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Effects of goat browsing on gambel oak communities in northern Utah

ROBERT A. RIGGS AND PHILIP J. URNESS

Abstract

Replicated populations of 5 shrub species were monitored over a 3-year period to assess community responses to intensive browsing by Spanish-type goats. Response variables included stem density, stem-size distribution skewness, stem diameter-stem production relations, and sprout abundance and weight. No species exhibited a density change. Size distribution skewness increased only in browsed oak (*Quercus gambelii* Nutt.) populations. Sprout weights also increased in browsed oak populations, but declined in comparably browsed serviceberry (*Amelanchier alnifolia* Nutt.) populations. The only other significant sprouting response was an increase in sprout numbers in browsed snowberry (*Symphoricarpos oreophilus* Gray) populations. Relationships between basal stem diameter and stem production of 4 species were altered by goat use. The slopes of these relations were consistently lower in browsed populations of oak and serviceberry than in adjacent control populations, indicating that browsing reduced productivity, especially of large stems. Conversely, slopes of rabbitbrush (*Chrysothamnus viscidiflorus lanceolatus* (Hook.) Nutt.) relations increased in goat-browsed pastures relative to those of control populations; rabbitbrush was avoided by goats. Similarly, big sagebrush (*Artemisia tridentata wyomingensis* Nutt.) was avoided and its stem production responded positively in communities subjected to goat browsing. Important cumulative effects of goat browsing included declines in productivity of serviceberry and oak, and an increase in that of sagebrush.

Key Words: browsing responses, stem density, size distribution skewness, sprouting response, stem-size—production relations

Control of Gambel oak on rangelands has been a long-standing interest of range managers. Improvements in cattle carrying capacity, livestock dispersal and handling, and soil moisture retention have been attributed to oak control (Marquiss 1972, Tew 1969). Not surprisingly, most research on this topic has been motivated by a desire to enhance livestock production via increases in herbaceous production that typically accompany oak control. Yet big game wintering on oakbrush ranges may benefit as well because oak control typically retards successional advance and increases browse availability (Kufeld 1977, 1983).

Gambel oak is deciduous and its apparent winter-time nutritive value is low compared to that of associated shrubs (Welch et al. 1983), especially nondeciduous species such as sagebrush (Kufeld et al. 1981). Yet Gambel oak is less susceptible to traditional shrub control techniques (i.e., fire, herbicides, mechanical control) than associated species (Kufeld 1983). Thus while traditional shrub-control methods can improve browse availability, they may also lower the nutritive value of the browse base by shifting species composition toward oak. Consequently, identification of management strategies capable of selective oak reduction is desirable. Selective control might also enhance herbaceous species, thereby serving both wildlife and livestock interests.

Controlled browsing by domestic goats may be a viable management alternative. Angora and milk-type goats have been used to control Gambel oak sprouts following mechanical treatment (Davis et al. 1975). More recently, Spanish goats have been shown to have greater potential for shrub control than either sheep or Angora goats (Warren et al. 1984), and to have dietary habits suited to selective control of Gambel oak under certain management constraints (Riggs et al. 1988). However, data concerning the effects of goats on entire oakbrush communities is lacking, despite the obvious implications that it might have for management of livestock and game range alike. In this paper we report the effects of summer-time goat use on a typical oakbrush winter range community in northern Utah.

Study Area

The study site is near the town of Henefer, at the interface between Wasatch chaparral and sagebrush-grass zones (Cronquist et al. 1972). Average annual precipitation and temperature are 350 mm and 7.1° C, respectively. The experiment was conducted in a typical low-elevation oakbrush community, occurring on a deep, loamy alluvial deposit. Elevation was 1,860 m. Slope was 13% and azimuth was 295° N. Oak stems ranged in height from a few centimeters to slightly over 2 m and the relative abundance of tall stems graded slightly from one end of the site to the other.

Methods

Treatment and Response Variables

Responses to goat browsing were investigated in 6 experimental oakbrush communities that were created by subdividing a naturally occurring parent community into smaller units. The parent community was first divided into three, 0.4-ha blocks, and each block was then subdivided into two, 0.2-ha pastures. One pasture in each block was subsequently stocked during the growing season with Spanish-type goat wethers while the other was maintained as a control pasture. Responses of each shrub species and of the herbaceous strata were then monitored annually in each of the 6 experimental units.

Stocked pastures each received, 1,340 goat-days per hectare in 1984, and 1,840 goat-days in 1985; they were rested in 1986. The treatment pastures were stocked with goats in a series of high-intensity, short-duration periods designed to maximize defoliation of Gambel oak. Additional information regarding the study site, stocking strategy, and dietary habits of the goats has been published elsewhere (Riggs et al. 1988).

The first response variable was the density of live, rooted shrub stems. Density was estimated for each shrub species during late June of each year. Stems were counted in 10 permanent 5-m^2 macroplots (Oldemeyer and Regelin 1980) in each pasture, and the data were compared by analysis of variance (ANOVA).

The second response variable was the stem-size distribution of live

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stems. The standardized skewness coefficient (g_1) was used to gauge shifts in these distributions. Size was calibrated each year, in terms of the cross-sectional basal diameter (mm), on 200 randomly selected stems in each population (Cole 1963). A standardized skewness coefficient was then calculated for each sample distribution, and the collection of coefficients was compared across treatments and years by ANOVA.

The third response variable was the relationship between stem size and stem production (i.e., size-specific production); this was estimated annually for non-sprouts in each experimental population using a size-stratified, random sample of 50 rooted stems. Size was calibrated in terms of cross-sectional basal diameter (mm). Stem productivity (g/stem) was calculated as the product of each stem's leader count and average leader weight ([stem production] = [mean twig weight] × [twig count]). Leader weights were predicted for a systematic subsample of leaders on each sample stem using twig-diameter-weight regressions. Parameters of the relationship (i.e., slope and intercept) were analyzed in sequence for treatment effects by an analysis of covariance in which the concomitant variable was basal diameter and the dependent variable was stem production. An intercept analysis was conducted only in the absence of significant slope differences. Both variables (basal diameter, production) were log-transformed to linearize the relationships for analysis.

Equations predicting size-specific stem production (Pr) were generated for experimental populations according to results of the covariate analysis. Separate equations were generated according to treatment if the covariance analysis detected differences in either slope or intercept; pasture samples were pooled to generate a common equation in the absence of any differences. Equations were generated using the log model: $\ln(Pr) = \ln(b\emptyset) + b1[\ln(D)]$; where Pr was production per stem (g/stem), D was basal stem diameter (mm), ln was the natural log function, and $b\emptyset$ and b1 were intercept and slope coefficients, respectively. For the sake of brevity, the antilog form of the equation, $Pr = b\emptyset(D)^{b1}$, with the coefficient of determination (r^2), is used in this paper.

In lieu of a covariate analysis, conditional tests for production homogeneity among populations were conducted for 4 of the 5 species (serviceberry, sagebrush, rabbitbrush, and snowberry) in 1984. Differences were not expected to occur during the first year, and an abbreviated analysis was considered adequate for detecting any initial differences that may have existed among the experimental populations. The methodology involved sampling the productivity of a predominant size class of stems in each population (rather than the entire size range) and subjecting the data to a blocked ANOVA for treatment effects; production homogeneity among populations was assumed in the absence of a significant test. None of these tests yielded significant results, and initial homogeneity was assumed among the various populations of these species. Gambel oak, on the other hand, was subjected to covariate analysis in all 3 years because it was the community dominant and target of the treatment.

Sprouting responses (frequency and weight of sprouts in the production samples) were treated separately. Rooted sprouts were excluded from the covariate production analysis because their size-production relations were expected to differ from those of nonsprouts (Rumble 1987). Rooted sprouts are composed only of current annual growth (CAG) while non-sprouts of equal diameter are composed of both CAG and old growth; thus separate analyses are required.

Utilization estimates were obtained at the same time as the production estimates. Twig utilization was defined as the percentage of CAG removed and/or killed by browsing. Utilized weights were predicted with the same regressions used to predict twig weights.

Herbaceous composition was estimated by ocular appraisal of basal area coverage, in 2 permanent 5-dm² microplots nested in each macroplot. In addition, two 1-m² circular plots were nested in each macroplot and clipped to obtain production estimates in August, 1986.

Finally, we constructed a cumulative-effects model using data for all the various response variables. Output was productivity by species (kg/ha), generated using point estimates for density, size distributions, stem size-production relations, and sprout responses derived in the foregoing analyses. Productivity was calculated for each species, under each treatment, by: (1) weighting the density estimates by the proportion of stems in various size classes; (2) weighting the resulting histograms by the size-specific productivity predicted for stems at the midpoint of each size, after adjusting for the proportions of sprouts and non-sprouts in each class; and (3) summing these size-class values.

Experimental Design

A 2-factor, complete block design was used to analyze the data. Main effects were blocks, goat use (without respect to density) and

Table 1. Initial botanical composition of experimental pastures, 1984[1].

Plant taxa	Control pastures Block #1	Block #2	Block #3	Stocked pastures Block #1	Block #2	Block #3	Mean ± S.E.[2]
Shrubs							
Amelanchier alnifolia	2.7	2.4	0.0	1.8	4.3	1.0	2.0 ± 0.6
Artemisia tridentata	3.5	10.6	2.0	5.2	0.8	7.4	4.9 ± 1.5
Berberis repens	0.2	3.4	0.0	1.3	5.2	5.0	2.5 ± 1.0
Chrysothamnus viscidiflorus	23.3	18.6	32.7	17.9	13.0	12.4	19.7 ± 3.1
Purshia tridentata	2.5	1.5	0.8	0.0	0.8	1.9	1.3 ± 0.4
Quercus gambelii	36.7	23.3	27.8	18.9	28.5	26.0	26.9 ± 2.4
Rosa sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.2 ± 0.2
Symphoricarpos oreophilus	4.6	36.5	19.9	25.5	17.7	10.8	19.2 ± 4.6
Graminoids							
Poa pratensis	8.8	7.7	16.4	16.0	12.1	11.5	12.1 ± 1.5
other[3]	0.9	2.5	0.2	0.9	0.8	1.1	1.1 ± 0.3
Forbs[2]	0.8	0.1	0.4	1.0	0.9	0.3	0.6 ± 0.2

[1]Shrub data are average, rooted-stem density per 5-m² macroplot; grass and forb data are average basal area coverage (%) per 10-dm² microplot.
[2]Differences between controls and stocked pastures were not significant ($p \leq 0.05$). Nomenclature follows Cronquist et al. (1972).
[3]Other graminoids were *Agropyron smithii, Agropyron spicatum, Bromus tectorum, Carex geyeri, Stipa columbiana, Stipa comata,* and *Poa fendleriana*. None of these accounted for ≥1% coverage in any pasture.
[4]Thirty-one forb species were recorded, but none averaged as much as 1% coverage. Species which composed as much as 1% coverage in at least one microplot included *Achillea millefolium, Antennaria microphylla, Aster integrifolius, Collinsia parviflora, Comandra umbellata, Erigeron pumilus, Gilia aggregata, Helianthella uniflora,* and *Lathyrus pauciflorus.*

years. Blocks were a random effect; both goat use and years were fixed. The year effect was a repeated measure. This design was used for ANOVA for stem density, stem-size distributions and sprout responses. Covariate ANOVA of size-specific stem productivity simply involved adding stem diameter to the design, as the con-commitant. RUMMAGE software was used to analyze the data (Bryce 1980).

Block-randomization was used to distribute goats because we suspected that utilization might differ among pastures. We based this suspicion on the height gradient observed among oak stems; if goats were unable to reach the tallest stems, utilization of oak would vary along the height gradient. The pastures had to be randomized prior to any browsing and we elected to use the block design, rather than a completely randomized design, in order to account for a potentially height-related utilization differential. However, we observed during the browsing periods that goats defoliated all stems without regard to height; this resulted from their ability to assume a bipedal stance while feeding, which allowed them to "ride down" even the tallest stems. Therefore, the height gradient became biologically unimportant, and we view our initial block-randomization as unnecessarily restrictive (i.e., a completely randomized design would have been appropriate). We have adhered to the block-randomized design for this analysis, but caution the reader that it is likely conservative. Consequently, we have also reported some results that were visually obvious to us, but only marginally significant in the context of the block-randomized analysis.

