nutrient content in mountain whitethorn.

In deerbrush leaves, significant differences between years were found in ADF, ADL, IVDDM, digestible energy, crude protein, and calcium (Table 1). In deerbrush twigs, there were yearly differences in NDF, ADF, ADL, crude protein, calcium, and phosphorus. No 1981 deerbrush samples were available for comparison, although differences between 1982 and 1983 followed a pattern similar to that in whitethorn leaves (high lignin, low IVDDM, and low digestible energy).

The whitethorn shrubs collected during the fall averaged 9.6 years of age (range 5–20 years) and grew under an average overstory crown closure of 27% (range 6–71%). Shrub age had no significant ($P>0.05$) effect on any dependent variable in whitethorn leaves. Crude protein increased significantly with increasing overstory crown closure but the relationship was weak ($r^2=0.15$). As crown closure increased, significant declines were noted in both IVDDM ($r^2=0.13$) and digestible energy ($r^2=0.14$).

Deerbrush shrubs collected during the fall averaged 7.7 years of age (range 2–14 years) and grew under an average overstory crown closure of 33% (range 0–72%). Overstory crown closure had no effect on any dependent variable in either deerbrush leaves or twigs. In deerbrush leaves, crude protein decreased significantly ($P<0.05$) with shrub age ($r^2 = 0.10$). In deerbrush twigs, NDF decreased with shrub age ($r^2 = 0.10$). As with whitethorn leaves, these relationships, although significant, were characterized by very low correlation coefficients.

Overstory effects on nutrient content of forest shrubs have not been well identified. Bitterbrush *(Purshia tridentata)* growing under natural stands of ponderosa pine in Oregon had higher ash and nitrogen-free extract concentrations and lower crude fiber than shrubs growing under thinned stands (Dealy 1966). Deepening shade resulted in increased crude protein, NDF, ADF, ADL, cellulose, calcium, and phosphorus in young plants of several southern browse species when grown under greenhouse conditions (Blair 1982, Blair et al. 1983). Increasing shade also resulted in declines in total nonstructural carbohydrates, IVDDM, neutral detergent solubles, and digestible energy in some species. Overstory characteristics were unrelated to crude protein, gross energy, and IVDDM in understory browse plants in loblolly pine *(Pinus taeda)* plantations in Virginia (Conroy et al. 1982).

Alaska blueberry *(Vaccinium alaskensis)* and bunchberry dogwood *(Cornus canadensis)* growing under open overstories in Alaska had greater concentrations of phenolics and total nonstructural carbohydrates and lower concentrations of crude protein and phosphorus than did plants growing under well developed overstories (Hanley et al. 1985). The differences may have been related to the availability of light, nutrients and the carbon:nutrient balance in the shrubs (Hanley et al. 1985).

Few overstory effects were seen in this study. Total precipitation is low, much of it falls as snow in the winter, and summer soil moisture conditions vary greatly from year to year in the southern Sierra Nevada. The results indicate that on these sites, total precipitation and available soil moisture might be more important than available light in determining plant nutrient content.

Conclusions and Management Recommendations

Neither mountain whitethorn nor deerbrush alone appeared to provide sufficient nutrients for optimum growth and development in mule deer. Particularly deficient were concentrations of phosphorus, digestible energy, and perhaps digestible protein. Also, digestion-inhibiting compounds may have been present in high levels. However, leaves of both species provide high concentrations of calcium and neutral detergent solubles. Such forages are valuable when consumed along with other species (Vangilder et al. 1982).

Mule deer rely heavily on browse, particularly mountain whitethorn, on summer ranges in the southern Sierra Nevada. They eat other forages, but recent studies have uncovered similar deficiencies (for example, in phosphorus concentrations) in meadow grasses, sedges, and forbs as well (Kie, unpub. data on file). Additional information on intake rates and the use of modeling techniques would provide insights on the relationships between quantity and quality (Hobbs and Swift 1985). The apparent deficiencies in several nutrients among both species of ceanothus and the uncertainty about total nutritional intake are sufficient to justify additional research on deer nutritional ecology in the Sierra Nevada.

Information is needed on nutrient intake on other seasonal ranges. For example, if deer can accumulate phosphorus during seasons of abundance, annual intake may be adequate despite deficiencies during part of the year (Hanley and McKendrick 1985). However, maturing trends in plant communities on spring migration and early summer ranges and declining nutritional quality may have been the ultimate cause of a long-term decline of the North Kings deer herd where this current study was done. If forage plants on both spring and summer ranges are deficient in some nutrients, then winter forage plants may be critical in balancing year-long nutritional needs of adult deer. In any case, late summer forage deficiencies may have a substantial adverse affect on newly weaned fawns.

Based on current findings, management plans for deer summer ranges should recognize the need for and provide a diversity of forages as well as productive stands of mountain whitethorn and deerbrush. However, opportunities to manipulate overstory stand structure as a mechanism to influence understory browse quality appear to be limited, particularly in light of annual variations caused by differences in weather patterns.

Literature Cited

Ammann, A.P., R.L. Cowan, C.L. Mothershead, and B.R. Baumgardt. 1973. Dry matter and energy intake in relation to digestibility in white-tailed deer. J. Wildl. Manage. 37:195-201.

Blair, R.M. 1982. Growth and nonstructural carbohydrate content of southern browse species as influenced by light intensity. J. Range Manage. 35:756-760.

Blair, R.M., R. Alcaniz, and A. Harrell. 1983. Shade intensity influences the nutrient quality and digestibility of southern deer browse leaves. J. Range Manage. 36:257-264.

Conroy, M.J., R.G. Oderwald, and T.L. Sharik. 1982. Forage production and nutrient concentrations in thinned loblolly pine plantations. J. Wildl. Manage. 46:719-727.

Countryman, C. 1982. Physical characteristics of some northern California brush fuels. USDA Forest Serv., Gen. Tech. Rep. PSW-61. Berkeley, CA.

Cronemiller, F.P. 1953. Deerbrush (sweetbirch) in California. USDA Forest Serv., Region 5. San Francisco, Calif.

Dealy, J.E. 1966. Bitterbrush nutrition levels under natural and thinned ponderosa pine. USDA Forest Serv., Res. Note PNW-33. Portland, OR.

French, C.E., L.C. McEwen, N.D. Magruder, R.H. Ingram, and R.W. Swift. 1956. Nutrient requirements for growth and antler development in the white-tailed deer. J. Wildl. Manage. 20:221-232.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). USDA Agr. Handb. 379, Washington, D.C.

Hagen, H.L. 1953. Nutritive value for deer of some forage plants in the Sierra Nevada. California Fish and Game 39:163-175.

Hanley, T.A., and J.D. McKendrick. 1983. Seasonal changes in chemical composition and nutritive value of native forages in a spruce-hemlock forest, southeastern Alaska. USDA Forest Serv., Res. Paper PNW-312. Portland, Ore.

Hanley, T.A., and J.D. McKendrick. 1985. Potential nutritional limitations for black-tailed deer in a spruce-hemlock forest, southeastern Alaska. J. Wildl. Manage. 49:103-114.

Hanley, T.A., R.G. Cates, B. Van Horne, and J.D. McKendrick. 1985. Forest stand age-related differences in apparent nutritional quality of forage for deer in southeastern Alaska. paper presented at 4th Annual Wildland Shrub Symposium, 7-9 August 1985, Snowbird, Utah. In press.

Hobbs, N.T., and D.M. Swift. 1985. Estimates of habitat carrying capaity incorporating explicit nutritional constraints. J. Wildl. Manage. 49:814-822.

Kie, J.G. 1985. Production of deerbrush and mountain whitethorn related to shrub volume and overstory crown closure. USDA Forest Service, Res. Note PSW-377. Berkeley, Calif.

Leslie, D.M., E.E. Starkey, and M. Vavra. 1984. Elk and deer diets in old-growth forests in western Washington, J. Wildl. Manage. 48:762-775.

McEwen, L.C., C.E. French, N.D. Magruder, R.W. Swift, and R.H. Ingram. 1957. Nutrient requirements of the white-tailed deer. Trans. N. Amer. Wildl. Conf. 22:119-132.

Mould, E.D., and C.T. Robbins. 1982. Digestive capabilities in elk compared to white-tailed deer. J. Wildl. Manage. 46:22-29.

NRC. 1976. Nutrient requirements of beef cattle, 5th ed. Nat. Res. Counc., Nat. Acad. Sci.

Robbins, C.T., P.J. Van Soest, W.W. Mautz, and A.N. Moen. 1975. Feed analyses and digestion with reference to white-tailed deer. J. Wildl. Manage. 39:67-79.

Tappeiner, J.C. II. 1980. Sierra Nevada mixed conifer. p. 118-119. *In:* F.H. Eyre (Ed.), Forest cover types of the United States and Canada. Soc. Amer. Forest., Washington, DC.

Tilley, J.M.A., and R.A. Terry. 1963. A 2-stage technique for the in-vitro digestion of forage crops. J. Brit. Grassl. Soc. 18:104-111.

Ullrey, D.E., W.G. Youatt, H.E. Johnson, L.D. Fay, and B.L. Bradley. 1967. Protein requirement of white-tailed deer fawns. J. Wildl. Manage. 31:679-685.

Ullrey, D.E., W.G. Youatt, H.E. Johnson, L.D. Fay, B.L. Schoepke, W.T. Magee, and K.K. Keahey. 1973. Calcium requirements of weaned white-tailed deer fawns. J. Wildl. Manage. 37:187-194.

Ullrey, D.E., W.G. Youatt, H.E. Johnson, A.B. Cowan, L.D. Fay, R.L. Covert, W.T. Magee, and K.K. Keahey. 1975. Phosphorus requirements of weaned white-tailed deer fawns. J. Wildl. Manage. 39:590-595.

Vangilder, L.D., O. Torgerson, W.R. Porath. 1982. Factors influencing diet selection by white-tailed deer. J. Wildl. Manage. 46:711-718.

Van Soest, P.J. 1982. Nutritional ecology of the ruminant. O&B Books, Corvallis, Ore.

Welch, B.L., J.C. Pederson, and W.P. Clary. 1983. Ability of different rumen inocular to digest range forages. J. Wildl. Manage. 47:873-877.

Nutrition of Sheep Grazing Crested Wheatgrass Versus Crested Wheatgrass-Shrub Pastures during Winter

A.E. GADE AND F.D. PROVENZA

Abstract

Grazing sheep on improved pastures during winter offers an economically attractive alternative to supplementation in sagebrush steppe ecosystems. We studied diet selection and nutrition of sheep grazing in crested wheatgrass *(Agropyron desertorum)* and crested wheatgrass-shrub *(Kochia prostrata, Atriplex canescens, Purshia tridentata, Artemisia tridentata, Chrysothamnus nauseosus, Ceratoides lanata)* pastures during early-January (period 1), mid-January (period 2), and late-January (period 3). Diet selection by esophageally fistulated sheep differed during each of the 3 periods because the amount of available forage changed with snow depth, trampling, and utilization. Sheep grazing crested wheatgrass (CW) pastures consumed diets that were about 55% mature grass and 45% green vegetative growth during periods 1 and 2, and 93% mature grass and 7% green vegetative growth during period 3. Sheep grazing crested wheatgrass-shrub (CWS) pastures consumed diets that were about one-half grass and one-half shrub during all periods. Organic matter intake (g • kg $BW^{.075}$), determined from total fecal output and in vitro digestibility estimates, were higher ($P = 0.036$) for sheep grazing CWS pastures than for sheep grazing CW pastures during periods 1 (38 vs. 28) and 3 (31 vs. 27), but were similar ($P<0.10$) during period 2 (28 vs. 26). Diets of sheep grazing CWS pastures contained more ($P = 0.002$) crude protein (%) than diets of sheep grazing CW pastures during periods 1 (9.0 vs. 5.8), 2 (7.3 vs. 6.6), and 3 (7.9 vs. 4.6). In vitro organic matter digestibilities (%) of diets of sheep in CW and CWS pastures were similar during period 1 (45 vs. 48), but higher ($P = 0.001$) for sheep grazing in CW pastures during periods 2 (46 vs. 29) and 3 (32 vs. 24). We stocked pastures heavily to accentuate differences between sheep diets in CW and CWS pastures during period 1-3; we believe results from period 1 best represent the potential nutritional benefits of shrubs on snowy winter ranges.

Harvesting hay during summer and feeding it during winter accounts for over half of the variable costs of ranching in the Intermountain West (Simonds 1980). The machinery, irrigation, fertilizer, seed, fuel, and labor associated with winter feeding of livestock represent a major expense for the livestock industry. Substantial savings would result if the amount of hay fed to livestock during winter could be reduced through enhanced management of winter ranges.

Salt desert shrub ecosystems, which constitute the traditional winter ranges in the Intermountain West, cannot support all animals that must be fed during winter. However, the sagebrush semidesert (West 1983a) and steppe (West 1983b) ecosystems of the region are much larger, and offer alternative wintering areas. About 4 million ha of these rangelands have been seeded with crested wheatgrass *(Agropyron desertorum* and *A. cristatum).* These species are renowned for their ease of establishment and tolerance of spring grazing, drought, and cold. Unfortunately, they tend to become fibrous at maturity, usually in early June. Thereafter, their palatability and nutritional quality decline rapidly (Murray et al. 1978). Knipfel (1977) concluded that mature crested wheatgrass was nutritionally inadequate for pregnant ewes.

Two properties of crested wheatgrass give it potential as a winter forage. Mature plants retain high levels of digestible carbohydrates offering a source of energy (Cook and Harris 1968, Cook 1972); and green vegetative growth produced, given adequate precipitation during fall, can persist throughout winter. However, it remains uncertain whether or not this vegetative growth contains sufficient protein for efficient digestion of fiber by ruminants (Moir and Harris 1962, Van Gylswyk 1970, Van Soest 1982).

Commercial protein concentrates are expensive and may be difficult to dispense on snowy winter ranges. Some species of shrubs maintain crude protein levels of 6–17% during winter (Cook and Harris 1977, Otsyina et al. 1982). Shrubs are not usually covered by snow, and could be a suitable source of protein and dry matter for livestock grazing crested wheatgrass ranges during winter.

The objective of our research was to examine the influence of shrub availability on diet selection, organic matter intake, and nutritional status of sheep grazing in crested wheatgrass pastures in winter.

Methods

Study Site

The study site is located 12 km south of Nephi in central Utah at 39.38° north latitude and 111.51° west longitude. The site is on an alluvial fan between 2 mountain ranges at 1,615 m elevation. Slopes are 0–4%. Soils are deep silt loam derived from shale, limestone, and sandstone. Average annual precipitation is 32 cm, 35–40% of which is snow. Weather fronts bring strong wind, particularly from the southwest, and the site is exposed to extreme chill factors and drifting snow during such episodes. The average temperature for December is -1.5° C and for January is 1.6° C.

The physical design of the experimental pastures consisted of 2 replications of 3.6 ha each. Each replication was split into a crested wheatgrass (CW) pasture (1.8 ha) and a crested wheatgrass-shrub (CWS) pasture (1.8 ha). The following species of shrubs were planted in discrete 0.2-ha blocks (17 rows • $block^{-1}$) within the CWS pastures (approximate number of shrubs in parentheses): forage kochia *Kochia prostrata* (714), fourwing saltbush *Atriplex canescens* (289), bitterbrush *Purshia tridentata* (357), sagebrush *Artemisia tridentata* subsp. *vaseyana* (357), rabbitbrush *Chrysothamnus nauseosus* var. *albicaulis* (357), winterfat *Ceratoides lanata* (714), and a mixture of all shrub species (714). In addition, the CWS pastures contained a 0.2-ha block of fourwing saltbush, bitterbrush, and CW, and a 0.2-ha block of CW.

Nutritional Parameters

Fifty-two nonpregnant ewes, primarily Columbia-Targhee crosses accustomed to foraging on rangelands, were used to provide data on weight response and to manipulate vegetation. We placed half of these sheep in CW and half in CWS pastures, similar to pastures described above, 17 days prior to the initiation of the experiment to allow animals to adapt to grazing conditions. Thirteen sheep were placed in each experimental pasture on 30 December 1982 and were removed on 29 January 1983.

In addition, 2 esophageally fistulated wethers were placed in each pasture. The diet of each animal was sampled on at least 2 days during each of 3 sample periods in early-January (1-5), mid-

Authors are extension agent, Cooperative Extension Service, University of Alaska, Kodiak 99615; and assistant professor, Range Science Department, Utah State University, Logan 84322. At the time of the research, the senior author was extension technician, Range Science Department, Utah State University.
This paper is published with the approval of the director, Utah Agr. Exp. Sta., Utah State Univ., Logan as journal paper No. 3018.
Manuscript accepted 29 May 1986.

January (15–20), and late-January (25–28). The collections began about 0800 hr and sheep were allowed to forage for about 45 min. Samples were placed in plastic bags, packed in snow, and immediately stored in a cooler. After each sample period, samples from each animal were composited and frozen.

Four ewes in each pasture were fitted with collection bags to estimate fecal output. Forage intake was determined using the equation:

$$\text{Organic matter intake} = \frac{\text{total fecal organic matter output}}{(100\text{-in vitro organic matter digestibility})\ (0.01)}$$

Values for fecal output and in vitro organic matter digestibility were averaged for animals within treatments for each of the 3 sample periods. The first 2 collection periods lasted 5 days, and the final collection period lasted 3 days.

We weighed animals and attached fecal collection bags the day before sampling. The rear of the bag was made of mesh screen to allow urine to pass through when a ewe squatted to urinate. We collected feces in the morning of each sample day and in the evening of the last day. Each sample was weighed, thoroughly mixed, and subsampled. Subsamples were frozen and later dried at 105° C and ashed at 600° C to determine dry and organic matter contents.

All animals were weighed before they were transported to the study site and at the beginning of each sample period. As the study progressed, snow depth and forage utilization levels increased, and some sheep were removed from the experimental pastures. As a result, 47 sheep were weighed in period 1, 46 in period 2, and 22 in period 3.

Laboratory Analyses

Samples from esophageally fistulated sheep were freeze-dried and then ground using a Wiley mill with a 20-mesh screen. Crude protein (% of dry matter) was determined on duplicate subsamples using the Kjeldahl technique (Harris 1970). In vitro organic matter digestibility was determined on triplicate subsamples using the Moore modification of the Tilley and Terry technique (Tilley and Terry 1963, Harris 1970). We obtained inoculum from a rumen-fistulated sheep fed alfalfa hay. Fiber and permanganate lignin (% of dry matter) were determined using techniques described by Goering and Van Soest (1970).

Half of each fistula sample was analyzed botanically using the microscope point technique (Harker et al. 1964). This technique allows estimation of dietary components within broad categories (e.g., minor <20%, moderate 21–50%, major >50%; Marshall and Squires 1979), therefore we urge caution in comparing results among shrub species. At least 100 observations were made of each sample, but more observations were made of large or diverse samples. Each observation of grass from CW and CWS pastures was recorded as mature or green vegetative growth. For CWS samples, shrub fragments were identified to species when possible. Results are presented as a percentage of recognizable plant species and parts.

Vegetation Utilization

Shrub utilization was estimated by measuring the percentage removal of current year's twig production (Smith and Urness 1962) on 17 sample plants of each species within each pasture. The 1982 production of crested wheatgrass was estimated prior to the experiment by clipping and drying 5 samples from 1-m² areas within each pasture. Pastures were sampled (10 plots • pasture^{-1}) when snow melted in the spring of 1983 to estimate how much green vegetative growth and mature grass had been utilized, and the percentage of crested wheatgrass lost to trampling and snow compaction. The pastures were not grazed between the end of our experiment and snowmelt.

Weather Records

Records were required to understand how winter weather affected diet selection and intake. Because weather instruments were not available on the study site, we used records from the official reporting station at Levan, Utah. Levan is 12 km south of the study site on the same elevational contour and has similar aspect and prevailing winds.

Data Analysis

The experimental design was a factorial with 2 replications. Pasture type (CW vs. CWS) was the main effect, and the experiment was repeated in early-, mid-, and late-January. Animals were subsamples in this design. We consider probability levels ≤0.10 significant.

Results

Nutritional Parameters

A significant interaction (P=0.036) occurred for organic matter intake (Table 1). During the first period, sheep in the CWS pastures consumed more than did sheep in the CW pastures. During period 2 intakes were similar, but sheep in the CWS pastures again consumed more in period 3. Body weights did not differ for sheep used to estimate fecal output in CW vs. CWS pastures during sample periods 1 (63 vs. 63 kg), 2 (62 vs. 64 kg), or 3 (62 vs. 61 kg).

Table 1. Nutritional aspects of diets of esophageally fistulated sheep grazing in crested wheatgrass (CW) or crested wheatgrass-shrub (CWS) pastures during early-January (Period 1), mid-January (Period 2), and late-January (Period 3) of 1983.

	Period 1 (Jan. 1–5)		Period 2 (Jan. 15–20)		Period 3 (Jan. 25–28)		All Periods	
Assay	CW	CWS	CW	CWS	CW	CWS	CW	CWS
Organic matter intake ($g.kg\ BW^{-0.75}$)	28^{a}	38^{b}	26^{a}	28^{a}	27^{a}	31^{b}	27^{a}	32^{a}
crude protein (%)	5.8^{a}	9.0^{b}	6.6^{a}	7.3^{b}	4.6^{a}	7.9^{b}	5.6^{a}	8.1^{b}
in vitro organic matter digestibility (%)	45^{a}	48^{a}	46^{a}	29^{b}	32^{a}	24^{b}	41^{a}	33^{b}
neutral detergent fiber (%)	70^{a}	57^{b}	70^{a}	64^{b}	73^{a}	64^{b}	71^{a}	61^{b}
lignin (%)	13.1^{a}	12.3^{a}	9.5^{a}	17.5^{b}	11.9^{a}	17.4^{b}	11.5^{a}	15.7^{b}

[a,b]Means within a period are significantly different (LSD 0.10 for organic matter intake; LSD 0.05 for crude protein, in vitro organic matter digestibility, neutral detergent fiber, and lignin).

Crude protein (CP) in diets of sheep in CWS pastures exceeded that of sheep in the CW pastures (P=0.002; Table 1). However, the magnitude of the effect depended on sample date (P=0.002).

We observed a similar time by treatment interaction (P=0.001; Table 1) for in vitro organic matter digestibility (IVOMD). IVOMD did not differ between pastures in period 1, but digestibilities of the CWS diets dropped sharply in period 2. The digestibilities of both diets declined in the final collection period, but remained lower for CWS than for CW diets.

CW diets were higher (P=0.017) than CWS diets in neutral detergent fiber (Table 1). CWS diets contained more lignin (P=0.012). A significant interaction (P=0.015) existed between time and treatment for lignin (Table 1). Lignin concentrations of both diets were similar during period 1, but were higher in CWS pastures during periods 2 and 3.

No significant differences in weight changes occurred between sheep in CW and CWS pastures. Small but significant (P=0.001) differences did occur at different sample dates. The average animal lost 3% of body weight during the adjustment period, gained 2% of it back between periods 1 and 2, and then lost 4% between periods 2 and 3.

Data from the botanical analysis are summarized in Table 2. During the first 2 sample periods, sheep in the CW pastures consumed diets that were about 50% green vegetative growth and 50%

Table 2. Botanical composition of diets of sheep grazing crested wheatgrass (CW) or crested wheatgrass-shrub (CWS) pastures during winter.

Plant species	Period 1 (Jan. 1-5) CW	Period 1 (Jan. 1-5) CWS	Period 2 (Jan. 15-20) CW	Period 2 (Jan. 15-20) CWS	Period 3 (Jan. 25-28) CW	Period 3 (Jan. 25-28) CWS
Grass						
Agropyron desertorum (mature)	57	36	54	58	93	48
Agropyron desertorum (green)	43	18	46	4	7	1
Total	100	54	100	62	100	49
Shrubs						
Artemisia tridentata ssp. *vaseyana*	—	28	—	19	—	24
Purshia tridentata	—	9	—	12	—	11
Atriplex canescens	—	6	—	5	—	0
Kochia prostrata	—	3	—	1	—	1
Chrysothamnus nauseosus var. *albicaulis*	—	0	—	1	—	15
Ceratoides lanata	—	0	—	0	—	0
Total	—	46	—	38	—	51

mature grass. During the third sample period, their diets averaged 93% mature grass and 7% green vegetative growth. Sheep in the CWS pastures consumed diets containing equal parts of shrub and grass throughout the experiment. Winterfat did not appear in the diet samples because it was present in low abundance and quickly utilized. Fourwing saltbush was utilized to a greater degree than the diet samples suggest because it was browsed in the afternoons.

Vegetation Utilization

Estimates of utilization of current year's shrub growth were as follows: winterfat, 100%; fourwing saltbush, 79%; bitterbrush, 52%; forage kochia, 34%; sagebrush, 29%; and rabbitbrush, 17%. Sheep stripped leaves from forage kochia and sagebrush, therefore their utilization estimates are conservative. Of the estimated 1,400 kg • ha^{-1} of grass in the CW pastures at the beginning of the experiment, about 92% was mature stems and leaves and 8% was green vegetative growth. During the experiment, sheep consumed about 39% of the mature crested wheatgrass and essentially all of the green growth. Most of the remaining mature grass (60%) was compacted by snow and trampled by sheep.

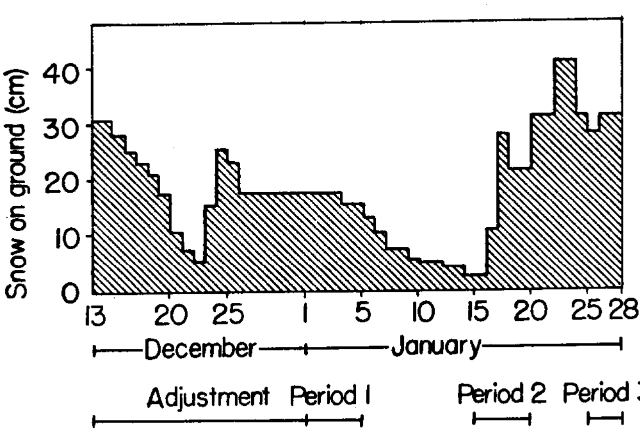


Fig. 1. *Snow depth at Levan, Utah, during December of 1982 and January of 1983. Levan is located 12 km south of the study site.*

Weather Records

Snow cover records for Levan, Utah, are presented in Figure 1. Four snow storms brought a total of 8.1 cm of precipitation, an equivalent of 65–100 cm of snow, or about 33% more than average. Snow was on the site throughout the experiment. The average December temperature was –3.5° C, 2.1° colder than normal. The average January temperature was 0.8° C, which is 2.4° warmer than normal. Temperatures ranged from –19.4 to 11.0° C.

Discussion

We stocked pastures heavily to accentuate differences between sheep diets in CW and CWS pastures. Cumulative stocking rates for the pastures were 0.2 AUM • ha^{-1} through period 1, 0.7 AUM • ha^{-1} through period 2, and 0.8 AUM • ha^{-1} through period 3. Our data suggest that lighter (e.g., 0.2-0.5 AUM • ha^{-1}) stocking rates are better because organic matter intake, nutrient content, and digestibility were higher, particularly for sheep in CWS pastures. Results from period 1, therefore, best represent the potential nutritional benefits of shrubs on snowy winter ranges.

Organic matter intake integrates a number of parameters that affect livestock performance, including nutritional characteristics of the diet and forage availability. Intake is apparently inversely related with cell wall content (Neutral Detergent Fiber, NDF) when diets contain more than 6–8% CP, but is directly related with CP at lower concentrations of CP (Van Soest 1982). Intake was well correlated with both NDF ($r = 0.91$) and CP ($r = 0.99$) for sheep in the CWS pastures, but poorly correlated with NDF ($r = -0.24$) and CP ($r = -0.27$) for sheep in the CW pastures. These results suggest that forage availability (Anrold 1970) also affected intake. We attribute the lower levels of intake by sheep in CW as compared to CWS pastures primarily to lack of forage availability caused by snow, and secondarily to physical and chemical characteristics of the forage. Rittenhouse et al. (1970) found that cattle consume considerably less forage when snow covers the ground (29g • kg BW$^{-0.75}$) than when it is absent (65g • kg BW$^{-0.75}$). In addition, metabolism and appetite of sheep may be lower during winter than at other times of year (Gordon 1964, Loudon 1985), which could also contribute to the relatively low levels of intake (Cordova et al. 1978) by sheep in both CW and CWS pastures.

The values for intake obtained by the technique we used are not absolute, but indicate relative differences (Cordova et al. 1978) that have significance for forages and environmental conditions similar to those in this experiment. Thus, results for the 3 sample periods illustrate the collective effects of snow depth and increasing levels of utilization on forage availability and intake. During period 1, grass availability was low while shrub availability and nutritional quality were high, and sheep in CWS pastures consumed 36% more forage per day than sheep in CW pastures. However, between periods 1 and 2 snow depth was low, grass availability was high, and sheep in CWS pastures consumed more grass and less shrub than in periods 1 and 3. As a result, intakes were comparable for sheep in CW and CWS pastures. During period 3, grass availability was again low, shrubs were still available but less nutritious, and sheep in CWS pastures consumed 15% more forage per day than sheep in CW pastures.

Throughout the experiment, diets of sheep in CWS pastures averaged 8.1% crude protein, above the 6–8% level generally recommended for ruminants (Van Soest 1982). In contrast, diets of sheep in CW pastures averaged 5.6% crude protein. During dry years or times of heavy snow accumulation, when green vegetative growth is scarce, supplemental protein obtained from shrubs might increase intake of mature crested wheatgrass. Otsyina et al. (1982) reported that mature crested wheatgrass contains 1.2–2.7% CP.

Relationships between crude and digestible protein (Holter and Reid 1959, Van Niekerk et al. 1967) may be misleading in comparing diet quality because shrubs often contain high levels of metabolites, such as tannins, that may lower protein availabilities (McLeod 1974, Rosenthal and Janzen 1979, Milton and Dintzis 1981, Mould and Robbins 1981). Nevertheless, many shrubs in the Intermountain West apparently contain enough digestible protein to meet the needs of ewes during gestation (Cook 1972, Cook and Harris 1977, Otsyina et al. 1982). Of the shrubs in our study, only bitterbrush contained appeciable levels of tannins (Provenza, unpubl. data).

The digestible organic matter contents of diets of sheep in CWS pastures were comparable to those for sheep in CW pastures at moderate stocking rates during sample period 1, but lower at higher rates during periods 2 and 3. The lignin contents of CWS diets were also comparable to those of the CW diets at moderate stocking rates, but were higher at increased levels of stocking. High lignin levels, caused by sheep consuming woodier portions of shrubs as utilization increased, probably caused the digestibilities of CWS diets to decline (Van Soest 1982).

Increased intake is generally positively correlated with body weight. The weights of sheep in this trial changed little, however, and the lack of correlation between intake and body weight for sheep grazing in CW vs. CWS pastures may indicate that the differences between diets for sheep in CW or CWS pastures were not of consequence. Alternatively, the grazing trial may have been too brief to detect changes in body weight between sheep in CW or CWS pastures (see Petersen and Lucas 1960).

Conclusions

Our preliminary findings suggest: (1) Shrubs were available when snow accumulated, which allowed sheep on CWS pastures to maintain higher levels of intake than sheep on CW pastures. (2) Shrubs allowed sheep to maintain adequate levels of crude protein, whereas sheep grazing on CW pastures were marginally deficient. Although crude protein concentrations remained high for sheep diets in CWS pastures, in vitro organic matter digestibilities declined markedly for sheep diets in CWS compared to CW pastures as utilization levels increased during sample periods 2 and 3. (3) We were unable to demonstrate different changes in body weight for sheep grazing in CW vs. CWS pastures perhaps because the nutritional differences were not of consequence, or perhaps because the trial was not of sufficient duration. (4) Compared to crested wheatgrass, relatively few shrubs were lost to trampling and snow compaction. Sheep could not graze about 60% of the mature crested wheatgrass because of snow compaction and trampling. However, trampling losses would likely be less at lower stocking rates. (5) We stocked pastures heavily to accentuate differences between sheep diets in CW and CWS pastures during periods 1–3; we believe results from period 1 best represent the potential nutritional benefits of shrubs on snowy winter ranges.

Literature Cited

Arnold, G.W. 1970. Regulation of food intake in grazing ruminants, p. 264-276. *In:* A.T. Phillipson (ed.), Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, London.

Cook, C.W. 1972. Comparative nutritive value of forbs, grasses, and shrubs, p. 303-310. *In:* C.M. McKell, J.P. Blaisdell, and J.R. Goodin (eds.), Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv. Gen. Tech. Rep. Int. 1.

Cook, C.W., and L.E. Harris. 1968. Effect of supplementation on intake and digestibility of range forages. Utah Agr. Exp. Sta. Bull. 475.

Cook, C.W., and L.E. Harris. 1977. Nutritive value of seasonal ranges. Utah Agr. Exp. Sta. Bull. 472.

Cordova, F.J., J.D. Wallace, and R.D. Pieper. 1978. Forage intake by grazing livestock: a review. J. Range Manage. 31:430-438.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analyses. Agr. Handb. No. 379.

Gordon, J.G. 1964. Effect of time of year on the roughage intake of housed sheep. Nature 204:798-799.

Harker, K.W., D.T. Torell, and G.M. Van Dyne. 1964. Botanical examination of forage from esophageal fistulas in cattle. J. Anim. Sci. 23:465-469.

Harris, L.E. 1970. Nutrition research techniques for domestic and wild animals. Vol. 1. Utah State Univ., Logan.

Holter, J.A., and J.T. Reid. 1959. Relationship between the concentrations of crude protein and apparently digestible protein in forages. J. Anim. Sci. 18:1339-1349.

Knipfel, J.E. 1977. Nutritional adequacy of altai wild ryegrass and crested wheatgrass, or of alfalfa-wheatstraw mixtures for the pregnant ewe. Can. J. Anim. Sci. 57:405-410.

Loudon, A. 1985. A gland for all seasons. New. Sci. 107:40-43.