Results

Utilization Levels

Sagebrush, rabbitbrush, and snowberry were consumed little by goats (Riggs et al. 1988). Sagebrush utilization was only 2.4% (SE = 0.8) for both twig and leaf material, with no differences between years. Utilization of rabbitbrush was 2.7% (SE = 0.8) and 3.4% (SE = 0.9) for twigs and leaves, respectively, and no difference occurred between years. Utilization of snowberry twigs and leaves, however, varied between years ($P<0.03$). Twig utilization increased from 0.8% (SE = 0.8) in 1984 to 39.8% (SE = 0.1) in 1985; likewise, leaf utilization increased from 1.4% (SE = 1.0) to 52.8% (SE = 0.2). The greater use of snowberry in 1985 apparently resulted from the greater number of animal-days applied to the stocked pastures that year.

Conversely, both serviceberry and Gambel oak were avidly consumed. Serviceberry browse was not abundant in the pastures and its utilization was high, despite a low occurrence in the diet (Riggs et al. 1988); utilization averaged 48.6% (SE = 3.4) and 53.3% (SE = 3.3) of twigs and leaves, respectively, with no significant difference between years ($P>0.10$). Utilization of oak fractions was lower ($P<0.05$) in 1984 than 1985. Twig utilization was 20.0% (SE = 0.3) in 1984 and 56.2% (SE = 0.3) in 1985; leaf utilization was 43.3% (SE = 8.1) and 64.3% (SE = 3.6) in 1984 and 1985, respectively.

Composition Responses

Pasture composition did not differ in 1984 at the outset of the experiment (Table 1). No changes ($P\leq0.10$) were detected in the subsequent 2 years, either in the density of shrub stems or in the basal area coverage of herbaceous species.

Dynamics of Stem-Size Distributions

Minimum and maximum stem diameters were stable throughout the study in all populations, and skewness of size distributions shifted in only the browsed oak populations ($P<0.08$, Fig. 1). All oak distributions were positively skewed in 1984, indicating an initial abundance of small stems relative to large ones. Skewness of all the browsed populations increased as the experiment progressed while that of the control populations remained constant;

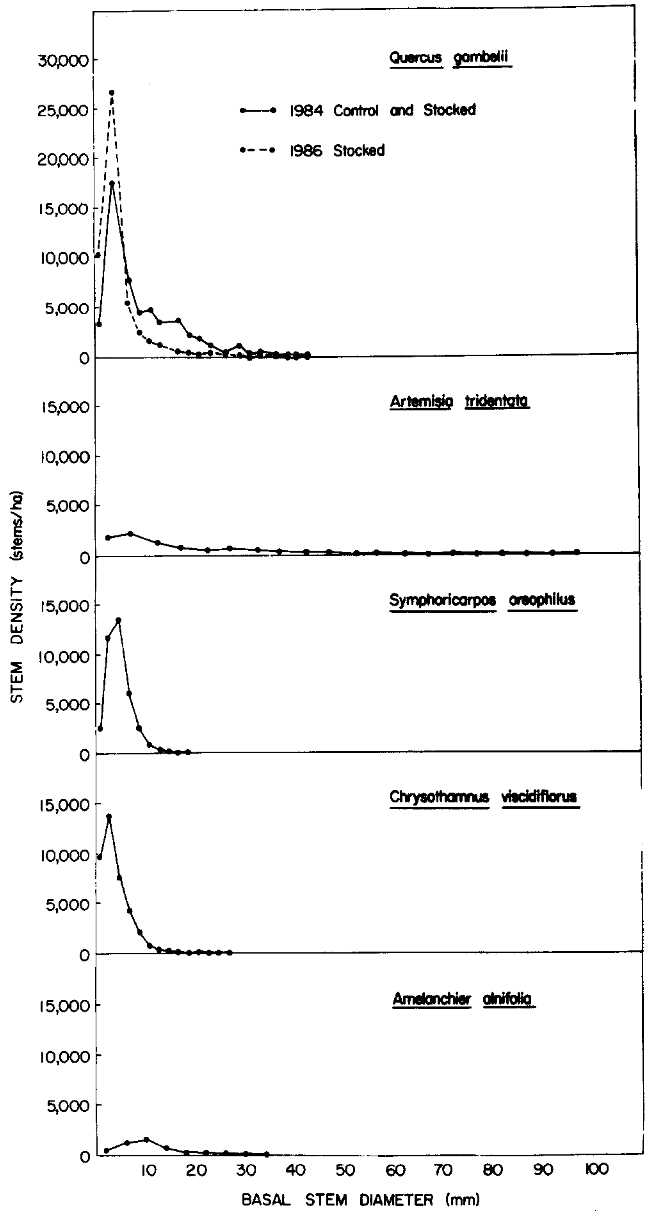

Fig. 1. *Pooled sample distributions of stem size in 1984 and 1986. Only the size distribution of oak was affected by goats.*

the treatment effect became significant in the third year (Fig. 2). This progressive skewing, at constant density, indicated that the relative abundance of smaller stems had increased in the population, and implied that both mortality of old stems and increased sprouting were involved. Both factors were visually obvious.

Sprout Responses

Browsing did not affect the sprouting rate of serviceberry populations. Sprouts composed 74% (SE = 5.6) of the rooted serviceberry stems less than 4 mm in diameter. This percentage did not differ among populations at any time during the 3-year period. However, sprout weights did differ between treatments ($P<0.09$). Sprout dry-weights averaged 0.58 g among control populations versus 0.21 g among browsed populations ($LSD_{.10}$ = 0.25).

Rabbitbrush sprouting was apparently unaffected. Rabbitbrush sprout diameters did not reach 2 mm and sprouts comprised about 66.7% (SE = 9.6) of all the rooted stems that were smaller than this diameter, regardless of treatment or year. Rabbitbrush sprouts

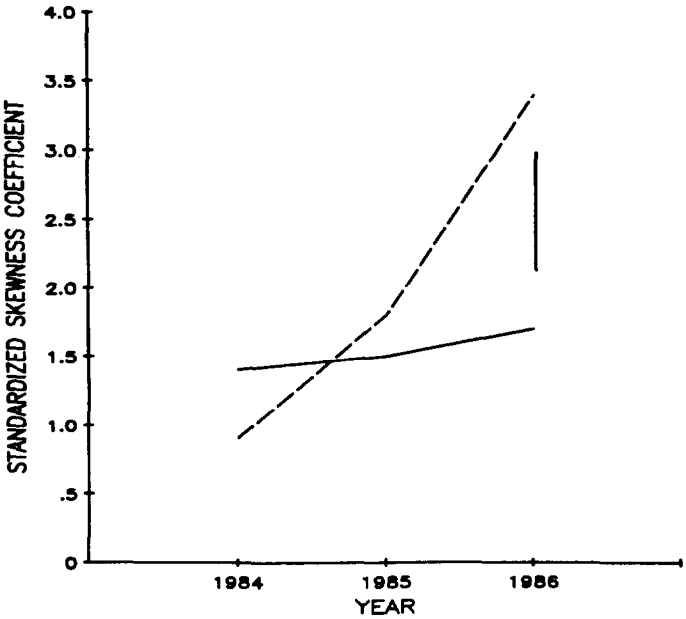

Fig. 2. *Changes in the standardized skewness coefficient for sample basal-diameter distributions of rooted oak stems, 1984–86. The vertical bar corresponds to the $LSD_{.10}$ between controls (solid line) and stocked pastures (dashed line) observed in 1986.*

averaged 0.35 g (SE = 0.10).

The increased skewness of stem-size distributions seen in the browsed oak populations was partially due to increased sprouting. Oak sprouts did not exceed 10 mm in diameter, and the proportion of sprouts occurring in subsamples of stems under 10 mm diameter varied significantly ($P<0.03$) by treatment and year. Sprout numbers increased in the stocked pastures but did not change in the controls (Fig. 3). Sprouts comprised 10.7% and 10.0% of all oak stems less than 10 mm diameter in 1984 and 1985, respectively. In 1986, sprouts comprised 90.0% of the browsed-population samples, but only 6.7% of the control samples. Browsing did not affect sprout weight in either 1984 or 1985 ($\bar{x}$ = 1.26 g SE = 0.59), but a weight difference was observed in 1986 when sprouts averaged 2.90 g and 1.15 g in browsed and control populations, respectively ($LSD_{.10}$ = 0.81).

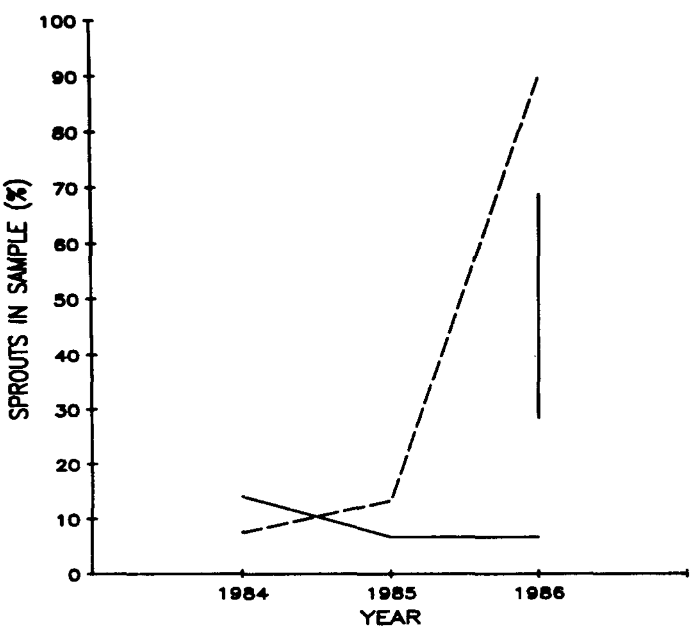

Fig. 3. *Changes in the percentage of live, rooted, oak stems under 10 mm basal diameter that were sprouts, 1984–86. The vertical bar corresponds to the $LSD_{.05}$ between controls (solid line) and stocked pastures (dashed line) observed in 1986.*

Snowberry did not exhibit a sprouting response. Basal diameter of snowberry sprouts seldom reach 4 mm (P = 0.03), and browsing did not alter the frequency of sprouts under this size. However, the proportion of sprouts in the subsamples did vary between years with regard to treatment ($P<0.05$). This proportion increased, in both browsed and control populations, from 31.7% in 1985 to 58.3% in 1986 ($LSD_{.05}$ = 25.9). Dry weight of snowberry sprouts was unaffected by either browsing or year; dry weights consistently averaged 0.52 g (SE = 0.06).

Covariate Production Responses to Nonsprouts

A highly significant ($P<0.0001$) relationship was observed between basal diameter and productivity of rooted serviceberry stems. Browsing had a significant effect on the slope of the relationship ($P<0.03$). Neither the main effect of year nor the treatment × year interaction was significant ($P>0.35$), indicating that the magnitude of the effect did not change between 1985 and 1986. Slope of the relation for control stems ($Pr = 0.22(D)^{1.47}$, $r^2 = 0.70$, n = 181) was more than twice that for browsed stems ($Pr = 0.28(D)^{0.63}$, r^2 = 0.32, n = 157) in both 1985 and 1986, indicating that the productivity of non-sprouts was reduced by browsing, especially that of larger stems. The relationship for browsed stems was weaker than that for controls.

Sagebrush also exhibited a highly significant ($P<0.0001$) relationship between basal diameter and productivity, and slope heterogeneity was detected between treatments in an analysis of vegetative production ($P<0.13$); as in the serviceberry analysis, neither the year effect nor the treatment × year interaction was significant. The slope of the relationship for control stems ($Pr = 0.09(D)^{1.63}$, r^2 = 0.87, n = 291) was lower than that for stems in stocked pastures ($Pr = 0.13(D)^{1.78}$, r^2 = 0.87, n = 292); strength of the relationship was the same in both treatments. The difference in vigor of plants was clearly visible in the pastures. We concluded that avoidance of sagebrush by goats conferred a competitive advantage to this species, and magnitude of the production response increased with plant size.

We also estimated production of reproductive leaders (RPr) by sagebrush plants, but only in 1986. The size-production relation was highly significant ($P<0.0001$), but weak ($RPr = 0.33(D)^{0.99}$, r^2 = 0.33, n = 292). No heterogeneity of slope or intercept was detected ($P>0.40$). Therefore, any reproductive response that may have occurred did not appear to extend beyond the presence of goats in the pastures.