Marshall, J.W., and V.R. Squires. 1979. Accuracy of quantitative methods used for the botanical analysis of oesophageal fistula samples. Trop. Grassl. 13:140-148.

McLeod, M.N. 1974. Plant tannins–Their role in forage quality. Nutr. Abstr. Rev. 44:803-815.

Milton, K., and F.R. Dintzis. 1981. Nitrogen-to-protein conversion factors for tropical plant samples. Biotropica 13:177-181.

Moir, R.J., and L.E. Harris. 1962. Ruminal floral studies in sheep X. Influence of nitrogen intake upon ruminal function. J. Nutr. 77:285-298.

Mould, E.D., and C.T. Robbins. 1981. Nitrogen metabolism in elk. J. Wildl. Manage. 45:323-344.

Murray, R.B., H.F. Mayland, and P.J. Van Soest. 1978. Growth and nutritional value to cattle of grasses on cheatgrass range in southern Idaho. USDA Forest Serv. Res. Pap. Int-199.

Otsyina, R., C.M. McKell, and G. Van Epps. 1982. Use of range shrubs to meet nutrient requirements of sheep grazing on crested wheatgrass during fall and early winter. J. Range Manage. 35:751-753.

Peterson, R.G., and H.L. Lucas. 1960. Experimental errors in grazing trials. Proc. 8th Internat. Grassl. Cong. (Reading, England) 747-750.

Rittenhouse, L.R., D.C. Clanton, and C.L. Streeter. 1970. Intake and digestibility of winter-range forage by cattle with and without supplements. J. Anim. Sci. 31:1215-1221.

Rosenthal, G.A., and D.H. Janzen (eds.) 1979. Herbivores. Their interaction with secondary plant metabolites. Academic Press Inc., New York.

Simonds, G. 1980. Impact of crop production and Intermountain cattle ranch efficiency. M.S. Thesis, Utah State Univ., Logan.

Smith, A.D., and P.J. Urness. 1962. Analysis of the twig length method of determining utilization of browse. Utah State Dept. Fish and Game Pub. 62-C.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. British Grassl. Soc. 18:104-111.

Van Gylswyk, N.O. 1970. The effect of supplementing low-protein hay on the cellulolytic bacteria in the rumen of sheep and on the digestibility of cellulose and hemicellulose. J. Agr. Sci. Camb. 74:169-180.

Van Niekerk, B.D.H., D.W.W.Q. Smith, and D. Oosthuysen. 1967. The relationship between the crude protein content of South African feeds and its apparent digestion by ruminants. Proc. S. Afr. Soc. Anim. Prod. 6:108-116.

Van Soest, P.J. 1982. Nutritional ecology of the ruminant. O & B Books Inc., Corvallis.

West, N.E. 1983a. Great basin-Colorado plateau sagebrush semi-desert. p. 331-349. *In:* N.E. West (ed.), Temperate Deserts and Semi-deserts. Elsevier, Amsterdam.

West, N.E. 1983b. Western Intermountain sagebrush steppe. p. 351-374. *In:* N.E. West (ed.), Temperate Deserts and Semi-deserts. Elsevier, Amsterdam.

Nitrate Reductase Activity of Kleingrass (*Panicum coloratum* L.) during Drought in the Northern Chihuahuan Desert

IAN M. RAY AND WILLIAM B. SISSON

Abstract

Plant nitrate (NO_3^--N) uptake rates are often low in desert environments because soil nitrogen levels are typically low, and mineralization and nitrification of nitrogen is moisture-dependent. During drought, leaf tissue NO_3^--N levels toxic to grazing animals can result because the enzyme responsible for NO_3^--N reduction (nitrate reductase; NR) is repressed during plant water stress. Seasonal leaf NR activity (in vivo), and NO_3^--N, total nitrogen, and leaf water (%) content of kleingrass (*Panicum coloratum* L.) plants growing in situ in the northern Chihuahuan Desert were determined. Total precipitation during the April through November growing season (11.5 cm) was 40% less than the long-term average (19 cm). This drought resulted in low NR activity, repressed plant growth, and water-stressed plants through most of the growing season. Seasonal and diurnal leaf NR activities were positively correlated ($P<.05$) with leaf water contents (%) and leaf water potentials, respectively. The latter correlation was significant only with young leaf tissue. Young leaf tissue reduced 29.6 μmol NO_3^--N • gDW^{-1} on 14 July when leaf water potentials exceeded -3.0 MPa. On 18 May, 7.1 μmol NO_3^--N • gDW^{-1} were reduced when older leaf tissue was present and leaf water potentials did not exceed -3.0 MPa. Leaf NO_3^--N accumulated to levels toxic to livestock during August, September, and October. The stem plus leaf sheath component of the aboveground biomass was the primary site for NR activity, and nitrogen and biomass allocation during 6 phenological stages (second through fifth leaf stages, and boot and immature seed stages). Immature seeds comprised only 12.3 % of the aboveground biomass and possessed 29.9% of the nitrogen and 62.2% of the total capacity of NO_3^--N reduction.

Frequent drought, low annual precipitation, and soil nitrogen levels are important factors that limit plant productivity and diversity in desert environments. Because soil nitrogen distribution and availability are closely correlated with soil biological activity, and, hence, soil moisture and temperature, periods of drought impose quantitative limitations on both soil moisture and nitrogen availability. Although many drought-adaptive attributes have been identified in plants (Blum 1983), an ability to compete for limited soil nitrogen (NO_3^--N) during drought and reduce it by continued nitrate reductase (NR) activity might be particularly important for drought tolerance. Although NH_4^+ is present in desert soils, exchangeable levels may be insufficient to supply plant needs. (Wallace et al. 1978), and desert perennial plants appear to take up NO_3^--N preferentially (Kirkby 1969).

The initial step in the metabolism of NO_3^--N to other nitrogenous compounds is accomplished by NR. The level and activity of this enzyme is, therefore, the rate-limiting step. Activity of NR is deleteriously affected by many factors that include: plant water deficits, high temperature, low irradiance levels, insect damage, and overmature plant tissue (Beevers and Hageman 1980). Leaf water relations have a profound effect on the level, stability, and activity of NR because this enzyme is induced by the NO_3^--N flux to the induction and assimilation sites (cytoplasm) rather than by the NO_3^--N content of leaves (Shaner and Boyer 1976 a,b). Thus, substantial water deficits within plants, soil, and atmosphere (i.e., drought) result in low available soil nitrogen levels and repressed NO_3^--N uptake and reduction capacity by plants. During drought, NO_3^--N can accumulate within plants to levels toxic to livestock (Tucker et al. 1961) when uptake exceeds reduction.

Successful introduction of new forage species into a desert environment is dependent upon many physiological attributes that include drought tolerance. An ability to compete with other plants for soil water and nutrients that are often limited is also an important component in the adaptability of forage plants to this type of habitat. The present study was undertaken to quantify seasonal NO_3^--N pools within kleingrass (*Panicum coloratum* L.), an introduced C_4 bunchgrass, and soils and to determine the seasonal capacity for NO_3^--N reduction within this species relative to soil and plant water status. A substantial reduction in precipitation (-40% from the long-term average) during the growing season (April through November) provided an opportunity to study the effects drought has on these nitrogen pools and their metabolism following uptake and translocation to leaves of kleingrass plants. A second objective was to partition biomass, nitrogen, and capacity for NO_3^--N reduction within aboveground plant components during 6 phenological stages (second through fifth leaf stages, and boot and immature seed stages).

Methods

The seasonal nitrate reductase (NR) activity study was conducted between April and November 1983 on mature kleingrass plants growing in an experimental plot on the Jornada Experimental Range (ca. 32° 34'N, 104° 48'W) near Las Cruces, N. Mex. The plants were initiated from seed within the plot in July 1975. Soil textures of the plot vary from fine loamy sand to sandy loam (Wink series; Typic Calciorthid). Average annual precipitation on the study site is 22.1 cm (52-year average). Annual precipitation during 1983 (16.5 cm) was 37% less than the long-term yearly average and resulted in a drought condition during the study period. April through November precipitation (11.5 cm) was 40% less than the long-term average (19.0 cm).

Four samples consisting of the youngest fully expanded leaves from 8 kleingrass plants were collected at approximately 10-day intervals during cloudless days from April through November for NR activity assays, and leaf water, NO_3^--N, and total nitrogen content determinations. Because leaf age composition of kleingrass plants varied throughout the study period, and the presence of young, recently expanded leaves were soil moisture dependent, leaf tissue samples representative of a single age group were not possible during the study. Tissue samples collected for analysis were, however, comprised of the youngest leaves present within each plant where nitrogen assimilation primarily occurs (Srivastava 1980). All tissue samples were collected within 0.5 hour of solar noon with the exception of 18 May and 14 July when 3 leaf tissue samples were collected prior to sunrise and every 1.5 hours thereafter to sunset. Tissue samples collected on 18 May and 14 July were immediately assayed for NR activity at the study site. All other samples were transported to the laboratory (approximately

The authors are a graduate research assistant, Department of Agronomy, University of Wisconsin, Madison, Wis.; and plant physiologist, Jornada Experimental Range, ARS, USDA, Department of Animal and Range Sciences, New Mexico State University, Las Cruces 88003. At the time of the research, Ray was an undergraduate student majoring in agricultural biology, Entomology and Plant Pathology Department, New Mexico State University, Las Cruces.

The authors are grateful to Dr. Glyn O. Throneberry, Entomology and Plant Pathology Department, New Mexico State University, for providing laboratory and greenhouse space and equipment needed to complete this study. Appreciation is also extended to M.L. Jack Roberts for allowing the authors to maintain sample plots within kleingrass pastures on his ranch.

The use of trade names does not constitute an official endorsement or approval by the United States Department of Agriculture.

This paper is Journal Article 1208, Agricultural Experiment Station, New Mexico State University, Las Cruces 88003.
Manuscript accepted 5 May 1986.

30 min) at 0° C in the dark for immediate NR activity analysis.

Leaf xylem pressure potentials were measured in the field using a PMS pressure bomb. Leaf water content was determined on 3 or 4 samples after drying the tissue for approximately 24 hours at 80° C. Precipitation data were collected by a U.S. Weather Bureau station located within 10 m of the study site. Soil water was measured gravimetrically on 3 replicate samples removed from 3 randomly selected sites within the Jornada study plot at both 18-and 38-cm soil depths.

The entire aboveground biomass of 4 plants was collected at solar noon (cloudless days) during 6 phenological stages (second through fifth leaf stages, and boot and immature seed stages) between 23 and 28 July to determine the proportion each component contributed to total aboveground plant dry weight, nitrogen, and NR activity. The plants were removed from an irrigated pasture 12.5 km south of Las Cruces, N. Mex.; the samples were transported to the laboratry (approximately 30 min) in the dark at 0° C for immediate NR activity analysis. Soil textures of the pasture vary from loam to fine sandy loam (Glendale series; Typic Torrifluvent).

Nitrate reductase activity (in vivo) was determined on 4 samples during the seasonal and phenological studies, and on 3 samples during the diurnal analyses on 18 May and 14 July. The assay procedure followed that of Hageman and Hucklesby (1971) with the zinc acetate/phenazine methosulfate modification of Scholl et al. (1974). Tissue samples were incubated in the assay medium in a N_2 atmosphere for 40 minutes at 30° C. The samples were thoroughly mixed during incubation by vigorous shaking every 10 minutes. Absorbance was read at 540 nm and nitrite produced was calculated using standard nitrite concentrations.

Oven-dried tissue was ground to 40-mesh for determination of NO_3^--N and total nitrogen content. Two subsamples from each of 3 or 4 replicate tissue samples were digested (block digestion) and total nitrogen analyzed using the colorimetric method involving the reaction of ammonium with sodium salicylate, sodium nitroprusside, and sodium hypochlorite with absorption readings at 660 nm (Technicon Industrial Systems, Industrial Method Number 334-74 W/B^+-N, 1977). Nitrate content was determined by the method of Cataldo et al. (1975). Nitrate extraction during the 1-hour incubation (45° C) period was increased by approximately 30% by vigorously agitating the samples every 10 minutes in a vortex shaker.

Results

Diurnal NR Activity

Diurnal NR activity of the youngest fully expanded leaves of kleingrass plants on the Jornada study site was low on 18 May 1983 (Fig. 1). There was no precipitation during the 30 days before 18 May (Fig. 2A) resulting in dry soil conditions (Fig 2B), and leaf water potentials exceeded −2.5 MPa during the middle 5 hours of the photoperiod (Fig. 1A). Maximum mean NR activity was 0.65 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$ when the mean leaf water potential was −2.6 MPa. Because no new leaf growth occurred during the 30-day period before 18 May, low diurnal NR activity is probably the result of both old leaf tissue and water stress.

Diurnal NR activity was considerably higher on 14 July (Fig. 1B) relative to 18 May, particularly in the early morning hours prior to solar noon. Mean leaf water potentials were consistently lower on 14 July than those measured on 18 May suggesting leaf water stress was more severe on 14 July. New leaf growth was initiated after 1.3 cm of precipitation occurred 3 days before 14 July. High NR rates measured on 14 July were, therefore, probably the result of high NR activity associated with young plant tissue. Minimal mean leaf water potential (−0.61 MPa) and maximum NR activity (4.96 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$) occurred on 14 July at sunrise (Fig. 1B). Leaf water potentials and NR activity decreased through the photoperiod to −3.21 MPa and 1.40 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$, respectively. Approximately 29.6 μmol NO_3^--N $\cdot gDW^{-1}$ was reduced by leaf tissue during the 14 July photoperiod and 7.1 μmol NO_3^--N $\cdot gDW^{-1}$ on 18 May. Leaf water

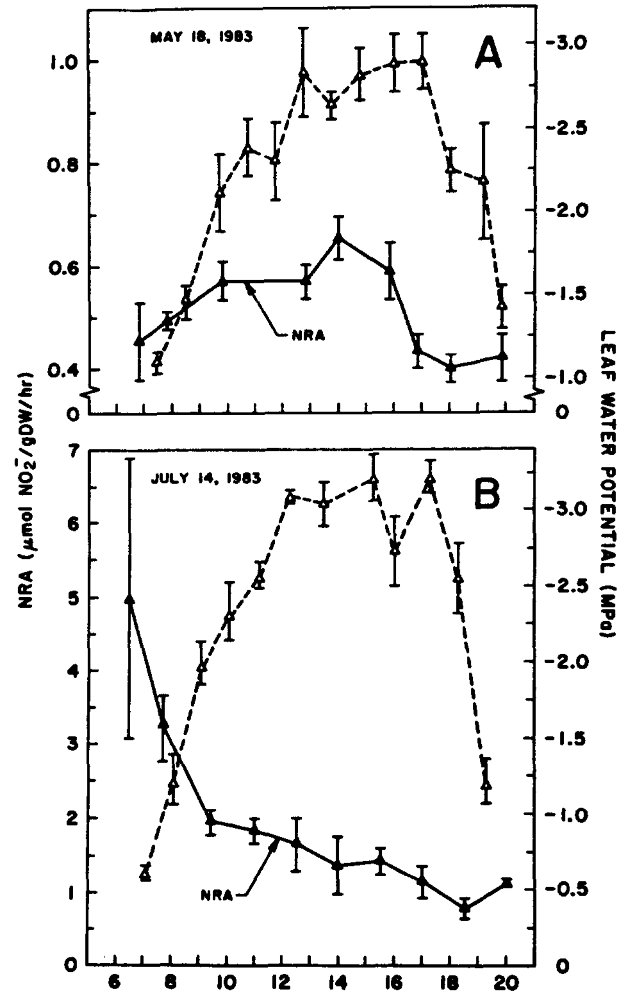


Fig. 1. *Leaf nitrate reductase activity (NRA) (closed triangles) and leaf water potential (MPa) (open triangles) of kleingrass (*Panicum coloratum *L.) in the northern Chihuahuan Desert during 18 May (A) and 14 July (B) 1983. Vertical bars represent ± 1 standard error of the mean, and each value is the mean of 3 replicates. Hours are Mountain Daylight Time.*

potentials were statistically correlated (r = .71; P<.05) with NR activity on 14 July while 18 May measurements were not (P>.05). There were no statistically significant (P<.05) relationships of leaf NR activity with either leaf NO_3^--N or total nitrogen content on either date.

Seasonal NR Activity

Maximum seasonal leaf NR activity at solar noon occurred on 14 July (1.63 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$), 3 days after 1.3 cm precipitation (Fig. 2A) on the Jornada study site. Soil water content (Fig. 2B) at 18-cm soil depth increased from 3.6% before this rain (10 July) to 5.1% on 14 July, and leaf water content was 53.1 and 60.8% (Fig. 2B) on 11 and 14 July, respectively. There was no precipitation on the study site between 12 July and 8 Aug. A marked decline in leaf NR activity occurred during this period with the seasonal low in both leaf water content (40%) and NR activity (0.18 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$; Fig. 2B) on 4 Aug. Increased NR activity and leaf water content concomitant with precipitation also occurred on 27 June, 19 Aug., and 13 and 18 Sept. Following each of these temporal increases in NR activity and leaf water content (%), NR activity declined to rates of 0.4 μmol $NO_2^- \cdot gDW^{-1} \cdot hour^{-1}$ or less. Seasonal NR activity and leaf water content (%) were statistically (P<.05), but not highly correlated (r=.53).

The maximum seasonal soil water content of 10.3% at 18-cm soil depth was measured on 12 Apr. (Fig. 2B). Young, rapidly growing leaves exhibiting a mean leaf water content of 76.1% were present on 12 Apr. Rapid depletion of soil water and minimal precipitation (Fig. 2A) thereafter resulted in soil water contents of less than 6%

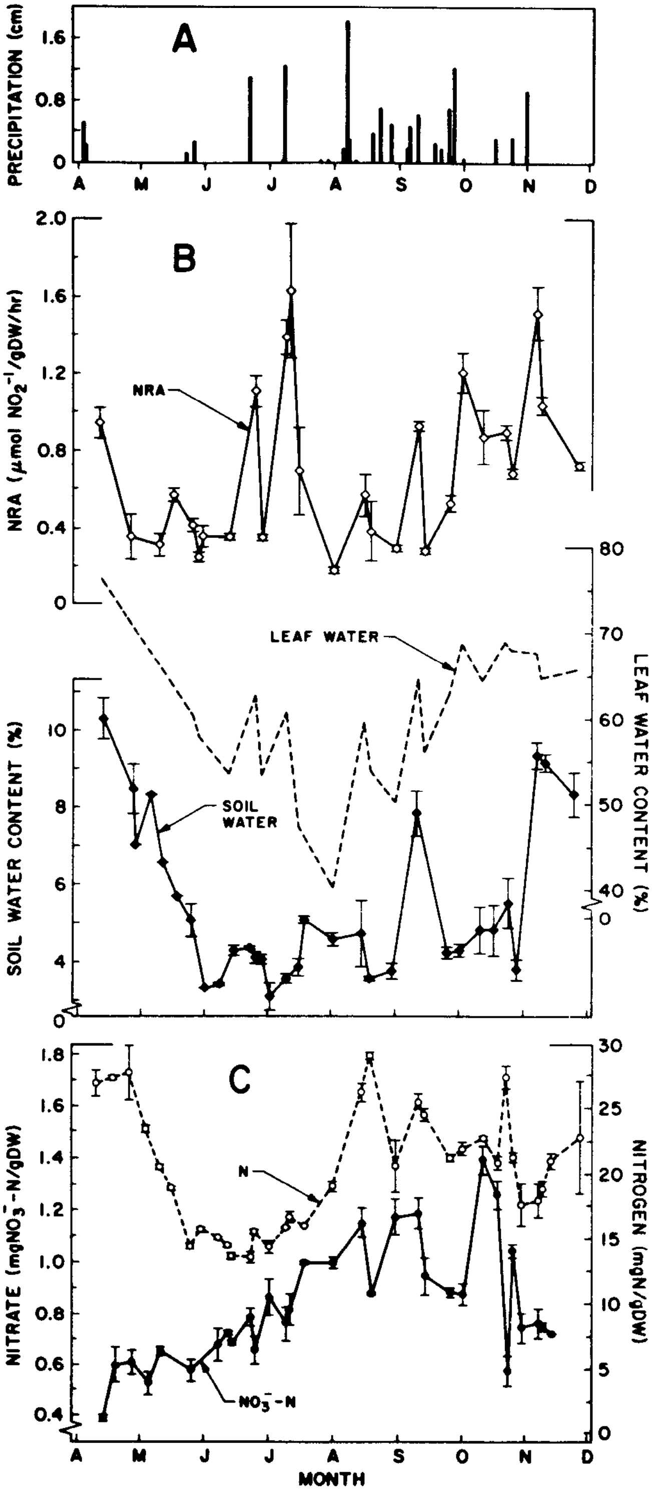


Fig. 2. *Leaf nitrate reductase activity (NRA) (B) (open squares), and leaf water (B) (dashed line), NO_3^--N (C) (closed circles) and total reduced-nitrogen (C) (open circles) content of kleingrass (*Panicum coloratum *L.) plants during April through November growing in situ in the northern Chihauhuan Desert. Soil water content (%) (B) (closed squares) at 18 cm soil depth and precipitation (A) are also shown. Vertical bars represent ± 1 standard error of the mean, and each value is the mean of 3 (soil water) or 4 (NRA, N and NO_3^--N) replicates. Leaf water content (%) varied less than 7% from the mean.*

at a 18-cm soil depth during June, July, and August. Soil water content exceeded 6% during only 1 sample day in September (22 Sept.), and during November after plant growth ceased. Maintenance of relatively high leaf water contents (>65%) in October was not reflected in elevated soil water contents at either 18-cm (Fig. 2B) or 38-cm (data not shown) soil depth. The high leaf water contents may have, in part, been due to a low evaporative demand resulting from the low air temperatures during October.

Nitrogen content (Fig. 2C) of the youngest leaf tissue present on kleingrass plants was above 27 mgN • gDW^{-1} during April and then declined to minimal levels of approximately 15 mgN • gDW^{-1} during May, June, and July. This decline was probably the result of rapid tissue growth and, consequently, a dilution of tissue nitrogen. This decreasing trend in tissue nitrogen content continued until leaf growth ceased when soil water content became low in mid-May. Leaf nitrogen levels remained relatively constant until the substantial increase in August following 2.4 cm of precipitation. Thereafter, no discernible trend in leaf nitrogen content was evident.

Leaf NO_3^--N levels(Fig. 2C) increased from mid-April through mid-September. This increase in plant tissue NO_3^--N content during drought is consistent with other studies (Morilla et al. 1973, Sisson and Throneberry 1986). Leaf NO_3^--N accumulated to levels toxic to livestock (>0.5% NO_3^--N • gDW^{-1}; Tucker et al. 1961) in August (18 Aug.), September 2 and 13 Sept.), and October (14 and 21 Oct.). Measurable levels of NO_3^--N were not found within the April through November soils samples removed from either the 18- or 38-cm soil depths.

Partition of Plant Biomass and NR Activity

The stem plus leaf sheaths component exceeded 50% of the aboveground biomass of kleingrass plants on the irrigated pasture study site during all 6 phenological stages (second through fifth leaf stages, and boot and immature seed stages) except for the third leaf stage (Fig. 3). This component reduced a minimum of 11.7% of the

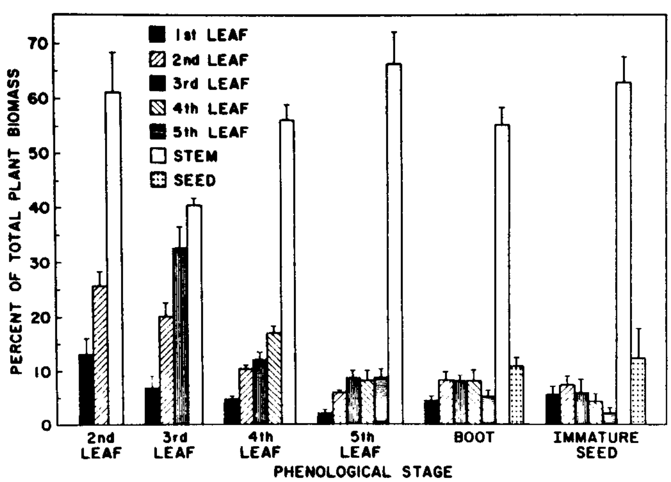


Fig. 3. *Percent of total plant biomass of the aboveground components of kleingrass (*Panicum coloratum *L.) growing in an irrigated pasture in the northern Chihuahuan Desert for the second, third, fourth, and fifth leaf stages, and boot and immature seed stages. Vertical bars represent ± 1 standard error of the mean, and each value is the mean of 4 replicates. The stem component includes the leaf sheaths.*

total aboveground NO_3^--N per plant during the third leaf stage, and a maximum of 42.2% when the fifth (flag) leaf matured (Fig. 4). Capacity for NO_3^--N reduction by the stem plus leaf sheaths increased through the fifth (flag) leaf stage and, thereafter, became less important as reproductive growth progressed. At the immature seed stage, developing seeds represented only 12.6% of the aboveground biomass but accounted for 62.2% of the capacity for NO_3^--N reduction per plant. Thus, seeds become a major sink for NO_3^--N and site for its reduction during development.

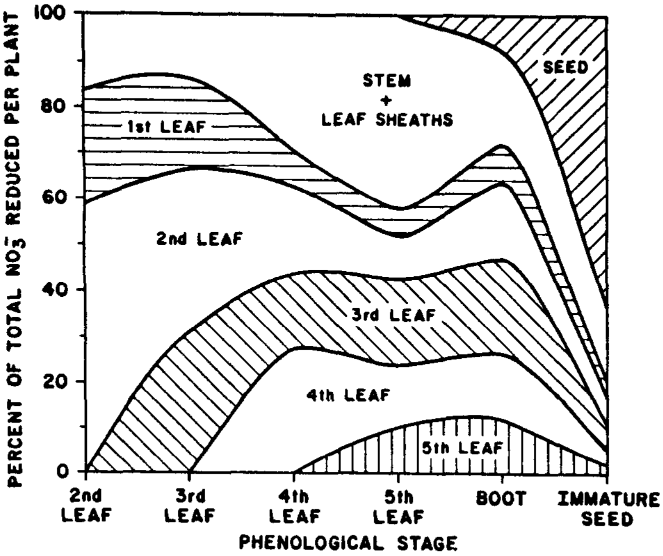


Fig. 4. *Percent of the total capacity for NO_3^--N reduction within each of the aboveground components of kleingrass (*Panicum coloratum *L.) growing in an irrigated pasture in the northern Chihuahuan Desert during the second, third, fourth, and fifth leaf stages, and boot and immature seed stages. Each value represents the mean of 4 replicates, and the standard errors of the mean ranged from 2.0 to 9.8.*

Leaves 2 through 4 possessed the capacity to reduce at least 28% (range of 28 to 59%) of the aboveground NO_3^--N reduced per plant when full leaf expansion was initially achieved (Fig. 4). Thereafter, capacity to reduce NO_3^--N by these leaves diminished to a minimum at the immature seed stage. The fifth (flag) leaf possessed the highest NR activity on a gDW basis ($\bar{x}$ = 0.98 μmol NO_2^- • gDW^{-1} • $hour^{-1}$) of the aboveground components when it achieved full expansion. Its small biomass (2.2% of the total aboveground plant biomass), however, resulted in the fifth leaf being of minor importance relative to NO_3^--N reduction capacity within the entire aboveground biomass of each plant.

Total nitrogen allocated to each aboveground component of kleingrass during 6 phenological stages is shown in Fig. 5. Nitrogen

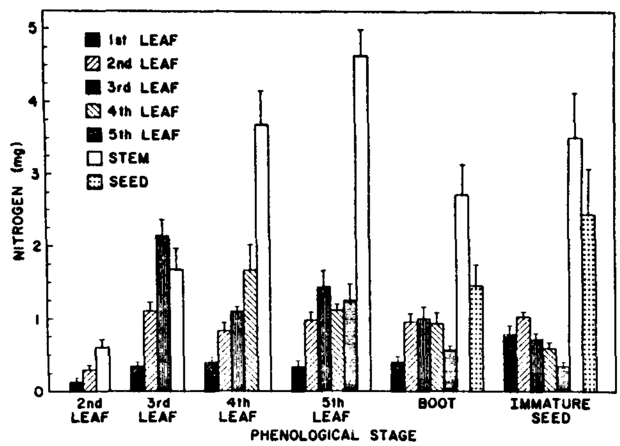


Fig. 5. *Allocation of nitrogen (mg) within each of the aboveground components of kleingrass (*Panicum coloratum *L.) growing in an irrigated pasture in the northern Chihuahuan Desert during the second, third, fourth, and fifth leaf stages, and boot and immature seed stages. Veritical bars represent ± 1 standard error of the mean and each value represents the mean of 3 or 4 replicates.*

content of the stem plus leaf sheaths was lower than the other plant components on a mgN • gDW^{-1} basis. The large biomass allocated to the stem plus leaf sheaths (Fig. 3), however, resulted in this component exhibiting the highest nitrogen content during all phenological stages evaluated, except the third leaf stage. Reallocation of nitrogen from leaves to other aboveground plant components was indicated by decreasing leaf nitrogen content following full leaf expansion. Developing seed possessed 10.8 and 12.3% of the aboveground biomass during the boot and immature seed stages (Fig. 3), respectively, and possessed 18.1 (boot stage) and 25.9% (immature seed) of the total aboveground nitrogen.

Discussion

Nitrate nitrogen (NO_3^--N) levels are generally low in desert soils (Nishita and Haug 1973, Charley and West 1975) and concentrations are largely dependent upon season (Rychert and Skujins 1973). Desert soil NO_3^--N concentrations commonly range between 0 to 4 ppm (Wallace et al. 1978). During this study, detectable levels of NO_3^--N were not found at either 18- or 38-cm soil depth. Wallace et al. (1978), recalculating the data of Nishita and Haug (1973), demonstrated that depth of rainfall penetration and root distribution primarily influenced NO_3^--N distribution in desert soils. Although soil microarthropods can decompose litter when soils are quite dry (Parker et al. 1984), mineralization and nitrification of soil nitrogen is moisture-dependent (Whitford et al. 1981). Consequently, absence of detectable soil NO_3^--N levels is probably due to the dry soils prevalent during most of the study. Nevertheless, NO_3^--N levels did increase in kleingrass leaves (Fig. 2) from April through August. Uptake of NO_3^--N and its translocation to leaves can, therefore, be inferred and at rates exceeding its reduction by NR within leaves. These increases in aboveground plant tissue NO_3^--N during drought are consistent with results of other studies and can be partially attributed to a decline in NR stability, synthesis, and activity during water stress (Morilla et al. 1973, Sisson and Throneberry 1986).

Leaf age was found in this (Fig. 1A, 1B, 4) and other studies (Harper and Hageman 1972, Srivastava 1980) to influence NR activity. Maximal NR activity is typically associated with young plant tissue, and a decline in activity accompanies tissue aging and senescence. Because NR induction in leaf tissue depends on the ability to synthesize proteins, repressed NR activity that accompanies leaf tissue aging is the result of a reduction or loss of protein synthesizing capacity (Srivastava 1980). The presence of young leaf tissue on 14 July (Fig. 1B) resulted in a reduction of 29.6 μmol NO_3^--N • gDW^{-1} as compared to 7.1 μmol NO_3^--N • gDW^{-1} on 18 May (Fig. 1A) when old leaf tissue was present. Higher NR activity associated with young leaves on 14 July occurred even though leaf water stress, as indicated by mean leaf water potentials, was more severe on 14 July than on 18 May.

Allocation of biomass (Fig. 3) and nitrogen (Fig. 5) within the aboveground components of kleingrass was similar through 6 phenological stages (second through fifth leaf stages, and boot and immature seed stages). Consequently, nitrogen content and total aboveground biomass were significantly ($P<.01$) related by the regression equation, Nitrogen = 10.36 + 3.23 ln B, where B is total aboveground biomass at each phenological stage. More than 50% of the aboveground biomass was allocated to the stem plus leaf sheaths component during all but the third leaf stage. Although this component had the lowest total nitrogen on a per unit weight basis, its large biomass resulted in this component exhibiting the highest nitrogen content during all but the third leaf stage. During reproductive growth, developing seeds became an important sink for nitrogen, a probable site for nitrogen reallocation from other aboveground components, and they possessed over 60% of the aboveground capacity to reduce NO_3^--N (Fig. 4). Thus, significant amounts of reduced-nitrogen and capacity for NO_3^--N reduction are allocated to developing seeds during the period of reproduction.

Leaf water contents and leaf water potentials were statistically correlated ($P<.05$) with NR activity on a seasonal (Fig. 2) and diurnal (14 July, Fig. 1) basis, respectively. This dependence on leaf water status results because NR is induced by the flux of NO_3^--N within plant tissue (Shane and Boyer 1976 a, b, Beevers and Hageman 1980). During drought, therefore, reductions in NO_3^--N uptake and translocation, and concomitant decreases in transpiration lower the NR substrate (NO_3^--N) flux and cause a reduction in NR synthesis and activity. The NO_3^--N storage pool—probably within the vacuole (Beevers and Hageman 1980)—is not readily translocated and is, therefore, not capable of inducing NR synthesis and activity. As a result, levels of NO_3^--N toxic to livestock can accumulate during drought when uptake exceeds reduction. Nitrate nitrogen accumulated within the leaf tissue of kleingrass during most of the growing season (Fig. 2C), and toxic levels (>0.5% NO_3^--N • gDW^{-1}, Tucker et al. 1961) were present during August, September, and October.

Soil- and plant-water deficits associated with a period of extended drought repress many, if not all, processes associated with NO_3^--N availability within soils, the capacity of plant roots to take up NO_3^--N, translocation of NO_3^--N to aboveground NR sites and its reduction. Survival of kleingrass, and its continued ability to take up soil NO_3^--N and translocate and reduce it during drought suggests that this plant is adapted to the northern Chihuahuan Desert. The tendency to accumulate NO_3^--N within leaves during drought may limit its introduction into arid rangelands. However, the elevated NO_3^--N levels found in the present study should be investigated further concerning livestock toxicity when kleingrass is consumed alone or as a component of the overall daily forage intake.

Literature Cited

Beevers, L., and R.H. Hageman. 1980. Nitrate and nitrite reduction. p. 115-168. *In:* B.J. Miflin (Ed.). The Biochemistry of Plants. A Comprehensive Treatise. Vol. 5, Amino Acids and Derivatives. Academic Press, New York, N.Y.

Blum, A. 1983. Genetic and physiological relationships in plant breeding for drought resistance. Agr. Water Manage. 7:195-205.

Cataldo, D.A., Haroon, M., Schrader, L.E., and V.L. Youngs. 1975. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Comm. Soil Sci. Plant Anal. 6:71-80.

Charley, J.L., and N.E. West. 1975. Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems in Utah. J. Ecol. 63:945-963.

Hageman, R.H., and D.P. Hucklesby. 1971. Nitrate reductase from higher plants. Meth. Enzymol. 23:491-503.

Harper, J.E., and R.H. Hageman. 1972. Canopy and seasonal profiles for nitrate reductase in soybeans (*Glycine max* L. Merr.). Plant Physiol. 49:146-154.

Kirkby, E.A. 1969. Ion uptake and ionic balance in plants in relation to the form of nitrogen nutrition. p. 215-235. *In:* I.H. Rorison (Ed.). Ecological Aspects of the Mineral Nutrition of Plants. Blackwell Scientific Pub., Oxford, England.

Morilla, C.A., J.J. Boyer, and R.H. Hageman. 1973. Nitrate reductase activity and polyribosomal content of corn (*Zea mays* L.) having low water potentials. Plant Physiol. 51:817-824.

Nishita, N., and R.M. Haug. 1973. Distribution of different forms of nitrogen in some desert soils. Soil Sci. 116:51-58.

Parker, L.W., P.F. Santos, J. Phillips, and W.G. Whitford. 1984. Carbon and nitrogen dynamics during the decomposition of litter and roots of a Chihuahuan Desert annual, *Lepidium lasiocarpum*. Ecol. Monog. 54:339-359.

Rychert, R.C., and J. Skujins. 1973. Microbial activity in arid soils. Utah Sci. 34:96-98.

Scholl, R.L., J.E. Harper, and R.H. Hageman. 1974. Improvements of the nitrate color development in assays of nitrate reductase by phenazine methosulfate and zinc acetate. Plant Physiol. 53:825-828.

Shaner, D.L., and J.S. Boyer. 1976a. Nitrate reductase activity in maize (*Zea mays* L.) leaves. I. Regulation by nitrate flux. Plant Physiol. 58:499-504.

Shaner, D.L., and J.S. Boyer. 1976b. Nitrate reductase activity in maize (*Zea mays* L.) leaves. II. Regulation by nitrate flux at low leaf water potential. Plant Physiol. 58:505-509.

Sisson, W.B., and G.O. Throneberry. 1986. Seasonal nitrate reductase activity of 3 genotypes of *Atriplex canescens* in the northern Chihuahuan Desert J. Ecol. 74:579-589.

Srivastava, H.S. 1980. Regulation of nitrate reductase activity in higher plants. Phytochem. 19:725-733.

Tucker, J.M., D.R. Cordy, L.J. Berry, W.A. Harvey, and T.C. Fuller. 1961. Nitrate poisoning in the livestock. Univ. California Agr. Exp. Sta. Ext. Serv. Circ. 506.

Wallace, A., E.M. Romney, G.E. Kleinkopf, and S.M., Soufi. 1978. Uptake of mineral forms of nitrogen by desert plants. p. 130-151. *In:* N.E. West and J. Skujins (Ed.). Nitrogen in Desert Ecosystems. Dowden, Hutchinson & Ross, Inc. Stroudsburg, Penn.

Whitford, W.G., D.W. Freckman, P.F. Santos, N.Z. Elkins, and L.W. Parker. 1981. The role of nematodes in decomposition in desert ecosystems. p. 98-116. *In:* D.W. Freckman (ed.) Nematodes in Soil Ecosystems. Texas A & M Press, College Station, Texas, USA.

Herbage Production Following Litter Removal on Alberta Native Grasslands

W.D. WILLMS, S. SMOLIAK, AND A.W. BAILEY

Abstract

Studies were conducted to determine the effects on herbage yield of removing mulch and standing dead plant litter during dormancy for up to 3 or more consecutive years. This information is required to obtain a better understanding of the implications of dormant season grazing on forage production. In 2 studies, mulch and standing litter were harvested at 3 or more annual frequencies from 2 × 2 m plots. One study was repeated in both the Fescue Prairie and Mixed Prairie communities and plant response was measured annually as the yield of herbage produced from treated and control plots. The second study was conducted in the Fescue Prairie on 3 sites and designed as a 3 × 3 Latin square. The treatments consisted of removing mulch and standing litter, removing and replacing this material, and a control. Estimates were made of the yield, species composition, and morphological characteristics of the grasss. A third study was made, in the Fescue Prairie, by defoliating individual rough fescue (*Festuca scabrella* Torr. var. *major* Vasey) plants a single time, at 5 and 15 cm above ground, and comparing them with a control. Herbage yields decreased as the annual frequency of mulch and litter harvests increased in the Mixed Prairie but not in the Fescue Prairie. In the Mixed Prairie, yields declined to 43% of the control after 3 years of treatment. Removing mulch and standing litter from rough fescue plants resulted in shorter but a greater number of tillers than in the control. The results were similar after 1 or 3 years of treatment.

Native grasslands in southern Alberta provide relatively good quality forage for fall and winter grazing (Johnston and Bezeau 1962). Although photosynthetic tissue is not removed when plants are harvested during dormancy, their subsequent growth is affected. In the first year after removing mulch and standing dead plant litter of rough fescue (*Festuca hallii* (Vasey) Piper (Sinton 1980) or bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. + Smith) (Sauer 1978, Willms et al. 1980), forage yields decreased while tiller densities increased. However, after 2 consecutive years of removing standing dead plant litter from rough fescue, yields were marginally greater and tiller densities were substantially increased (Sinton 1980).

Plant litter helps conserve soil moisture by reducing soil temperature and evaporation (Weaver and Rowland 1952, Hopkins 1954). However, reduced soil temperatures in spring will delay plant growth (Weaver and Rowland 1952) and may result in reduced herbage yield (Dyksterhuis and Schmutz 1947, Penfound 1964) and in a reduced diversity in the plant community (Weaver and Rowland 1952).

Native grasslands in southern Alberta have evolved with buffalo grazing on the Mixed Prairie in summer and on the Fescue Prairie in winter (Johnston and MacDonald 1967). This would suggest that grasses of the Fescue Prairie should be tolerant of winter grazing. However, the effects of removing mulch and harvesting standing dead plant litter on herbage production have not been examined very extensively. Clarke et al. (1947) reported yields from plots harvested after plant senescence, over a 9-year period, but assumed no effect of removing standing dead plant material and had no control treatment.

These studies were initiated to determine the effects of removing mulch and standing litter during the dormant season on forage production in the Fescue Prairie and Mixed Prairie grasslands.

Materials and Methods

Site Description

Two study areas were located on the Fescue Prairie and one on the Mixed Prairie of southern Alberta. One Fescue Prairie site was at the University of Alberta Ranch, Kinsella (150 km SE of Edmonton), and the other at the Agriculture Canada Range Research Substation, Stavely (90 km NW of Lethbridge). The soils, climate, and vegetation of the Kinsella area have been described by Bailey and Anderson (1978) while the Stavely area was described by Willms et al. (1985). Major differences in the plant communities at 2 Fescue Prairie sites were the associated species and the presence or absence of rhizomes on rough fescue. At Kinsella, the rough fescue is rhizomatous and is a species *(F. hallii)* distinct from the tufted rough fescue (*F. campestris* Rydb.; or *F. scabrella* Torr. var. *major* Vasey) found at Stavely (Looman and Best 1979, Pavlick and Looman 1984). The rhizomatous form is associated with western porcupine grass (*Stipa spartea* Trin. var. *curtiseta* Hitchc.) while the tufted form is associated with Parry oat grass (*Danthonia parryi* Scribn.). The soils at both areas were orthic black chernozemic (Argic Cryoboroll). Precipitation averaged 432 mm at Kinsella and 614 mm at Stavely (Table 1). The latter area was subject to chinook winds.

Table 1. Precipitation (mm) from April to August during the period of studies at 3 locations in Alberta.

						Long term average[1]	
Location	1977	1978	1979	1980	1981	Apr.-Aug.	Annual
Manyberries	162	239	187	187	200	211	327
Stavely	301	605	273	303	326	351	614
Kinsella			220	417	148	285	432

[1]Average precipitation for 30 years at Stavely and Manyberries and 18 years at Kinsella.

The Mixed Prairie site, situated at the Agriculture Canada Research Substation at Manyberries (185 km SE of Lethbridge), was typical of the *Stipa-Bouteloua* Faciation described by Coupland (1961). The soils were calcareous brown chernozemic (Aridic Haploboroll) and precipitation averaged 327 mm.

In all experiments the material considered as mulch included the classes of fresh mulch and humic mulch while the standing dead plant litter included the accumulation of dead leaves and culms and represented cured herbage as described by Dyksterhuis and Schmutz (1947).

Experiment 1

Single sites were selected at the Stavely and Manyberries Research Substations which had been protected from grazing for about 30 years. At each site, plots (2 × 2 m) were arranged in a matrix of 8 rows and 10 columns. Two contiguous rows were selected, systematically, in each year for treatment beginning in 1977, 1978, and 1979. All plots within each row were nested and treated identically. Plots in 1 row were treated as a control in the

Authors are range ecologists, Agriculture Canada, Research Station, Lethbridge, Alberta T1J 4B1; and professor of range management, Dept. of Plant Science, the University of Alberta, Edmonton T6G 2P5.

The authors are grateful for the statistical advice given by B. Schaalje. Technicians B.W. Kesler and R.G. Gschaid assisted with the field work. The study at Kinsella was partly supported by a grant from the Agricultural Research Council of Alberta, Farming for the Future, to Dr. A.W. Bailey.
Manuscript accepted 17 April 1986.

initial year of selection while plots in the other row had mulch and standing litter removed by raking in early spring while plants were dormant. Plots in the 2 remaining rows represented the control in 1980 and 1981, respectively. The control plots had all mulch and standing litter removed at the time of harvest. Herbage yields in control and treated plots were estimated by harvesting 1-m^2 quadrats in the center of each plot in late September. The control plots were harvested once in the initial year of selection, while the treated plots were harvested in each year of the study. The forb and grass components were sorted and, together with the mulch/litter fraction, were dried and weighed.

Two methods were used to analyze the data. One method was to determine the trend of herbage yields in relation to frequency of defoliation. In this test, the frequency of defoliation was the main effect while the row, with nested plots, was the replicate. The main effect was partitioned into linear and quadratic components, each with 1 df, and tested using their interaction with replication as the error term (2 df). The number of replications was 3, one for each year in which treatments were initiated in a row.

The year effect was removed prior to analysis by transforming the estimates of herbage yield to a proportion of yield of the control for that year. We assumed that yields from control plots were representative of potential site productivity for the year in which they were obtained.

In order to avoid using a control, a second method was used to show the impact of repeated dormant season defoliation on yield. Average yields were tabulated by the year in which they were harvested and by the number of harvest-years. No further analysis was attempted since the plots were nested within a row and each row represented a single number of harvest-years. The basis for comparison, therefore, was across rows (harvest-years) within the same year of harvest. Although this approach eliminated the year effect, it assumed that each row was representative of the site.

Experiment 2

A second study, consisting of 2 experiments, was conducted at Stavely to determine the first-year effects of removing standing dead plant litter on rough fescue plants. Individual plants, randomly selected for each treatment, represented the experimental unit.

In each experiment, the treatments consisted of defoliating 10 rough fescue plants by clipping at 5 or 15 cm, or no disturbance (control). In the first experiment, plants were defoliated only in early spring (1982) for 3 treatments while in the second experiment, plants were defoliated in fall (1982) or spring (1983) for a total of 5 treatments. All treatments were imposed during plant dormancy. Mulch was removed within 20 cm from around the base of defoliated plants.

Treatment response was assessed in late summer following the first growing season after treatment by measuring plant circumference and height, harvesting the plants at ground level, separating old growth from new growth and determining dry matter, and counting tillers and determining their densities and weights. The data were analyzed using least squares analysis and single degree of freedom contrasts to test between specific treatments (Steel and Torrie 1980).

Experiment 3

Three sites were selected at Kinsella on grassland that had been protected from grazing for 30 years and from mowing for 8 years. At each site, plots were established in a 3 $\times$ 3 Latin square and treated by (1) removing standing dead plant litter and mulch, (2) removing standing dead plant litter and mulch and returning it to the plot, and (3) leaving the plot undisturbed (Control). Each plot was 2 $\times$ 2 m and the standing dead plant litter was harvested with a Mott mower in late April in 1979, 1980, and 1981. The mower cut standing dead plant material 6 cm above the ground but the flailing action of the cutters picked up most of the mulch below that level. Tillers may have emerged by that time but green foliage was not removed by the mower.

The treatment effect was measured in August 1981, after cessation of plant growth. A 0.5-m^2 quadrat was centrally located within each treatment plot. Species response to the treatments was measured from 5, 100-cm^2 subplots in each quadrat. Tiller heights were determined in the field, the subplots were then harvested, the plant species separated, and tillers counted. This was followed by harvesting the entire quadrat by removing the standing dead plant litter and harvesting the herbage to ground level. The harvested material and litter were dried and weighed.

Tiller numbers of individual species were converted to a percentage for all species but, prior to analysis, the data were transformed by the square root. Percentages greater than 80 were subtracted from 100 before transformation as recommended by Steel and Torrie (1980). The data were analyzed using least squares analysis and contrasts were tested as before.

Results

Experiment 1

Litter and mulch yielded an average of 805 g/m^2 at Stavely and 57 g/m^2 at Manyberries in the initial year of treatment. Neither the linear nor quadratic trends of herbage yields, as a proportion of the control, with frequency of litter removal, were significant (P>0.05) at either Stavely or Manyberries. However, at Stavely grass yields remained constant while forb yields tended to increase with increasing number of harvest-years while at Manyberries both grass and forb yields tended to decrease (Table 2).

Table 2. Herbage yields, as a proportion of the control (%), in relation to number of harvest-years at 2 locations (n = 30).

Location	Harvest-years	Grass	Forbs	Total
Stavely	1	75	106	77
	2	74	123	76
	3	71	144	76
	SEM	13	58	08
Manyberries	1	75	56	72
	2	51	49	50
	3	44	42	43
	SEM	11	15	11

Herbage yields, harvested the same year but representing different number of harvest-years, are shown in Table 3. At Stavely, combined grass and forb yields were greater following 2 years of harvesting than after 1 year. Yields, in 1980 and 1981, were virtually identical from plots harvested from 2 to 5 consecutive years. Yields of forb or grass types showed no consistent trends with number of harvest-years. Average grass and total herbage yields at Manyberries declined with increasing number of harvest-years.

Experiment 2

Rough fescue tillers were shorter (P<0.05) the first year after removing litter and mulch at Stavely (Table 4). Plant heights were affected (P<0.05) by the severity of removing standing dead plant litter but not by the season in which it was removed. Plant weight was not affected (P<0.05) by the treatment. Removing standing dead plant litter also resulted in an increase (P>0.05) in tiller density but a decrease (P<0.05) in tiller weight.

Experiment 3

At Kinsella, clipping and removing litter resulted in a small (P>0.05) increase in herbage yield (Table 5). However, a significant (P<0.05) increase in yield was obtained when litter was replaced. The differences among treatments were contributed mostly by the forb component of the herbage. The proportion of rough fescue decreased (P<0.05) from 82% in the control to 70% on clipped plots although total weight remained the same. Replacing mulch and litter, after clipping, yielded a recovery of less than

Table 3. Herbage yields (g/m²) in relation to the number of harvest-years within the year of harvest (n = 10 plots nested within 1 row).

	Year harvested	No. of harvest-years				
Stavely		1	2	3	4	5
Grasses	1978	181	222			
	1979	108	106	121		
	1980		117	105	116	
	1981			127	103	127
Forbs	1978	42	25			
	1979	12	29	34		
	1980		13	24	14	
	1981			24	47	24
Total	1978	223	247			
	1979	120	135	155		
	1980		130	129	130	
	1981			151	150	151
Manyberries						
Grasses	1978	54	34			
	1979	50	32	22		
	1980		15	14	12	
	1981			25	25	21
Forbs	1978	8	7			
	1979	4	4	2		
	1980		1	1	1	
	1981			2	3	2
Total	1978	62	41			
	1979	54	36	24		
	1980		16	15	13	
	1981			27	28	23

one-third that in the control. Most of the replaced litter was lost during the 3-year period (Table 5).

Total tiller density increased (($P<0.05$) as a result of clipping and removing litter (Table 6). The proportion of rough fescue tiller decreased and sedge (*Carex* spp.) tillers increased ($P<0.05$) when litter was replaced following removal (Table 6). Inflorescences of western porcupine grass increased ($P<0.05$) and rough fescue decreased where litter was removed (Table 7).

Removing litter resulted in shorter tillers of rough fescue (Table 7) as did the effect of removing and replacing litter. Western porcupine grass tiller heights were not affected by the removal or removal and replacement of litter.

Discussion

Removing standing dead plant litter and mulch over a 3-year period resulted in marginally greater herbage yields in the Fescue Prairie but lower yields in the Mixed Prairie. There was no evidence that the trends of increasing or decreasing herbage yields continued beyond 3 years although it is possible that the species composition had not stabilized. In the Fescue Prairie at Kinsella, the increase in herbage yield after harvesting was largely the result of greater forb production.

Under more arid conditions in the Mixed Prairie at Manyberries, herbage yields were depressed to about 43% of the control plots over a 3-year period where litter was removed. Both grass and forb yields declined ($P>0.05$). Although the differences in response between the Stavely and Manyberries sites were not examined, they were probably related to the moisture regime of each area and to the inhibition of growth by mulch and standing dead plant litter.

Removing litter in more xeric areas should induce a moisture deficit more readily than in mesic areas because infiltration of rainfall is less deep and roots are nearer to the soil surface. Consequently, water available to the plants would be lost more readily than where infiltration and rooting were deep. Although the large amounts of litter at Stavely (805 g/m²) would substantially reduce evaporation, the effect on inhibiting plant growth was, apparently, more important. Weaver and Rowland (1952) found that similar quantities of litter removed in big bluestem (*Andropogon gerardi* Vitman) and switchgrass (*Panicum virgatum* L.) grassland reduced yields from 26 to 57%. However, at Manyberries, the net effect of litter (57 g/m²) was to enhance productivity, presumably through the conservation of soil moisture.

Although forbs contributed most to the increase in herbage yield following litter removal on Fescue Prairie at Kinsella, tiller density of grass also increased, suggesting improved production potential. The increase in total tiller density was offset by shorter and lighter tillers.

Tillering appeared to be stimulated within the first growing season after removing litter from rough fescue plants at Stavely

Table 5. Herbage yields and litter present (g/m²) after 3 consecutive years of treatment in the rough fescue *(F. hallii)* grasslands at Kinsella ($\bar{x}$ ± SEM, n = 9).

Treatment	Grass	Forbs	Total	Litter
Control (1)	142 ± 10	11 ± 6	152 ± 8	282 ± 13
Clip/replace (2)	149 ± 9	33 ± 5	182 ± 7	80 ± 13
Clip/remove (3)	148 ± 9	19 ± 5	167 ± 7	14 ± 13
Contrasts				
1 vs 2	NS[1]	*	*	*
1 vs 3	NS	NS	NS	*
2 vs 3	NS	NS	NS	*

[1]Contrasts not significant ($P>0.05$).
*Contrasts significant ($P<0.05$).

Table 4. The first year effect of removing mulch and standing dead plant litter on several morphological characteristics of rough fescue *(F. scabrella)* plants at Stavely ($\bar{x}$ ± SEM, n = 9).

Defoliation treatment		Height (cm)		Weight/plant (g)		Tillers (1983)	
Season	Ht (cm)	1982	1983	1982	1983	Number	Weight (mg)
fall	5	—[1]	35 ± 1.8	—	37 ± 5.3	232 ± 36	153 ± 26
spring	5	45 ± 1.7	38 ± 1.9	32 ± 4.0	32 ± 5.6	222 ± 39	146 ± 28
fall	15	—	51 ± 1.6	—	41 ± 4.8	246 ± 33	178 ± 24
spring	15	49 ± 1.6	50 ± 2.0	30 ± 3.8	43 ± 5.8	284 ± 40	153 ± 28
Control		60 ± 1.9	63 ± 1.8	34 ± 4.4	38 ± 5.8	168 ± 37	303 ± 39
Contrasts							
Control vs others		*	*	NS	NS	NS	*
Defoliation (5 cm vs 15 cm)		NS[2]	*	NS	NS	NS	NS
Defoliation (spring vs fall)		—	NS	—	NS	NS	NS

[1]Treatment not applied in 1982.
[2]Contrasts not significant ($P>0.05$).
*Contrasts significant ($P<0.05$).

Table 6. Total tiller density (no./500 cm²) and proportion (%) of total tillers of major species after 3 consecutive years of treatment in the rough fescue *(F. hallii)* grasslands at Kinsella ($\bar{x}$ ± SEM, n = 9).

Treatment	Total/500 cm²	Proportion percent of total: Rough fescue $\sqrt{100\text{-}\%}$[1] (%)[2]	Sedge $\sqrt{100\text{-}\%}$[1] (%)[2]	Western porcupine grass $\sqrt{\%}$[1] (%)[2]
Control (1)	198	2.8 ± 0.40 (92)	1.9 ± 0.32 (3.5)	0.9 ± 0.11 (0.4)
Clip/replace (2)	354	4.1 ± 0.37 (83)	2.8 ± 0.29 (8.1)	0.8 ± 0.10 (0.2)
Clip/remove (3)	474	3.2 ± 0.37 (89)	2.7 ± 0.30 (7.3)	1.0 ± 0.10 (0.4)
Contrasts				
1 vs 2	*	*	*	NS
1 vs 3	*	NS[3]	NS	NS
2 vs 3	*	NS	NS	NS

[1]Transformation applied prior to analyses.
[2]Back transformed data in brackets.
[3]Contrasts not significant (P>0.05).
*Contrasts significant (P<0.05).

Table 7. Tiller heights (cm) and inflorescences (no./m²) of 2 grasses after 3 consecutive years of treatment in the rough fescue *(F. hallii)* grasslands at Kinsella (n = 9).

Treatment	Rough fescue: Tiller height	Rough fescue: Infloresences	Western porcupine grass: Tiller height	Western porcupine grass: Infloresences
Control (1)	38	8.1	25	1.1
Clip/replace (2)	28	6.3	22	4.1
Clip/remove (3)	26	2.9	19	10.4
SEM	1.3	5.4	2.1	2.7
Contrasts				
1 vs 2	*	NS	NS	NS
1 vs 3	*	NS	NS	*
2 vs 3	NS[1]	NS	NS	*

[1]Contrasts not significant (P>0.05).
*Contrasts significant (P<0.05).

(Table 4) and Kinsella (Sinton 1980). Litter insulates the soil against incident radiation thereby reducing light and temperature at the soil surface. Tillering in grasses is affected by temperature and light (Langer 1963, Laude 1972) while the interaction between them is critical (Mitchell 1953). Factors which lead to greater surplus energy within the plant promote tillering (Langer 1963). Consequently, removing the shading effect of the litter should stimulate tillering.

Removing standing dead plant litter resulted in shorter plants. The cause for the effect was not clear but it was likely related to an altered microenvironment since photosynthetic tissue was not removed. Soil moisture deficit, higher soil temperature, and greater light intensity at the crown are all enhanced by removing standing dead plant litter and may affect leaf length.

The plant response to defoliation was the same whether the treatment was applied in spring or fall. However, the severity of standing dead plant litter removal, as indicated by the influence of litter replacement on height of defoliation, did affect response. Although replacing litter could not duplicate the amount or distribution of litter on undisturbed plots, the effect was to produce a response that was generally between that achieved by complete removal and no disturbance. An important exception was in the yield of forbs from each treatment (Table 5). Replacing litter increased forb yields, perhaps by suppressing the expansion of grasses. Evidently forbs, consisting primarily of prairie sage (*Artemisia ludoviciana* Nutt.), could take better advantage of conditions presented by the redistributed litter than could grass.

The results from the studies imply that dormant season grazing would have no negative effect on forage yield in the Fescue Prairie but, rather it might enhance plant vigor by stimulating tillering in grasses. In the Mixed Prairie, however, grazing during dormancy might be expected to decrease forage yields as a result of removing standing dead plant litter. Because of this reduction in yield, stocking rates in the Mixed Prairie should be based on forage yields from grazed areas. This reduction in yield from ungrazed ranges has also been shown by Lacey and Van Poollen (1981) and confirms earlier observations (Smoliak et al. 1985) that forage production on grazed fields is about 40% of that on ungrazed fields.

Literature Cited

Bailey, A.W., and M.L. Anderson. 1978. Prescribed burning of a *Festuca-Stipa* grassland. J. Range Manage. 31:446-449.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:135-167.

Dyksterhuis, E.J., and E.M. Schmutz. 1947. Natural mulches or "litter" of grasslands: with kinds and amounts on a southern prairie. Ecology 28:163-179.

Hopkins, H.H. 1954. Effects of mulch upon certain factors of the grassland environment. J. Range Manage. 7:255-258.

Johnston, A., and L.J. Bezeau. 1962. Chemical composition of range forage plants of the *Festuca scabrella* association. Can. J. Plant Sci. 42:105-115.

Johnston, A., and M.D. MacDonald. 1967. Floral initiation and seed production in *Festuca scabrella* Torr. Can. J. Plant Sci. 47:577-583.

Lacey, J.R., and H.W. Van Poollen. 1981. Comparison of herbage production on moderately grazed and ungrazed western ranges. J. Range Manage. 34:210-212.

Langer, R.H.M. 1963. Tillering in herbage grasses. Herb. Abst. 33:141-148.

Laude, H.M. 1972. External factors affecting tiller development, p. 146-154. *In:* Younger, V.B. and C.M. McKell (eds.), The biology and utilization of grasses. Academic Press, New York.

Looman, J., and K.F. Best. 1979. Budd's Flora of the Canadian Prairie Provinces. Agr. Can. Publ. 1662.

Mitchell, K.J. 1953. Influence of light and temperature on the growth of ryegrass (*Lolium* spp.). II. The control of lateral bud development. Physiol. Plant 6:425-443.

Pavlick, L.E., and J. Looman. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, F. campestris (F. scabrella* var. *major),* and *F. hallii* in Canada and the adjacent part of United States. Can. J. Bot. 62:1739-1749.

Penfound, W.M.T. 1964. Effects of denudation on the productivity of grassland. Ecology 45:838-845.

Sauer, R.H. 1978. Effect of removal of standing dead material on growth of *Agropyron spicatum.* J. Range Manage. 78:121-122.

Sinton, H.M.M. 1980. Effect of burning and mowing on *Festuca hallii* (Vasey) Piper, *Festuca scabrella* Torr. M.Sc. Thesis, Univ. of Alberta, Edmonton.

Smoliak, S., B.W. Adams, B.G Schuler, R.A. Wroe, S.G. Klumph, and W.D. Willms. 1985. Forage production on selected native prairie sites in southern Alberta. Res. Br. Agr. Can. Tech. Bull. 1985-3E. Lethbridge.

Steel, R.G.D, and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. McGraw-Hill Book Co., New York.

Weaver, J.E., and N.W. Rowland. 1952. Effects of excessive natural mulch development, yield, and structure of native grassland. Bot. Gaz. 114:1-19.

Willms, W., A.W. Bailey, and A. McLean. 1980. Effects of clipping or burning on some morphological characteristics of *Agropyron spicatum*. Can. J. Bot. 58:2309-2312.

Willms, W.D., S. Smoliak, and J.F. Dormaar. 1985. Effects of stocking rate on a rough fescue grassland vegetation. J. Range Manage. 38:220-225.

Establishment of Range Grasses on Various Seedbeds at Creosotebush [*Larrea tridentata*] Sites in Arizona, U.S.A., and Chihuahua, Mexico

JERRY R. COX, MARTHA H. MARTIN-R., FERNANDO A. IBARRA-F., AND HOWARD L. MORTON

Abstract

Perennial grasses were seeded by drilling or broadcasting on 4 mechanical and 3 herbicidal weed control and/or seedbed preparation treatments at 4 semidesert grassland sites invaded by creosotebush *(Larrea tridentata)* in the Chihuahuan and Sonoran Deserts. The cultivars 'Cochise' Atherstone lovegrass *(Eragrostis lehmanniana* × *Eragrostis trichophera)* and 'Catalina' Boer lovegrass *(Eragrostis curvula* var. *conferta)* lovegrasses were initially established and persisted in 6 of the 8 plantings on disk plowed and disk plowed plus contour furrowed seedbeds. These grasses were established and persisted in 2 of the 5 plantings made in creosotebush stands treated with tebuthiuron [*N*-(5-(1,1-dimethylethyl)-1,3,4-thiadizol-2-yl)-*N*-*N'*-dimethylurea] at 0.5, 1.0, and 1.5 kg a.i/ha rates. Grasses established initially on two-way railed and land imprinted areas usually died within 3 or 4 years.

Creosotebush *(Larrea tridentata)*, a woody perennial shrub, has invaded the semidesert grasslands within the Chihuahuan and Sonoran Deserts of North America (Humphrey 1958, Buffington and Herbel 1965, Hastings and Turner 1965). As creosotebush densities increase, perennial grass densities decline (Anderson et al. 1957). Therefore, it is desirable to replace creosotebush with perennial grasses to reduce soil erosion, increase infiltration, and provide forage for domestic livestock.

Jerry Cox and Howard Morton are range scientist and supervisory plant physiologist, respectively; USDA, Agricultural Research Service, Aridland Watershed Management Research Unit, 2000 E. Allen Road, Tucson, Ariz. 85719; Martha Martin-R. and Fernando Ibarra-F. are head of the Department of Range Management and Technical Director, respectively, CIPES, Periferico OTS S/N, Conjunto UGRS, Postal 1754, Hermosillo, Sonora, Mexico. When this study was initiated Martha Martin-R. and Fernando Ibarra-F. were graduate students, School of Renewable Natural Resources, University of Arizona, Tucson.

Appreciation is extended to Consejo Nacional de Ciencia y Tecnologia (Mexico) for financial support; Elanco Products Company for the herbicide and fencing materials at the Mexican sites; Drs. Luis Carlos Fierro, Thomas N. Johnsen, Jr., and Gilbert L. Jordan for technical assistance; personnel at Rancho Experimental La Campana, Chihuahua, Mexico, and Aridland Watershed Management Research Unit, Tucson, Ariz., for setting up plots, applying treatments, and collecting data; and ranchers Eloy Morales, Sergio Mendoza, and Gilberto Valdez for permission to use their land and housing facilities. The Rocky Mountain Forest and Range Experiment Station gave permission to use land at the Santa Rita Experimental Range.

Lovegrass seeds were provided by U.S. Dep. Agr., Soil Conservation Service, Plant Materials Center, Tucson, Arizona. Kleingrass and sideoats grama seeds were provided by Rancho Experimental La Campana. Buffelgrass seeds were provided by Centro de Investigacions Pecuarias del Estado Sonora, Carbo, Sonora, Mexico.

Manuscript accepted 5 May 1986.

For the past 90 years creosotebush management has consisted of mechanical tillage to reduce creosotebush competition and prepare a seedbed for seeding perennial grasses (Cox et al. 1982). Mechanical tillage disturbs surface soils and aids in rainwater infiltration (Jordan 1981), but seedings at creosotebush site were seldom successful and the treated area is usually reinvaded by creosotebush or annual forbs and grasses (Cox et al. 1984a).

Pelleted tebuthiuron [*N*-(5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl)-*N*-*N'*-dimethylurea] effectively controls creosotebush (Jacoby et al. 1982) and perennial grasses can be established if grass seeds and pellets are applied at the same time (Baur et al. 1977). Grass seedlings, however, may not survive if pellets are applied after seeds germinate because seedling roots encounter the herbicide as it moves through the upper soil profile (Baur 1979).

The semidesert grasslands of the southwestern U.S.A. and northern Mexico are of great importance to the livestock industry, but the chances of reestablishing forage grasses are low because of erratic precipitation in summer. Therefore, it is important to address the effects of precipitation on plant establishment, persistence, and forage production.

More than 300 forb, grass, and shrub species have been sown at 400 locations in the southwestern U.S.A. and northern Mexico during the past 90 years (Cox et al. 1982). A successful seeding was more likely to occur if seed of the following species were sown prior to the summer rains: (1) 'A-68' Lehmann lovegrass *(Eragrostis lehmanniana)*, (2) 'A-84' and (3) 'Catalina' Boer lovegrass *(E. curvula* var. *conferta)*, (4) 'Cochise' Atherstone lovegrass *(E. lehmanniana* × E. trichophera), (5) 'S-75' Kleingrass *(Panicum coloratum)*, (6) 'Premier' sideoats grama *(Bouteloua curtipendula)*, and (7) 'common' buffelgrass *(Cenchrus ciliaris)*.

Researchers have evaluated either the relationships between mechanical seedbed preparation and grass establishment or chemical seedbed preparations and grass establishment, but have not attempted to directly compare both seedbed preparations. The purpose of this study was to compare establishment potential and persistence of 7 perennial grasses sown in mechanically and chemically prepared seedbeds.

Methods

The study was conducted at the Santa Rita Experimental Range

Table 1. Site characteristics and soil classification for seeding study sites at Santa Rita Experimental Range (SRER) Arizona, U.S.A. and at Ranchos La Reforma, Los Pozos and El Toro, in Chihuahua, Mexico.