Rabbitbrush populations also exhibited a highly significant stem diameter-production relationship ($P<0.0001$). There was no slope heterogeneity between treatments without respect to years ($P>0.35$). However, there was significant heterogeneity between years without respect to treatment ($P<0.03$); slope of the relationship declined significantly from 1985 to 1986 (Table 2). In addition, a treatment × year interaction was indicated ($P<0.14$). No slope differential was detected between treatments in 1985; in 1986, the control relationship had a lower slope than did the treatment relationship (Table 2). We concluded that a size-specific decline in stem productivity had occurred in both treatments, but the decline was less precipitous in the stocked pastures where goats had avoided this species during the previous 2 years. The difference was visually obvious in 1986.

Oak also exhibited a significant over-all relationship between stem diameter and stem production ($P<0.0001$). Slope heterogeneity was detected between treatments without respect to years ($P<0.10$), and among years without respect to treatment ($P<0.02$).

Table 2. Comparisons of stem diameter-production regression, P = bØ(D)b1, for rabbitbrush, 1985–86.

Treatment	Year	bØ	bl	Adjusted r^2	n
Treatment Comparisons (without respect to year)[1]					
Controls	Both	0.83	0.92	0.46	256
Stocked	Both	0.74	1.05	0.46	259
Year Comparisons (without respect to treatment)[2]					
Both	1985	0.62	1.18 a	0.61	264
Both	1986	0.94	0.82 b	0.36	251
Treatment × Year Comparisons[3]					
Controls	1985	0.65	1.15 a	0.65	132
Stocked	1985	0.57	1.23 a	0.54	132
Controls	1986	1.01	0.71 b	0.31	124
Stocked	1986	0.88	0.92 c	0.42	127

[1]Difference between slopes is not significant.
[2]Unlike letters denote a difference between slopes ($p \leq 0.02$).
[3]Unlike letters denote differences among slopes ($p \leq 0.14$).

However, the treatment ×year interaction was not significant (P = 0.254).

The treatment effect was obvious (Fig. 4). However, it was not visually apparent until 1985, suggesting that the interaction was a real phenomenon despite the low statistical significance. We felt that the low significance might well have resulted from the conservative experimental design (which was unnecessarily restrictive). Consequently, Table 3 displays the regression coefficients at the interaction level, as well as at the level of the main effects. Comparison of the regression coefficients at the level of the main effects indicates that the browsing effect was consistent throughout the study, and that slopes dropped in 1985 (regardless of treatment), and then rebounded in 1986 (regardless of treatment). In contrast, comparison of the regression coefficients at the level of the interaction suggests that there was not a great disparity of regression coefficients between treatments until after 1984. The statistical analysis forces one to conclude that the first interpretation is the appropriate one. However, failure to detect the interaction simply may have resulted from the conservative, block-randomized analysis[1]. Therefore, we caution against any expectation of depressing oak stems with only 1 season of browsing, even at the heavy stocking level we employed. In either case, timing of the browsing effect may be a trivial point from a practical perspective if one considers that imposing goat browsing for only one year seems unlikely in most operational settings. The important point is that repeated browsing will certainly reduce oak vigor.

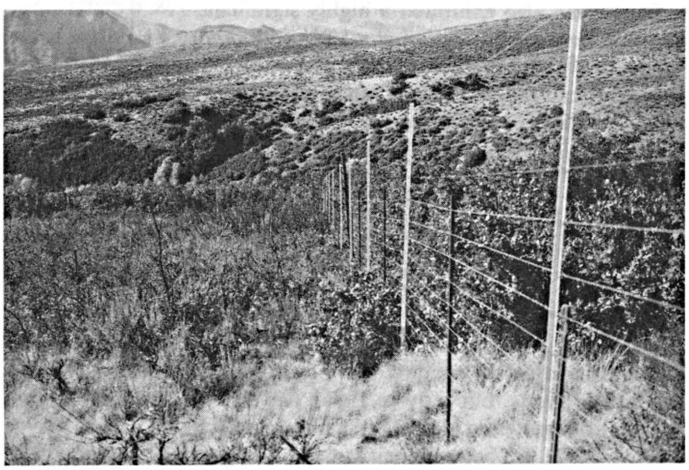

Fig. 4. *Fence-line comparison illustrates the difference in productivity of browsed oak stems (left) and unbrowsed controls (right), 1986.*

[1]Reanalysis of the data in the context of a completely randomized design found the interaction effect to be significant ($P < 0.05$). However, there is no theoretical justification for conducting such an analysis (Anderson 1970).

Table 3. Comparisons of stem diameter-production regression, P = bØ(D)b1, for Gambel oak, 1984–86.

Treatment	Year	bØ	bl	Adjusted r^2	n
Treatment Comparisons (without respect to year)[1]					
Controls	all	0.25	1.64 a	0.78	424
Browsed	all	1.32	0.64 b	0.22	375
Year Comparisons (without respect to treatment)[2]					
Both	1984	0.40	1.41 a	0.77	272
Both	1985	0.40	1.17 b	0.40	283
Both	1986	0.34	1.40 a	0.33	244
Treatment × Year Comparisons[3]					
Controls	1984	0.37	1.46	0.75	134
Controls	1985	0.21	1.57	0.80	148
Controls	1986	0.22	1.85	0.88	142
Browsed	1984	0.43	1.36	0.81	138
Browsed	1985	0.93	0.68	0.21	135
Browsed	1986	0.69	0.76	0.21	102

[1]Unlike letters indicate a difference between slopes ($p \leq 0.10$).
[2]Unlike letters indicate differences among slopes ($p \leq 0.02$).
[3]Slope differences are not statistically significant ($p > 0.25$) in a block-randomized analysis.

Snowberry stems also exhibited a highly significant relationship between basal diameter and production ($P < 0.0001$), but neither of its parameters was affected by treatment, year, or their interaction ($P < 0.35$). Consequently, the data were pooled over treatments and years to generate a single regression ($Pr = 0.50(D)^{1.22}$, $r^2 = 0.54$, n = 504). We concluded that productivity of non-sprouts was not affected to a significant extent by the browsing treatment or by differences in growing conditions between years.

Cumulative Effects on Shrubs

Reduced productivity of mature serviceberry stems, coupled with reduced sprout vigor, lowered productivity of browsed serviceberry populations. Productivity of model control population was 26 kg/ha versus 4 kg/ha for a browsed population (Fig. 5).

In the case of Gambel oak, all variables responded to the intense browsing, and the net effect was a severe (78%) reduction in productivity of populations (Fig. 5). Model output for control populations was 754 kg/ha, with only 0.4% of this produced by sprouts. In sharp contrast, browsed populations produced only 166 kg/ha, and 61% of this was sprouts. This comparison was calculated using the main-effect differences in Table 3, rather than the interaction-level differences; it may be conservative.

Sagebrush was the only shrub to show a strong positive response. Neither its density nor its size distribution was changed by goats, but the increase in stem production moved population productivity markedly upward. Model output for combined vegetative and reproductive production was 236 kg/ha under control conditions, versus 494 kg/ha with goats (Fig. 5). The difference between treatments was obvious.

Productivity of rabbitbrush and snowberry populations was not markedly affected. Rabbitbrush productivity was 132 kg/ha in 1984. Neither the control nor the treatment values differed much in 1986 (106 kg/ha and 128 kg/ha, respectively). Model production for snowberry was 134 kg/ha in both treatments.

Herbaceous Production

Clipping data suggested that understory production increased in the stocked pastures, relative to the controls. However, statistical

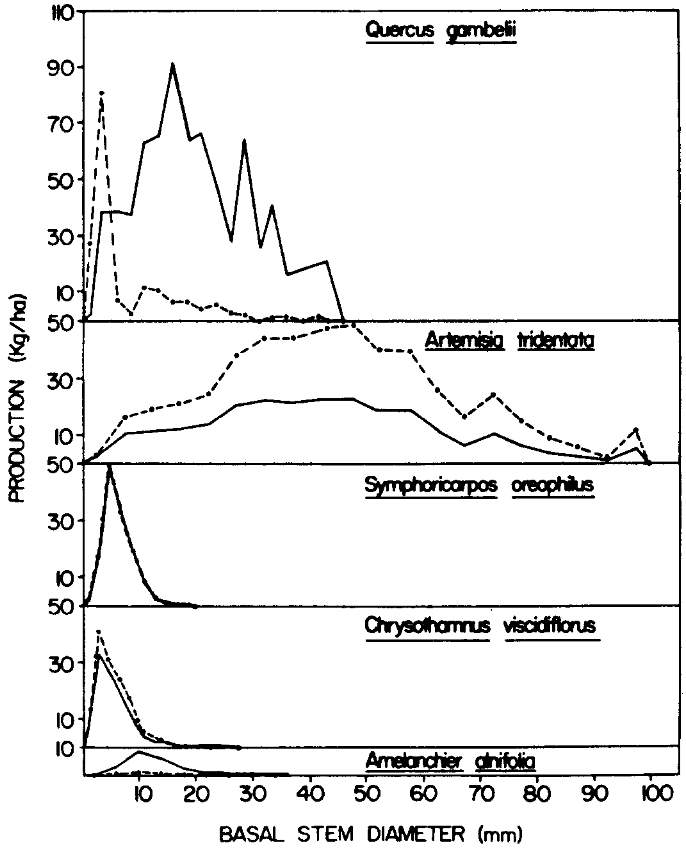

Fig. 5. *Net effect of goats on productivity of shrub populations (kg/ha), 1986. Curves plot productivity of various size classes for control populations (solid lines) versus populations in goat-stocked pastures (broken lines). Areas underneath curves reflect productivity of model populations.*

evidence was weak. In 1986, graminoid production averaged 420 kg/ha (SE = 45) across control pastures, compared to 660 kg/ha (SE = 43) across stocked pastures, but the difference was not significant ($P<0.6$). Likewise, forb production was only 90 kg/ha (SE = 8) across the controls versus 110 kg/ha (SE = 8) across stocked pastures ($p>0.8$). The pooled estimate for graminoids and forbs was 510 kg/ha (SE = 49) and 780 kg/ha (SE = 48) in controls and stocked pastures, respectively, with no significant difference.

Herbage density varies spatially in oakbrush because distribution of the various shrub species is clumped. Lack of statistical significance likely resulted from randomly locating the plots and the small number of plots (n = 20 per pasture). The treatment effect was significant when grass and forb data were pooled across pastures (i.e., n = 60 plots per treatment without respect to block replication), and the means compared on the basis of the pooled variance ($LSD_{0.05} = 51$). An increase in herbaceous production is expected following uniform shrub control in oakbrush communities (Marquiss 1972, Moinat 1956, Price 1938). Likewise, a positive herbaceous response should be expected following a partial shrub reduction, but its spatial variability should be greater than that following a uniform shrub removal. We concluded that herbage production had increased in the goat-browsed pastures. Increased sampling may have detected the treatment effect, but the sampling level required may have been prohibitive without prior stratification of plots according to shrub composition.

Discussion

Both serviceberry and Gambel oak were reduced by browsing in this experiment, and by utilization levels that were not as extreme as those required to harm these species in earlier clipping studies (Young and Payne 1948, Shepherd 1971). The apparently lower resilience to goat browsing might be attributed to a timing difference between ungulate browsing and artificial clipping. Clipping is generally imposed between mid-summer and early fall, after plants have been afforded some opportunity to store nutrients. In contrast, we initiated goat browsing in late spring and repeated it during the course of the growing season (Riggs et al. 1988); thus the opportunity to store nutrients may have been reduced, and resilience reduced accordingly (Engle et al. 1983). Stem damage also resulted from animals gnawing on bark below the point of current annual growth, and this probably lowered stem vigor as well.

Positive or neutral responses observed for sagebrush, green rabbitbrush, and snowberry contrasted sharply with the largely negative responses which Kufeld (1983) reported for these species following chaining, spraying or burning. However, minor components of the community that are palatable (e.g., serviceberry) may be negatively impacted. Results in other areas will be affected by stocking strategy, species composition, and relative palatability of community components.

Long-term effects are yet to be assessed, and rate of return to prebrowsed conditions will be of particular interest. The short-term results presented here suggest increased herbaceous production for other livestock, and goat-induced changes in the browse base may well be beneficial to big game wintering on such communities. Sagebrush is higher in crude protein and dry matter digestibility, and lower in indigestible fiber, than associated deciduous species in winter (Kufeld et al. 1981, Welch 1983, Welch et al. 1983). Thus such treatment may benefit wintering ungulates, assuming that they would adjust their dietary behavior (botanical composition, dry matter intake) so as to take advantage of increased sagebrush availability.