Sites	Elevation	Mean[1] precipitation		Mean extreme temperature[1]		Soils	
		Summer	Winter	Max.	Min.	Series	Classification[2]
	---m---	---mm---		---° C---			
SRER	970	190	130	44	4	Anthony	loamy, thermic, Typic Torrifluvent
La Reforma	1,500	240	160	37	−16	Kimbrough	loamy, mixed, thermic, shallow Petrocalcic, Calciustoll
Los Pozos	1,400	150	105	40	−10	Jerag	loamy, mixed, thermic, shallow, Petrocalcic Ustollic Paleargid
El Toro	1,380	160	110	42	−13	Algerita	loamy, mixed, thermic, coarse, Ustollic Typic Calciorthid

[1]Means are from COTECOCA. (1978), Green and Martin (1967).
[2]Soil classification is from Soil Survey Staff (1975).

(SRER), 40 km south of Tucson, Ariz., in the Sonoran Desert; Rancho La Reforma, 60 km east of Parral, Chihuahua; Rancho Los Pozos, 20 km northeast of Aldama, Chihuahua; and Rancho El Toro, 100 km east of Villa Ahumada, Chihuahua; all are within the Chihuahuan Desert.

Elevation is least at SRER, intermediate at Los Pozos and El Toro, and greatest at La Reforma (Table 1). Precipitation distribution is approximately 60% in summer and 40% in winter at all sites. Freezing temperatures infrequently occur in winter at SRER, but are common in winter and spring at La Reforma, Los Pozos, and El Toro. Slope inclination varies from 2 to 16% at La Reforma, and from 0 to 5% at the other 3 sites. Surface soil textures at the 4 sites are sandy loam and a caliche hard pan is present from 5 to 100 cm.

Creosotebush is the predominant shrub species except at La Reforma where it shares codominance with whitethorn *(Acacia constricta)* and shrubby senna *(Cassia wislizenii)*. Desert zinnia *(Zinnia pumila)* and mariola *(Parthenium incanum)* are present at SRER. Whitethorn, mesquite (*Prosopis* spp.), and tarbush *(Flourensia cernua)* are present at Los Pozos and El Toro.

Each study site was fenced to exclude livestock in summer 1981. The following 8 seedbed preparations were applied on 50 by 100-m plots: (1) untreated check, (2) two-way railing, (3) disk plowing, (4) disk plowing plus contour furrowing, (5) land imprinting, and tebuthiuron pellets containing 20% active ingredient (a.i.) hand applied at rates of (6) 0.5, (7) 1.0, and (8) 1.5 kg/ha.

Three 2.65-m lengths of railroad steel were bolted together to form a triangle and weighted with rocks (approximately 770 kg). The rail was pulled over the plot twice in opposite directions. A standard 3-bottom disk plow on a 3-point hitch weighing 500 kg was used at the Mexican sites, and a pull-type 3-bottom disk plow weighing 2,000 kg at SRER. Both disk plows had 64-cm disks which penetrated soils to 30 cm. A border disk constructed contour furrows at 10-m intervals.

The land imprinter, fabricated from 1.27-cm steel plate, consisted of 2 nondirectional geometric forms (V-pitter and pit-digger) welded on separate 1 by 1 m cylinder capsules. Capsules were linked on an axle shaft. Capsules were filled with water, and iron boxes located at the front and rear were filled with rocks to aid in soil penetration (Dixon and Simanton 1980). Total weight was approximately 4 metric tons.

The tebuthiuron pellets were distributed on 20 swaths, spaced 5 m apart along the 100-m plot length, and on 10 swaths, spaced 5 m apart along the 50-m plot width. The clay pellets were 3.2 mm in diameter and approximately 4.8 mm in length.

Mechanical seedbeds were prepared between 15 June and 17 July in 1981, and between 26 May and 27 June in 1982. Land imprinted seedbeds were prepared at all sites only in 1982. The herbicide was applied in May both years.

Seeds of 'A-68' Lehmann lovegrass, 'A-84' and 'Catalina' Boer lovegrass, 'Cochise' Atherstone lovegrass, 'S-75' Kleingrass, 'Premier' sideoats grama and 'common' buffelgrass, hereafter referred to as species, were either drilled across all seedbeds or hand broadcast on mechanically prepared seedbeds. Buffelgrass was seeded only at Los Pozos in 1981, but at all sites in 1982.

Table 2. Density and forage production of range grasses averaged over 7 or 8 seedbed preparations following drill seeding in summer 1981 and 1982 at Santa Rita Experimental Range, Arizona, U.S.A.

Year		Grass						
		Lovegrasses						
Seeded	Evaluated[1]	A-68	Cochise	A-84	Catalina	Kleingrass	Sideoats grama	Buffelgrass
		Density (Plants/m²)						
1981	1981	0^{c}	1^{b}	1^{b}	1^{b}	1^{b}	3^{a}	
	1982	1^{b}	2^{a}	1^{b}	2^{a}	2^{a}	2^{a}	
	1983	1^{b}	3^{a}	1^{b}	4^{a}	1^{b}	1^{b}	
	1984	1^{b}	6^{a}	1^{b}	6^{a}	1^{b}	1^{b}	
1982	1982	4^{c}	11^{a}	2^{c}	7^{b}	7^{b}	3^{c}	8^{ab}
	1983	1^{b}	1^{b}	1^{b}	3^{a}	1^{b}	1^{b}	2^{ab}
	1984	1^{c}	7^{a}	1^{c}	4^{b}	1^{c}	1^{c}	1^{c}
		Forage Production (g/m²)						
1981	1983	1^{d}	212^{a}	80^{c}	178^{a}	59^{c}	142^{b}	
	1984	15^{c}	351^{a}	37^{c}	164^{b}	109^{bc}	106^{bc}	
1982	1983	47^{d}	217^{b}	129^{c}	236^{ab}	110^{c}	151^{bc}	283^{a}
	1984	94^{d}	417^{a}	81^{d}	223^{b}	134^{c}	113^{cd}	184^{bc}

[1]Means in rows followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

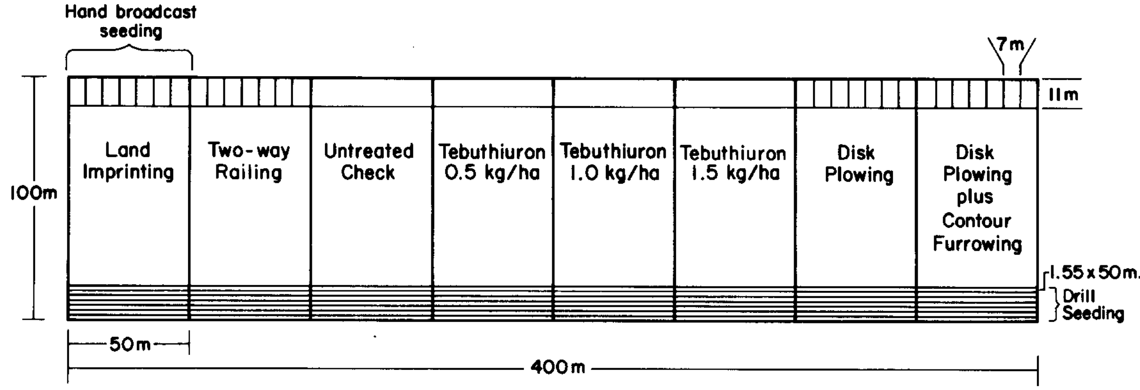


Fig. 1. *The relationship between drill seeding and hand broadcast seeding subplots within an 8-plot group of chemical and mechanical seedbeds.*

With the exception of buffelgrass and sideoats grama, seed were sown with a precalibrated half-size rangeland drill in 5 rows spaced 31 cm apart at SRER in 1981 and at all sites in 1982. Planting depths ranged from 0 to 2.5 cm because of rough terrain and drill inaccuracy. Buffelgrass and sideoats grama glumes had not been removed and seed would not pass uniformly through the drill. These species were hand broadcast directly into furrows after the drill passed.

At the Mexican sites in 1981 and at all sites in 1982, seed were hand broadcast immediately after two-way railing, disk plowing, and disk plowing plus contour furrowing. When a plot was to be land imprinted in 1982, seed were either hand broadcast on the soil surface or drill coulters were raised and seed deposited directly on soil. After seed had been sown, the plot was imprinted.

Subplot size for each species was 1.55 by 50 m (77.5 m^2) in drill seeded areas and 7 by 11 m (77 m^2) in hand seeded areas. Lovegrass seeds were sown at pure live seed (PLS) rates of 1.5 kg/ha, Kleingrass at 2.0 kg/ha, buffelgrass at 3.0 kg/ha, and sideoats grama at 5 kg/ha (Huss and Aguirre 1974, Jordan 1981). Seed were planted by hand and drill at the same PLS rates on mechanically prepared seedbeds to allow a comparison of the 2 planting techniques.

Data Collection

Twenty 30 by 60-cm quadrats were randomly selected within each seeded subplot. The 2 exterior drill rows and the outer 1 m of the hand broadcast subplots were omitted. We counted the numbers of seeded species in all quadrats, and clipped plants at the soil surface in 5 randomly selected quadrats. Forage was estimated in the remaining 15 quadrats (Pechanec and Pickford 1937) and clipped areas were omitted in future sampling dates. Clipped samples were dried in a forced-draft oven at 40° C for 48 h, and dry weights from unclipped field samples estimated using regression techniques (Campbell and Cassady 1949).

We measured plant density annually in fall 1981–1984 on subplots sown in 1981, and in fall 1982–1984 on subplots sown in 1982. We measured forage production in fall 1983 and 1984 on subplots sown in 1981 and 1982. Rainfall was measured on site.

Experimental Design

Each study area was divided into 2 parts; 1 for treatment in 1981 and 1 for treatment in 1982. Each part was subdivided into 24 plots, 50 by 100 m. The experimental design was a randomized block with 3 replications.

Six grasses were drill seeded across 7 seedbeds in 1981 at SRER, and 7 grasses were drill seeded across 8 seedbeds in 1982 at all sites. Space and lack of equipment maneuverability limited a complete randomization of species; therefore, species were randomized within each block (Fig. 1). Because seedbed preparations and grasses are randomized at different levels, the design is a strip-block (Federer 1967). There is no main plot in the design and we tested seedbed preparations, grasses and the seedbed preparation by grasses interaction with the same error term.

Six grasses were hand broadcast on 3 mechanically prepared seedbeds at 2 sites, and 7 grasses at 1 site in 1981; and 7 grasses hand broadcast on 4 mechanically prepared seedbeds at 4 sites in 1982. Seedbeds and grasses were completely randomized and the design was a split-plot, with seedbeds as main plots and grasses as subplots (Fig. 1).

Density and forage production data from the 20 quadrats within each subplot were averaged and the mean considered a replication. The amount and distribution of summer rainfall was highly variable among sites in the same year, and among years at the same site.

Table 3. Mean density and forage production of 6 or 7 grasses on 8 seedbed preparations following drill seeding in summer 1981 and 1982 at Santa Rita Experimental Range, Arizona, U.S.A.

Year			Mechanical Seedbeds				Chemical Seedbeds		
							Active Rate Tebuthiuron		
Seeded	Evaluated[1]	Control	Two-way Railing	Disk Plowing	Disk Plowing plus Contour Furrowing	Land Imprinting	0.5	1.0	1.5
		Density (Plants/m^2)							
1981	1981	0^{c}	2^{b}	2^{b}	4^{a}		0^{c}	0^{c}	0^{c}
	1982	0^{b}	1^{a}	1^{a}	2^{a}		2^{a}	2^{a}	1^{a}
	1983	1^{b}	2^{ab}	4^{a}	2^{ab}		2^{ab}	2^{ab}	2^{ab}
	1984	1^{b}	1^{b}	1^{b}	1^{b}		3^{a}	4^{a}	4^{a}
1982	1982	2^{c}	8^{b}	12^{a}	14^{a}	4^{c}	4^{c}	3^{c}	3^{c}
	1983	1^{c}	2^{b}	3^{ab}	4^{a}	1^{c}	1^{c}	1^{c}	1^{c}
	1984	1^{bc}	2^{b}	3^{ab}	4^{a}	1^{bc}	2^{b}	3^{ab}	4^{a}
		Forage Production (g/m^2)							
1981	1983	4^{d}	136^{b}	226^{a}	291^{a}		51^{c}	29^{c}	18^{c}
	1984	42^{c}	118^{bc}	99^{bc}	142^{b}		148^{b}	203^{a}	232^{a}
1982	1983	10^{d}	202^{b}	385^{a}	466^{a}	12^{d}	137^{c}	81^{c}	57^{cd}
	1984	80^{c}	158^{b}	215^{a}	290^{a}	153^{b}	99^{c}	224^{a}	206^{ab}

[1]Means in rows followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

Table 4. Density and forage production of range grasses averaged over 3 mechanical seedbed preparations following hand broadcasting in summer 1981 at 3 sites in Chihuahua, Mexico.

		Grass						
Year		Lovegrasses						
Site	Evaluated[1]	A-68	Cochise	A-84	Catalina	Kleingrass	Sideoats grama	Buffelgrass
		Density (Plants/m²)						
La Reforma	1981	0^{d}	9^{c}	0^{d}	8^{c}	51^{a}	30^{b}	
	1982	0^{c}	2^{b}	0^{c}	1^{b}	11^{a}	9^{a}	
	1983	0^{b}	1^{a}	0^{b}	1^{a}	1^{a}	1^{a}	
	1984	0^{b}	1^{a}	0^{b}	0^{b}	1^{a}	1^{a}	
Los Pozos	1981[2]	2^{b}	7^{ab}	0^{c}	5^{ab}	9^{a}	4^{b}	10^{a}
	1982[2]	2^{b}	4^{b}	0^{c}	5^{b}	10^{a}	2^{b}	11^{a}
	1983[2]	2^{b}	2^{b}	0^{c}	2^{b}	3^{b}	2^{b}	6^{a}
	1984[2]	1^{b}	2^{a}	0^{c}	2^{a}	1^{b}	1^{b}	2^{a}
El Toro	1981	2^{c}	32^{a}	2^{b}	39^{a}	36^{a}	44^{a}	
	1982	4^{c}	14^{b}	2^{c}	16^{b}	21^{ab}	23^{a}	
	1983	2^{c}	10^{ab}	2^{c}	9^{b}	15^{a}	12^{ab}	
	1984	2^{b}	4^{a}	1^{b}	4^{a}	5^{a}	5^{a}	
		Forage Production (g/m²)						
La Reforma	1983	0^{b}	1^{a}	0^{b}	1^{a}	1^{a}	1^{a}	
	1984	0^{c}	7^{b}	0^{c}	0^{c}	38^{a}	18^{b}	
Los Pozos	1983[2]	6^{b}	11^{b}	0^{c}	14^{b}	14^{b}	6^{b}	66^{a}
	1984[2]	12^{b}	23^{b}	0^{c}	5^{b}	8^{b}	8^{b}	43^{a}
El Toro	1983	19^{bc}	59^{a}	10^{c}	25^{b}	28^{b}	21^{b}	
	1984	35^{b}	87^{a}	9^{c}	36^{b}	33^{b}	24^{b}	

[1]Means in rows followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.
[2]Grazed by cattle.

Because of this, statistical comparisons are site specific for seedbed preparations and grasses within a year. Data were subjected to analyses of variance to determine differences ($\alpha = 0.05$) among seedbed preparations, grasses, and the seedbed preparations by grasses interaction. Interactions were not significant; therefore, only differences among seedbed preparations and grasses are presented. A Duncan's new multiple range test was used to separate means (Steel and Torrie 1960).

Results

Drill Seeding

Summer thunderstorm activity began prior to mechanical seedbed preparation and planting at SRER in 1981. Soil moisture observations while disk plowing indicated penetration to 30-cm depths; however, the surface 10 cm was dry when seeds were drilled on 15 and 16 July. A 10-minute storm deposited 20 mm during 17 July. After the storm, runoff was observed exiting control and chemically prepared seedbeds, but not mechanically prepared seedbeds. We observed 'Cochise' and 'Catalina' lovegrasses, Kleingrass, and sideoats grama seedlings during late July on mechanically prepared seedbeds, while no seedlings were observed on control and chemically prepared seedbeds.

Some 'Cochise', 'Catalina', and 'A-84' lovegrasses, Kleingrass, and sideoats grama seedlings which germinated in July 1981 were present on the mechanically prepared seedbeds in fall 1981 (Tables 2 and 3), although late July and August were dry (Fig. 2). All grasses were present on all seedbed preparations in fall 1983 and 1984. Grass seedling emergence in herbicidal treatments in fall 1982 indicated that seed sown in soil might have remained viable for more than one growing season. Seedlings might have survived because the herbicide had leached from the upper soil profile (Baur 1979, Ibarra-F. 1984) and shrub competition for water and nutrients decreased (Mutz and Scifres 1975).

Immediately after mechanical seedbed preparation and planting in 1982 the summer rainy season began. Storms occurred at 3- to 5-day intervals with 209 mm recorded by 15 August. By 20 July seedlings of all species were observed in mechanical, chemical, and control seedbeds.

Initially sideoats grama densities were greatest in the 1981 plantings, while 'Cochise' lovegrass and buffelgrass densities were greatest in the 1982 plantings (Table 2). However, by 1984 'Cochise' and 'Catalina' lovegrass densities were greater ($\alpha = 0.05$) than the other grasses in both the 1981 and 1982 plantings. Increases in 'Cochise' and 'Catalina' lovegrass densities between 1983 and 1984 are attributed to seed germination at cooler temperatures, fall precipitation, and chemical seedbed preparation.

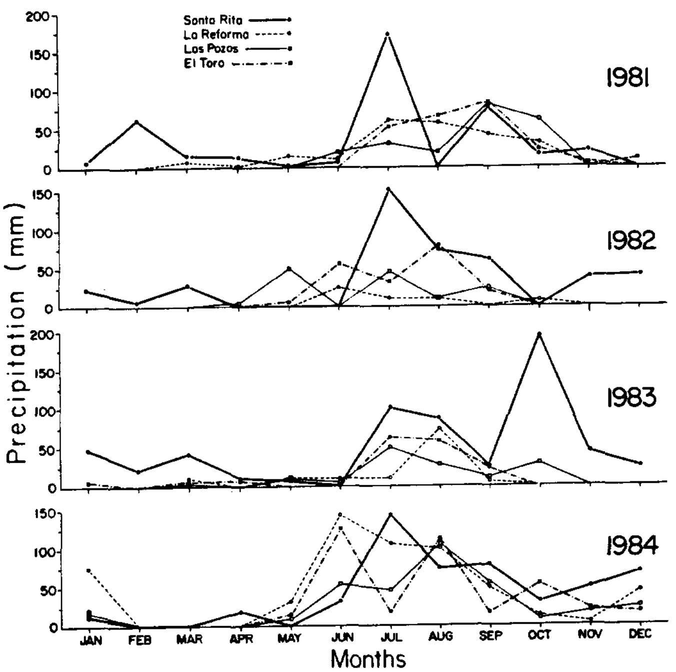


Fig. 2. *Monthly amounts of precipitation (mm) from 1981 to 1984 at Santa Rita Experimental Range (SRER), Arizona, U.S.A., La Reforma, Los Pozos and El Toro, Chihuahua, Mexico.*

Seeds of grasses sown in the field were germinated under simulated summer, fall, winter and spring soil temperature regimes. 'Cochise' and 'Catalina' lovegrass seeds germinated in summer, fall and spring regimes (Martin-R. and Cox 1984) while the remaining

Table 5. Mean density and forage production of 6 or 7 grasses on 3 mechanical seedbed preparations following hand broadcast seeding in summer 1981 and 3 sites in Chihuahua, Mexico.

Site	Year Evaluated[1]	Two-way Railing	Disk Plowing	Disk plowing Plus contour furrowing
		Density (Plants/m²)		
La Reforma	1981	16[a]	17[a]	15[a]
	1982	1[b]	5[a]	5[a]
	1983	0[b]	1[a]	1[a]
	1984	0[b]	1[a]	1[a]
Los Pozos	1981[2]	2[b]	8[a]	6[a]
	1982[2]	3[b]	6[a]	7[a]
	1983[2]	1[b]	3[a]	3[a]
	1984[2]	0[b]	1[a]	1[a]
El Toro	1981	16[b]	33[a]	29[a]
	1982	6[b]	18[a]	16[a]
	1983	2[b]	11[a]	12[a]
	1984	0[b]	6[a]	8[a]
		Forage Production (g/m²)		
La Reforma	1983	0[b]	1[a]	1[a]
	1984	0[b]	6[a]	15[a]
Los Pozos	1983[2]	3[b]	17[a]	29[a]
	1984[2]	0[b]	14[a]	14[a]
El Toro	1983	4[b]	38[a]	38[a]
	1984	0[b]	52[a]	52[a]

[1]Means in rows followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.
[2]Grazed by cattle.

grasses germinated only in summer regimes (USDA-ARS, unpublished data).

In fall 1983, 188 mm of precipitation was recorded at SRER between 3 and 7 October, 10 days after the 1983 sampling was completed. By 20 October new 'Cochise' and 'Catalina' lovegrass seedlings began to emerge in the 1981 and 1982 plantings on chemically treated areas (Tables 2 and 3). Of the 'Catalina' lovegrass seedlings observed all appeared in the original drill furrows, while 50% of the 'Cochise' lovegrass seedlings appeared in the drill furrows and 50% appeared in undisturbed areas under the canopies of dead creosotebush plants. 'Cochise' and 'Catalina' lovegrass seed germination and seedling emergence in fall 1983 suggests: (1) seeds of both species are remaining viable in soil for 1 or 2 years, (2) 'Cochise' lovegrass seeds from existing mature plants are colonizing new areas, and (3) a competitive relationship between creosotebush and perennial grasses for water and nutrients does exist (Mutz and Scifres 1975).

'Cochise' and Catalina' lovegrasses and buffelgrass (planted in 1982) forage production was generally greater than that of the other species in 1983 on the 1981 and 1982 plantings (Table 2). By 1984, however, 'Cochise' lovegrass forage production was superior ($\alpha = 0.05$) to that of all other grasses. In 1983 more forage was produced on 2-way railed and plowed seedbeds in the 1981 and 1982 plantings (Table 3). Following the establishment of additional 'Cochise' and 'Catlina' lovegrass plants in chemically prepared seedbeds, in fall 1983 forage production in plowed, railed, and chemically (1.0 and 1.5 kg/ha) prepared seedbeds was similar ($\alpha = 0.05$). In imprinted seedbeds the density and forage production of seeded species was generally less than in plowed and chemically (1.0 and 1.5 kg/ha) prepared seedbeds. Initial stand densities were influenced by soil sluffing which covered newly emerging seedlings in the furrow pit.

At the 3 Mexican sites seeded species were not present on mechanical and chemical seedbeds drill seeded in 1982. Failures were due to below-normal summer rainfall in 1982 and 1983 (Fig. 2) and ants, which we observed harvesting seeds from drill rows.

Hand Broadcast Seeding

Total annual precipitation in 1981 was 42% below the long-term average of 400 mm at La Reforma, 18% below the average of 253 mm at Los Pozos, and 18% below the average of 270 mm at El Toro (Martin-R. 1984, Fig. 2). Nevertheless, seedlings of most species were present on the 3 mechanically prepared seedbeds in fall 1981 (Table 4). Seedlings emerged following early summer rains at El Toro, but following late summer and early fall rains at La Reforma and Los Pozos. Densities were similar on the 3 mechanically prepared seedbeds at La Reforma in 1981, but were greater on plowed than on 2-way railed seedbeds at Los Pozos and El Toro (Table 5).

Total annual precipitation was 87, 47, and 29% below normal in 1982 at La Reforma, Los Pozos, and El Toro, respectively, while 130% above normal at SRER (Martin-R. 1984, Fig. 2). Seedlings failed to survive at La Reforma and Los Pozos.

Immediately after planting at El Toro in 1982 the summer rains began, but they were followed by 50 consecutive dry days in July and August. Thunderstorm activity resumed in early September. Seedlings of all species were present in fall 1982 on the 1982 plantings (Table 6), but heights varied from 1 to 3 cm. We suspect seedlings emerged from seed that germinated in September. More seedlings were present in plowed seedbeds than in 2-way railed and imprinted seedbeds (Table 7).

Grasses that emerged in either late August or September at La Reforma and Los Pozos in 1981, and El Toro in 1982, were small and leaves were yellow in 1982. The majority of these plants died between 1982 and 1984. When rainfall conditions improved in

Table 6. Density and forage production of range grasses averaged over 4 mechanical seedbed preparations following hand broadcast seeding in summer 1982 at El Toro, Chihuahua, Mexico and Santa Rita Experimental Range (SRER), Arizona, U.S.A.

	Year	Grass						
		Lovegrasses						
Site	Evaluated[1]	A-68	Cochise	A-84	Catalina	Kleingrass	Sideoats grama	Buffelgrass
		Density (Plants/m²)						
El Toro	1982	1[b]	10[a]	1[b]	5[ab]	6[ab]	2[b]	10[a]
	1983[2]	0[b]	1[a]	0[b]	1[a]	1[a]	1[a]	1[a]
	1984	0[b]	1[a]	0[b]	0[b]	1[a]	1[a]	1[a]
SRER	1982	11[c]	32[ab]	32[ab]	32[ab]	39[a]	29[b]	38[a]
	1983	5[cd]	21[a]	14[b]	14[b]	4[d]	9[c]	19[c]
	1984	1[b]	12[a]	14[a]	10[a]	1[b]	3[b]	10[a]
		Forage Production (g/m²)						
El Toro	1983[2]	0[c]	15[a]	0[c]	2[b]	4[b]	4[b]	9[ab]
	1984	0[c]	31[a]	0[c]	0[c]	36[a]	6[b]	7[b]
SRER	1983	50[bc]	108[a]	29[c]	63[b]	21[c]	37[c]	124[a]
	1984	95[b]	189[a]	104[b]	120[b]	47[bc]	118[b]	151[a]

[1]Means in rows followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

Table 7. Mean density and forage production of 7 range grasses on 4 mechanical seedbed preparations following hand broadcast seeding in summer 1982 at El Toro, Chihuahua, Mexico and Santa Rita Experimental Range (SRER), Arizona, U.S.A.

Site	Year evaluated[1]	Two-way railing	Disk plowing	Disk plowing plus contour furrowing	Land imprinting
		Density (Plants/m²)			
El Toro	1982	4^b	7^a	7^a	1^b
	1983[2]	0^b	1^a	1^a	0^b
	1984	0^b	1^a	1^a	0^b
SRER	1982	28^b	41^a	45^a	8^c
	1983	16^a	11^a	13^a	3^b
	1984	7^b	6^b	13^a	2^b
		Forage Production (g/m²)			
El Toro	1983[2]	0^b	8^a	11^a	0^b
	1984	0^b	10^a	18^a	0^b
SRER	1983	34^b	89^a	117^a	7^c
	1984	115^{ab}	128^a	159^a	68^b

[1]Means in rows followed by the same letters are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.
[2]Grazed by cattle.

Mexico during 1984 (Fig. 2) the survivors produced minor quantities of forage (Tables 4 and 6). Seedlings in 2-way railed and imprinted seedbeds eventually died, while a portion of the seedlings in plowed seedbeds survived (Tables 5 and 7).

Seedlings of all species hand seeded in summer 1982 at SRER were greatest in plowed, intermediate in 2-way railed, and least in imprinted seedbeds (Tables 6 and 7). With the exception of 'A-68' lovegrass, all species densities exceeded 28 plants/m². By 1984 'Cochise', 'A-84', and 'Catalina' lovegrasses and buffelgrass densities exceeded 9 plants/m² while 'A-68' lovegrass, Kleingrass, and sideoats grama densities were less than 4 plants/m².

Comparisons of Drill and Hand Broadcast Seedings

Mean grass densities resulting from drilling at SRER in 1981 and 1982 were 1.2 and 6.0 plants/m² after the initial growing seasons on the 1981 and 1982 plantings, respectively (Table 2). Densities increased in the 1981 plantings, decreased in the 1982 plantings, but were about the same (2.7 and 2.3 plants/m²) on both plantings by fall 1984. Mean seedling densities at SRER on the 1982 hand broadcast areas were 5.0 and 3.2 times greater than on drill seeded areas in 1982 and 1984, respectively (Tables 2 and 6). Mean forage production on the drill seeded areas was 2.7 and 1.5 times greater than on the hand broadcast area in 1983 and 1984, respectively. Mean densities after hand broadcast seeding in Mexico varied from 5.3 to 25.8 plants/m² after the initial growing season in 1981, but varied from 0.5 to 3.5 plants/m² in 1984 (Table 4).

When 2 dry summers followed in sequence, grass seedlings were not present in drilled or hand broadcast seeded areas, such as at La Reforma and Los Pozos on the 1982 plantings. At El Toro grass seedlings were not present in drill seeded areas but were present in hand broadcast areas in 1982.

The density and forage production of grasses sown with the drill, at SRER in 1981 and 1982, were initially greater on plowed and railed seedbeds than on chemical, imprinted and control seedbeds (Table 3). By fall 1984, density and forage production were either greater on the 1.0 and 1.5 kg/ha chemically treated seedbeds or similar on chemically and mechanically prepared seedbeds. Plants from hand broadcast and drilled seed on plowed seedbeds persisted and produced more forage than plants on railed and imprinted seedbeds (Table 3, 5, 7).

Discussion

The amount and distribution of summer rainfall needed to initially establish perennial grasses on semiarid southwestern U.S.A. and northern Mexico rangelands occurs in 1 of 10 summers (Cox and Jordan 1983). By utilizing drought tolerant plant materials such as 'Cochise' and 'Catalina' lovegrasses, and mechanical and chemical seedbed preparations which dramatically reduce creosotebush competition (Ibarra-F. 1984), we were able to initially establish perennial grasses in 6 of our 8 attempts. Unfortunately, initial establishment does not appear to be related to persistence and grasses initially established in late summer following a dry early summer usually die in following years.

It is important to note that total summer precipitation at SRER was 1.3, 1.3, and 1.6 times greater than the long-term average in 1982, 1983 and 1984, respectively (Green and Martin 1967). The probability of this pattern continuing for another summer, or this cycle repeating within the next 50 to 60 years is remote (Sellers and Hill 1974, Osborn 1983).

Two-way railing and land imprinting disturb the soil surface; however, neither treatment effectively reduces creosotebush competition (Ibarra-F. 1984) and initially established perennial grasses die within 3 or 4 years. Disk plowing significantly reduces creosotebush competition but it also eliminates native perennial grasses found under or near the creosotebush. If plowing and seeding are conducted prior to a summer, plowing kills existing native perennial grasses; and seeded species if initially established can not be expected to produce abundant forage, even when rainfall conditions improve.

Available nitrogen, which is typically low in semidesert soils (Skujins 1981), is concentrated under creosotebush canopies (Cox et al. 1984a). Mechanical seedbed treatments tend to mix surface soils and redistribute nitrogen over the treated area. If nitrogen under creosotebush is adequate for perennial grass seedling growth, but concentrations between plants are inadequate, then soil mixing could result in a seedbed where the average nitrogen concentration is less than ideal for initial seedling growth (Cox et al. 1984b). In summers with above-average rainfall the dilution of nitrogen may not be important because seedling roots expand and occupy a greater soil volume. However, when seedling growth is limited by water, the redistribution of nitrogen may have a dramatic effect on seedling growth and future survival.

Tebuthiuron at 1.0 and 1.5 kg/ha rates effectively reduced creosotebush competition (Ibarra-F. 1984), and seeded grasses emerged and persisted when summer rainfall was above average. As creosotebush competition declined, both seeded species and native perennial grasses dominated the treated area. Establishment of 'Cochise' and 'Catalina' lovegrasses with the native grasses resulted in a diverse grassland community. The higher herbicide rates did not appear to damage the native perennial grass when applied prior to the occurrence of a summer with below-average rainfall and native grasses dominated the site in 2 to 3 years even when the seeded species were not established.

Ranchers and researchers have over-estimated the grazing capacity of seeded areas and have not correctly managed such areas after perennial grasses were established (Cox et al. 1982). Ranchers who wish to seed perennial grasses on disk plowed or chemical seedbeds should answer the following questions: (1) Will I fence the seeded area and manage it separately from untreated portions of the same pasture? (2) Can I afford to completely rest the seeded area for 2 or more years? and (3) Will I set stocking rates based on the perennial forage produced in the driest summer? If one or more of these questions is answered negatively, the seeded treatment will likely fail because of management, even if initially successful. If a failure occurs, the rancher can expect reinvasion by shrubs, accelerated erosion, and a direct dollar loss.

Literature Cited

Anderson, D., L.P. Hamilton, H.G. Reynolds, and R.R. Humphrey. 1957. Reseeding desert grassland ranges in southern Arizona. Arizona Agr. Exp. Sta. Bull. 249.

Baur, J.R. 1979. Establishing kleingrass and bermudagrass pastures using glyphosate and tebuthiuron. J. Range Manage. 32:119-122.
Baur, J.R., R.W. Bovey, and E.C. Holt. 1977. Effect of herbicide on production and protein levels in pasture grasses. Agron. J. 69:846-851.
Buffington, L.C., and C.H. Herbel. 1965. Vegetation changes on a semidesert grassland range. Ecological Monogr. 35:139-164.
Campbell, J.B., and J.T. Cassady. 1949. Determining forage weight on southern forest ranges. J. Range Manage. 2:30-32.
COTECOCA., 1978. Coeficientes de Agostadero de la Republica Mexicana. Estato de Chihuahua. Secretaria de Agricultura y Ganaderia Mexico, D.F. [In Spanish].
Cox, J.R., H.L. Morton, T.N. Johnsen, Jr., G.L. Jordan, S.C. Martin, and L.C. Fierro. 1982. Vegetation restoration in the Chihuahuan and Sonoran Deserts of North America. USDA-Agr. Res. Serv. ARM-W-28.
Cox, J.R., and G.L. Jordan. 1983. Density and production of seeded range grasses in southeastern Arizona. J. Range Manage. 36:649-652.
Cox, J.R., H.A. Schreiber, and H.L. Morton. 1984a. The initial growth of two range grasses from nonfertilized and fertilized soils collected from creosotebush communities in the southwestern United States. J. Range Manage. 36:726-729.
Cox, J.R., J.M. Parker, and J.L. Stroehlein. 1984b. Soil properties in creosotebush communities and their relative effects on the growth of seeded range grasses. Soil Sci. Soc. Amer. J. 48:1442-1445.
Dixon, R.M., and R. Simanton. 1980. Land imprinting for better water management. Symposium on watershed management. Vol. II. Amer. Soc. Civil Eng. p. 809-825. Boise, Idaho.
Federer, W.T. 1967. Experimental design, theory and application. Oxford & IBS Publishing Co. New Delhi, India.
Green, C.R., and S.C. Martin. 1967. An evaluation of precipitation, vegetation and related factors on the Santa Rita Experimental Range. Univ. Arizona, Institute of Atmospheric Physics. Tech. Rep. on Metorology and Climatology of Arid Regions. No. 17.
Hastings, J.R., and R.M. Turner. 1965. The changing mile. Univ. Arizona Press, Tucson.
Huss, L.D., and E.L. Aguirre. 1974. Fundamentos de manejo de pastizales. Departamento de Zootecnia. Instituto Tecnologico y de Estatios Superiores de Monterrey. Monterrey, N.L. [In Spanish].
Humphrey, R.R. 1958. The desert grassland; a history of vegetational changes and an analysis of causes. Bot. Rev. 24:193-252.
Ibarra-F., F.A. 1984. Brush control, forage production and tebuthiuron residues in soils and plants at four creosotebush *(Larrea tridentata)* sites in the Chihuahuan and Sonoran Deserts. M.S. Thesis, Univ. Arizona, Tucson.
Jacoby, P.W., D.N. Ueckert, and F.S. Hartman. 1982. Control of creosotebush *(Larrea tridentata)* with pelleted tebuthiuron. Weed Sci. 30:307-310.
Jordan, G.L. 1981. Range reseeding and brush management. Ariz. Agr. Exp. Sta. Bull. No. T81121.
Martin-R., M.H., and J.R. Cox. 1984. Germination profiles of introduced lovegrasses at six constant temperatures. J. Range Manage. 37:507-509.
Martin-R., M.H. 1984. Establishment of range grasses on various seedbeds at four *Larrea tridentata* sites in Chihuahua, Mexico and Arizona, U.S.A., M.S. Thesis, Univ. Arizona, Tucson.
Mutz, J.L., and C.J. Scifres. 1975. Influence of soil texture and planting depth on buffelgrass emergence. Rangeland Resources Research 1971–1974. Texas Agr. Exp. Sta., Texas A&M, College Station.
Osborn, H.B. 1983. Precipitation characteristics affecting hydrologic responses of southwestern rangeland. USDA - Agr. Res. Serv. ARM-W-34.
Pechanec, J.F., and G.F. Pickford. 1937. A weight estimate method for determination of range or pasture production. J. Amer. Soc. Agron. 29:894-904.
Sellers, W.D., and R.H. Hill. 1974. Arizona climate (1931-1972). Univ. Arizona Press, Tucson.
Skujins, J.J. 1981. Nitrogen cycling in arid ecosystems. *In:* F.E. Clark and T. Rosswell (ed.), Terrestrial nitrogen cycles. Ecol. Bull. (Stockholm) 33:477-491.
Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agr. Handb. 436. U.S. Government Printing Office, Washington, DC.
Steel, R.G.D, and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw Hill. New York.

CALL FOR ABSTRACTS
GRAZING LIVESTOCK NUTRITION CONFERENCE
July 23-24, 1987
Jackson Wyoming

Abstracts will be presented as poster sessions and will compliment invited papers in the areas of:

Factors Influencing Energy Requirements of Livestock
Techniques for Estimating Nutrient Intake and Utilization
Factors Influencing Digesta Flow
Supplementation Practices

Abstract and program information can be obtained from:

Grazing Livestock Nutrition Conference
Department of Animal Science
University of Wyoming
Laramie, WY 82071

Effect of Herbicides and Handweeding on Establishment of Kleingrass and Buffelgrass

B.W. BOVEY, R.E. MEYER, M.G. MERKLE, AND E.C. BASHAW

Abstract

In the greenhouse, kleingrass [*Panicum coloratum* (L.) 'Selection 75'] and buffelgrass [*Cenchrus ciliaris* (L.) 'Nueces'] were tolerant of preemergence application of butylate (*S*-ethyl bis(2-methylpropyl)carbamothioate) and early postemergence sprays of barban (4-chloro-2-butynyl 3-chlorophenylcarbamate) and siduron [*N*-(2-methylcyclohexyl)-*N'*-phenylurea]. Kleingrass tolerated early postemergence sprays of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), but bromoxynil injured buffelgrass. In the field, the most promising treatments for kleingrass establishment, compared with handweeding, included postemergence sprays of 2,4-D [(2,4-dichlorophenoxy)acetic acid], preemergence application of siduron, and ropewick application of glyphosate [*N*-(phosphonomethy)-glycine]. Once established, kleingrass seedlings tolerate extreme drought during the growing season where weeds had been controlled.

Kleingrass *(Panicum coloratum)* and buffelgrass *(Cenchrus ciliaris)* are warm-season, perennial grasses native to South Africa that are highly important for livestock use on Texas rangelands (Holt and Bashaw 1976). These grasses, however, are sometimes difficult to establish in the field because of poor seedling vigor and severe competition from weeds. Few data are available on the use of herbicides for weed control in newly planted areas of kleingrass or buffelgrass.

Previous investigations (Bovey et al. 1979) showed that greenhouse-grown kleingrass tolerated preemergence and early postemergence sprays of propazine (See Table 1 for chemical names) at 1.1 kg/ha, but did not tolerate picloram, 2,4-D, dicamba, hexazinone, or tebuthiuron at similar rates. In another greenhouse study (Bovey et al. 1980), propazine was the only herbicide of 9 investigated that showed promise for both pre- and post emergence applications in kleingrass and buffelgrass. Buffelgrass tolerated preemergence sprays of clopyralid but 2,4-D, dicamba, 2,4,5-T, triclopyr, hexazinone, and tebuthiuron were phytotoxic (Bovey et al. 1983). When 45 days old, buffelgrass tolerated postemergence applications of 2,4-D, dicamba, clopyralid, and picloram at 2.2 kg/ha, but top growth production was reduced by most rates of tebuthiuron and hexazinone.

In these experiments, we determined the tolerance of greenhouse-grown kleingrass and buffelgrass seedlings to several preemergence or postemergence herbicides as listed in Table 1. Herbicides were selected based on excellent weed control potential but their phytotoxicity to kleingrass and buffelgrass was usually unknown. Similar treatments also were evaluated in the field to determine their potential for weed control and for kleingrass establishment.

Materials and Methods

Greenhouse Experiments

Kleingrass 'Selection 75' and buffelgrass 'Nueces' seedlings were grown in the greenhouse in pots 9.5 cm in diam and 7 cm deep containing a 1:1:1 Bleiberville clay (Udic Pellustert): sand: peat moss mixture. Twenty-five seeds of each grass were placed uniformly in each plot and covered with 5 mm of sand. Five replica-

Authors Bovey, Meyer, and Bashaw are research agronomist, plant physiologist, and geneticist, USDA-ARS, Dep. Range Sci., Dep. Range Sci., and Dep. Soil and Crop Sci., Texas A&M Univ., College Station 77843; Merkle is professor, Dep. Soil and Crop Science, Texas A&M Univ., College Station 77843.

Cooperative investigation of USDA, Agr. Res. Serv. and the Texas Agr. Exp. Sta., Texas A&M Univ. This paper reports the results of research only. Mention of a pesticide in his paper does not constitute a recommendation by the USDA nor does it imply registration under FIFRA.

Manuscript accepted 2 April 1986.

Table 1. Common names, chemical names, and type of activity of herbicides used in this study.

Common name		Type of activity[1]
Acifluorfen	5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid	pre, poe
Asulam	methyl[-4-aminophenyl)sulfonyl]carbamate	poe
Barban	4-chloro-2-butynyl 3-chlorophenylcarbamate	poe
Bifenox	methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate	pre, poe
Bromoxynil	3,5-dibromo-4-hydroxybenzonitrile	poe
Butylate	*S*-ethyl bis(2-methylpropyl)carbamothioate	ppi, pre
Butylate + dichlormid	butylate + (2,2-dichloro-*N,N*-di-2-propenyl-acetamide) (24:1 mixture)	ppi, pre
Clopyralid	3,6-dichloro-2-pyridinecarboxylic acid	poe
Cyanazine	2-([4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino)-2-methylpropanenitrile	pre, poe
Dalapon	2,2-dichloropropanoic acid	poe
Dicamba	3,6-dichloro-2-methoxybenzoic acid	poe
Diclofop	(±)-2-[4-(2,4-dichlorophenoxy)phenoxy] propanoic acid	pre, poe
2,4-D	(2,4-dichlorophenoxy)acetic acid	poe
Diethatyl	*N*-(chloroacetyl)-*N*-(2,6-diethylphenyl) glycine	pre
EPTC	*S*-ethyl dipropyl carbamothioate	ppi
EPTC + dichlormid	EPTC + (2,2-dichloro-*N,N*-di-2-propenylacetamide) (12:1 mixture)	ppi
Ethofumesate	(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate	pre
Glyphosate	*N*-(phosphonomethyl)glycine	poe
Hexazinone	3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione	pre, poe
Metribuzin	4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one	pre, poe
Oryzalin	4-(dipropylamino)-3,5-dinitrobenzenesulfonamide	pre
Oxadiazon	3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)1-3,4-oxadiazol-2-(3*H*)-one	pre
Oxyfluorfen	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene	pre, poe
Picloram	4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid	poe
Profluralin	*N*-(cyclopropylmethyl)-2,6-dinitro-*N*-propyl-4-(trifluoromethyl)benzenamine	ppi
Propazine	6-chloro-*N,N'*-bis(1-methylethyl)1-3,5-triazine-2,4-diamine	pre
Pyrazon	5-amino-4-chloro-2-phenyl-3*(2H)*-pyridazinone	pre, poe
Siduron	*N*-(2-methylcyclohexyl)-*N'*-phenylurea	pre
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid	poe
Tebuthiuron	*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea	pre, poe
Terbutryn	*N*-(1,1-dimethylethyl)-N'-ethyl-6-(methylthio)-1,3,5-triazine-2,4-diamine	pre poe
Triclopyr	[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid	poe
Trifluralin	2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl)-benzenamine	pre
Vernolate	S-propyl dipropylcarbamothioate	ppi

[1]Source: Weed Science Terminology. 1985. Weed Sci. Soc. Am. Supple. 1, 33:1-23. pre = preemergence; ppi = preplant incorporated; poe = postemergence.

tions (pots) were used for each treatment. Unless otherwise indicated, herbicides were applied either preemergence one day after planting or postemergence 10 to 14 days after emergence when seedlings were in the 2-leaf stage and were 2 to 6 cm tall.

Herbicides (Tables 1, 2, 3, and 4) were applied in water at a volume of 93.5 L/ha at rates of 0.6, 1.1, and 2.2 kg/ha in a laboratory sprayer (Bouse and Bovey 1967). The pots were returned to the greenhouse and hand-watered after 24 hours with a sprinkler and daily thereafter. Mean night and day greenhouse temperatures were 28 and 35° C, respectively, from June to October 1980.

Since kleingrass and buffelgrass showed considerable tolerance to butylate and siduron when applied preemergence, we incorporated these herbicides at 0.6, 1.1, 2.2 and 4.5 kg/ha into the soil by watering immediately after treatment (Table 4). In previous experiments, butylate was neither incorporated into the soil nor watered into the soil until 24 hours after application. Because butylate will vaporize from the surface of moist soil, it was desirable to investigate the effect of soil incorporation of butylate. In these experiments the commercial preparation of butylate + dichlormid (24:1), a safener for corn *(Zea mays)* was included.

Postemergence herbicides were evaluated by visually estimating either percent desiccation, percent dead plants, or both per pot. Plants showing complete desiccation were considered dead. Injury from preemergence herbicides was evaluated by visually estimating the percent of plants failing to emerge (percent dead plants) compared with the controls of percent desiccation of emerged plants, if any. Evaluations were made 14 days after treatment. All experiments were conducted twice in a completely randomized design, and data were pooled for presentation. Data were subjected to analysis of variance and means were compared using Duncan's multiple range test (Steel and Torrie 1980).

Table 4. Desiccation (injury) of kleingrass and buffelgrass 14 days after treatment with butylate + dichlormid (24:1) and siduron applied preemergence and watered immediately after planting in the greenhouse.[1]

Herbicide	Rate	Kleingrass	Buffelgrass
	(kg/ha)	(%)	
Butylate + dichlormid (24:1)	0.6	19 de	0 d
	1.1	14 e	10 cd
	2.2	17 e	13 b-d
	4.5	27 c	39 a-d
Siduron	0.6	31 c	29 a-d
	1.1	25 cd	54 a-c
	2.2	40 b	50 ab
	4.5	75 a	68 a
Untreated	—	15 e	9 cd

[1]Values in columns followed by the same letter do not differ significantly at the 5% level according to Duncn's multiple range test.

Field Experiments

Treatments were made at 2 locations in Texas in 1980 and 1981. The College Station and Wellborn site consisted of Lufkin fine sandy loam, a member of the fine montmorillonitic, thermic Vertic Albaqualfs. The predominant weed at College Station was broadleaf signalgrass *(Brachiaria platyphylla).* Other species included southern crabgrass *(Digitaria ciliaris),* junglerice *(Echinochloa colonum),* Texas panicum *(Panicum texanum),* common purslane

Table 2. Desiccation (injury) of kleingrass and buffelgrass 14 days after treatment with preemergence herbicides in the greenhouse.[1]

Herbicide	Rate, kg/ha[2] 0.6 Kleingrass	0.6 Buffelgrass	1.1 Kleingrass	1.1 Buffelgrass	2.2 Kleingrass	2.2 Buffelgrass
	(%)					
Butylate	6 i	6 h	4 i	9 h	3 i	8 h
Pyrazon	11 hi	38 e-g	35 f-h	50 d-f	96 ab	94 ab
Profluralin	19 g-i	91 ab	53 d-f	96 ab	94 ab	100 a
Trifluralin	41 e-g	86 a-c	50 d-f	95 ab	88 a-c	99 a
Diclofop	69 b-d	95 ab	84 a-c	96 ab	96 ab	99 a
Bifenox	81 a-c	62 c-e	92 a-c	87 a-c	99 ab	100 a
Oryzalin	94 ab	69 b-d	98 ab	81 a-c	98 ab	97 a
Oxyfluorfen	100 a	100 a	100 a	100 a	100 a	100 a
Untreated	10 hi	8 h	10 hi	8 h	10 hi	8 h

[1]Acifluorfen, cyanazine, diethatyl, ethofumesate, metribuzin, and oxadiazon, terbutryn, were highly phytotoxic to kleingrass and buffelgrass (94 to 100% desiccation) at 0.6, 1.1, and 2.2. kg/ha.
[2]Values within all columns for each grass species followed by the same letter do not differ significanlty at the 5% level according to Duncan's multiple range test.

Table 3. Desiccation (injury) of kleingrass and buffelgrass 14 days after treatment with postemergence herbicides in the greenhouse.[1]

Herbicide	Rate, kg/ha[2] 0.6 Kleingrass	0.6 Buffelgrass	1.1 Kleingrass	1.1 Buffelgrass	2.2 Kleingrass	2.2 Buffelgrass
	(%)					
Bromoxynil	17 i-n	43 j-o	22 h-n	43 j-o	29 i-j	69 e-j
Barban	12 mn	20 n-q	14 k-n	22 l-q	18 i-n	16 o-q
Pyrazon	12 mn	11 q	17 i-n	16 o-q	60 de	90 a-d
Asulam	18 i-n	72 b-i	24 k-m	77 a-f	27 h-l	78 a-f
Diclofop	41 fg	97 a-c	80 bc	99 a	90 ab	100 a
Bifenox	14 k-n	13 q	21 i-n	30 m-q	30 g-i	45 i-n
Cyanazine	96 a	88 a-d	100 a	100 a	100 a	100 a
Untreated	10 n	14 q	10 n	14 q	10 n	14 q

[1]Acifluorfen, metribuzin, oxyfluorfen and terbutryn, were highly phytotoxic to kleingrass and buffelgrass (99 to 100% desiccation) at 0.6, 1.1, and 2.2 kg/ha.
[2]Values within all columns for each grass species followed by the same letter do not differ significantly at the 5% level according to Duncan's multiple range test.

(Portulace oleracea), horse purslane *(Trianthema portulacastrum)*, redroot pigweed *(Amaranthus retroflexus)*, carpetweed *(Mollugo verticillata)*, yellow nutsedge *(Cyperus esculentus)*, and prostrate spurge *(Euphorbia supina)*. At Wellborn the primary weedy species were woolly croton *(Croton capitatus)* and yellow nutsedge, with scattered plants of western ragweed *(Ambrosia psilostachya)*, Johnsongrass *(Sorghum halepense)*, bermudagrass *(Cynodon dactylon)*, brownseed paspalum *(Paspalum plicatulum)*, and roundseed dichanthelium *(Dichanthelium sphaerocarpon)*. Herbicide, handweeded, or mowing treatments were applied to 3 by 6-m plots in triplicate. Kleingrass 'Selection 75' was seeded with a modified row-crop planter calibrated to deliver 2.5 kg/ha pure live seed in 6 rows spaced 0.5 m apart in each plot. All herbicides were applied in water with a hand carried boom at a spray volume of 187 L/ha at a pressure of 207 kPa. In 1980, vernolate, EPTC, EPTC + dichlormid and butylate were applied preplant incorporated (ppi) on 5 May; propazine, pyrazon, and siduron were applied preemergence (pre) on 13 May; and bromoxynil, asulam, 2,4-D, and glyphosate were applied postemergence (poe) on 11 June at both locations. Preplant incorporated treatment consisted of hand raking the herbicide into the soil to a depth of 2.5 cm. A handweeded, weed-free treatment was also included. In 1981, preplant, preemergence, and postemergence herbicides were applied 21 and 24 April, and 11 May, respectively. Kleingrass was planted on 21 April. The same herbicide treatments were applied in 1981 as in 1980 with the addition of preemergence sprays of dalapon and glyphosate, 4 ropewick treatments with glyphosate, and mowing. Ropewick treatments consisting of a 1.1 mixture of glyphosate and water were made on 11, 20, and 27, May and 8 June 1981. Mowed plots left an 8-cm stubble. Plots of one treatment were mowed 28 May and 14 July, and in another, only 14 July. A handweeded, as needed, weed-free treatment was included at both sites in both years. Herbicides and rates used are presented in the tables.

Density of kleingrass and major weeds was recorded approximately 1 month after treatment by counting each species in 5 randomly selected 25 by 25-cm areas in each plot. Kleingrass and weed counts were converted to plants per m^2 for each plot. Percent ground cover for each species was also visually estimated after 6 months in each treated area. Data were analyzed as a randomized complete block design with means compared using the Fisher Least Significant Difference Test (LSD) at the 5% level (Steel and Torrie 1980).

Results and Discussions

Greenhouse Experiments

Butylate applied preemergence did not reduce germination or seedling growth of kleingrass at rates up to and including 2.2 kg/ha (Table 2). Kleingrass was tolerant to pyrazon and profluralin at 0.6 kg/ha but was killed at 2.2 kg/ha. Acifluorfen, bifenox, cyanazine, diclofop, diethatyl, ethofumesate, metribuzin, oryzalin, oxadiazon, oxyfluorfen, terbutryn, and trifluralin were highly injurious regardless of rate, usually killing most or all plants. As with kleingrass, butylate was the only herbicide that did not injure buffelgrass. All other herbicides, at all rates, severely injured buffelgrass.

Of the postemergence treatments, kleingrass and buffelgrass tolerated barban at all rates (Table 3). Kleingrass also tolerated bromoxynil, pyrazon, and bifenox at 0.6 and 1.1 kg/ha. Acifluorfen, cyanazine, metribuzin, oxyfluorfen, and terbutryn were extremely phytotoxic to seedling kleingrass and buffelgrass even at the lowest application rate. Buffelgrass tolerated bifenox and pyrazon at 0.6 and 1.1 kg/ha but was injured by asulam, bromoxynil, and diclofop at these rates.

When applied preemergence and watered into the soil immediately after treatment, butylate + dichlormid did not injure either kleingrass at rates below 4.5 kg/ha or buffelgrass at 4.5 kg/ha or less (Table 4). Siduron applied preemergence usually injured both kleingrass and buffelgrass (Table 4). As rates of siduron increased, injury to the grasses generally increased. Siduron applied postemergence at rates of 2.2 kg/ha did not injure 14-day-old seedlings of either kleingrass or buffelgrass (data not shown).

Field Experiments-Kleingrass Tolerance

In 1980 propazine at 2.2 kg/ha and pyrazon and siduron at 2.2 and 4.5 kg/ha significantly ($P>0.05$) reduced kleingrass numbers compared to the untreated areas at Wellborn (Table 5). At College Station, vernolate at 2.2 kg/ha and pyrazon at 4.5 kg/ha and siduron at 2.2 and 4.5 kg/ha reduced kleingrass stands. When butylate + dichlormid (hereafter called butylate) + propazine were combined at 2.2 + 2.2 kg/ha, kleingrass numbers were reduced compared to the untreated areas at College Station. No other preplant incorporated or preemergence herbicides reduced kleingrass stands compared to the untreated areas. At both locations the

Table 5. Effect of herbicides, mowing, and handweeding on kleingrass populations 1 month after treatment at Wellborn and College Station, TX.[1]

Herbicide or treatment	Rate	Year and location: 1980 Wellborn	1980 College Station	1981 Wellborn	1981 College Station
Preplant incorporated	(kg/ha)	(Plants/m^2)			
EPTC + dichlormid	2.2	129	147	142	17
	4.5	77	81	23	20
EPTC	2.2	88	83	64	9
	4.5	130	165	44	8
Vernolate	2.2	135	71	90	7
	4.5	89	87	7	0
Butylate + dichlormid	2.2	139	184	41	56
	4.5	100	134	36	13
Preemergence					
Propazine	1.1	57	154	21	0
	2.2	14	108	0	0
Pyrazon	2.2	7	109	67	13
	4.5	3	23	0	0
Siduron	2.2	7	46	29	17
	4.5	0	46	4	3
Butylate + Propazine	1.1 + 1.1	48	84	3	0
	2.2 + 2.2	42	61	0	0
Handweeded		176	178	194	128
Untreated		120	164	52	43
LSD 5% for ppi & pre herbicides		84	85	86	53
Postemergence					
Asulam	2.2	13	87	1	1
2,4-D	1.1	58	78	61	4
Bromoxynil	1.1	33	37	21	37
Dalapon	4.5	—	—	6	9
Glyphosate	1.1	—	—	33	2
Ropewick Application on (1:1 water: Glyphosate)					
(5/11/81)	—	—	—	89	8
(5/20/81)	—	—	—	83	21
(5/27/81)	—	—	—	95	85
(6/17/81)	—	72	70	109	16
Mowed once (5/28/81)	—	—	—	90	24
Mowed twice (5/28 and 7/14/81)	—	—	—	67	44
Handweeded	—	99	119	134	63
Untreated	—	50	132	46	37
LSD 5% for poe herbicides		55	101	73	52

[1]Areas were seeded 9 May 1980 and 21 April 1981 at Wellborn and College Station, TX respectively. Preplant incorporated, preemergence, and postemergence herbicides were applied on 5 May, 13 May, and 11 June 1980 and 21 April, 24 April, and 11 May 1981, respectively. Handweeded as needed.

handweeded areas tended to have the highest kleingrass stands (176–178 plants/m^2) but they were not always significantly ($P>0.05$) higher than some of the herbicide treatments (Table 5).

In 1980, none of the herbicides applied postemergence significantly ($P>0.05$) reduced kleingrass numbers compared to the untreated plots (Table 5). Kleingrass numbers in the handweeded areas at Wellborn were higher (99 plants/m^2) than when treated with asulam (13 plants/m^2) or bromoxynil (33 plants/m^2).

In 1981, highest kleingrass numbers in areas treated with preplant incorporated and preemergence herbicides occurred at both locations in the handweeded areas except for EPTC + dichlormid applied at 2.2 kg/ha at Wellborn (Table 5). Plots treated with all other preplant incorporated or preemergence herbicides were no different from the untreated plots. Postemergence applications of asulam, bromoxynil, dalapon, and glyphosate significantly reduced kleingrass populations at Wellborn compared to populations in the handweeded area (Table 5). At College Station, kleingrass survival was reduced by postemergence sprays of asulam, 2,4-D, dalapon, and glyphosate and ropewick application with glyphosate on 11 May 1981 when compared with kleingrass population in the handweed treatment. But no treatment reduced kleingrass at either site when compared with that in the untreated plots.

In 1980, 6 months after treatment at Wellborn, most successful establishment of kleingrass occurred when treated with 2,4-D (45% ground cover) or in areas handweeded (68% ground cover) (Table 6). Only selected treatments as listed in Table 5 are shown in Table 6 since most were no different from the untreated areas. Areas receiving siduron at 2.2 and 4.5 kg/ha had the least kleingrass, but were usually no different from other treatments. At College Station, handweeding was most successful in establishing kleingrass cover; other treatments were unsuccessful (Table 6).

Table 6. Effect of herbicides, mowing, and handweeding on percent ground cover of kleingrass 6 months after seeding on 9 May 1980 and 21 April 1981 at Wellborn and College Station, TX.

Herbicide or treatment	Rate	Year and location			
		1980		1981	
		Wellborn	College Station	Wellborn	College Station
Preemergence	(kg/ha)	(% ground cover)			
Siduron	2.2	4	7	7	37
	4.5	5	3	7	27
Postemergence					
2,4-D	1.1	45	5	30	3
Ropewick Application on (1:1 water: glyphosate)					
(5/11/81)	—	—	—	37	18
(5/20/81	—	—	—	42	2
(5/27/81)	—	—	—	27	18
(6/17/81)	—	14	21	18	8
Mowed once (5/28/81)	—	—	—	33	22
Mowed twice (5/28 and 7/14/81)	—	—	—	38	10
Handweeded	—	68	82	88	85
Untreated	—	10	15	20	3
LSD 5%		20	15	12	15

[1]Areas were seeded 9 May 1980 and 21 April 1981 at Wellborn and College Station, TX respectively. Preplant incorporated, preemergence and postemergence herbicides were applied on 5 May, 13 May, and 11 June 1980 and 21 April and 11 May 1981, respectively. Handweeded as needed.

In 1981, handweeded areas were also the most successful for kleingrass establishment at both locations with 85% or more ground cover (Table 6). Areas receiving application of glyphosate by the ropewick appicator on 11 or 20 May were successful in kleingrass establishment (37% or more ground cover) at Wellborn. Mowing once (28 May) or twice (28 May and 14 July) 1981 also increased kleingrass cover. At the College Station site, the siduron treatment at 2.2 and 4.5 kg/ha had 27 and 37% ground cover of kleingrass, respectively, compared to 3% for the untreated areas (Table 6).

In 1980, below-normal rainfall was received (drought conditions) during the growing season (data not shown). Excellent stands of kleingrass occurred where weeds were controlled (handweeded) to conserve soil moisture. In 1981, even though adequate rainfall was received, only treatments that successfully controlled weeds allowed sufficient kleingrass populations to survive (Tables 5 and 6).

Dry weights of kleingrass and weeds produced at College Station on areas treated in 1981 are shown in Table 7. The handweeded plots produced the most kleingrass (4,458 kg/ha over dry weight), 7 months after treatment. Application of siduron at 4.5 kg/ha produced 1,352 kg/ha of kleingrass. Broadleaf weeds were most abundant in the asulam, dalapon, and siduron treated areas (844 kg/ha or more). Most treatments, including glyphosate and dalapon, allowed abundant weedy grass production. Predominant grasses were broadleaf signalgrass and southern crabgrass. Dry weight production of kleingrass and weeds were not taken at Wellborn because of livestock use prior to harvest.

Table 7. Effect of herbicides, mowing, and handweeding on dry weight production of kleingrass and weeds 7 months after seeding kleingrass on 21 April 1981 at College Station, TX.[1]

Herbicide	Type of application	Rate	Kleingrass[2]	Weeds[2]	
				Grasses	Broadleaf
		(kg/ha)			
Siduron	pre	2.2	724	676	939
Siduron	pre	4.5	1352	371	879
Asulam	poe	2.2	42	1844	1149
2,4-D	poe	1.1	0	1328	0
Glyphosate	poe	1.1	66	1328	0
Dalapon	poe	4.5	222	646	844
Mowed twice[3]	—	—	132	1083	0
Mowed once[3]	—	—	377	335	0
Handweeded	—	—	4458	60	0
Untreated	—	—	0	1765	24
LSD 5%			848	712	706

[1]Preemergence and postemergence herbicides applied on 24 April and 11 May 1981 respectively. Handweeded as needed.
[2]Kleingrass and weeds were harvested 17 November 1981.
[3]Mowed once on 14 July, and mowed twice on 28 May and 14 July 1981.

Weed Control-Wellborn

Most of the herbicides were not effective in controlling yellow nutsedge in 1980 and 1981 1 month after treatment (data not shown). Butylate + propazine at 2.2 + 2.2 kg/ha significantly reduced yellow nutsedge in 1981 (42 plants/m^2 for the treated plots versus 176 for the untreated plots).

Woolly croton was controlled by EPTC + dichlormid, EPTC, vernolate, pyrazon, and (butylate + propazine in 1980 and 1981, all at a total of 4.5 kg/ha (data not shown). In 1980 and 1981 woolly croton numbers were also reduced by propazine at 1.1 and 2.2 kg/ha, pyrazon at 2.2 kg/ha, and butylate + propazine at 1.1 + 1.1 kg/ha when compared to the untreated area. Aside from handweeded treatment, woolly croton was controlled by 2,4-D at 1.1 kg/ha both years, by bromoxynil at 1.1 kg/ha in 1980, and by mowing on 28 May 1981.

Six months after application, none of the treatments effectively suppressed yellow nutsedge (data not shown). Propazine, pyrazon, butylate + propazine, asulam, 2,4-D, and ropewick applications of glyphosate controlled woolly croton. Mowing also significantly ($P>0.05$) reduced woolly croton.

Weed Control-College Station

One month after treatment, handweeding was the only treatment that controlled signalgrass in 1980 compared with the untreated areas (data not shown). In 1981, siduron at 2.2 and 4.5 kg/ha, butylate + propazine at 1.1 + 1.1 and 2.2 + 2.2 kg/ha, asulam at 2.2 kg/ha, dalapon at 4.5 kg/ha, glyphosate at 1.1 kg/ha, and mowing effectively controlled signalgrass.

Six months after plot establishment in 1980, only handweeding and mowing controlled signalgrass. Southern crabgrass was suppressed in plots treated with 2.2 or 4.5 kg/ha of siduron and 4.5 kg/ha of pyrazon. In 1981, all herbicides were ineffective in controlling signalgrass.

Conclusions

Greenhouse Experiments

Butylate was the only preemergence herbicide that did not significantly injure kleingrass or buffelgrass at rates of 2.2 kg/ha or less. Kleingrass tolerated applications of pyrazon at 0.6 or 1.1 kg/ha but buffelgrass was injured. Kleingrass tolerated profluralin at 0.6 kg/ha. All other herbicides applied preemergence caused extensive injury to both grasses. Bromoxynil applied postemergence was not phytotoxic to kleingrass at 0.6 or 1.1 kg/ha and may have promise for broadleaf weed control in newly seeded stands. Bromoxynil, however, was injurious to buffelgrass. Kleingrass and buffelgrass were tolerant to postemergence treatments of barban and siduron up to and including 2.2 and 4.5 kg/ha, respectively. Kleingrass also tolerated postemergence sprays of pyrazon and asulam at 1.1 kg/ha.

Field Experiments

At Wellborn, kleingrass tolerated most thiocarbamate herbicides and propazine at 1.1 kg/ha or propazine + butylate, but pyrazon and siduron sometimes reduced seedling populations of kleingrass. Most herbicides did not control yellow nutsedge, but several, including 2,4-D, controlled woolly croton. After 6 months in 1980, highest kleingrass cover occurred in the 2,4-D and handweeding treatments. In 1981, kleingrass establishment was best after treatment with glyphosate by ropewick application, mowing, or handweeding. At College Station, most promising kleingrass establishment was obtained in handweeded plots or areas treated with siduron.

These experiments demonstrate the difficulty of establishing forage grasses from seed because of dry weather and severe weed competition. Kleingrass seedlngs have a high drought tolerance and tenacity if weed control is adequate to allow growth and development, as demonstrated by handweeding. Several chemical and mowing treatments were reported that showed promise for effective weed control and successful kleingrass establishment.

Literature Cited

Bouse, L.F., and R.W. Bovey. 1967. A laboratory sprayer for potted plants. Weeds 15:89-91.

Bovey, R.W., J.R. Baur, and E.C. Bashaw. 1979. Tolerance of kleingrass to herbicides. J. Range Manage. 32:337-339.

Bovey, R.W., J.R. Baur, M.G. Merkle, and E.C. Bashaw. 1981. Response of kleingrass and buffelgrass to herbicides. Agron. J. 72:53-55.

Bovey, R.W., H. Hein, Jr., and R.E. Meyer. 1984. Effect of herbicides on the production of common buffelgrass *(Cenchrus ciliaris).* Weed Sci. 32:8-12.

Holt, E.C., and E.C. Bashaw. 1976. Developing improved grasses and legumes. Chap. 1, p. 7-9, *In:* E.C. Holt and R.D. Lewis (ed.) Grass and Legumes in Texas. Development, Production, and Utilization. Texas Agr. Exp. Sta. Res. Monogr. 6.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Book Co. Inc., N.Y.