Several response variables were monitored in this experiment, but these were not equally sensitive to goats. Stem density was insensitive in this study despite a rather intense sampling scheme. Similarly, skewness of stem-size distributions did not respond except in the case of oak, which was severely browsed. Stem diameter-production relationships were more sensitive than either density or size-distribution of populations in this experiment. Whether this holds in studies concerned with more moderate treatments and/or long-term successional dynamics remains to be seen.

Predictive power of the stem diameter-production relations, as reflected by r^2 values, varied among species and may be expected to vary with treatment severity as well. The relationship was strong for species that had fairly wide ranges of basal stem diameter and stem production (e.g., sagebrush, serviceberry, and oak). In contrast, rabbitbrush and snowberry populations exhibited limited ranges for these variables, and weaker regression relationships. Little difference in precision was observed between control populations and those that were only moderately stressed or enhanced (e.g., rabbitbrush, snowberry, and sagebrush), but precision declined markedly if stem damage was severe (e.g., serviceberry and oak). High short-term variance may not persist over the long term, and it may not be expected to appear at all in long-term studies concerned with more subtle browsing treatments.

We employed the standardized skewness coefficient to detect size-distribution changes in this study, but it may not be an appropriate response variable in other situations. In this study, experimental populations were demarcated via subdivision of a single parent community. Neither minimum nor maximum stem sizes varied among pastures initially, and no changes in these parameters were detected during the course of the experiment. Therefore, the range and location of size distributions were constant, and only changes in shape of the distributions were a concern. Skewness is a shape statistic, but it is insensitive to differences in scale or location among distributions. Location differences, in particular, are apt to occur in field experiments that employ experimental designs based on site characteristics or stand history. For example, a shrub population on a ridge might have a very different stem-size range than another population in an adjacent swale. Likewise, shrub stands of different ages might be expected to have different size ranges. Also, locational shift may be more apt to develop in long-term experiments than in short-term studies like this one. Where locational shift does occur, the coefficient of variation, or the gini coefficient, may be more appropriate response variables than skewness (Bendel et al. 1989).

Literature Cited

Anderson, V.L. 1970. Restriction errors for linear models (an aid to develop models for designed experiments). Biometrics 26:255-268.

Bendel, R.B., S.S. Higgins, J.E. Teberg, and D.A. Pyke. 1989. Comparison of skewness coefficient, coefficient of variation, and gini coefficient as measures of inequality. Oecologia (Berlin). In Press.

Bryce, G.R. 1980. Data analysis in Rummage II. Dep. Stat., Brigham Young Univ., Provo, Utah.

Cole, G. 1963. Range survey guide. Grand Teton Natur. Hist. Assoc., Moose, Wyo.

Cronquist, A., A.H. Holmgren, N.H. Holmgren, and J.L. Reveal. 1972. Intermount. Flora, Vol. 1. Hafner Publ. Co.

Davis, G.G., L.E. Bartel, and C.W. Cook. 1975. Control of Gambel oak sprouts by goats. J. Range Manage. 28:216-218.

Engle, D.M., C.D. Bonham, and L.E. Bartel. 1983. Ecological characteristics and control of Gambel oak. J. Range Manage. 36:363-365.

Kufeld, R.C. 1977. Improving Gambel oak ranges for elk and mule deer by spraying with 2,4,5-TP. J. Range Manage. 30:53-57.

Kufeld, R.C. 1983. Responses of elk, mule deer, cattle, and vegetation to burning, spraying, and chaining of Gambel oak rangeland. Colorado Div. Wildl. Tech. Pub. 34.

Kufeld, R.C., M. Stevens, and D.C. Bowden. 1981. Winter variation in nutrient and fiber content and in vitro digestibility of Gambel oak (*Quercus gambelii*) and big sagebrush (*Artemisia tridentata*) from diversified sites in Colorado. J. Range Manage. 34:149-151.

Marquiss, R.W. 1972. Soil moisture, forage, and beef production benefits from Gambel oak control in southwestern Colorado. J. Range Manage. 25:146-150.

Moinat, A.D. 1956. Comparative yields of herbage from oak scrub and interspersed grasslands in Colorado. Ecology 37:852-854.

Oldemeyer, J.L., and W.L. Regelin. 1980. Comparison of 9 methods for estimating density of shrubs and saplings in Alaska. J. Wildl. Manage. 44:662-666.

Price, R. 1938. Artificial reseeding on oak-brush ranges in central Utah. USDA Circ. 458.

Riggs, R.A., P.J. Urness, and T.A. Hall. 1988. Diets and weight gains of Spanish goats used to control Gambel oak. Small Ruminant Res. 1:259-271.

Rumble, M.A. 1987. Using twig diameters to estimate browse utilization on three shrub species in southeastern Montana. p. 172-175 *In:* Proc.—Symp. on Plant-Herbivore Interactions. USDA Forest Serv. Gen. Tech. Rep. INT-222.

Shepherd, H.R. 1971. Effects of clipping on key browse species in southwestern Colorado. Colo. Div. Game, Fish and Parks Tech. Pub. 28.

Tew, R.K. 1969. Converting Gambel oak sites to grass reduces soil-moisture depletion. USDA Forest Serv. Res. Note INT-104.

Warren, L.E., D.N. Ueckert, and J.M. Shelton. 1984. Comparative diets of Rambouillet, Barbado, and Karakul sheep and Spanish and Angora goats. J. Range Manage. 37:172-180.

Welch, B.L. 1983. Big sagebrush: nutrition, selection, and controversey. p. 21-33. *In:* K.L. Johnson (ed.). Proc. First Utah Shrub Ecology Workshop. Utah State University, Logan.

Welch, B.L., S.B. Monsen, and N.L. Shaw. 1983. Nutritive value of antelope and desert bitterbrush, Stansbury cliffrose, and apache-plume. p. 173-185. *In:* Proc. Res. and Manage. of Bitterbrush and Cliffrose in Western North America. USDA Forest Serv. Gen. Tech. Rep. INT-152.

Young, V.A., and G.F. Payne. 1948. Utilization of key browse species in relation to proper grazing practices in cut-over western white pine lands in northern Idaho. J. Forest. 46:35-40.

Observations on white-tailed deer and habitat response to livestock grazing in south Texas

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Abstract

Since short duration grazing (SDG) was introduced to Texas, concern for white-tailed deer *(Odocoileus virginianus)* has magnified because they are a species of major economic importance to ranchers. The objective of this study was to observe the effects of SDG and continuous yearlong grazing (CG) on home ranges and movement indices of female deer, and on forage availability. The study was conducted on the Rob and Bessie Welder Wildlife Refuge, near Sinton, Texas. The study area included a 10-pasture SDG cell and a CG pasture, each stocked at 2.8 ha/auy. Cattle grazed each SDG paddock 2 to 8 days; paddocks were rested 32 to 47 days. A total of 3,861 radio-fixes from 11 does was collected over an 11-month study period in 1983. Monthly and annual home ranges of does were similar ($P>0.05$) between SDG (207 ha) and CG (229 ha). However, white-tailed deer traveled 35% more ($P<0.05$) between fixes in SDG (449 m) than in CG (332 m) from May to August, a time of greatest physiological and nutritional stress for female deer in south Texas. Also, does avoided ($P<0.05$) cattle during 2 cycles of the SDG rotation. The primary trend observed was for the deer under SDG to avoid cattle concentrations by alternating between preferred habitats rather than a predictable paddock-to-paddock movement. In general, there were few differences in total grass and forb cover between SDG and CG. However, several forage species important to deer were less frequent ($P<0.05$) under SDG than CG.

Key Words: continuous grazing, home range, movement indices, *Odocoileus virginianus*, radio telemetry, short duration grazing

Over the last 30-40 years, dramatic changes have taken place in Texas grazing management. Initially, continuous grazing (CG), where animals dictated their own patterns of use, was most common. In the 1950's and 1960's, those at the forefront in grazing management in Texas shifted from continuous grazing to multi-herd, multi-pasture management programs such as the Merrill 3-herd, 4-pasture regimen (Bryant et al. 1982). By 1961, a 1-herd, multi-pasture approach to non-selective grazing was introduced (Howell 1978). This approach reached Texas in the late 1960's with the high-intensity, low-frequency (HILF) regimen, a variation of nonselective grazing (Acocks 1966). Short duration grazing (SDG), requiring shorter grazing periods, shorter rest periods, and more grazing cycles per year than HILF (Bryant et al. 1982), emerged in the mid- to late 1970's. Generally, SDG has grazing periods of 7 days or less, rest periods from 30 to 60 days, and grazing cycles short enough to allow 6 or more rotations per year (Savory 1979).

Livestock, vegetation, and soil responses to SDG in Texas are well documented (Heitschmidt et al. 1982a, 1982b, 1982c); however, data on white-tailed deer *(Odocoileus virginianus)* response to SDG are relatively few. Guynn and White (1984) found no difference in deer densities between SDG and a 3-herd, 4-pasture grazing regimen.

We compared home range sizes and movement indices of adult female white-tailed deer between a SDG and a CG pasture; evaluated deer locations relative to cattle rotation through the SDG cell; and compared vegetation responses between SDG and CG.

Study Area

The study was conducted on the Rob and Bessie Welder Wildlife Foundation Refuge near Sinton, Texas. The refuge comprises 3,157 ha of native rangeland adjacent to the Aransas River in San Patricio County. It is located in the Coastal Bend region, a transitional zone between the Gulf Prairies and Marshes and the South Texas Plains (Gould 1975).

Prior grazing history of the SDG site was a HILF system stocked at a moderate rate of 5.7 ha/animal unit year (auy) for 8 years, while the CG pasture was continuously grazed at a stocking rate of 5.7 ha/auy for 8 years (Drawe and Cox 1978). In 1982, SDG was initiated and stocking was increased to 2.8 ha/auy; the CG pasture was maintained under continuous yearlong grazing, but at the identical stocking rate (2.8 ha/auy) of SDG.

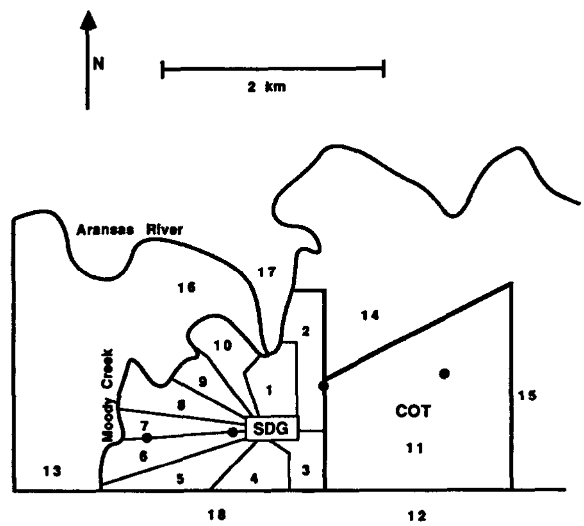

Fig. 1. *The short-duration grazing (SDG) cell (Locations 1-10), continuous grazing (CG) pasture (Location 11), and other areas of female white-tailed deer use (Locations 12-18). • = tracking station location. Grazing rotations on the SDG cell began in Location 10 and proceeded clockwise.*

The SDG cell consisted of 219 ha sub-divided into 10 equal-sized paddocks (Fig. 1). Water, salt, and supplemental feed were located in the cell center, but livestock also had access to water from the Aransas river and Moody Creek, which bordered the SDG cell on the west and north. Each SDG paddock was grazed from 2 to 8 days and rested 32 to 47 days, depending on vegetation response.

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Table 1. Mean monthly 95% ellipse home ranges (ha), based on monthly activity centers, of female deer under a short duration and continuous grazing on the Welder Wildlife Refuge, 1983.

Grazing system		Month										
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SDG	$\bar{x}$[1]	—	419	316	175	186	233	151	193	162	92	143
	SE	—	14	5	13	44	115	9	68	15	20	37
	n[2]	—	3	3	3	4	3	2	4	3	2	2
CG	$\bar{x}$	323	440	545	179	109	137	100	145	158	160	221
	SE	55	66	152	63	21	37	37	1	33	26	74
	n	5	6	5	3	5	3	3	2	4	3	4

[1]Means within months were not significantly (P>0.10) different.
[2]n = number of deer.

The 253-ha CG pasture had water, salt, and feeding facilities available at 2 locations.