Enhancing Germination of Spiny Hackberry Seeds

TIMOTHY E. FULBRIGHT, KAY S. FLENNIKEN, AND GARY L. WAGGERMAN

Abstract

Establishment of spiny hackberry (*Celtis pallida* Torr.) in plantings for wildlife has been hampered by low seed germination. We evaluated methods for enhancing germination of spiny hackberry by subjecting seeds to: (1) chemical scarification with 2.9 mol liter^{-1} H_2O_2, 0.71 mol liter^{-1} NaOCl, and concentrated (18 mol liter^{-1}) H_2SO_4; (2) rinsing with water; (3) 0, 0.3, 1.4, 2.9, and 4.3 mmol liter^{-1} gibberellic acid (GA); (4) 0.02 mol liter^{-1} KNO_3; (5) mechanical scarification, or (6) moist heat (30° C) followed by moist prechilling at 7° C for 2 weeks. Untreated seeds exhibited higher percent germination in the light than in the dark. Percentage germination at 30° C and germination rate were increased in the light and in the dark by either 1.4 mmol liter^{-1} GA or 3 days of moist heat (30° C) followed by a 2-week moist prechill at 7° C. A combination of mechanical scarification + 1.4 mmol liter^{-1} GA + 3 days moist heat (30° C) followed by moist prechilling for 2 weeks at 7° C increased germination from 1% (controls) to 49%. Germination varied slightly with seed source, but a large proportion of all lots was dormant. Spiny hackberry seeds can be treated with a combination of mechanical scarification + 1.4 mmol liter^{-1} GA + 3 days moist heat (30° C) followed by moist prechilling for 2 weeks at 7° C before planting to increase percentage and rate of germination.

Spiny hackberry (*Celtis pallida* Torr.), a densely branched evergreen shrub, occurs from central Texas to Arizona, and south to Mexico (Vines 1960). Spiny hackberry is browsed by white-tailed deer (*Odocoileus virginianus* Raf.) (Everitt 1983c), and its fruits are relished by birds (Vines 1960, Scifres 1980). The shrub is highly favored as a nesting site by white-winged dove (*Zenaida asiatica* L.) (Brown et al. 1977), and it provides excellent cover for quail (*Colinus virginianus* L., *Lophortyx gambelii* Cambell) (Warnock 1977, Thornburg 1982, Lehmann 1984). Thus, there is considerable interest in establishment of spiny hackberry for wildlife food and cover.

Several species of *Celtis,* including spiny hackberry, exhibit seed dormancy. Hackberry (*C. occidentalis* L.) germination is greatly enhanced through fermentation of the fruits for 3 days at room temperature and subsequent removal of pulp before stratification (Bonner 1974). Hackberry and sugar hackberry (*C. laevigata* Willd.) seeds require 60 to 90 days of stratification at 5° C, while netleaf hackberry (*C. reticulata* Torr.) seeds require 120 days of stratification at 5° C (Bonner 1974). The objective of this study was to determine if germination of spiny hackberry seeds could be enhanced by selected treatments.

Methods

Spiny hackberry fruits were collected from native populations in Cameron, Kleberg, and Hidalgo Counties, Texas. Soils of the Cameron County collection site were Willacy fine sandy loam, a fine-loamy mixed, hyperthermic Udic Arguistoll, and Raymondville clay loam, a fine, mixed, hyperthermic Vertic Calciustoll. Soils of the Kleberg County site were Orelia fine sandy loam, a fine-loamy, mixed, hyperthermic Typic Ochraqualf and Willacy fine sandy loam. Soil of the Hidalgo County site was Rio Grande silt loam, a coarse-silty, mixed (calcareous), hyperthermic Typic Ustifluvent. Fruits were macerated in a fruit press to separate seeds from pulp (Young et al. 1981). Care was taken not to damage seeds. Seeds were air-dried at 25° C and stored in cloth bags at 15° C and 40% relative humidity. Seeds from Cameron County were used in all experiments except when sources were compared.

Seeds were germinated on blotter paper underlain by a layer of creped cellulose (kimpack) placed in plastic boxes measuring 13.0 by 13.5 by 3.5 cm with tightly fitting lids (Fulbright et al. 1983). Substrata were moistened with 100 ml of distilled water or the appropriate test solution. Seeds were treated with thiram [bis dimethylthiocarbamoly) disulfide] to minimize fungal growth.

Seeds were considered germinated when part of at least 1 cotyledon was visible and radicles extruded to 5 mm. Counts were made weekly for 14 days in pilot experiments and daily in final experiments. Germination rate (GR) was calculated by the equation of Maguire (1962) where GR is the sum of the quotients of the number of seeds germinated each day divided by the number of days for germination.

Experiments were conducted at 30° C in controlled environmental chambers. Several authors have reported 30° C to be within the optimum temperature range for germination of various woody plant species in South Texas (Scifres 1974; Alaniz and Everitt 1978, 1980; Everitt 1983a, 1984). Seeds were exposed to cool-white flourescent lights for 12 hours daily or were germinated in the dark. Photosynthetic photon flux density averaged 26 μmol m^{-2} s^{-1}. Dark conditions were maintained by wrapping plastic boxes in aluminum foil and seeds were briefly exposed to light during counts.

Treatments evaluated in pilot experiments included: (1) soaking seeds in 2.9 mol liter^{-1} hydrogen peroxide (H_2O_2) for 10, 20, and 30 min followed by a 5-min rinse in large volumes of tap water (Young et al. 1981); (2) soaking seeds in 0.71 mol liter^{-1} sodium hypochlorite (NaOCl) for 10, 20, and 30 min followed by a 5-min rinse in large volumes of tap water (Stidham et al. 1980); (3) soaking seeds in concentrated (18 mol liter^{-1}) sulfuric acid (H_2SO_4) for 2, 4, 6, and 10 min followed by a 5-min rinse in large volumes of tap water (Young et al. 1981); (4) rinsing seeds in running water for 12, 24, 36 and 48 hours to remove soluble inhibitors (Young et al. 1981); (5) germinating seeds on substrata moistened with 0.3, 1.4, 2.9, and 4.3 mmol liter^{-1} solutions of gibberellic acid (GA) (Mayer and Poljakoff-Mayber 1975); (6) germinating seeds on substrata moistened with 0.02 mol liter^{-1} potassium nitrate (KNO_3) (Young et al. 1981); (7) nicking seeds with a razor (mechanical scarification) (Kissock and Haferkamp 1983); (8) moist prechilling seeds for 2 weeks at 7° C (Young et al. 1981); and (9) incubating imbibed seeds at 30° C for 1 week followed by moist prechilling at 7° C for 2 weeks (Young et al. 1981).

Two final experiments were conducted following pilot experiments. In the first experiment, effects of (1) mechanical scarification, (2) 1.4 mmol liter^{-1} gibberellic acid (GA), (3) 3-day moist heat treatment followed by 2-weeks of moist prechilling at 7° C, and (4) light (12 hours daily) were determined in a 2 by 8 factorial experiment. A 3-day moist heat treatment was used in final experiments because a few seeds germinated after 3 days at 30° C. The experiment was conducted twice, once in December 1984 and again in early January 1985 with seeds harvested in late May and early June 1984.

Effects of seed source and seed treatments on germination were determined in the second experiment. Seeds from the 3 sources were either untreated or were scarified, subjected to a 3-day moist heat treatment followed by a 2-week moist prechill at 7° C, and germinated on substrata moistened with 1.4 mmol liter^{-1} GA. The experiment was conducted in December 1984 and early January

Authors are faculty researcher and research fellow, Caesar Kleberg Wildlife Research Institute, Campus Box 218, Texas A&I University, Kingsville 78363; and area manager, Las Palamos Wildlife Management Area, Texas Parks and Wildlife Department, 4200 Smith School Road, Austin 78744.

Research was funded by the Texas Parks and Wildlife Department and the Caesar Kleberg Foundation for the Wildlife Conservation. Authors wish to thank Dr. R. Bingham for his assistance with the statistical analyses.

Manuscript accepted 6 March 1986.

1985 with seeds harvested in mid-July 1984.

A randomized complete-block design was used in all experiments. Each treatment was assigned to 4 plastic boxes containing 25 seeds each in pilot experiments. In other experiments, each treatment was assigned to 4 plastic boxes containing 50 seeds each and experiments were repeated twice. Data from the pilot GA experiment were analyzed by response curve analysis to examine the relationship between percent germination and GA concentration (Snedecor and Cochran 1967). Data from other experiments were analyzed by analysis of variance (Snedecor and Cochran 1967). Data were subjected to arcsine $\sqrt{0.01 \times \%}$ transformation before analysis of variance. Tukey's test was used at the 0.05 level of probability to identify mean differences when F values for treatments were significant. Untransformed data are reported in the text and in tables 1, 3, and 4. All differences discussed in the following section were significant at the 0.05 level of probability unless other stated.

Results and Discussion

Chemical scarification (with 2.9 mol liter^{-1} H_2O_2, 0.71 mol liter^{-1} NaOCl, and concentrated H_2SO_4), rinsing seeds in running tap water to leach out water soluble inhibitors, and germinating seeds on substrata moistened with 0.02 mol liter^{-1} KNO_3 did not increase germination (data not shown). Germinating seeds on substrata moistened with 0, 0.3, 1.4, 2.9, and 4.3 mmol liter^{-1} GA resulted in 10, 17, 27, 23, and 36% germination ($Y=14.0 + 4.8X$, $\tau = 0.62$), respectively, for intact seeds, and 9, 45, 40, 52, and 52% germination ($Y = 27.2 + 7.0X$; $\tau = 0.60$), respectively, for mechanically scarified seeds. Moist prechilling seeds for 2 weeks at 7° C did not increase germination. Placing seeds on moist blotter paper at 30° C for 1 week followed by moist prechilling 2 weeks at 7° C increased germination from 21% (controls) to 43%.

Percent germination of seeds treated 3 days with moist heat (30° C) followed by moist prechilling at 7° C for 2 weeks (hereafter referred to as "heat/chill") did not differ significantly ($P>0.05$) from percent germination of seeds treated with 1.4 mmol liter^{-1} GA or mechanical scarification (Table 1). Percent germination of heat/-chilled seeds and seeds treated with GA was higher than controls in the light and in the dark. For mechanically scarified seeds, percent germination was higher than controls in the dark but not in the light.

Table 1. Effects of selected presowing seed treatments on percentage germination of spiny hackberry seeds at 30° C.

Seed treatment	Light regime	
	Light	Dark
Control	32e[1]	20e
Mechanical scarification (SC)	35de	34cd
1.4 mmol liter^{-1} gibberellic acid (GA)	42cd	35bcd
3-Day moist heat (30° C)/2-week moist prechill (7° C) (heat/chill)	43bcd	35cd
SC + GA	41cde	27de
SC + heat/chill	49bc	44ab
GA + heat/chill	52ab	38abc
SC + GA + heat/chill	62a	45a

[1]Means in a column followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's test. Data for light and dark regimes were analyzed separately because the light by seed treatment interaction was significant ($P<0.01$).

Heat/chilling combined with mechanical scarification or GA increased germination more in the light than did mechanical scarification or GA applied individually (Table 1). Percent germination of seeds treated with mechanical scarification + GA + heat/chill was about twice that of controls regardless of light treatments.

The light by seed treatment interaction was significant for percent germination (Table 2). Percent germination was similar between light and dark for seeds that were mechanically scarified, treated with GA, heat/chilled, or mechanically scarified + heat/chilled. For untreated seeds and seeds treated with mechanical scarification + GA, GA + heat/chilling, and mechanical scarification + GA + heat/chilling, percent germination was higher in the light than in the dark. Our results were not consistent with findings for seeds of several other woody plants of South Texas, which germinated equally well in darkness and light (Scifres and Brock 1969; Scifres 1974; Everitt 1983 a,b, 1984).

Table 2. Analysis of variance for the effects of selected presowing seed treatments on percentage germination of spiny hackberry seeds at 30° C.

Source of variation	df	Mean square[1]	F	Probability of a >F
Replication (R)	7	0.020		
Seed treatments (T)	7	0.133	28	0.0001
Error a (RXT)	49	0.005		
Light (L)	1	0.317	103	0.0001
Error b (RXL)	7	0.003		
TXL	7	0.013	4	0.0015
Error (RXTXL)	49	0.003		

[1]Arcsine $\sqrt{\% \times 0.01}$ transformed percent germination.

Germination rate was similar among seeds treated with mechanical scarification alone, GA alone, and heat/chill alone (Table 3).

Table 3. Effects of selected presowing seed treatments on germination rate of spiny hackberry seeds at 30° C.

Seed treatment	Light regime	
	Light	Dark
Control	1.8 c[1]	1.2 e
Mechanical scarification (SC)	2.1 bc	2.1 cd
1.4 mmol liter^{-1} gibberellic acid (GA)	2.6 bc	2.2 c
3-Day moist heat/2-week prechill (heat/chill)	2.8 b	2.2 c
SC + GA	2.7 bc	1.5 de
SC + heat/chill	3.9 a	3.1 ab
GA + heat/chill	4.5 a	2.7 bc
SC + GA + heat/chill	4.7 a	3.4 a

[1]Column means followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's test. Data for light and dark regimes were analyzed separately because the light by seed treatment interaction was significant ($P<0.01$).

Germination rate of mechanically scarified seeds was higher than that of controls in the dark but not in the light. The light by seed treatment interaction was significant ($P<0.01$) for germination rate. Germination rate was higher in the light than in the dark for seeds treated with mechanical scarification + GA, GA + heat/chill, and mechanical scarification + GA + heat/chill. Germination rate was similar under light and dark conditions for other treatments. Treating seeds with either mechanical scarification + heat/chill, GA + heat/chill, or mechanical scarification + GA + heat/chill produced higher germination rates in the light than applying mechanical scarification alone, GA alone, or heat/chill alone (Table 3). In the dark, mechanical scarification + heat/chill and mechanical scarification + GA + heat/chill produced higher germination rates than any treatment applied singly.

Ease of establishment would be increased if populations of spiny hackberry with inherently low seed dormancy were available. Seeds of sources examined in the second final experiment were highly dormant. Mechanical scarification + 1.4 mmol liter^{-1} GA + heat/chill enhanced germination of seeds from all sources (Table 4). Seeds from Cameron County exhibited higher percent germination than seeds from Hidalgo County, but germination rates were similar. Germination rate of seeds from Cameron County was higher than that of seeds from Kleberg County, but percentage germination was similar between sources.

Differences in percentage of seeds germinated and rate of germi-

Table 4. Effects of seed source and a combination of mechanical scarification + 1.4 mmol liter^{-1} GA + 3-day moist heat (30° C) treatment followed by 2-weeks of moist prechilling at 7° C (SC+GA+heat/chill) on spiny hackberry germination at 30° C with 12 hours of light daily.

Parameter and treatment	Seed source: Cameron	Kleberg	Hidalgo	Seed treatment means
Germination (%)				
Control	3	1	1	1
SC+GA+heat/chill	52	49	47	49**
Seed source means	27a[1]	25ab	24b	
Germination rate				
Control	0.09	0.05	0.02	0.05
SC+GA+heat/chill	4.27	3.70	3.78	3.92**
Seed source means	2.18a	1.87b	1.90ab	

**Significantly different from controls ($P<0.01$).
[1]Means in a row followed by the same letter were not significantly different at the 0.05 level of probability according to Tukey's test.

nation for the same treatment between experiments were attributed to differences in seed age and time of harvest. Untreated seeds harvested in late May and early June in Cameron county exhibited 10% germination in July (pilot GA experiment) and 20% germination in December and early January in the dark (Table 1). Untreated Cameron County seeds harvested in mid-July produced only 3% germination in the light in December and early January (Table 4) compared to 32% for seeds harvested in late May and early June germinated during the same time period (Table 1). Differences in germination of different aged seeds may have resulted from afterripening.

Our results indicate treating spiny hackberry seeds with mechanical scarification + 1.4 mmol liter^{-1} GA + 3 days moist heat (30° C) followed by moist prechilling for 2 weeks at 7° C before planting will increase percentage and rate of germination. This treatment is similar to 3-day fermentation at room temperature followed by scarification reported by Bonner (1974) to enhance germination of hackberry. Enhancement of germination by GA and moist heat followed by moist prechilling indicates that dormancy in spiny hackberry seeds may be caused partly by physiological mechanisms, but further research is needed to determine exact causes of dormancy.

Literature Cited

Alaniz, M.A., and J.A. Everitt. 1978. Germination of Texas ebony seeds. J. Rio Grande Valley Hort. Soc. 32:95-100.

Alaniz, M.A., and J.H. Everitt. 1980. Germination of anacua seeds. J. Rio Grande Valley Hort. Soc. 34:75-80.

Bonner, F.T. 1974. *Celtis* L. Hackberry, p. 298-300. *In:* C.S. Schopmeyer (technical coordinator), Seeds of Woody Plants in the United States. USDA, Agr. Handb. 450.

Brown, D.E., D.R. Blankenship, P.K. Evans, W.H. Kiel, Jr., G.L. Waggerman, and C.K. Winkler. 1977. White-winged dove *(Zenaida asiatica)*, p. 246. 272. *In:* G.C. Sanderson (ed.), Management of Migratory Shore and Upland Game Birds in North America. Internat. Ass. of Fish and Wildlife Agencies, Washington, D.C.

Everitt, J.H. 1983a. Seed germination characteristics of 3 woody plant species from southern Texas. J. Range Manage. 36:246-249.

Everitt, J.H. 1983b. Seed germination characteristics of 2 woody legumes (Retama and Twisted Acacia) from South Texas. J. Range Manage. 36:411-414.

Everitt, J.H. 1983c. Effects of plant shredding on nutrient content of 4 south Texas deer browse species. J. Range Manage. 36:779-781.

Everitt, J.H. 1984. Germination of Texas persimmon seed. J. Range Manage. 37:189-192.

Fulbright, T.E., E.F. Redente, and A.M. Wilson. 1983. Germination requirements of green needlegrass (*Stipa viridula* Trin.). J. Range Manage. 36:390-394.

Kissock, D.C., and M.R. Haferkamp. 1983. Presowing seed treatment effects on germination of *Engelmannia pinnatifida* and *Indigofera miniata* var. *leptosepala*. J. Range Manage. 36:94-97.

Lehmann, V.W. 1984. Bobwhites in the Rio Grande Plain of Texas. Texas A&M Univ. Press, College Station.

Maguire, J.D. 1962. Speed of germination-aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2:176-177.

Mayer, A.M., and A. Poljakoff-Mayber. 1975. The germination of seeds. Pergamon Press, Oxford.

Scifres, C.J. 1974. Salient aspects of huisache seed germination. Southw. Natur. 18:383-392.

Scifres, C.J. 1980. Brush management-principles and practices for Texas and the southwest. Texas A&M Univ. Press, College Station.

Scifres, C.J., and J.H. Brock. 1969. Moisture-temperature interrelations in germination and early seedling development of honey mesquite. J. Range Manage. 22:334-337.

Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods, 6th edition. The Iowa State University Press, Ames.

Stidham, N.D., R.M. Ahring, J. Powell, and P.L. Claypool. 1980. Chemical scarification, moist prechilling, and thiourea effects on germination of 18 shrub species. J. Range Manage. 33:115-118.

Thornburg, A.A. 1982. Plant materials for use on surface-mined lands in arid and semi-arid regions. USDA-SCS, SCS-TP-157.

Vines, R.A. 1960. Trees, shrubs and woody vines of the southwest. University of Texas Press, Austin.

Warnock, B.H. 1977. Wildflowers of the Davis Mountains and Marathon Basin, Texas. Sul Ross State University, Alpine, Texas.

Young, J.A., R.A. Evans, B.L. Kay, R.E. Owen, and J. Budy. 1981. Collecting, processing, and germinating seeds of western wildland plants. USDA-SEA, ARS-W-3.

Broadcasting Grass Seed to Revegetate Sandy Soils

ERIC KOCHER AND J. STUBBENDIECK

Abstract

This study was conducted to determine the effects of tillage, irrigation levels, seed coating rates and species on grass establishment. Sand bluestem [*Andropogon gerardii* var. *paucipilus* (Nash) Fern.] and little bluestem [*Schizachyrium scoparium* (Michx.) Nash] seeds were coated with a lime and nutrient slurry at 3 rates and broadcast on abandoned cropland in the Nebraska Sandhills. A mixture of noncoated switchgrass [*Panicum virgatum* L.] and sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood] was also broadcast. Three levels of irrigation were applied during the seeding year. Seedling establishment was higher on the disked areas than on nontilled areas. Establishment increased as irrigation level increased. Establishment of sand bluestem and little bluestem were similar, while establishment of the switchgrass-sand lovegrass mixture was less. Under the conditions of this experiment, seed coating rate had no influence on establishment.

Development of land in the Nebraska Sandhills for row crop cultivation under center-pivot irrigation became a common practice during the 1970's. In the past few years, many marginal sites have been abandoned, leaving large areas of exposed sand. Revegetation of these sites is necessary to prevent extensive soil movement and expansion of these areas and to return them to productive land.

Drilling has been the most effective method of planting grass seed (Hyder et al. 1955, Eckert and Evans 1967). However, aerial seeding may cover larger areas in a relatively short time at low cost (Killough 1950).

Several important native grasses of the Sandhills Prairie have fluffy seed. Broadcasting this type of seed resulted in uneven distribution (Killough 1950). Seed distribution was improved by coating the seed prior to seeding (Stewart 1949), but seed coating was shown to reduce germination (Scott 1975). Soil moisture is critical to seedling establishment, and, as a result, supplemental irrigation improved grass establishment (Campbell and Swain 1973).

This study was initiated to determine the effects of tillage, irrigation levels, seed coating rates, and species on grass establishment in the Nebraska Sandhills.

Materials and Methods

The study site is located near the northern border of Custer County, Nebraska. Ipage loamy fine sand (mixed, mesic Aquic Ustipsamment) occupies about two-thirds of the study area. Valentine fine sand (mixed, mesic Typic Ustipsamment) occupies the remaining one-third. The topography is level to slightly rolling.

Growing season extends from early May to the middle of September. Average annual precipitation is 55 cm, with about 80% occurring between 1 April and 30 May (NOAA 1981). Climax vegetation is primarily a mixture of native tall, mid-, and shortgrass prairie species along with other species of plants adapted to sandy soils (Keeler et al. 1980).

Eighty hectares of rangeland were plowed, a well was drilled, and a center pivot irrigation system was placed on the field in 1971. The land was used to produce corn [*Zea mays* L.] for 10 years. Crop production levels were unacceptable, and the decision was made to revegetate the area with native grasses. Sudangrass [*Sorghum vulgare* Pers.] was grown on the land in 1981, the year prior to initiation of the study.

Treatment design was a split-split plot with tillage as the whole plot, irrigation as the sub-plot, and seeding treatment on the sub-sub plot treatment. Tillage consisted of shallow disking or no tillage. Plots were disked with a tandem double disk 1 day prior to seeding. A residue of forage sorghum with a height of about 25 cm remained on the untilled plots. Experimental design for irrigation was a randomized complete block with 2 replications.

The nozzles on the irrigation system were changed to apply water treatments in concentric circular bands. Bands were 60 m in width and received a total of either 0, 2, or 4 cm of supplemental water. These bands were arranged as a randomized complete block with 2 replications as sub-plots of the tillage treatments. Water was applied in 3 equal amounts from 15 to 17 July, 21 to 22 July, and 27 to 29 July. The irrigation schedule was based on moisture stress. Precipitation during the growing season of 1982 was 36 cm.

Seven seeding treatments were applied as sub-sub plots of the tillage by irrigation treatments. Each sub-sub plot was 18 m² in size. 'Goldstrike' sand bluestem [*Andropogon gerardii* var. *paucipilus* (Nash.) Fern.] and 'Cimmarron' little bluestem [*Schizachyrium scoparium* (Michx.) Nash] seeds were coated with a mixture of 82.0% lime, 9.0% phosphoric acid, 5.4% sulfur, 2.0% ammoniacal nitrogen, 1.3% zinc, and 0.3% iron. Seed was coated at heavy, light, and zero application rates (Table 1). An additional seeding treatment was a mixture of 'Pathfinder' switchgrass [*Panicum virgatum* L.] and 'Nebraska 27' sand lovegrass [*Erogrostis trichoides* (Nutt.) Wood]. Rates of seeding for all treatments are presented in Table 1. Seeds were broadcast by hand from 11 to 13 May 1982. Rain fell at the study site on 10, 11, 13, 19, 20, and 24 May 1982. Consequently, all of the plots received rain following seeding. Total precipitation during May 1982 was 14 cm. Experimental design for seeding treatments was a completely randomized design with 24 replications.

Table 1. Seeding rate (total seeds/0.1 m²) and pure live seeds/0.1 m²) and germination percentage of grass species seeded in 1982.

Species	Seed Coating Rate (coating weight): seed weight)	Germination %	Rateof Seeding: Total seeds per 0.1 m²	Pure live seeds per 0.1 m²
Sand bluestem	0.0:1.0	73	32	23
	1.0:1.0	73	32	23
	2.3:1.0	73	39	28
Little bluestem	0.0:1.0	52	72	37
	0.7:1.0	52	75	39
	1.4:1.0	52	116	60
Mixture:				
Switchgrass		86	27	23
Sand lovegrass		77	18	14

Seedling density was measured on 24 and 25 September 1982. Seven 0.1-m² frames were randomly placed within each plot and the numbers of seedlings were recorded. Seedling density measurements were collected again on 7 June 1983 and on 15 August 1983. The data were subjected to analysis of variance.

Since the treatments were seeded at different rates (Table 1), the

Authors are former graduate research assistant and professor (range ecology), Department of Agronomy, University of Nebraska, Lincoln 68583, respectively. Eric Kocher is currently graduate assistant, Department of Agricultural Economics, Oklahoma State University, Stillwater 74074.

Published as Paper Number 7840, Journal Series, Nebraska Agricultural Experiment Station.
Manuscript accepted 17 February 1986.

data were standardized by determining percentage establishment before the analysis was performed. Establishment was determined by dividing seedling density (seedlings/0.1 m^2) by seeding rate (pure live seed/0.1 m^2) and multiplying this value by 100. Seedling density was assumed to possess a Poisson distribution (Personal communication, Kent Eskridge, Department of Biometrics, University of Nebraska-Lincoln). Since analysis of variance assumes that data for the dependent variables are normally distributed, the data for seedling density were normalized by adding 0.5 to the recorded values for each frame and taking the square root of this number (Steel and Torrie 1980).

Under the conditions of this experiment, an establishment rate of over 4% on the last sampling date was projected to become a satisfactory stand. This level of establishment would not only provide erosion protection, but it would also provide forage to grazing livestock during the third growing season (1984) after seeding.

Results and Discussion

Tillage

Disking prior to broadcasting resulted in higher seedling survival for all 3 data collection periods (Table 2). Surface litter on untilled land was abundant and prevented many of the broadcasted seeds from reaching the soil surface and obtaining adequate soil contact. In contrast, disking incorporated surface litter into the soil and removed or reduced the initial barrier that prevented seed from reaching the soil. Disking altered the microrelief, which improved seed contact with the soil. It was observed that disking also provided early control of field sandbur [*Cenchrus longispinus* (Hack.) Fern.], which was the most abundant weed. This may have reduced competition enough to improve seedling growth and survival.

Table 2. Establishment (%) of seeded species for two tillage treatments during 1982 and 1983.

Tillage treatment	Sampling date: September, 1982	June, 1983	August, 1983
	--------	%	--------
Disk	6.0a*	5.0a	5.1a
No-till	3.8b	3.3b	3.6b

*Means within a column followed by different letters are significantly different at the .05 level of probability.

Irrigation

Irrigation increased seedlng establishment (Table 3). Irrigation comprised a small percentage of the total water received by the seedlings during 1982 (Table 4). Since a linear response did occur, timing of irrigation may have been equally or more important than total irrigation. Precipitation following seeding was above average (Table 4). If precipitation had been lower, irrigation probably would have been more critical to seedling establishment.

Addition of irrigation water may help to assure stand establishment during dry years. It also may be possible to reduce seedling rates to help offset the cost of irrigation.

Table 3. Establishment (%) of seeded species for three irrigation rates during 1982 and 1983.

Irrigation treatment	Sampling date: September, 1982	June, 1983	August, 1983
	--------	%	--------
Zero	4.4	3.8	3.9
Low	4.9	4.2	4.4
High	5.5	4.6	4.7
Linear contrast	NS	*	*

*Significant at the .10 probability level.

Seedling Treatment

Establishment of the 3 seeding treatments was different for all 3 data collection periods (Table 5). Establishment rates between sand bluestem and little bluestem were not different for all 3 data collection periods. Establishment of both sand bluestem and little bluestem was higher than establishment of the switchgrass-sand lovegrass mixture. Sand bluestem and little bluestem stands were adequate for erosion protection and forage production, but the switchgrass-sand lovegrass mixture was not.

Table 5. Establishment (%) of individual species during 1982 and 1983.

Seeding treatment	Sampling date: September, 1982	June, 1983	August, 1983
	--------	%	--------
Little bluestem	5.5	4.3	4.4
Sand bluestem	4.8	4.2	4.2
Switgrass-sand lovegrass (mixture)	3.3	3.2	3.3
$LSD_{.05}$	0.9	0.6	0.2

Coating Rates

Establishment percentages for the different coating rates were

Table 4. Total monthly precipitation (mm) and departures from normal for January, 1982 through December, 1983, at Anselmo, Nebraska.[1]

Month	1982 Precipitation[1]	1982 Departure	1983 Precipitation	1983 Depature	Normal[2]
			mm		
January	11	0	4	− 7	11
February	1	− 14	4	− 11	15
March	22	− 13	95	+ 60	35
April	67	+ 10	55	− 2	57
May	140	+ 52	131	+ 43	88
June	88	− 6	216	+122	94
July	22	− 69	114	+ 23	91
August	112	+ 40	35	− 37	72
September	17	− 35	27	− 25	52
October	100	+ 71	38	+ 9	29
November	56	+ 37	84	+ 65	19
December	49	+ 37	12	0	12
Annual	685	+110	815	+240	575

[1]NOAA 1982
[2]Based on the 30-year period from 1951 to 1980.

not different for any of the 3 data collection periods. The seed coating was highly soluble, and precipitation immediately following seeding was intense enough to wash the majority of the coating from the seed. As a result, any negative affect the coating may have had on seed germination was either greatly reduced or removed.

Interactions

The tillage by irrigation interaction was significant for 3 seeding treatments: only the little bluestem (August, 1983), sand bluestem and little bluestem (September, 1982), and little bluestem (September, 1982). The high irrigation treatment was the most sensitive to tillage treatment, since it resulted in the greatest increase in establishment between no tillage and disking. Higher seedling establishment on disked plots over no tillage for the low irrigation treatment was greater than, or equal to, the increase in establishment associated with the highest irrigation over no irrigation.

The tillage by seeding treatment interaction was significant for all sampling periods. Sand bluestem showed the greatest response to the pre-broadcast tillage treatment. If the area was disked before broadcasting, establishment of little bluestem plants increased more than did survival of the switchgrass-sand lovegrass mixture. The tillage by irrigation and seeding treatment interactions indicate that treatment responses were greater on disked areas than on untilled areas.

Optimum Treatment Combination

The combination of treatments which produced the highest seedling establishment was disking before planting, high level of irrigation, and little bluestem as the seeding treatment. Since establishment was not affected by coating rate, the lowest coating rate at which seed distribution would still be uniform would be the ideal coating rate.

Conclusions

Under conditions of this study, disking before broadcast seeding consistently resulted in greater establishment of the seeded species than did no tillage. While this was successful in this study, disking was not compared to any other methods of improving seed to soil contact. Other mechanical methods of seedbed preparation or seed incorporation by drilling may also be successful.

Linear contrasts were significant, which indicated a direct positive relationship between irrigation level and seedling survival. Total amount of water applied made up a small percentage of total water available during the growing season. The fact that a linear response did occur indicates timing of irrigation was important.

Differences in survival were found between seeding treatments. Survival of the switchgrass-sand lovegrass mixture was lower than the average survival of the little bluestem and sand bluestem treatments. Survival rates between sand bluestem and little bluestem were not different.

Survival rates for different coating rates were not different. However, the coating was washed off the seed by rain soon after broadcasting. Any effect the coating may have had on survival was removed by the rain. Distribution of the coated seed after broadcasting was uniform, therefore, the coating served its purpose.

Tillage by treatment interactions indicated a greater response to treatment levels in the disked plots. Therefore, treatment level selection for the treatments evaluated in this study is more important when the area to be seeded is disked than it is when untilled areas are seeded.

Literature Cited

Campbell, M.J., and F.G. Swain. 1973. Factors causing losses during the establishment of surface-sown pastures. J. Range Manage. 26:355-359.

Eckert, R.E., Jr., and R.A. Evans. 1967. A chemical-fallow technique for control of downy brome and establishment of perennial grasses on rangeland. J. Range Manage. 20:35-41.

Hyder, D.N., F.A. Sneva, and W.A. Sawyer. 1955. Soil firming may improve range seeding operations. J. Range Manage. 8:159-153.

Keeler, K.H., A.T. Harrison, and L.S. Vescio. 1980. The flora and sandhills prairie communities of Araphao Prairie, Arthur County, Nebraska. Prairie Natur. 12:65-78.

Killough, J.R. 1950. Reseeding the range by airplane. J. Range Manage. 3:33-41.

NOAA. 1981. Climatological data: Nebraska. Vol. 86. Nat. Oceanic and Atmospheric Admin., Washington, D.C.

Scott, D. 1975. Effects of seed coating on establishment. New Zealand J. Agr. Res. 18:59-67.

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

Stewart, G. 1949. Range reseeding by airplane compared with standard ground methods. Agron. J. 41:283-288.

Gully Migration on a Southwest Rangeland Watershed

H.B. OSBORN AND J.R. SIMANTON

Abstract

Most rainfall and almost all runoff from Southwestern rangelands are the result of intense summer thunderstorm rainfall. Gully growth and headcutting are evident throughout the region. A large, active headcut on a Walnut Gulch subwatershed has been surveyed at irregular intervals from 1966 to present. Runoff at the headcut was estimated using a kinematic cascade rainfall-runoff model (KINEROS). The headcut sediment contribution was about 25% of the total sediment load measured downstream from the headcut; and the sediment contribution from the swale drainage above the headcut, as estimated from a depth-integrated pumping sampler, was about the same. Although more data are needed to quantify sediment contributions from other tributary watersheds, the total contribution from gully banks and headcuts on Walnut Gulch must be an important portion of the total sediment load.

The 150-km² Walnut Gulch Experimental Watershed, near Tombstone, Arizona, is typical of much of the semiarid rangeland in the southwestern United States. Walnut Gulch is a tributary of the San Pedro River. Most rainfall and almost all runoff from these rangelands are the result of intense summer thunderstorm rains of short duration and limited areal extent. Gully growth and headcutting have been evident throughout the region, including Walnut Gulch. In 1975, a project was initiated to determine the gully and headcut contribution to sediment loads at several runoff-measuring stations on Walnut Gulch. One of the principal objectives of the program was to determine the rate of headcut development and the proportional headcut contribution to the total watershed sediment yield. The object of this study was to determine movement and sediment contribution of a major headcut on watershed 63.011, a subdrainage of Walnut Gulch.

Historical Background

The most intensive study of gully erosion in the United States was carried out by H.A. Ireland, C.F.S. Sharpe, and D.H. Eargle, and published in USDA Technical Bulletin 633 (1939). Although the study area was on the Piedmont of South Carolina, the report serves as a landmark effort in understanding gully erosion and headcut migration elsewhere. In their report, they stated:

> "Almost all gullies result from the acceleration of runoff, or from an unnatural concentration of flowing water. Acceleration and concentration of water have been brought about in various ways, and gullies may be classified into several groups on the basis of their origin. Increased amounts of runoff result from overgrazing, burning, deforestation, or denuding of the land by cultivation. Concentration of the runoff is caused by construction of roads and railroads, with their accompanying ditches, by construction of terraces and terrace outlets, by contour plowing followed by breaking-over of furrows during heavy rains, and by stock paths which, in many cases, become rills and gullies. Acceleration of the movement of water in stream channels is sometimes brought about by clearing of brush from the banks, a practice which often results in accelerated bank erosion."

The theory of erosional processes has been covered by many, including Beasley (1972) and Thormes (1980). The mechanisms of erosion and sediment movement from gullies have been reported by others, including Piest, Bradford, and Spomer (1975) and Piest, Bradford, and Wyatt (1975). However, most of the available data on gully erosion is from farmlands, rather than rangelands.

The southeastern Arizona geologic record indicates gullying has occurred in the past, but the most recent intense episode of accelerated gullying appears to have begun in the 1880's (Hastings and Turner 1965). Gullies in the 2 major stream channels of southeastern Arizona, the San Pedro and Santa Cruz Rivers, began because of man's activities in the flood plains and were accelerated by increased runoff from overgrazed tributary watersheds. From meandering perennial streams, both the San Pedro and Santa Cruz became incised ephemeral channels. The gullies proceeded to develop from the major channels upward into the tributary watersheds. Gullies migrated well into Walnut Gulch from the San Pedro. The advance of gullies has slowed as the amount of contributing runoff area to each decreased, but a few gullies are still very active. The most active gullies are those with large contributing areas remaining, a result of restricted headcutting at one or more times during the upward migration.

Watershed Description

Watershed 63.011 (824 hectares) is located in the upper part of Walnut Gulch Experimental Watershed. There are 10 weighing-type recording raingages located on, or immediately adjacent to, the watershed (Fig. 1). Runoff stage is measured with an A-35

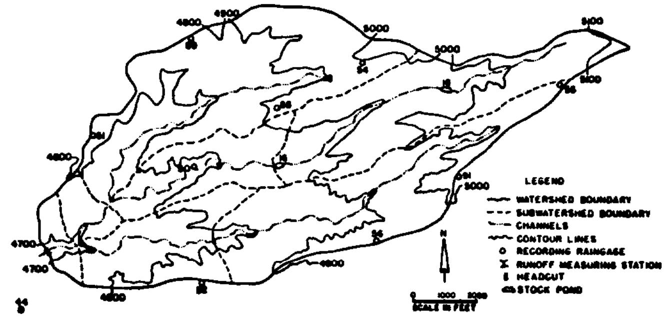


Fig. 1. *Contour and description map of subwatershed 63.011, Walnut Gulch.*

water-level recorder at a super-critical flume at the watershed outlet. The subwatershed has a mixed grass/brush cover, with the predominant soil a Hathaway-Nickel gravelly loam.

There are 3 major subdrainages on 63.011, the north, central, and south branches (Fig. 1). The incised sand-bottomed channel reaches almost to the upper end of the north branch. Runoff from the central branch is largely controlled by 2 earthen-diked tanks. The lower of the 2 tanks has overflowed in only 1 of 20 years of record.

An incised sand-bottomed channel extends about halfway up the south branch. At the upper end of the incised channel, a headcut is currently cutting through a broad swale (Fig. 2). The near-vertical walls of the headcut on the south branch average about 2.5 meters in depth (Fig. 3). The swale is predominantly a Comoro sandy loam for the upper 250 to 500 mm, becoming fine gravelly loam below 1 meter, grading into a lightly cemented conglomerate, and finally, a well-cemented caliche conglomerate at 2 to 3 meters.

A depth-integrated-pumping sampler was installed in 1976, in the south branch swale above the headcut. Suspended sediment samples were collected for most runoff events from 1977 through 1982. A measuring station was located in a narrow channel section downstream from the headcut, in 1978. The station consisted of a

Authors are research hydraulic engineer and hydrologist, USDA-ARS, Southwest Rangeland Watershed Research Center, 2000 East Allen Road, Tucson, Ariz. 85719.
Manuscript accepted 27 January 1986.

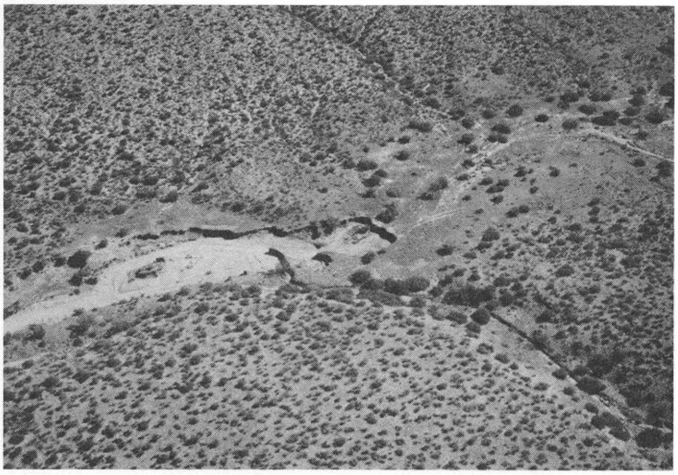


Fig. 2. *Headcut on south branch of watershed 63.011, Walnut Gulch, September 1973.*

trapezoidal weir, a pump sampler, and a stilling well with an FW-1 water-level recorder. Samples were collected for only 4 events before the station was destroyed by the storm of 27 August 1982. Only suspended sediment samples were taken, because the swale above the headcut showed no evidence of bedload movement (the channel bottom was grass lined), and there was no practical method of sampling bedload below the headcut.

Fig. 3. *Upstream face of headcut on south branch of watershed 63.011, Walnut Gulch, September 1982.*

Headcut Erosion

At the time Walnut Gulch was first instrumented (1955), the advance of the headcut on the south branch had been slowed by an unusually well-consolidated conglomerate barrier. Unfortunately, no surveys were made at that time. Apparently, gully growth on the north branch of subwatered 63.011 was not similarly constrained, and the knickpoint had moved much farther up the similar-sized subdrainage. Once the south branch gully had broken through the constraining material, it proceeded to cut rapidly through a broad swale.

The first complete topographic survey of the headcuts was made in 1966. Subsequent topographic surveys were made in 1973, 1976, 1981, and 1982. The current contributing drainage area above the headcut on the south branch is 200 hectares. In contrast, the contributing drainage above the north branch headcut is only 24 hectares.

Headcuts on Walnut Gulch have tended to be either linear or dendritic. Linear headcuts usually follow old roads or trails. Dendritic headcuts are common in broad swales where gullies progress as fingers along lines of least resistance. On watershed 63.011, the headcuts are dendritic, with the irregular advance apparently controlled primarily by resistance of roots from small trees and large shrubs, rather than by differences in soils. The trees and large shrubs tend to bind the soil beneath them, which then is left to form peninsulas and islands after erosion by the small- to medium-sized runoff events. These are then eroded away by subsequent major events (Fig. 4).

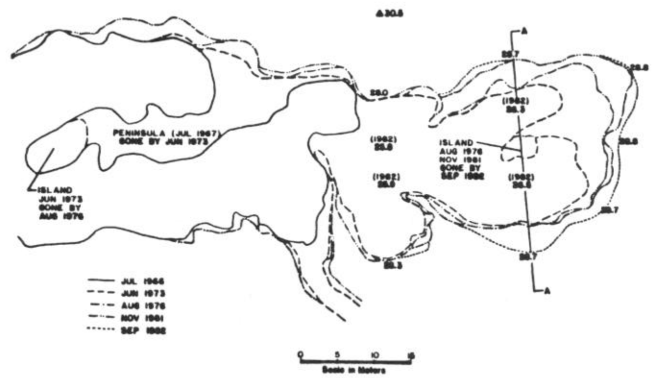


Fig. 4. *Headcut migration on south branch of subwatershed 63.011, Walnut Gulch.*

The upward migration of the headcut, on the south branch, has been documented from the 5 topographic surveys (Fig. 4). The constantly changing dimensions of the gully below the headcut have also been documented by these surveys (Fig. 4 and 5).

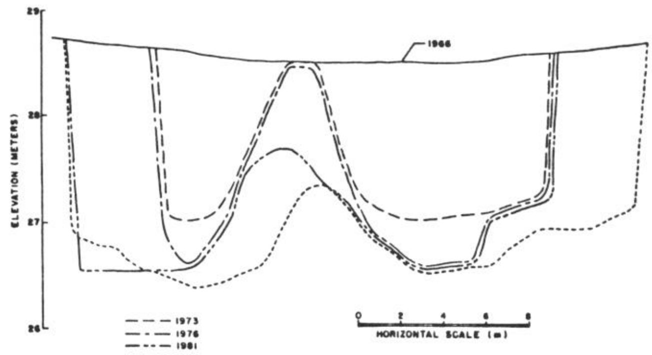


Fig. 5. *Cross-section looking upstream, headcut on south branch of subwatershed 63.011, Walnut Gulch.*

Between the 1966 and 1973 surveys, the period of most rapid gully growth, about 1,230 m^3 of material were removed (Fig. 6). Another 610 m^3 were eroded between the 1973 and 1982 survey (Fig. 6), for a total contribution of 1,840 m^3.

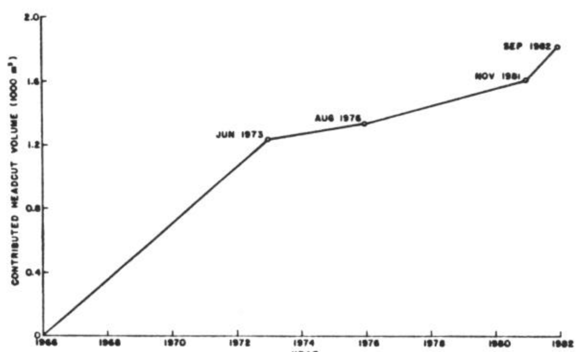


Fig. 6. *Sediment contributed from headcut, south branch of subwatershed 63.011, Walnut Gulch, 1966-1982.*

To make a quantitative evaluation of the headcut contribution to total sediment loads, we had to estimate peaks and volumes of discharge above the headcut from 1966 through 1982. To accomplish this, we adapted a kinematic cascade rainfall/runoff model, KINEROS (Rovey et al. 1977; Lane and Woolhiser 1977, Smith 1981). KINEROS includes a subroutine for estimating channel dimensions and infiltrations which can be adapted for both swale and incised channels. Model parameters were determined by matching simulated and actual hydrographs for watershed 63.011 at the watershed outlet. The parameters for the larger watershed were used in simulating the hydrographs for each event on the south branch above the headcut. We felt the watershed above the south branch headcut was large enough and similar enough to the entire watershed to justify using the same parameters. Simulated peaks and volumes for the major events (peaks greater than 3.0 m^3/sec) are shown in Table 1. The 20 major events, between 1966 and 1982, produced about 330,000 m^3 of runoff from the 200-hectare watershed, which was about 75% of the total runoff volume of 440,000 m^3. Runoff volumes were calculated for each year from 1966 through 1982 (Fig. 7), and the accumulated runoff volumes were compared to the sediment contributed by headcutting for each period between surveys (Fig. 8). Between 1966 and 1973, the headcut sediment contribution amounted to about 0.7% of the total runoff volume. Between 1973 and 1982, the headcut sediment contribution was about 0.24% of the total runoff volume.

Table 1. Simulated runoff peaks and volumes (greater than 3 m/³sec and 5000 m³, respectively) for a 200-hectare subwatershed above headcut on the south branch of 63.011, Walnut Gulch watershed (1966–1982).

Date	Est. Peak	Est. Volume	Date	Est. Peak	Est. Volume
	(m^3/sec)	(1000 m^3)		(m^3/sec)	(1000 m^3)
28 Jul 66	6.1	11.4	27 Jul 66	8.3	14.9
30 Jul 66	15.1	29.2	5 Sep 76	5.5	12.9
6 Aug 66	3.9	8.2	31 Jul 77	3.0	7.9
13 Aug 67	5.0	8.2	1 Sep 77	3.1	7.1
10 Sep 67	24.6	41.9	5 Sep 77	3.0	9.5
20 Jul 70	13.2	18.1	4 Aug 80	7.5	13.3
18 Aug 71	4.9	14.6	15 Jul 81	7.3	16.8
21 Aug 73	3.3	5.5	10 Aug 81	3.9	6.6
22 Aug 75	7.6	11.4	27 Aug 82	31.0	58.2
13 Sep 75	4.5	9.8	11 Sep 82	9.5	23.3

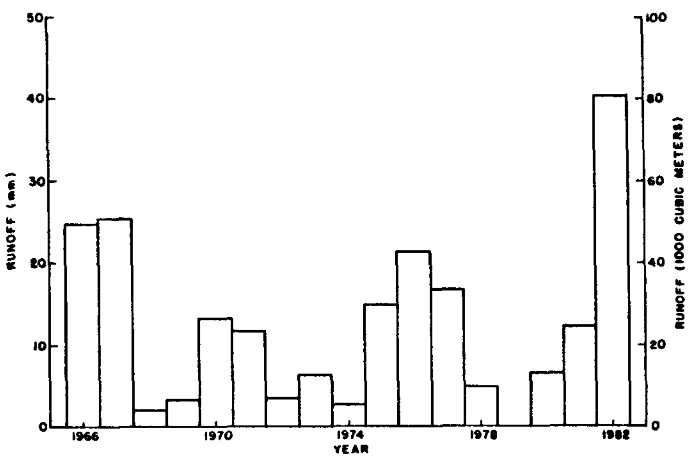


Fig. 7. *Simulated annual runoff volumes at headcut on south branch of subwatershed 63.011, Walnut Gulch, 1966-1982.*

Piest et al. (1975) noted in a study of midwestern farmlands that headcutting occurred from even fairly moderate events. We attempted, unsuccessfully, to correlate headcut movement with peak discharge. Headcutting appeared to be best correlated with the number of events, rather than event magnitude. For example, there were 3 events in 1982, 1 of which was the largest during the 16-yr period of record; yet the gully growth, per unit volume of runoff, was slightly below average. The near-record event did cause major changes in the gully downstream from the headcut.

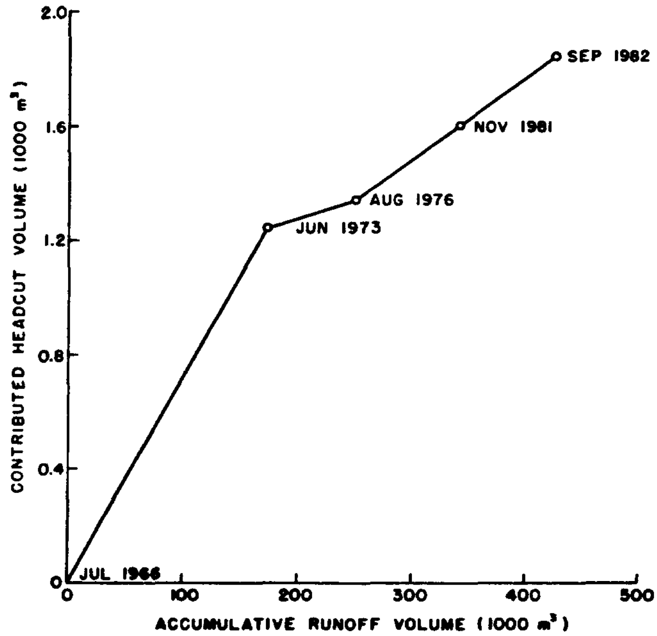


Fig. 8. *Comparison of accumulated runoff volumes and contributed headcut sediment volumes on the south branch of of subwatershed 63.011, Walnut Gulch, 1966-1982.*

Suspended sediment samples were collected in the swale above the headcut for 18 events from 1977 through 1982. Suspended sediment concentration, by weight, varied up to 1.8%, but maximum concentrations were less than 1% from 16 of the 18 events. There was no evidence of a significant bedload. Based on the available samples and the simulated runoff data, sediment concentration above the headcut averaged about 0.5%. The average total headcut sediment contribution for the same period, based on topographic surveys and simulated runoff, was also about 0.5% of the runoff volume.

Sediment samples were collected below a concrete weir downstream from the headcut for only 4 events. Sediment in the samples ranged up to 3 mm in size, and bedload was not measured. Concentrations varied up to 4.8%. From these few samples, and other samples at other flume-weirs on Walnut Gulch, we concluded that suspended sediment concentrations (≤3 mm) averaged about 2% in the incised channel below the headcut.

Discussion

Headcutting on Walnut Gulch can produce a significant portion of the sediment load from specific watersheds. On a 200-hectare subwatershed, the estimated headcut sediment contribution was about 25% of the suspended sediment load estimated from samples collected in the incised channel downstream from the headcut. Suspended sediment contribution from the swale drainage above the headcut was on the same order as the total conribution from the active headcut (as estimated from topographic surveys)—about 0.5% by weight. The remaining 50% resulted from bank sluffing downstream from the active headcut area.

Since the headcut on the south branch of 63.011 is one of the most active on Walnut Gulch, the overall contribution from headcutting on Walnut Gulch is probably less than 25% of the suspended sediment load. Osborn et al. (1976) found that very small, gullied watersheds could produce up to 3 times the total sediment loads as similar-sized nongullied watersheds. More data are needed to quantify these losses on larger watersheds. However, the total contribution from gullies and headcuts is an important part of sediment transport.

Literature Cited

Beasley, R.P. 1972. Erosion and sediment pollution Control. Iowa State University Press.

Hastings, J.R., and R.M. Turner. 1965. The changing mile. University of Arizona Press.

Ireland, H.A., C.P. Sharp, and D.H. Eargle. 1939. Principles of gully erosion in the Piedmont of South Carolina. USDA Tech. Bull. 633, Washington, D.C.

Lane, L.J., and D.A. Woolhiser. 1977. Simplification of watershed geometry affecting simulation of surface runoff. J. Hydrol. 35:173-190.

Osborn, H.B., J.R. Simanton, and K.G. Renard 1976. Use of the universal soil loss equation in the semiarid Southwest. p. 41-49. *In:* Soil Erosion: Prediction and Control. Proc. Nat'l. Conference on Soil Erosion, Soil Conservation Soc. of America, Ankeny, Iowa.

Piest, R.F., J.M. Bradford, and R.G. Spomer. 1975. Mechanisms of erosion and sediment movement from gullies. p. 162-176. *In:* Present and Prospectiv Technology for Predicting Sediment Yields and Sources, Proc. Sediment Yield Workshop, USDA-ARS-S-40.

Piest, R.F., J.M. Bradford, and G.M. Wyatt. 1975. Soil erosion and sediment transport from gullies. J. Hydraulics Div., Proc. ASCE, 101(HY1):65-80.

Rovey, W.W., D.A. Woolhiser, and R.E. Smith. 1977. A distributed kinematic model of uplant watersheds. Hydrology Paper No. 93, Colorado State University, Fort Collins, Colorado.

Smith, R.E. 1981. A kinematic model for surface mine sediment yield. Trans. ASAE Special Edition. Vol. 24:1508-1514.

Thornes, J.B. 1980. Erosion processes of running water and their spatial and temporal controls: A theoretical viewpoint. p. 129-182. *In:* Soil Erosion, edited by M.J. Kirby and R.P.C. Morgan. John Wiley and Sons, New York, N.Y.

Determining Range Condition from Frequency Data in Mountain Meadows of Central Idaho

JEFFREY C. MOSLEY, STEPHEN C. BUNTING, AND M. HIRONAKA

Abstract

Although a useful method for monitoring changes in species composition, frequency sampling does not provide herbage production or cover data needed to use existing range condition guides. Responding to this need, frequency sampling procedures were investigated for determining range condition. Eighteen mountain meadow sites were sampled with 100 nested frequency quadrats. These quadrats had 5 plot sizes contained (nested) within 1 frame: 5×5 cm, 10×10 cm, 25×25 cm, 25×50 cm, and 50×50 cm. Rooted frequency of occurrence within each plot size was recorded by species. Discriminant analysis related a site's frequency data to its known range condition class, resulting in 2 range condition guides for mountain meadows based on frequency data. One guide was formulated with data from the 10×10-cm quadrat size, and a second guide was based on summed data from the 4 largest plot sizes. Both guides had equal resolution, correctly classifying 15 of 18, or 83%, of sites examined. Our procedures should prove valuable in developing condition guides based on frequency data in other areas and in other vegetation types.

Among the first to recognize that plants could be used as indicators of successional stages were Sampson (1919) and Jardine and Anderson (1919). Dyksterhuis (1948, 1949) refined the idea of plants as successional indicators and developed range condition classes based on a site's existing vegetation in relation to the site's potential climax. Continuing the work of Weaver and Hansen (1941), Dyksterhuis used the terms *decreasers, increasers,* and *invaders* to describe a species' ecological response to grazing pressure. Decreasers and increasers are species of undisturbed climax communities, whereas invaders are nonclimax species. Greater relative proportions of decreasers and increasers to invaders indicate higher successional stages. Current U.S. Soil Conservation Service (SCS) range analysis procedures use the decreaser, increaser, and invader concepts (USDA 1976).

In contrast to Dyksterhuis' purely ecological approach, Parker (Parker, K.W. 1951. A method for measuring trend in range condition on national forest range. USDA, Forest Service Mimeo.) introduced a condition classification concept that included livestock production and soil stability as *additional* criteria for evaluating plant species. Similar to the decreasers, increasers, and invaders presented by Dyksterhuis, Parker developed categories of *desirables, intermediates,* and *least desirables.* But Parker, instead of relying solely on a species' ecological role, included forage quality, palatability, and rooting characteristics as criteria for classifying species into his desirability groups. Most U.S. Forest Service (USFS) regions use Parker's desirable, intermediate, and least desirable categories in their range analysis procedures. Because different criteria are employed to judge plant species, the USFS and SCS methods may differ dramatically in their condition ratings of the same plant community.

Whichever species classes are used in evaluating a site's range condition, those of Dyksterhuis or those of Parker, an investigator must first record the plant community's species composition. Species composition is the relative abundance of the species present in a plant community and is usually determined by measuring yield, cover, density, or frequency. It is important to realize that composition estimates will differ depending upon which measure is used. Since species composition is a relative comparison, it describes a community only in relation to the parameter upon which the composition estimates are based. Estimates of composition based on different parameters are not equivalent. For sampling ease and repeatability, a stable, objective measure is preferred for estimating

Authors are research assistant, Range and Wildlife Management Department, Texas Tech University, Lubbock 79409; associate professor and professor of range resources, University of Idaho, Moscow 83843. At the time of the research, the senior author was research assistant, Range Resources Department, University of Idaho, Moscow 83843.

Research was funded in part by USDA Science and Education Administration Grant No. 59-2161-1-2-082-0 and Forest, Wildlife and Range Exp. Sta., University of Idaho Contribution No. 278. The authors gratefully acknowledge personnel of the Boise, Payette, and Sawtooth National Forests for their assistance with this study.

Manuscript accepted 17 February 1986.

species composition. Estimates based on yield or cover, however, fluctuate with seasonal and yearly climatic changes (Craddock and Forsling 1938, Odum 1960). And density, although a stable vegetation parameter, is often difficult and time consuming to measure, especially when plants reproduce vegetatively (Strickler and Stearns 1963). In contrast to these other parameters, perennial plant frequencies are simple to obtain, objective, and relatively stable from season to season and year to year (Hyder et al. 1966, Mueller-Dombois and Ellenburg 1974).

Frequency is based on presence or absence of a species in a given number of repeatedly placed small quadrats. A species' frequency is the percentage of quadrats in which it occurs, varying from 0 to 100%. Because frequency is simple to obtain, objective, and relatively stable from season to season and year to year, frequency sampling is advantageous for monitoring changes in species composition. But as mentioned above, species composition based on frequency is not equivalent to composition by yield or cover—the inputs needed to use many current range condition guides. Frequency sampling can be used to monitor changes of individual species, but there is presently no way to describe these changes in terms of range condition classes. Development of condition guides based on frequency data would preclude the need to use 2 different sampling methods, 1 for monitoring changes of particular species and an additional method for classifying a site's range condition.

Study Area

During the summers of 1982 and 1983, 18 dry mountain meadow sites were sampled within 6 USFS grazing allotments in central Idaho. Study sites were located on 3 national forests and 4 different ranger districts: Lowman and Cascade Districts on the Boise National Forest, McCall District on the Payette National Forest, and Stanely Zone of the Sawtooth National Recreation Area on the Sawtooth National Forest. Study sites ranged in elevation from 1,920 to 2,135 m (6,300 to 7,000 ft), and annual precipitation varied from 500 to 1,020 mm (20–40 in) with approximately 70% occurring as snow. Central Idaho's dry meadow vegetation is a complex mixture of graminoids and forbs. Common species include sedge (*Carex* spp. L.), timber oatgrass (*Danthonia intermedia* Vasey), tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), western yarrow (*Achillea millefolium* L.) and mountain dandelion (*Agoseris glauca* (Pursh.) Raf.). It must be kept in mind that a dry meadow is a distinct vegetation type, different from a mountain grassland or open conifer type. Meadows, as defined in this study, are characterized by predominantly herbaceous vegetation, low-lying topography, and a relatively high water table. Whereas wet meadows remain wet or moist throughout the year, dry meadows are moist in the spring but usually become dry by midsummer.

Methods

Of 18 sites sampled, 6 sites were sampled in each of 3 condition classes—good, fair, and poor—as determined by USFS range analysis and trend study records. USFS (Region 4) range condition estimates are based on 2 vegetation factors, vegetal composition and plant production, and 2 soil factors, ground cover and soil erosion. These factors are measured, evaluated against optimal standards outlined in the Range Analysis Handbook (USDA 1981), and tabulated into 2 scores—a vegetation condition rating and a soil condition rating. The lower of the 2 scores is used as the overall range condition rating and is described by condition classes: excellent, good, fair, poor, and very poor. In this study, the vegetation condition rating was the lower of the 2 scores on all sites sampled. Therefore, throughout this study range condition is equated with vegetation condition. Of the 5 USFS range condition classes, only 3 were sampled. Excellent and very poor condition classes were not represented because too few sites in these condition classes were found within this vegetation type.

A 30.5×30.5-m (100×100-ft) macroplot was established on each study site. This macroplot consisted of 5 parallel 30.5-m transect lines spaced 7.6 m (25 ft) apart. A 30.5-m transect was used because this was the length chosen by the USFS (Region 4) for their updated range trend analysis procedures (USDA 1981). Vegetation was sampled within a nested frequency quadrat that had several smaller plot sizes contained (nested) within 1 frame. This quadrat was placed at 1.5-m (5-ft) intervals along the 5 transects, resulting in 100 quadrats per site. One hundred quadrats adequately sampled most of the common species at $\propto = .20 \pm 10\%$. This sampling intensity was considered the maximum practical amount for land management personnel; additional plots or transects would be time prohibitive.

Data for nested plots of 5 sizes were simultaneously recorded, and rooted frequency of occurrence within each quadrat was recorded by species. A plant was considered present if any portion was rooted within the quadrat (Greig-Smith 1983). Plot sizes were 5×5 cm, 10×10 cm, 25×25 cm, 25×50 cm, and 50×50 cm. Data were analyzed to assess appropriateness of the different quadrat sizes. The smallest quadrat that sampled a site's most abundant species at 63–86% frequency was considered the proper size (Curtis and McIntosh 1950). The 10×10-cm quadrat met this criterion on the majority of study sites. The 3 larger plot sizes were valuable in measuring widely-spaced, broadleaved perennial forbs. The 5×5-cm quadrat was considered too small for frequency sampling most dry mountain meadows.

Once vegetation was sampled, percent species composition was determined for each plot size by dividing number of occurrences for each species by total number of occurrences in the sample (USDA 1981). Since the 10×10-cm quadrat was selected as most appropriate, its composition estimates were used for initial data analysis. Percent composition of each species was tabulated according to the species' desirability rating—desirable, intermediate, or least desirable (USDA 1981). As mentioned above, these categories developed by the USFS are approximately equivalent to the decreaser, increaser, and invader groupings used by other agencies. Desirability ratings were then totalled, thus providing relative frequency percent composition for each desirability category.

Discriminant analysis procedures in SAS (Helwig and Council 1979) were then used to classify sites into range condition classes based on their frequency data. This method of analysis was chosen for its relative simplicity and repeatability between workers. Discriminant analysis is a multivariate statistical procedure that attempts to predict group membership based on one or several predictor variables. This is accomplished by finding that combination of predictor variables that maximizes the differences among the groups. To begin separating condition classes based on frequency data, 2 numeric variables were chosen, the relative frequency percent of desirables and of intermediates. Of the 3 potential variables—desirables, intermediates, and least desirables—any 2 were acceptable. This was because the 3 values add up to 100% and knowing any 2 also provides the third value. The percentages of desirables and intermediates were selected because these are the 2 values used in the current USFS (Region 4) range condition method. In the existing procedure the percent desirables and intermediates, based on yield, are located in a chart that provides a vegetal composition rating. USFS personnel are thus accustomed to using these 2 values.

To begin the analysis, the percentages of desirables and intermediates were standardized to have a mean of 0 and a standard deviation of 1. This was to facilitate later comparisons. Procedures in SAS then developed a classification equation for each of the 3 range condition classes. These equations followed the form

$$S_j = c_{jo} + c_{j1}y_1 + c_{j2}y_1$$

where y_1 and y_2 were the percentages of desirable and intermediate species, respectively. The coefficients (c_j) in these equations were weighted to characterize the condition classes as statistically distinct as possible based on the desirability percentages. Each site then received a classification score (S_j) for each condition class.

The site was classified into the condition class for which it had the highest classification score. Accuracy was evaluated by comparing the known classification groupings to the condition class groupings derived from discriminant analysis (Tabachnick and Fidell 1983).

Thus far the analysis has considered only data from a single plot size. Other frequency sampling research, however, has demonstrated that summation of frequencies from several plot sizes improved frequency sampling's ability to detect changes in species composition (Smith 1982). Based on this information, summed standardized frequency values were used to determine whether this would improve frequency sampling's ability to classify range condition. Data analysis continued by summing frequencies of 4 plot sizes—10×10 cm, 25×25 cm, 25×50 cm, and 50×50 cm. A species' frequency could now total 400% compared to 100% with only a single plot size. Once summed, percent composition was again determined by dividing number of occurrences for each species by total number of occurrences of all species in the sample. These new species composition figures were totalled according to desirability rating and also tested with discriminant analysis.

Results and Discussion

When using statistical methods to develop ecological models or guides, numerous choices must be made concerning which variables to include. These choices can be based partially on statistics, but decisions must be tempered by a researcher's field experience and the anticipated applications of the model or guide.

In this study the 2 variables chosen were the relative frequency percent of desirable and intermediate species. Relative frequencies were used to facilitate constructing a scorecard suitable for inclusion in a handbook. Total frequencies, as opposed to relative frequencies, did not supply the endpoints necessary to build a scorecard to cover all possible combinations. Relative frequency percent composition of indicator species was not used because there is no species that occurs on all dry mountain meadow sites. It should be noted that frequencies of all species sampled were included in the relative frequency composition estimates. Composition estimates are thus influenced by total number of species identified, and different persons with varying plant identification skills could obtain slightly different composition estimates. But the condition guides developed by this study were developed from data sampled at a species identification level consistent with most USFS range technicians. Because of this, results obtained are believed to be highly repeatable among the people expected to use these condition guides.

Standardized classification equations based on 10×10-cm quadrat data are shown in Table 1. Since desirable and intermediate

Table 1. Standardized classification equations based on 10×10-cm quadrat data for classifying study sites into range condition classes.

Condition class	Classification Equations
Good	$S_g = -1.38325 + 2.72326y_1 + 1.51771y_2$
Fair	$S_f = -0.01313 - 0.08634y_1 - 0.18689y_2$
Poor	$S_p = -1.26108 - 2.63695y_1 - 1.33081y_2$

y_1 = standardized percent relative frequencies of desirables.
y_2 = standardized percent relative frequencies of intermediates.

values were initially standardized, resulting coefficients in the classification equations can be compared. The coefficients show the relationship between percentage of desirable and intermediate species on a site and the site's condition class. Good condition sites are characterized by high percentages of desirable and intermediate species; few least desirables are present. In contrast, poor condition sites have fewer desirables and intermediates and more least desirables. The coefficients reflected this relationship. Coefficients for good condition sites were positive, whereas coefficients for poor condition sites were negative. Coefficients for fair condition sites approximated the midpoint between the poor and good condition values.