Methods

Deer Home Range and Movement Indices

Radio telemetry was used to monitor white-tailed deer home ranges and movements in the SDG cell and CG pasture. In the winter of 1982–83, drop nets were used to capture 8 and 10 female deer in the SDG cell and CG pasture, respectively. Deer were fitted with radio collars and cattle ear tags, and weights and ages were recorded. After deer losses from death or movement off the area, sufficient data for analysis were obtained on 6 adult female deer in the SDG cell and 5 adult female deer in the CG pasture.

Deer were monitored from 6 February to 31 December 1983 using a null radio telemetry system (Hallberg et al. 1974). Each deer was located from 3 permanent tracking stations, 4 times/day (dawn, noon, dusk, 2300 hours), for 5 consecutive days. Each 5-day sampling period was separated by 5 days of no tracking, resulting in approximately 60 fixes per month for each deer.

Triangulation of 3 azimuths was used to plot locations for each animal. Accuracy of the telemetry system was estimated as ±2°. A location was deemed unreliable and excluded from data analysis if the area of the error polygon (Springer 1979) was ≥1.3 ha. A total of 3,861 radio-fixes were used in analysis. Mean size of all acceptable error polygons was 0.2 ha. All reliable fixes were within 1.6 km of their respective tracking stations.

Monthly home ranges were determined by the 95% ellipse technique (Jennrich and Turner 1969). A one-way analysis of variance was used to test for differences between home range sizes of deer with activity centers (Hayne 1949) in the SDG cell or the CG pasture.

To compare relative movements of deer within the SDG cell and CG pasture, deer fixes were plotted on a map overlay of the study area. Movement indices for individual deer were determined by summing distances between successive fixes in each 5-day sample period. Monthly means were computed for each deer within a grazing treatment by summing distance data across each 5-day sampling period within a month and dividing by the total number of fixes for that month. Means were compared using a one-way ANOVA.

Deer Response to Cattle Rotation

Deer response to movement of the cattle herd under SDG was determined based on deer distribution frequency tables comparing deer locations relative to the paddock cattle occupied within each complete grazing cycle. The independent variable in the frequency distribution tables was cattle location; dependent variables were potential deer locations and presence/absence of deer in any 1 of 18 potential locations, both inside and outside the SDG cell (Fig. 1). A G-test was used to determine if deer significantly (α = 0.05) responded to cattle during the rotation by testing for homogeneity of deer frequency distributions among cattle locations (Kullback 1959).

Deer Habitat

Vegetative cover and frequency were monitored monthly on the SDG cell and CG pasture. Only those grass and forb species which comprised 2% or more of deer diets on the Welder Wildlife Refuge (Kie et al. 1980) were measured. Woody vegetation was not sampled because of its low occurrence in deer diets (Chamrad and Box 1968, Kie et al. 1980).

Cover and frequency were measured using six 0.10-m^2 rectangular quadrats placed at random intervals along each of 10 random transects in each grazing treatment. Cover was estimated, to the nearest 1%, by species by quadrat (Daubenmire 1959). Mean cover was calculated by month and compared between treatments using a one-way ANOVA. Frequency of occurrence was calculated monthly by dividing the number of quadrats containing a particular species by the total number of quadrats. Chi-square analysis was used to compare species frequency between SDG and CG.

Because of the size and nature of this experiment, the SDG and CG programs could not be replicated. Therefore, animal and vegetational variances within treatments were used for analyses. This approach is considered valid when time and cost preclude replication of a large experiment (Hurlbert 1984, Guthery 1987).

Table 2. Mean movement indices (m) for female deer captured in the short duration grazing cell and the continuously grazed pasture on the Welder Wildlife Refuge, 1983.

Grazing system		Month										
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SDG	$\bar{x}$[1]	519a	582a	556a	465a	406a	398a	525a	435a	395a	301a	426a
	SE	26	38	17	14	34	35	44	47	36	17	54
	n[2]	113	240	235	206	174	128	201	193	178	163	181
CG	$\bar{x}$	461a	663a	589a	396b	279b	274b	380b	332a	374a	382b	412a
	SE	19	36	16	12	30	33	41	49	39	19	62
	n	219	261	269	279	214	147	229	182	150	134	138

[1]Means within months were not significantly (P>0.05) different.
[2]n = number of fixes.

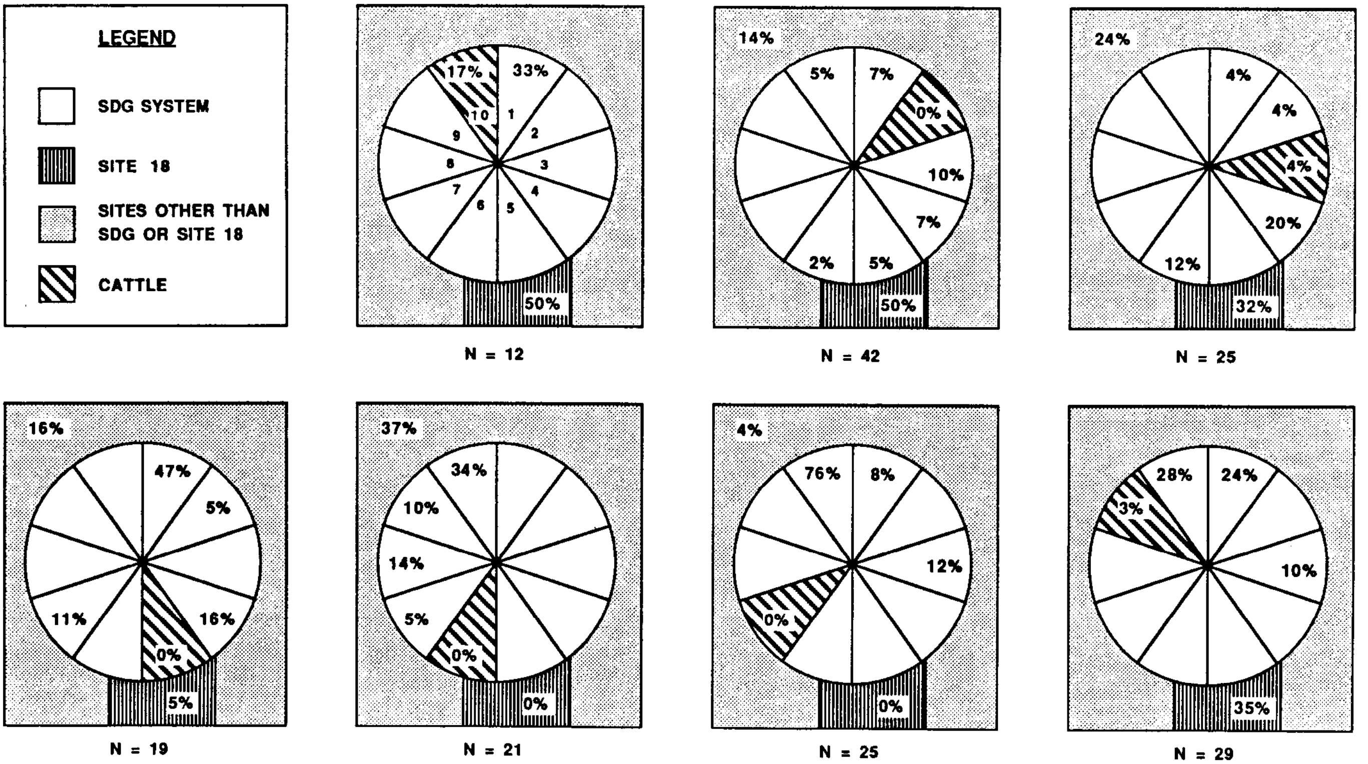

Fig. 2. *Schematic diagrams illustrating the significantly (P<0.05) correlated distributions of female deer locations relative to cattle location on the SDG cell at the Welder Wildlife Refuge. Successive diagrams indicate distributions on 8 March, 9–12 March, 18–20 March, 21–22 March, 28–29 March, 30 March–1 April, and 7–9 April, 1983. N = number of deer locations.*

Results and Discussion

Deer Home Range and Movement Indices

Home Range

Monthly deer home ranges were similar (P>0.10) between the SDG cell and CG pasture (Table 1). Large standard errors of the means indicated large variability during some months in home range size among individual deer. On a HILF grazing treatment, Adams (1978) found high stocking rates of livestock did not cause deer on the Welder Refuge to abandon their home ranges. Our radio-collared deer also showed fidelity to their home ranges during this study, regardless of grazing treatment and even though cattle stocking rates were relatively high (2.8 ha/auy) in both SDG and CG.

Mean home range size in this study was 218 ha. Inglis et al. (1979) reported a mean home range size of 84 ha for 25 does on the Welder Refuge, based on data collected from 1966 to 1970. During that period, the Refuge was only lightly grazed (7.2–7.7 ha/auy) by steers, and deer densities were 44% higher than 1982–1983 densities. Thus, intensive grazing programs and higher stocking rates or deer densities may have affected home range sizes on the Refuge. These hypotheses demand further investigation to determine the long-term relationships between white-tailed deer densities, home range sizes, and livestock grazing in south Texas.

Movement Indices

Examination of mean distances between fixes indicated deer traveled more during March and April than other months in both SDG and CG (Table 2). This peak corresponded with rapid vegetation growth during spring green-up and appears unusual since forage availability would be greatest at this time. Deer traveled least during early summer and fall on SDG and CG, with moderate travel during winter.

Throughout the entire 11-month study period, average distance between fixes was 10% greater under SDG than CG. Deer traveled significantly farther between fixes (P<0.05) under SDG than CG during May, June, July, and August (Table 2). The greatest differences were in June and July when deer traveled 46% and 45% farther between fixes, respectively, in SDG than CG, while the May to August average was 35% greater.

Deer are well adapted for energy conservation, but any disturbance which alters behavior can potentially depress productivity. Moen (1978) found white-tailed deer have their lowest metabolism in winter and their highest in summer. Fetal growth increases rapidly during late gestation (Verme 1963). Energy demands for the doe are at their highest level during the first 2 months of lactation (Moen 1978). Thus, late pregnancy and early lactation result in increased energy demands. This period of high energy demands by deer at the Welder Wildlife Refuge occurs in April and May (late gestation) and June and July (early lacatation). The observed increase in distance moved by female deer on the SDG cell during these physiologically important months warrants further investigation. In particular, studies of deer energy intake and expenditure under SDG are necessary to determine if increased activity during spring and summer negatively affects reproduction.

Deer Response to Cattle Rotation

Deer avoided (P<0.05) cattle as the herd moved through the SDG cell in 2 of the 8 grazing cycles during 1983. These significantly correlated grazing cycles were from 8 March to 9 April 1983 (Fig. 2), and from 17 May to 17 June 1983 (Fig. 3). Deer responded to cattle during the grazing cycle from 10 April to 16 May by moving their activity centers off the SDG cell and the Refuge to site 18. Radio fixes taken on deer did not always coincide with cattle presence in every paddock of the SDG cell. Thus, data were not