Classification equations based on 10×10-cm quadrat data correctly classified 15 of 18 sites examined, or 83% (Table 2). All good condition sites were classified correctly; the error was encountered between fair and poor condition sites. No fair or poor condition sites were placed into the good condition class. An analysis of desirable and intermediate percentages shows that differences between poor and fair sites were not as distinct as between good and fair sites (Table 2). Misclassification of 2 sites, Corduroy Meadow (b) and Big Meadow, can be attributed to their relatively desirable species composition yet low herbage production in relation to assumed site potential. As explained earlier, current USFS (Region 4) condition classification guidelines combine vegetal composition and site productivity into a single score. This makes it difficult for our classification scheme based solely on vegetal composition to correctly classify sites where low productivity offsets relatively desirable species composition. We are unable to explain misclassification of the Stanley Creek site.

Table 2. Site comparison of range condition classification based on 10×10-cm quadrat frequency data.

Site Name	% Composition D[1]	I	L	Actual Condition Class	Classified by Frequency
Cache Creek	77	13	10	Good	Good
Elk Meadow	62	33	5	Good	Good
Hartley Meadow	56	41	3	Good	Good
Poker Meadow	75	8	17	Good	Good
Sater Meadow	49	44	7	Good	Good
Stanfield Meadow	57	33	10	Good	Good
Bearskin Meadow	56	7	37	Fair	Fair
Corduroy Meadow (a)	47	38	15	Fair	Fair
Dead Cow Meadow	52	24	24	Fair	Fair
Pen Basin	67	11	22	Fair	Fair
Pole Creek	46	25	29	Fair	Fair
Stanley Creek	40	29	31	Fair	Poor*
Ayers Meadow	18	12	70	Poor	Poor
Big Meadow	54	8	38	Poor	Fair*
Bruce Meadow	43	19	38	Poor	Poor
Corduroy Meadow (b)	36	43	21	Poor	Fair*
Little East Fork	40	28	32	Poor	Poor
Tyndall Meadow	39	22	39	Poor	Poor
Accuracy					83%

* = Misclassified sites.
D[1] = Desirables, I = Intermediates, L = Least Desirables

The summation technique formulated a second set of similar standardization classification equations. Identical relationships existed between coefficients in these equations as discussed in reference to the 10×10-cm quadrat equations in Table 1. Classification equations formulated by summation also correctly classified 15 of 18 sites. The 3 sites misclassified were Corduroy Meadow (b), Stanley Creek, and Bruce Meadow (Table 3). Corduroy Meadow (b) and Stanley Creek were also misclassified by the single plot size data. Reasons for this technique misclassifying the Bruce Meadow site are unclear.

Classification results were considered sufficiently accurate to warrant development of range condition guides. Using non-standardized classification equations developed from the 10×10-cm quadrat data, a classification score was calculated for each possible combination of desirable and intermediate percentages. This resulted in the condition guide shown in Figure 1. This chart can be used with relative frequency data from a 10×10-cm quadrat to estimate range condition. Begin by locating percent desirables on the left scale and percent intermediates on the bottom scale. Point of interception of the 2 lines gives the range condition rating. The range condition estimate is thus made from the relationship of

Table 3. Site comparison of range condition classification based on summation frequency data.

Site Name	% Composition D[1]	I	L	Actual Condition Class	Classified by Frequency
Cache Creek	67	18	15	Good	Good
Elk Meadow	57	35	8	Good	Good
Hartley Meadow	64	23	13	Good	Good
Poker Meadow	64	16	20	Good	Good
Sater Meadow	48	41	11	Good	Good
Stanfield Meadow	50	35	15	Good	Good
Bearskin Meadow	54	10	36	Fair	Fair
Corduroy Meadow (a)	48	35	17	Fair	Fair
Dead Cow Meadow	47	22	31	Fair	Fair
Pen Basin	57	16	27	Fair	Fair
Pole Creek	49	23	28	Fair	Fair
Stanley Creek	38	31	31	Fair	Poor*
Ayers Meadow	34	15	51	Poor	Poor
Big Meadow	52	5	43	Poor	Poor
Bruce Meadow	49	18	33	Poor	Fair*
Corduroy Meadow (b)	37	42	21	Poor	Fair*
Little East Fork	39	29	32	Poor	Poor
Tyndall Meadow	45	19	36	Poor	Poor
Accuracy					83%

* = Misclassified sites.
D[1] = Desirables, I = Intermediates, L = Least Desirables

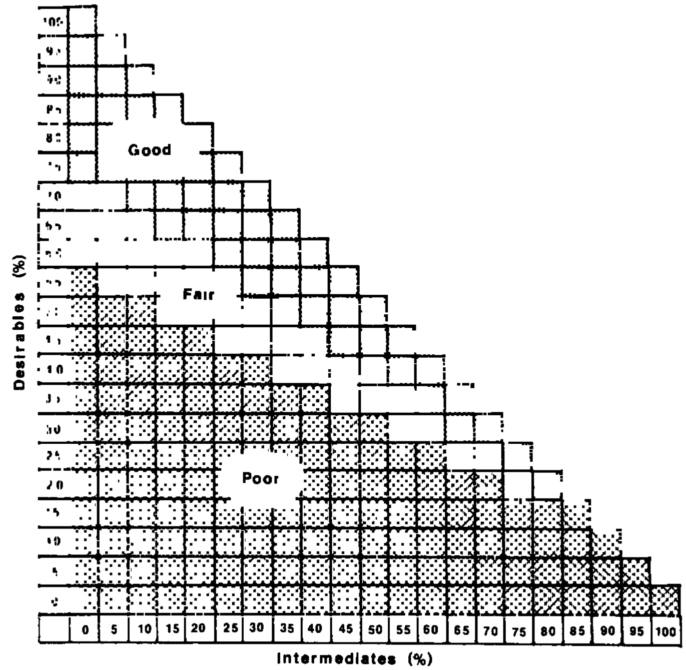


Fig. 1. *Range condition classification guide for use with relative frequency data from a 10×10-cm quadrat.*

desirables to intermediates, and not the amount of a single group. This explains the wide limits for desirables and intermediates in each condition class. A similar condition guide was formulated using non-standardized classification equations developed from the summed data. This guide can be used to estimate range condition with frequency data from 4 summed plot sizes: 10×10 cm, 25×25 cm, 25×50 cm, and 50×50 cm. Since sites in excellent and very poor condition were not sampled, these condition classes could not be included in these guides. This is not to suggest that these classes do not exist. Excellent and very poor condition classes would be shown in the extreme top and lower left sections, respectively, of Figure 1. The exact division, however, between these and the other condition classes is not known.

Summary and Conclusions

Range condition can be estimated with frequency data. This study developed 2 range condition guides for mountain meadows, 1 based on a single plot size and a second guide based on summation of 4 plot sizes. Both guides were equally accurate, correctly classifying 83% of sites examined. Since no increase in accuracy was experienced with summation, this additional effort does not appear necessary. However, if data are to be summed for monitoring changes of individual species as recommended by Smith (1982), it seems only logical to use the same data for range condition classification.

Because frequency is affected by plant size, plant distribution, and plant density (Kershaw 1973), relationships between frequency and range condition are specific to individual areas and vegetation types. This study was conducted in dry mountain meadows of central Idaho and so the condition guides presented here are specific for this area and this vegetation type. However, the procedure used here to develop these guides should be useful in any area and in any vegetation type. The level at which future guides need to be developed will depend on the variability present within each particular vegetation type. Vegetation within the meadows sampled in this study was fairly homogeneous despite occurring over a large geographical area. More variable vegetation types may require more localized sampling. Also, the existing USFS vegetation type classification system is not as refined as some systems used elsewhere (e.g., range site, habitat type). If a more complex classification system were used to subdivide dry mountain meadows, for example, frequency-condition relationships should correlate even more closely.

The procedure developed by this study involved accumulating frequency data on sites where condition class was already known. Discriminant analysis was then used to develop classification equations that maximized the distance between condition classes based on frequency data. Consequently, these condition guides do not represent a new classification system. Any possible deficiencies in the present USFS condition standards still exist. The guides presented here merely relate frequency data to the current standards, enabling land managers to estimate range condition by frequency sampling.

Finally, our procedure is not limited to relating frequency data to range condition only as condition is determined by current USFS (Region 4) methodology. There is no apparent reason why discriminant analysis cannot be used to relate frequency data to range condition, regardless of the criteria presently used to determine vegetation condition. Individuals or agencies currently using other plant community characteristics to classify condition, such as cover or density, should also be able to use our procedure to develop their own range condition guides based on frequency data. However, because frequency characterizes only vegetation, this procedure cannot be used to relate frequency to range condition based on nonvegetation attributes such as soil stability or percent ground cover.

Literature Cited

Craddock, G.W., and C.L. Forsling. 1938. The influence of climate and grazing on spring-fall sheep range in southern Idaho. USDA Tech. Bull. 600.

Curtis, J.T., and R.P. McIntosh. 1950. The interrelations of certain analytic synthetic phytosociological characters. Ecology 31:434-455.

Dyksterhuis, E.J. 1948. The vegetation of the Western Cross Timbers. Ecol. Monog. 18:325-376.

Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. J. Range Manage. 2:104-115.

Greig-Smith, P. 1983. Quantitative plant ecology. Univ. of California Press, Berkeley.

Helwig, J.T., and K.A. Council (eds.). 1979. SAS user's guide. SAS Institute, Cary, N.C.

Hyder, D.N., R.E. Bement, E.E. Remmenga, and C. Terwillger, Jr. 1966. Vegetation-soils and vegetation-grazing relations from frequency data. J. Range Manage. 19:11-17.

Kershaw, K.A. 1973. Quantitative and dynamic plant ecology. William Clowes and Sons, London.

Jardine, J.T., and M. Anderson. 1919. Range management on the national forests. USDA Bull. 790.

Mueller-Dombois, D., and H. Ellenburg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York.

Odum, E.P. 1960. Organic production and turnover in old field succession. Ecology 41:34-39.

Sampson, A.W. 1919. Plant succession in relation to range management. USDA Bull. 791.

Smith, S.D. 1982. The frequency plot method as an improved technique for measuring successional trend. M.S. Thesis. Univ. of Idaho.

Strickler, G.S., and F.W. Stearns. 1963. The determination of plant density. *In:* Range Research Methods, a Symposium. USDA Forest Serv. Misc. Pub. 940.

Tabachnick, B.G., and L.S. Fidell. 1983. Using multivariate statistics. Harper and Row, New York.

USDA. 1976. Soil Conservation Service national range handbook. Notice 1.

USDA. 1981. Forest Service (Region 4) range analysis handbook. Amendment No. 11.

Weaver, J.E., and W.W. Hansen. 1941. Native midwestern pastures—their origin, composition and degeneration. Nebraska Conserv. Bull. 22.

Use of a Metal Detector to Locate Permanent Plots

JEFFREY WEIGEL AND CARLTON M. BRITTON

Marking permanent sampling plots for easy relocation without affecting test results can be difficult, particularly in grazing studies. Aboveground plot markers may change animal movements and behavior, be pulled up or knocked over by livestock, alter treatment effects, or attract unwanted human attention. Protruding markers can also damage vehicles or injure livestock and researchers.

In a study evaluating impacts of cattle trampling on grass seedling emergence, a series of plots were established. It was imperative that plot markers not alter cattle behavior, making belowground markers a necessity. Repeated sampling during and between grazing periods required that plots be easily relocated.

Each plot was marked at 2 corners with 35-cm lengths of 1.0-cm diameter steel reinforcing rod inserted vertically into the soil, with tops flush with or slightly below the surface. Approximate plot locations were mapped from relatively permanent reference landmarks, such as exclosure fences used in the study. Fence corners, bench marks, or other reasonably permanent reference landmarks could also be used. Soft aluminum plant tags recording direction and distance to each plot were installed at reference points.

Prior to each sampling period, a ferromagnetic metal detector (Schonstedt Model GA-52B) was used to relocate plots. Differences in magnetic fields caused by plot markers are translated to changes in frequency of an audible tone emitted by the detector. Approximate plot locations were found using reference point directions and pacing. The detector was then used. Using a sweeping motion, large areas were quickly searched, requiring only approximate plot locations from pacing. Once located, plots were temporarily marked with wire flags. It was possible for one person to relocate and mark 32, 0.25-m^2 plots spread over 2 ha in about 1 hr using this system. To relocate similarly marked plots without the metal detector would require extensive, precise measurement from reference points and would be time-prohibitive.

Iron markers (1.25-cm diameter carbon steel pipe) commonly used by surveyors are more easily detected than the 1.0-cm diameter reinforcing rod but cost 3 times more ($1.50/m vs. $0.35/m). A ferromagnetic detector (cost: $550.00) was selected because of its sensitivity to steel and iron and lack of response to nonferrous materials such as water, aluminum, brass, and copper. Plot relocation can be improved by installing plastic-sealed magnetic caps ($1.75 each) atop one marker per plot. The caps greatly enhance detectability in dense vegetation where it is difficult to sweep the detector arm.

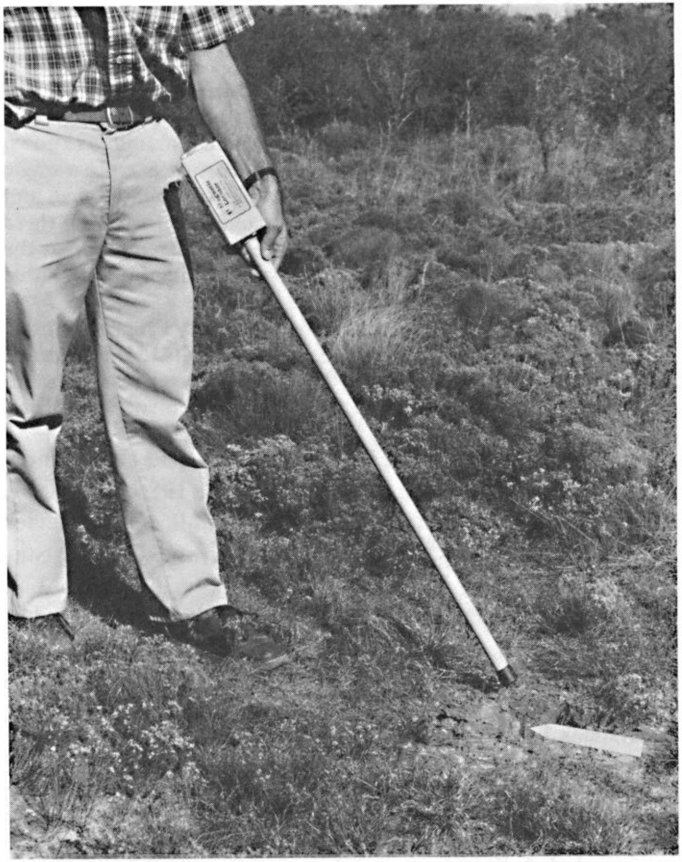


Fig. 1. *Metal detector locating steel stake (arrow) which would be below the soil surface.*

The authors are graduate research assistant and associate professor, Department of Range and Wildlife Management, Texas Tech University, Lubbock, Texas 79409.

This article is contribution No. T-9-430 of the College of Agricultural Sciences, Texas Tech University.

Manuscript accepted 18 March 1986.

Book Reviews

Flora of the Great Plains. 1986. The Great Plains Flora Association. Ronald L. McGregor, Coordinator. Univ. Press of Kansas. 1,392 p.

The new plant key and flora appears to have been developed with the resource manager in mind. For one thing the key seems to be at least as easy to use as others for the region. The region includes Kansas, Nebraska, South Dakota, North Dakota, Wyoming, and Colorado, plus Eastern Montana and NE New Mexico, NW Oklahoma, and adjacent Texas. Also included are the western 2 to 3 counties in Minnesota, Iowa, and Missouri.

One of the features throughout the flora that is especially useful is that each species is thoroughly described phenotypically, taxonomically, geographically and in regards to usual habitat occurrence. Specifically, each species, especially the major ones, is much more thoroughly described than is necessary simply to key the species. Synonyms are listed; additionally, common names are frequently listed and are included in a useful index.

This is the first comprehensive floristic treatment of the Great Plains since 1932 when P.A. Rydberg presented his book. The current flora was sectionally authored by members of the Great Plains Flora Association, who reside primarily at universities from North Dakota through Kansas. The result is that the families appear to be treated with a uniformly high level of expertise, although some inconsistency may occur. Published literature (through 1982) is referenced and intertwined with the field experiences and herbaria searches of the individual authors.

From a range management perspective, it appears that the authors have simplified our task of species identification. For example, with *Agropyron cristatum,* crested wheatgrass, the statement is made that, "...several forms have been introduced, the separation of our plants into more than one taxon proves impractical." Therefore, *A. pectiniforme* is listed as a synonym and *A. cristatum, A. desertorum,* and *A. sibiricum* are considered the same species. In another example, *Plantago patagonica* is the name used to draw together three forms of our annual plantago (known variously as woolly plaintain or bracted indianwheat) into a single species with three varieties, var. *breviscapa,* var. *patagonica,* and var. *spinulosa,* with this logic: "In their extreme forms the three varieties are easily separated, but all three have been found at the same location and the recognition of varieties is of questionable taxonomic merit."

Single copies are available from the University Press of Kansas, 329 Carruth, Lawrence, KS 66045, ph. 913/864-4154. Price after July 15, 1986 is $55.00, plus 1.50 postage. Kansas residents add $2.54 tax.—*Jim Johnson* SDSU Range Management Specialist.

Ecosystems of the world, hot deserts and arid shrublands. Vol 12A, 1985, 366 p., $111; Vol 12 B, 1986, 451 p. M. Evenari, I. Noy-Meir, and D.W. Goodall, eds.; Elsevier Science Publishers, P.O. Box 1663, Grand Central Station, New York, N.Y. 10163 U.S.A. (or P.O. Box 330, 1000 AH Amsterdam, The Netherlands)

This two volume set is part of an ambitious program to describe the major ecosystems of the world in a detailed and authoritative manner. Twelve of twenty-nine recognized terrestrial and aquatic ecosystems have now been published, with these two volumes being the latest.

Hot deserts are distinguished from cold deserts as those normally receiving little or no snow. All continents except Europe have examples, and in addition, the southern portion of Madagascar is included. World-renowned local authorities have authored separate chapters for each of the 13 hot deserts described. They are (1) the Mojave, Sonoran, and Chihuahuan deserts of North America; (2) the Monte Desert and other subtropical semiarid biomes of South America; (3) the Peruvian-Chilean Deserts, (4) the hot deserts of Australia; (5) deserts of the Middle East; (6) deserts of the Arabian Peninsula; (7) the Thar Desert; (8) deserts and arid zones of Northern Africa; (9) hot deserts of Egypt and Sudan; (10) the Sahel zone North of the Equator; (11) the Namib Desert; (12) the Karoo and Southern Kalahari; and the arid region of Madagascar.

The individual chapters treat the desert regions in detail, describing geographic location and physical characteristics, climate, plant zones and species present, animals, the impact of man, and other items.

Volume 12A begins with four chapters covering general characteristics of hot deserts. These include the desert environment, biogeography of the desert flora, adaptations of plants and animals to the desert environment, and desert ecosystem structure and function. The final chapter of Volume 12B provides an integrated view of hot desert ecosystems, based on the foregoing chapters.

These two books provide a wealth of information of value to range management professionals. They are filled with an aggregate of useful reference material, particularly useful to managers and research personnel seeking a reservoir of related knowledge.—*Ed*

Improvement of Desert Ranges in Soviet Central Asia. 1985. Nina T. Nechaeva (ed). Harwood Academic Publ. P.O. Box 786, Cooper Station, NY 10276. $130.00, cloth, 327 p.

Soviet Central Asia has the greatest similarities to our Intermountain rangelands of any other place on earth. It is therefore regrettable that political and language barriers have limited the exchange of ideas on how to better manage rangelands in comparable ecological contexts. The volume edited by Nechaeva affords us a rare view of how range improvements have been done in the republics of Kazahhistan, Uzbekistan, and Turkmenistan over the last four decades.

Soviet range ecologists recognized that little improvement over productivity was being obtained by grazing management alone. Karakul sheep production (mainly for pelts) has been limited by pronounced seasonal and inter-annual variability in the amounts and nutritional quality of native forage. About a hundred centuries of unrestricted livestock grazing and fuel harvest had left, especially near water sources, low statured vegetation dominated by plants that could survive such disturbances. It is thus not surprising that a concerted effort over the last four decades has led to recommendations on how to establish "agrophytocoenoses" (artificial plant communities) that are 10–30 times more productive than the residual vegetation. This new vegetation reconstructed with their more productive and palatable native species has usually been established via seeding after tillage. The Soviets have routinely used mixtures of several growth forms in order to utilize soil moisture at various depths of the soil and at varying times of the year. These multi-species stands make year-long utilization of rangeland forage possible and thus greatly reduce costs of animal production. Separate chapters on piedmont, sandy, clay, and gypsum deserts show how the approaches have been altered to fit the various regions and range sites.

Since Soviet science doesn't make use of the types of experimental design and statistical analysis we are accustomed to, we must take on faith many statements on the relative importance of various factors such as species, planting, dates, depths, and tillage methods. Means (without any expression of variance) in tabular form are the only reported data. Photos of vegetation before and after treatment are probably selected for best case presentation, just as many western researchers do. It would have been desirable to have photos of the type of equipment used, although there is little evidence that they have copied designs from the U.S. or Australia.

Many of the plant materials they use could be tried elsewhere. Those interested in enhancing browse and forb components on rehabilitated American rangelands should be aware that there are many more ecotypes of some we are already trying (e.g. *Kochia prostrata)* plus palatable species of *Artemisia, Astragalus, Camphorosma, Ceratoides, Salsola, Allenia, Mausola, Smirnowia, Onobrychis,* etc., that we could try here. There are also other tillage approaches we could try, e.g., sand-storing furrows on salt flats. Since the Soviets found enhanced success with pelleted seeds, presoaking of seed and sheep trampling of broadcast seed, we must ask why these techniques are not in favor elsewhere.

Because this book was not as closely edited as it should have been, the reader is going to be frustrated in places by ambiguities. Terms and concepts peculiar to Soviet literature could have been explained within parentheses following their first usage to save the western reader some puzzlement. For instance, is the "phytogeneous field" concept similar to our "island of fertility" notion or something new and different we should be aware of? Regardless of the volume's shortcomings, it should be consulted by those involved in land rehabilitation in other desert rangelands of the world. Unfortunately, this will probably have to be done by interlibrary loan since the cost of this volume severely limits the number of shelves it can appear on.—*Neil E. West,* Department of Range Science, Utah State University, Logan, Utah.

Game Harvest Mangement. Edited by Samuel L. Beasom and Sheila F. Roberson. 1985. Caesar Kleberg Wildlife Research Institute, Texas A & I University, Campus Box 218, Kingsville, Texas 78363. 374 pp. $20.00 hardbound, $15.00 softbound.

This book represents the culmination of 38 papers presented at the Third International Symposium of the Caesar Kleberg Wildlife Research Institute in Kingsville, Texas. The symposium focused on knowledge pertaining to the establishment of harvest quotas and responses of a variety of animals to those prescribed harvests. The introduction further quantified the purpose of the symposium when it stated: "To adequately fulfill the responsibility of stewardship over wild game populations, biologists must understand the consequences of all outside influences. To this end, this symposium was designed about one potentially major influence—hunting. A knowledge of the impacts to and responses of all wild game species populations to varied intensities of hunting or rates of harvest should be a requisite to the establishment of hunting seasons or offtake quotas."

A wide array of philosophies and approaches utilized by various wildlife agencies are presented, relating to how differing species or birds and animals respond to manipulation of their numbers through harvest. Models and indices are also given regarding such items as animal population responses to harvest, estimating wildlife populations, population fluctuations over time as well as the simulation of populations and effects of certain variables on that particular population.

The book includes several major headings including: (1) Techniques for Establishing Harvest Quotas and Monitoring Harvest, (2) Responses of Deer Populations to Harvest Strategies, (3) Harvest Strategies for Other Mammals, and (4) Response of Game Bird Populations to Harvest Strategies. Also included is a section of other abstracts which did not fit into any of the above headings.

More specific topics covered include: the philosophy of modern game harvest management; censusing techniques of deer and other species; utilization of aerial survey data and other survey methods for setting harvest quotas; computer models for harvest management, and management of other species including black bear, collared peccary, mountain gazelle, red deer, quail, American woodcock, and several species of grouse.

This book provides significant information relative to the management of wild animal populations through harvesting. A large amount of current knowledge and ideas pertaining to this phase of wildlife management is presented and this information should be of value to those people interested with the wildlife resource.—*Danny O. Stroud,* Yoder, Wyoming.

BOOKS RECEIVED FOR REVIEW

Complimentary copies available to volunteer reviewers. Contact Dr. Grant A. Harris, Department of Forestry and Range Management, Pullman, Wash. 99164.

Aspen: Ecology and management in the western US. 1985. Norbert V. DeByle and Robert P. Winokur, Ed Supt. Documents, Wash. D.C. 20408. Price ?

Ecology of Natural Resources. 1985. Francois Rama Ramade. John Wiley and Sons. (translated from French by W.J. Duffin) price ?

Population Ecology; A unified study of animals and plants, 1986. Michael Begon & Martin Mortimer. Second Ed. Sinauer Associates, Inc, Sunderland, Mass 01375-0407 Price? paper

The Background of Ecology,—Concept and theory. 1985. Robert P. McIntosh, Cambridge Univ. Press 510 North Ave. New Rochelle, NY 10801 $39.50

Ecology, Impact Assessment, and environmental planning. 1985. Walter E. Westman. John Wiley and Sons. (Price ?)

Ecology. 1986. Paul Colinvaux, John Wiley and Son price ?

Foundations for a national biological survey, 1986. Ke Chung Kim and Lloyd Knutson, Eds. Museum of Natural History, Univ Kansas, Lawrence, Kansas 66045, $18 paper.

International savanna symposium, 1984, 1985. J.C. Tothill and J.C. Mott Eds. Farnham House, Farnham Royal, Slough S12 3bn, UK. $47.50 paper.

The biology and agronomy of *Stylosanthes. 1984.* Helen M. Stace and L.A. Edye Eds. Academic Press Australia, Sidney (price ?)

Biochemistry of Storage Carbohydrates in Green Plants. 1985. P.M. Dey, R.A. Dixon eds. Academic Press Inc, Orlando FL 32887 $79.00 cloth

Arizona soils. 1985. David M. Hendricks. College of Agriculture, Univ. Arizona, Price?

Environmental Economy. 1986. R. Brooker, and M. Corder Eds. Methuen, Inc. 29 West 35th St. New York, NY 10001, $40 cloth

The Ranchers; A book of Generations. Stan Steiner, U Oklahoma Press, Norman Mar. $8.95.

Principles and methods of reclamation science 1986. Charles C. Reith & Loren D. Potter Eds. Univ. of New Mexico Press, Albuquerque, NM 87131 $30, cloth, 17.50 paper

Conservation Biology: the science of scarcity a diversity. 1986. Michael E. Soule, Ed. Sinauer Associates, Sunderland, Mass 01375. $46 .50 cloth $27 paper

Wildlife conservation evaluation. 1986. Michael B. Usher, Ed. Chapman and Hall, 29 West 35th Street, New York, NY 10001. price ?

Mammals of Arizona. 1986. Donald F. Hoffmeister. Univ. Arizona Press, 1615 East Speedway, Tucson AZ 85719. $49.95 cloth

Beef, brush and bobwhites: Quail management in cattle country. 1986. Fred S. Guthery. Caesar Kleberg Wildlfe Institute, Texas A&I Univ. Kingsville, Texas 78363. $12.50 paper. 17.50 hard

Livestock and wildlife management during drought. Robert D. Brown, Ed. 1985. Caesar, Kleberg WL Research Institute, Texas A&I Univ. Campus Box 218, Kingsville TX 78363 price ?

Systems analysis and simulation in wildlife and fisheries science. 1986. William E. Grant. John Wiley and Sons, One Wiley Drive, Somerset, NJ 08873. $47.50 cloth.

Wild Horses of the Great Basin. 1986. Joel Berger, University of Chicago Press. Chicago. $24.95 hard.

Building models for conservation and wildlife management. 1986. A.M. Starfield and A.L. Bleloch MacMillan Publishing Co. 866 3rd Ave. New York NY 10022

Conserving soil. Insights from socioeconomic research. 1986. Stephen B. Lovejoy and Ted L. Napier, EDS. Soil Cons. Soc. America, Publ. 7515 NE Ankeny Road, Ankeny, Iowa 50021 $8.00 cloth

Index, Volume 39

E

F

G

H

Q

R

S

JOURNAL OF RANGE MANAGEMENT

Official bimonthly publication of

Society for Range Management

Volume 39, 1986

Table of Contents

Volume 39, 1986

Number 1, January

Number 2, March

Number 3, May

Number 4, July

Number 5, September

Number 6, November

INSTRUCTIONS FOR AUTHORS: This page is reproduced from the *Handbook and Style Manual for the Journal of Range Management.* Copies of the complete booklet (12 pages) are available for $1.25 (single copy) or $1.00 each for 2 or more copies from the Society for Range Management, 2760 West Fifth Avenue, Denver, CO 80204.

Preface

Although not intended as an exhaustive presentation on manuscript preparation, this *Handbook and Style Manual* was prepared with the less experienced author in mind. Points of style, however, must be followed by all authors. Manuscripts submitted after 30 June, 1984, and not conforming to *JRM* style as designated here, will be returned to authors for correction before being sent out for review.

From time to time, this manual will be revised. The inside back cover of the *Journal* will carry brief instructions for authors and will advise them of style changes or a new edition of the style manual.

Introduction

Eligibility

The *Journal of Range Management* is a publication for reporting and documenting results of original research. Previously published papers are unacceptable and will not be considered for publication. Exceptions to this criterion are research results that were originally published as Department Research Summaries, Field Station Reports, Abstracts of Presentations, and other obscure and nontechnical handout publications. Manuscripts submitted to the *JRM* are the property of the *Journal* until published or released back to the author(s). Manuscripts may not be submitted elsewhere while they are being considered for this journal. Papers not accepted for publication are automatically released to the authors.

Kinds of Manuscripts

Journal Articles report original findings in Plant Physiology, Animal Nutrition, Ecology, Economics, Hydrology, Wildlife Habitat, Methodology, Taxonomy, Grazing Management, Soils, Land Reclamation (reseeding), and Range Improvement (fire, mechanical, chemical). *Technical Notes* are short articles (usually less than two printed pages) reporting unique apparatus and experimental techniques. By invitation of the Editorial Board, a *Review Paper* may be printed in the journal. *Viewpoint* articles or *Research Observations* discussing opinion or philosophical concepts regarding topical material or observational data are acceptable. Such articles are identified by the word *viewpoint* or *observations* in the title.

Manuscript Submission

Contributions are addressed to the Editor, Journal of Range Management, 2760 West Fifth Avenue, Denver, Colorado 80204. Manuscripts are to be prepared according to the instructions in this handbook. If the manuscript is to be one of a series, the Editor must be notified. Four copies of the complete manuscript, typed on paper with numbered line spaces, are required. Authors may retain original tables and figures until the paper is accepted, and send good quality photocopies for the review process. Receipt of all manuscripts is acknowledged at once, and authors are informed about subsequent steps of review, approval or release, and publication.

Manuscripts that do not follow the directives and style in this handbook will be returned to the authors by the Editor. A manuscript number and submission date will be assigned when the paper is received in the appropriate format.

Manuscript Review

Manuscripts are forwarded to an Associate Editor, who usually obtains two or more additional reviews. Reviewers remain anonymous. Where reviewers disagree, the Associate Editor, at his discretion, may obtain additional reviews before accepting or rejecting a manuscript.

The Associate Editor sends the approved manuscript, with recommendation for publication, to the Editor, who notifies the author of a projected publication date. Manuscripts found inappropriate for the *JRM* are released to the author by the Associate Editor. Manuscripts returned to an author for revision are *returned to the Associate Editor* for final acceptability of the revision. Revisions not returned within 6 months, are considered terminated. Authors who consider that their manuscript has received an unsatisfactory review may file an appeal with the Editor. The Editor will then determine the seriousness of the situation, and may select another Associate Editor to review the appeal. The Associate Editor reviewing the appeal will be provided with copies of all correspondence relating to the original review of the manuscript. If the appeal is sustained, a new review of the manuscript may be implemented at the discretion of the Editor. Manuscripts will not be sent for second reviews merely on the possibility of finding Associate Editors more favorable to the manuscript.

Page Proofs

Page proofs are provided to give the author a final opportunity to make corrections of errors caused by editing and production. Authors will be charged when extensive revision is required because of author changes, even if page charges are not assessed for the article. One author per paper will receive page proofs. These are to be returned to the Editor within 48 hours after being received. If a problem arises that makes this impossible, authors or their designates are asked to contact the Editor immediately so that adjustments can be made. Unproofed articles will not appear in the *Journal*. To avoid delays in production, delayed proof articles will be rescheduled into later issues when space is available.

Page Charges and Reprint Orders

Where funds are available, authors are expected to pay current page charges. Since most research is funded for publication, it will be assumed that the authors are able to pay charges unless they indicate otherwise, in writing, when submitting a manuscript. When funds are unavailable to an author, no page charges will be assessed. Only the Editor will have knowledge of fund status for page charges. The Associate Editors and reviewers will accept or reject a manuscript on content only.

An order form for reprints is sent to one author with the page proofs or shortly thereafter. Information as to price and procedure are provided at that time. The minimum order is 100; no reprints are provided free of charge.

Basic Writing Style for Journal Articles

Every paper should be written accurately, clearly, and concisely. It should lead the reader from a clear statement of purpose through materials and methods, results, and to discussion. The data should be reported in coherent sequence, with a sufficient number of tables, drawings, and photographs to clarify the text and to reduce the amount of discussion. Tables, graphs and narrative should not duplicate each other.

Both authors and reviewers are responsible for insuring that the *Journal* manuscripts are clear, concise, and accurate. Editors encourage authors to have manuscripts thoroughly reviewed by colleagues in their own institution and elsewhere before being submitted. Peer review before submission insures that publications will present significant new information or interpretation of previous data,and will speed *JRM* review processes.