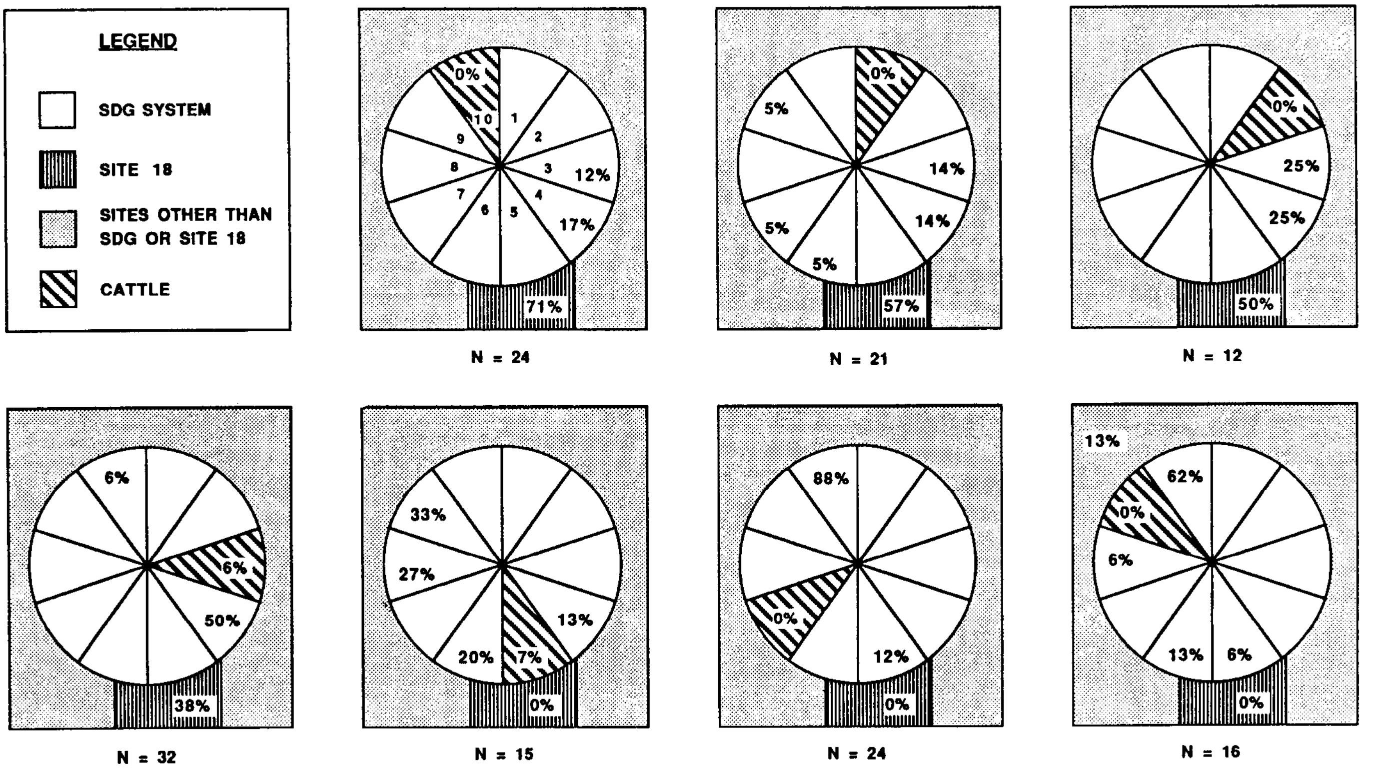

Fig. 3. *Schematic diagrams illustrating the significantly (P<0.05) correlated distributions of female deer locations relative to cattle location on the SDG cell at the Welder Wildlife Refuge. Successive diagrams indicate distributions on 17–18 May, 19–21 May, 27 May, 28–31 May, 6–7 June, 8–10 June, and 16–17 June, 1983. N = number of deer locations.*

available on deer when cattle were in paddocks 1, 4, and 8 of the March–April cycle and paddocks 4, 6, and 8 of the May–June cycle.

Behavioral patterns during both grazing cycles indicated deer preferred to position themselves off the SDG cell at site 18 whenever cattle were in paddocks 10, 1, 2, and 3 (Figs. 2 and 3). Site 18 was on an adjacent ranch that was grazed continuously yearlong at approximately 4.0 ha/auy, a relatively heavy rate. Fidelity for this site diminished as the cattle herd moved clockwise from paddock 10 to paddock 3. Cattle presence in paddocks 5, 6, or 7 caused a dramatic shift in deer distribution as they avoided site 18 and deer moved to paddocks 8, 9, 10, and 1 on the north side of the SDG cell. Thus, deer showed fidelity for 2 major sites and shifted back and forth as cattle approached either site. Although there was a secondary trend for deer to concentrate in paddocks 3 and 4, immediately in front of cattle rotation (Figs. 2 and 3), the primary trend was for the deer under SDG to avoid cattle concentrations by alternating between preferred habitats rather than a consistent paddock-to-paddock movement.

Although deer commonly used site 18, they consistently returned to the SDG cell. The apparent preference of the deer for the SDG cell may have been a consequence of fidelity to their home ranges or a preference for some particular aspect (i.e., forage, cover, lack of hunting) of the Refuge or the cell, but these hypotheses could not be tested in this study. Behavioral studies of the factors influencing site fidelity in white-tailed deer are suggested.

Adams (1978) and Kruger (Welder Wildlife Refuge progress report), studying deer response to HILF on the Welder Wildlife Refuge, felt social intolerance of deer for cattle may have caused some movement out of paddocks. McMahan (1966) and Kramer (1973) found deer clearly avoided livestock. Therefore, deer avoidance of cattle under SDG is not surprising.

Deer Habitat

Five grass species and 13 forb species designated as important to deer (Kie et al. 1980) were monitored from February to December 1983 on the SDG cell and CG pasture. Two important deer forage species, lazy daisy *(Aphanostephus ramossissimus)* and ironweed *(Vernonia texana)*, were not encountered in either SDG or CG, while purple lovegrass *(Eragrostis spectabilis)* and orange zexmenia *(Zexmenia hispida)* were found only during 1 month's sampling. Thus, cover and frequency trends are reported for 14 forage species.

Monthly percent cover was similar ($P>0.05$) between the 2 areas throughout the study period for doveweed *(Croton monanthogynus)*, bladderpod *(Lesquerella argyraea)*, evening primrose *(Oenothera speciosa)*, Texas frogfruit *(Phyla incisa)*, prairie coneflower *(Ratibida columnaris)*, Texas wintergrass *(Stipa leucotricha)*, snoutbean *(Rhynochosia minima)*, rescuegrass *(Bromus unioloides)*, and sedge *(Carex brittoniana)*. Percent cover was greater ($P<0.05$) on the CG pasture for western ragweed *(Ambrosia psilostachya)* during November, false mallow *(Malvastrum aurantiacum)* during July, wood sorrel *(Oxalis dillenii)* during October, vine mesquite *(Panicum obtusum)* during June through October, and common frogfruit *(Phyla nodiflora)* during April through September and November. During all other months of the study percent cover of these species was similar ($P>0.05$) on the 2 sites. No species was greater in monthly percent cover on the SDG cell during this study.

Generally, forage species important to deer were more common in the CG pasture, allowing greater opportunity for deer to encounter key food plants. Monthly percent frequency was greater ($P<0.05$) on the CG pasture for western ragweed during March and November, false mallow during May, July, and August, evening primrose during November, wood sorrel during October, Texas frogfruit during February and November, common frogfruit during March through December, rescuegrass during February through April and December, sedge during February, May, and December, and vine mesquite during May through November. Percent frequency was greater ($P<0.05$) on the SDG cell for bladderpod during December, evening primrose during February through May, and wood sorrel during July. Frequency was similar ($P>0.05$) between the 2 sites during all other months for the species mentioned above, and for doveweed, prairie coneflower, snoutbean, and Texas wintergrass throughout the study.

Kie et al. (1980) found rescuegrass, *Panicum* spp., and Texas wintergrass to be the most important grass species in adult deer diets on the Welder Wildlife Refuge. Rescuegrass (important in deer diets during late winter and early spring) and vine mesquite (late summer through early spring) both were more common on the CG pasture during these periods. Texas wintergrass, an important winter forage, was equally common on the 2 areas. Kie et al. (1980) reported false mallow was the most important forage species in deer diets on the Refuge, particularly during summer through late fall. This species was most common on the CG pasture during summer and equally common on SDG and CG throughout the rest of the year. Among the forbs, other important species in deer diets were western ragweed (summer) and prairie coneflower (early spring through summer). These species were equally common on the 2 areas during these periods.

Conclusions

We found female white-tailed deer traveled slightly farther between radio fixes on a SDG cell than under CG over the year. During the late spring and summer, distances between radio fixes were significantly ($P<0.05$) greater under SDG. Thus, SDG could increase energy demands during periods of gestation and fawn-raising, but the level, if any, at which added travel depressed reproduction is unknown. In the spring and early summer, deer clearly avoided SDG paddocks where cattle were concentrated. In general, there was no difference in monthly vegetative cover between SDG and CG. However, several forage species important to deer were less common under SDG than CG.

Literature Cited

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

Adams, N.E. 1978. The effects of cattle on white-tailed deer distribution. M.S. Thesis, Texas A&I Univ., Kingsville.

Bryant, F.C., F.S. Guthery, and W.M. Webb. 1982. Grazing management in Texas and its impact on selected wildlife, p. 94-112. *In:* J.M. Peek and P.D. Dalke (eds.), Wildlife-livestock relationships symposium proceedings 10. Univ. Idaho, For., Wildl., and Range Exp. Sta., Moscow.

Chamrad, A.D., and T.W. Box. 1968. Food habits of white-tailed deer in south Texas. J. Range Manage. 21:158-164.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northw. Sci. 33:43-64.

Drawe, D.L., and J.E. Cox. 1978. A coordinated range research program for the Welder Wildlife Foundation Refuge, p. 34-43. *In:* D.L. Drawe (ed.), 1st Welder Wildlife Foundation Symp. Proc., Corpus Christi, Tex.

Gould, F.W. 1975. Texas plants, a checklist and ecological summary. Texas Agr. Exp. Sta., Texas A&M Univ., College Station.

Guthery, F.S. 1987. Guidelines for preparing and reviewing manuscripts based on field experiments with unreplicated treatments. Wildl. Soc. Bull. 15:306.

Guynn, D.E., and L.D. White. 1984. Savory grazing method effect on white-tailed deer in the Edwards Plateau of Texas, p. 80-82. *In:* T.R. Krausman and N.F. Smith (eds.), Deer in the southwest: a symposium. School of Renewable Natur. Res., Univ. Ariz. Tucson.

Hallberg, D.L., F.J. Janza, and G.R. Trapp. 1974. A vehicle-mounted directional antenna system for biotelemetry monitoring. Calif. Fish and Game 60:172-177.

Hayne, D.W. 1949. Calculation of size of home range. J. Mamm. 30:1-18.

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

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

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

Howell, L.N. 1978. Development of multi-camp grazing systems in the Southern Orange Free State, Repub. So. Afr. J. Range Manage. 31:459-465.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54:187-211.

Inglis, J.M., R.E. Hood, B.A. Brown, and C.A. DeYoung. 1979. Home range of white-tailed deer in Texas coastal prairie brushland. J. Mamm. 60:377-389.

Jennrich, R.I., and F.B. Turner. 1969. Measurement of non-circular home range. J. Theoret. Biol. 22:227-237.

Kie, J.G., D.L. Drawe, and G. Scott. 1980. Changes in diet and nutrition with increased herd size in Texas white-tailed deer. J. Range Manage. 33:28-34.

Kramer, A. 1973. Interspecific behavior and dispersion of two sympatric deer species. J. Wildl. Manage. 37:288-300.

Kullback, S. 1959. Information theory and statistics. John Wiley and Sons, Inc., New York.

McMahan, C.A. 1966. Suitability of grazing enclosures for deer and wildlife research on the Kerr Wildlife Management Area, Texas. J. Wildl. Manage. 30:151-163.

Moen, A.N. 1978. Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. J. Wildl. Manage. 42:715-738.

Savory, A. 1979. Range management principles underlying short duration grazing. Beef Cattle Sci. Handb. 16:375-379. Agr. Serv. Found., Clovis, Calif.

Springer, J.T. 1979. Some sources of bias and sampling error in radio triangulation. J. Wildl. Manage. 43:926-935.

Verme, L.J. 1963. Effect of nutrition on growth of white-tailed deer fawns. Trans. North Amer. Wildl. Nat. Res. Conf. 28:431-443.

Toxicological investigations on Toano, Wasatch, and stinking milkvetches

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Abstract

Toano milkvetch (*Astragalus toanus* Jones) synthesizes the β-D-glucoside of 3-nitro-1-propanol (miserotoxin), a highly toxic aliphatic nitro compound, and also accumulates toxic levels of selenium. The toxicity of Toano milkvetch to 1-week-old chicks was compared with Wasatch milkvetch [*Astragalus miser* var. *oblongifolius* (Rydb.) Cronq.], which contains only miserotoxin but does not accumulate selenium; stinking milkvetch (*Astragalus praelongus* Sheld.), which accumulates selenium but does not contain miserotoxin; and a combination of Wasatch milkvetch and stinking milkvetch. The LD_{50} for chicks fed Toano milkvetch was 67.8 mg NO_2/kg plus 2.7 mg Se/kg of body weight. The LD_{50} for Wasatch milkvetch was 105 mg NO_2/kg and for stinking milkvetch 5.9 mg Se/kg. The LD_{50}s of a combination of Wasatch milkvetch and stinking milkvetch were 66.1 mg NO_2/kg and 2.7 mg Se/kg. When miserotoxin and selenium were fed together, either in Toano milkvetch or the Wasatch-stinking milkvetch combination, the LD_{50} for each compound was significantly lower than when they were fed separately. If seleniferous and nitro-bearing species grow sympatrically, livestock might be poisoned at lower concentrations of the individual toxic compounds if they grazed both species.

Key Words: *Astragalus toanus, Astragalus miser* var. *oblongifolius, Astragalus praelongus,* selenium, nitro compound, miserotoxin

Toxic compounds in the genus *Astragalus* include aliphatic nitro compounds (Williams and Barneby 1977), selenium (Rosenfeld and Beath 1964), and swainsonine (Molyneux and James 1982). The latter compound is an indolizidine alkaloid that causes locoism. Generally these poisonous compounds do not occur in the same species of *Astragalus.* Although swainsonine has been detected in nitro-containing and selenium-accumulating species, the species in which the concentration of swainsonine is high enough to cause the loco syndrome neither contain nitro compounds nor accumulate selenium.

Toano milkvetch (*Astragalus toanus* Jones) is the only species in the genus known to absorb toxic levels of selenium (Barneby 1964) and to synthesize aliphatic nitro compounds (Williams and Barneby 1977). The nitro compound was subsequently identified as miserotoxin, the β-D-glucoside of 3-nitro-1-propanol (Stermitz and Yost 1978). Miserotoxin hydrolyzes to 3-nitro-1-propanol (3-NPOH) in the rumens of cattle and sheep (Williams et al. 1970). This nitro compound is rapidly absorbed into the circulatory system and subsequently converted to 3-nitropropionic acid (3-NPA) (Muir et al. 1984, Pass et al. 1984). The effects of 3-NPA are two-fold: the nitrite complexes with ferrous hemoglobin to produce methemoglobin, and the 3-NPA affects the brain, central nervous system, and vital organs (James et al. 1980). Selenium adversely affects most vital organs.

Toano milkvetch is a member of the *Astragalus* section Pectinati (Barneby 1964). The plant is a robust, sparsely leafy perennial adapted to desert and semidesert conditions. Toano milkvetch is found in western Box Elder County, Utah, westward to the upper reaches of the Humboldt River in Nevada and along the Snake River in western Idaho. The showy pink-purple flowers appear in early May to early June. Toano milkvetch is not known to cause livestock losses, probably because it is not abundant, and it completes its life cycle and becomes dormant quickly.

The presence of dual poisons in plants has been noted in galenia [*Galenia pubescens* (Eckl. and Zeyh.) Druce] (Williams 1979), red spinach (*Trianthema triquetra* Rottb. ex Willd.) (Everist 1981), and kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) (Everist 1981), all of which may accumulate toxic levels of soluble oxalates and nitrates if ample water and nitrogen are available.

Toano milkvetch is of interest because it can be used to compare the synergistic effects of 2 poisons, both within the same plant, with other poisonous milkvetches that contain either miserotoxin or selenium but not both. The study compares the toxicity to chicks of Toano milkvetch (selenium and miserotoxin) with Wasatch milkvetch [*Astragalus miser* var. *oblongifolius* (Rydb.) Cronq.] (miserotoxin), and stinking milkvetch (*Astragalus praelongus* Sheld.) (selenium), and a combination of Wasatch milkvetch and stinking milkvetch.

Materials and Methods

Toano milkvetch was collected 4 May 1987 (full flower) and 12 May 1987 (late flower and pod), along Utah Highway 30, 10 miles east of the Nevada-Utah line. Wasatch milkvetch was collected during vegetative growth in the mountains near Logan, Utah, and vegetative stinking milkvetch was collected in the Henry Mountains of southern Utah. Wasatch and Toano milkvetch were oven-dried at 50° C for 24 hr. Stinking milkvetch was air-dried. All material was ground to pass a 40-mesh screen and stored in sealed containers until used.

The 3 milkvetches were analyzed for aliphatic nitro compounds using the method described by Williams and Norris (1969). Selenium was analyzed fluorometrically (Olson 1969) by H.F. Mayland, USDA-ARS, Kimberly, Idaho.

One-week-old Leghorn cockerels (50 ± 4 g) were used to bioassay the test material for toxicity. The chicks were removed from food and water overnight (15 hr) to empty the crop. Twenty chicks were used per dose and the experiment was repeated once. The plant material was encapsulated in No. 4 gelatin capsules and administered by hand each morning.

Wasatch milkvetch was fed at 114.0, 106.5, 99.6, and 93.1 mg NO_2/kg. Toano milkvetch was fed at 79.4, 71.1, 63.9, and 57.5 mg NO_2/kg. Since Toano milkvetch contained 350 ppm selenium, the above dosage also contained 3.2, 2.8, 2.6, and 2.3 mg Se/kg. Stinking milkvetch was fed at 6.6, 6.1, 5.6, and 5.3 mg Se/kg. Wasatch milkvetch was fed at 77.9, 68.8, 60.7, and 53.6 mg NO_2/kg plus stinking milkvetch at 3.1, 2.8, 2.4, and 2.1 mg Se/kg, or the same amount of selenium found in Toano milkvetch with the equivalent concentration of NO_2. Chicks were dosed between 8 and 9 a.m. on 2 consecutive days, observed for toxic signs, and the LD_{50} was determined 24 hr after the second dosage.

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Table 1. Toxicity to chicks of miserotoxin and selenium from Wasatch, Toano, and stinking milkvetches.

Species	Dose		No. chicks died[1]	LD_{50}		LD_{50}
	Mg NO_2/kg	Mg Se/kg		Mg NO_2/kg	Mg Se/kg	95% C.I. (mg/kg)
Toano milkvetch	79.4	3.2	20	67.8	2.7	NO_2 = 66.22 – 69.34
	71.1	2.8	17			Se = 2.70 – 2.72
	63.9	2.6	2			
	57.5	2.3	0			
Wasatch milkvetch + stinking milkvetch	77.9	3.1	20	66.1	2.7	NO_2 = 64.86 – 67.30
	68.8	2.8	14			Se = 2.58 – 2.72
	60.7	2.4	2			
	53.6	2.1	0			
Wasatch milkvetch	114.0	—	20	105.0	—	NO_2 = 103.28 – 106.66
	106.5	—	12			
	99.6	—	2			
	93.1	—	0			
Stinking milkvetch	—	6.6	20	—	5.9	Se = 5.77 – 5.98
	—	6.1	15			
	—	5.6	3			
	—	5.3	0			

[1]Twenty chicks were used per dose. Mean of 2 experiments. Number of deaths 24 hr after second feeding.

Dosages within the range of LD_0 and LD_{100} were determined from preliminary experiments. Geometrical progression for doses within these parameters were determined in accordance with the method of Weil (1952) for determining LD_{50}s. LD_{50}s were determined by probit transformation with a confidence level of 95%.

Results and Discussion

Miserotoxin analyses (expressed as mg NO_2/g of plant) for the 3 milkvetches were: Wasatch milkvetch, 11.6 mg/g; Toano milkvetch, 8.8 mg/g; and stinking milkvetch, 0.0 mg/g. Toano milkvetch contained 350 ppm selenium when collected 4 May and 150 ppm selenium on 12 May. Only the 4 May material was used. Stinking milkvetch contained 1,040 ppm selenium.

All chicks died when dosed with Wasatch milkvetch at 114 mg NO_2/kg, but there were no fatalities in the group fed at 93.1 mg/kg (Table 1). The mortality among chicks fed Toano milkvetch was 100% at 79.4 mg NO_2/kg but no deaths occurred at the lowest dose. The toxicity of a combination of Wasatch and stinking milkvetch was similar to Toano milkvetch with 100% mortality at 77.9 mg NO_2/kg and 3.1 mg Se/kg. Compared to the selenium in Toano milkvetch, or in the Wasatch and Toano milkvetch combination, twice as much selenium from stinking milkvetch was required to produce 100% mortality.

The LD_{50} for chicks fed Wasatch milkvetch was 105.0 mg NO_2/kg and the LD_{50} for stinking milkvetch 5.9 mg Se/kg (Table 1). The LD_{50} for Toano milkvetch was 67.8 mg NO_2/kg and 2.7 mg Se/kg. When Wasatch milkvetch and stinking milkvetch were fed together, the LD_{50}s were 66.1 mg NO_2/kg and 2.7 mg Se/kg. When miserotoxin and selenium were fed in Toano milkvetch, or from a combination of Wasatch and stinking milkvetches, the LD_{50}s for mg NO_2/kg and mg Se/kg were not significantly different. The LD_{50} for both mg NO_2/kg and mg Se/kg in Toano milkvetch and the Wasatch-stinking milkvetch combination was significantly different when compared with the LD_{50}s of NO_2/kg in Wasatch milkvetch and selenium in stinking milkvetch fed alone.

Chicks affected by miserotoxin or a combination of miserotoxin and selenium became depressed and stood with heads lowered and feathers ruffled. They fequently lost their balance and fell on their sides. In fatal cases the birds became paralyzed, comatose, and died. Chicks fed only selenium became depressed, stood with head lowered and ruffled feathers, but did not exhibit the loss of muscular coordination noted in chicks that received miserotoxin. In fatal cases, these chicks gradually became weaker, then comatose before death.

These data indicated that significantly larger amounts of selenium and miserotoxin must occur in separate plants to equal the toxicity of both compounds in one plant. If seleniferous and nitro-bearing species grew sympatrically, animals might be poisoned at lower concentrations of the individual compounds if they grazed both species.

The effects of dual poisoning in chicks by selenium and miserotoxin cannot be used to predict responses in domestic livestock that might consume the same compounds. Livestock are generally poisoned at lower doses (mg/kg of body weight) of these poisons than are chicks. The minimum lethal doses of selenium (administered orally as selenite) are 3.3 mg/kg of the body weight for horses, 3 mg for cattle, and 15 mg for swine (Rosenfeld and Beath 1964). A steer and a sheep died after they were gavaged with miserotoxin-containing plants at 25 and 37.5 mg NO_2/kg, respectively (Williams and James 1975, Williams and James 1978).

The additive or synergistic effect of two or more compounds involving selenium has practical application not only on the range but also where selenium, nitrates, and other compounds accumulate from runoff from seleniferous soils and cropped (thus fertilized) lands. Problems from the accumulation of selenium and other toxic compounds are particularly likely to occur when runoff terminates in basins that have no natural outlets. Deformities in waterfowl and embryos in their eggs have been observed in wildlife refuges fed by water from seleniferous soils and crop lands (Ohlendorf et al. 1986). The ingestion of selenium in combination with other poisonous elements or compounds may cause toxic syndromes in humans, wildlife, and livestock not observed with toxicosis from selenium alone.

Literature Cited

Barneby, R.C. 1964. Atlas of North American *Astragalus.* Memoirs of the New York Botanical Garden, Vol. 13. Bronx, New York.

Everist, S.L. 1981. Poisonous plants of Australia. Angus and Robertson, PTY, Ltd., Sydney, Australia.

James, L.F., W.J. Hartley, M.C. Williams, and K.R. Van Kampen. 1980. Field and experimental studies in cattle and sheep poisoned by nitrogen bearing *Astragalus* or their toxins. Amer. J. Vet. Res. 41:377-382.

Molyneux, R.J., and L.F. James. 1982. Loco intoxication: indolizidine alkaloids of spotted locoweed *(Astragalus lentiginosus).* Science 216:190-191.

Muir, A.D., W. Majak, M.A. Pass, and G.S. Yost. 1984. Conversion of 3-nitro-propanol (miserotoxin aglycone) to 3-nitropropionic acid in cattle and sheep. Toxicol. Lett. 20:137-141.

Ohlendorf, H.M., D.J. Hoffman, M.K. Saiki, and T.W. Aldrich. 1986. Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irrigation drainwater. Sci. Total Environ. 52:49-63.

Olson, O.E. 1969. Fluorometric analysis of selenium in plants. J. Assoc. Offic. Anal. Chem. 52:627-634.

Pass, M.A., W. Majak, A.D. Muir, and G.S. Yost. 1984. Absorption of 3-nitro-propanol and 3-nitropropionic acid from the digestive system of sheep. Toxicol. Lett. 23:1-7.

Rosenfeld, I., and O.A. Beath. 1964. Selenium. Academic Press, New York.

Stermitz, F.R., and G.S. Yost. 1978. Analysis and characterization of nitro compounds from *Astragalus* species, p. 371-378. *In:* R.F. Keeler, K.R. Van Kampen, and L.F. James (eds.), Effects of poisonous plants on livestock, Academic Press, New York, N.Y.

Weil, C.S. 1952. Tables for convenient calculation of median-effective dose (LD_{50} or ED_{50}) and instructions in their use. Biometrics 8:249-263.

Williams, M.C. 1979. Toxicological investigations on *Galenia pubescens*. Weed Sci. 27:506-508.

Williams, M.C., and R.C. Barneby. 1977. The occurrence of nitro-toxins in North American *Astragalus* (Fabaceae). Brittonia 29:310-326.

Williams, M.C., and L.F. James. 1975. Toxicity of nitro-containing *Astragalus* to sheep and chicks. J. Range Manage. 28:260-263.

Williams, M.C., and L.F. James. 1978. Livestock poisoning from nitro-bearing *Astragalus*, p. 379-389. *In:* R.F. Keeler, K.R. Van Kampen, and L.F. James (eds.), Effects of poisonous plants on livestock, Academic Press, New York, N.Y.

Williams, M.C., and F.A. Norris. 1969. Distribution of miserotoxin in varieties of *Astragalus miser* Dougl. ex Hook. Weed Sci. 17:236-238.

Williams, M.C., F.A. Norris, and K.R. Van Kampen. 1970. Metabolism of miserotoxin to 3-nitro-1-propanol in bovine and ovine ruminal fluids. Amer. J. Vet. Res. 31:259-262.

The effect of cattle grazing on the growth and miserotoxin content of Columbia milkvetch

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Abstract

The growth and miserotoxin content of Columbia milkvetch (*Astragalus miser* Dougl. var. *serotinus* (Gray) Barneby) were examined following grazing of early growth by cows at a grassland site in southern British Columbia. Grazing behavior and forage consumption of cows were observed. Growth of Columbia milkvetch was determined by measuring the freeze-dried weight of each plant and miserotoxin levels were determined by a rapid screening method. Cows had a tendency to either avoid Columbia milkvetch or to consume it incidentally with other forage so long as there was adequate grass available. As grass became scarce the use of Columbia milkvetch increased. After being grazed, the rate of growth and the toxicity of Columbia milkvetch were substantially reduced. In comparison to ungrazed plants, the aboveground biomass of grazed plants was reduced by more than 50% and the average miserotoxin content per plant was reduced by more than 75% during a 6-week period of regrowth. While early grazing may reduce the potential hazard of Columbia milkvetch to livestock, the plant is not a preferred species and may not be consumed by cattle until other forage becomes scarce. Heavy grazing intensity may, in turn, result in low vigor of bunchgrasses and a deterioration of range condition which may result in more weeds in the plant community. Clearly these aspects of management require further study.

Key Words: *Astragalus miser;* toxicity; growth; biomass; diets; selection

Columbia milkvetch (*Astragalus miser* Dougl. var. *serotinus* (Gray) Barneby), also known as timber milkvetch, and about 50 other species of *Astragalus* (Fabaceae) contain toxic glycosides of 3-nitro-1-propanol (Williams and Gomez-Sósa 1986). Miserotoxin, 3-nitro-1-propyl β-D-glucopyranoside, is the poisonous glycoside in 10 species and varieties of *Astragalus* that occur on rangelands in western North America (Stermitz and Yost 1978). In ruminants, miserotoxin is rapidly hydrolyzed by microbial enzymes of the rumen and the liberated nitroalcohol is rapidly absorbed and converted to 3-nitropropionic acid, an oxidation that is probably catalyzed by hepatic alcohol dehydrogenase (Majak et al. 1984, Pass et al. 1985). The nitroacid is the lethal metabolite and it is a potent inhibitor of mitochondrial enzymes essential to respiration (Gustine and Moyer 1983, Gould et al. 1985).

In an earlier study, we determined the effect of clipping on the growth and miserotoxin content of Columbia milkvetch in southern British Columbia (Majak et al. 1988). Growth was determined by measuring the freeze-dried weight of individual plants and the miserotoxin content of each plant was determined by a rapid screening procedure that permitted the analysis of a large number of plants. In response to early clipping in the spring, the biomass and toxicity of Columbia milkvetch were reduced by about 50% in both years (1984 and 1986) of the study. In practical terms, these results indicated that early grazing of Columbia milkvetch could reduce the potential hazard of the poisonous plant significantly. If cattle grazed the plant at early stages of growth when the biomass was small and the amount of toxin per plant was low, then the subsequent availability and toxicity of Columbia milkvetch would be reduced. This could be especially beneficial in a "second pass" situation where livestock forage on regrowth. The present study was conducted to verify the results of the earlier clipping trial. Biomass and miserotoxin content were again determined but this time in response to the effects of actual grazing and not mechanical clipping, which may not necessarily simulate the animals' feeding habits.

Materials and Methods

The experiment was conducted in a fenced paddock (37 × 44 m) at the rough fescue (*Festuca scabrella* Torr.) grassland site near Kamloops, B.C., which was described previously (Majak et al. 1988).

Plant community composition was estimated by establishing 3, 36-m long transects across the paddock. Cover values using a modified loop technique (10-cm loop) were taken at 1-m intervals

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along the transects. All plants rooted within the loop were recorded. This technique had been tested against the point frame method and found to give comparable results in this community (D. Quinton unpublished data). Biomass production was estimated by clipping 6 randomly located 1-m plots to ground level.

In the grazing trial 3 Hereford cows (3 years old) and their calves grazed the paddock from noon 6 May to noon 12 May 1987. The cattle were put in an adjacent holding pen to minimize trampling on the study site. Water was available at all times. Observations on grazing behavior were made at 0600, 1200, and 2000 h using the bite count technique (Reppert 1960). Labor constraints of other responsibilities dictated that all observations were not made during all time periods on all days. Each cow was followed closely by 1 of 3 observers who recorded a minimum of 700 bites per grazing time. The average period of observation was 54 min and the cattle were observed for a total time of 11 h. Bites of bunch grasses and the larger forbs were recorded by species. When cows were grazing a mixture of species among the larger plants it was impossible to identify intake by individual species so mixtures were recorded.

To measure the effects of grazing on Columbia milkvetch, the size (basal area × height) of 120 plants within the paddock ("grazed" plants) and 140 plants adjacent to the paddock ("ungrazed" plants) was determined before the grazing trial started. Grazed and ungrazed plants were arranged by volume from smallest to greatest and then sorted, according to size, into 20 blocks of 6 plants each in the case of grazed plants and 7 plants each in the case of ungrazed plants. One plant from each grazed block was randomly assigned to each of the 6 grazed groups within the paddock. Similarly, one plant from each ungrazed block was randomly assigned to each of the 7 ungrazed groups adjacent to the paddock. This ensured an even disribution of biomass in all sample groups. To provide base data one ungrazed group adjacent to the paddock was harvested when grazing began. All grazed plants were measured following grazing to estimate the degree of use. After the grazing period ended, 1 ungrazed and 1 grazed group of 20 plants (excised at the base just above the crown) was collected each week for 6 weeks from 12 May to 23 June. Data were collected in a design of 2 treatments and 6 harvest dates (Table 1).

Table 1. Experimental design for collecting groups of grazed (C) and ungrazed (U) Columbia milkvetch plants after the grazing period which ended on 12 May 1987. Each group contained 20 plants.

Regrowth period (week)	Sampling Date						
	12 May	19 May	26 May	2 June	9 June	16 June	23 June
0	U	U	U	U	U	U	U
1		G					
2			G				
3				G			
4					G		
5						G	
6							G

Freshly collected plants were freeze-dried and extracted individually. Miserotoxin concentrations were estimated by the rapid, colorimetric procedure described previously (Majak et al. 1988). Fifty plant extracts were also analyzed by high pressure liquid chromatography (HPLC) to check the accuracy of the colorimetric method. Extracts were treated with 10% $ZnSO_4.7H_20$ (1 volume) and 0.5 N NaOH (0.5 volume) to precipitate protein prior to HPLC. Duplicate HPLC determinations were facilitated with a Varian 9090 auto sampler. The HPLC column was cleaned with a methanol gradient between injections of plant extracts (Muir and Majak 1984). The differences in miserotoxin values obtained by the 2 methods were calculated and the accuracy of the colorimetric method was estimated from the standard deviation (SD) of the differences.

The effects of grazing and regrowth time on plant weight (g of dry matter), toxin concentration (percent miserotoxin), and the total amount of toxin per plant were examined by analysis of variance. The amount of toxin per plant was transformed to logs for analysis. Linear and quadratic curves were fitted using polynomial regression (Freund and Littell 1981).

Results and Discussion

Eighty-seven percent of the total production of 242 g/m² (dry matter) was grasses (Table 2). *Festuca scabrella,* occurring in less than 20% of the cover loops (Table 3), accounted for more than one-half the total biomass production. Columbia milkvetch, occurring in 44% of the cover plots, accounted for 59% of the total production (30.4 g/m²) of forbs.

Table 2. Average production of rough fescue grassland paddock near Kamloops, B.C. during a grazing trial in May 1987.

Species	Percentage of total production	Dry matter g/m² ± SE
Festuca scabrella	54.2	131.2 ± 39.9
Grass and grass-like plants[1]	24.8	60.0 ± 19.5
Agropyron spicatum	8.3	20.1 ± 15.1
Astragalus miser	7.5	18.2 ± 4.4
Forbs[2]	5.2	12.6 ± 1.0

[1]Grass and grass-like plants may contain species of *Poa, Carex, Juncas, Koelaria* and *Stipa.*
[2]Forbs may contain species of *Achillea, Erigeron, Ranunculus, Calachortus, Tragopogon, Delphinium, Aster, Antennaria, Taraxacum, Cerastium* and *Saxifraga.*

Table 3. Cover classes of forage inside 37×44 m paddock for grazing of Columbia milkvetch in southern B.C.

Percent cover	Species
80–100%	None
60– 80%	*Poa pratensis*
40– 60%	*Astragalus miser, Achillea millefolium*
20– 40%	*Antennaria, Koelaria, Montia/Rannunculus*
1– 20%	*Agropyron spicatum, Festuca scabrella, Koeleria, Cerastium, Fritillaria, Tragopogon, Collinsia, Microsteris, Taraxacum, Erigeron, Juncus, Delphinium, Calochortus, Balsamorhiza, Aster, Spartina, Stipa, Poa sandbergii, Lithospermum, Polygonum, Comandra, Crepis*

Preliminary observations of cow diets (Table 4) showed that cows initially consumed the *Festuca* and *Poa* grass/forb mix. Cows made several passes over the paddock regrazing plants that

Table 4. Diets of 3 cows grazing Columbia milkvetch paddock during 6–12 May 1987 in southern B.C.

Day	% of total bites				
	Agropyron spicatum	*Festuca scabrella*	Grass/forb mix[1]	Grass/forb/- vetch mix[1]	*Astragalus miser*
1	1.9	49.7	47.4	0.4	0.7
2	1.2	21.2	45.0	30.6	2.1
3	1.7	13.7	72.7	10.1	1.8
4	1.6	43.7	24.7	28.4	1.7
5	4.2	24.0	62.2	2.3	7.3
6	0.9	17.0	77.9	0.0	4.5
Average	1.8	22.7	60.4	12.2	2.9

[1]Mixes may contain species of *Poa, Carex, Juncus, Koelaria, Stipa.* Forbs, including vetch made up less than 10% of composition.

had been initially selected. After 2 days of grazing, most *Festuca* plants had been grazed with some plants showing severe use. At this time most of the palatable forage in the paddock had some degree of usage. Most Columbia milkvetch consumed early in the study was taken incidentally in conjunction with other forages by cow #2 (Table 5), which grazed mainly the grass/forb/vetch component of the community in a nonselective manner. Columbia

Table 5. Consumption of Columbia milkvetch by individual cows in a rough fescue paddock in B.C. during 6–12 May 1987.

		% of total bites		
		Cow 1	Cow 2	Cow 3
Day:				
1	12 NOON	0.7	0.6	0.0
	8 PM		3.2	
2	6 AM		8.7	0.2
	12 NOON	0.0	0.9	
	8 PM		1.6	0.4
3	6 AM		2.5	0.2
	12 NOON		3.8	0.5
4	6 AM	1.1	2.2	0.4
	8 PM		2.0	
5	6 AM	2.3	2.0	
	8 PM			9.6
6	6 AM	1.8	8.1	

milkvetch plus other forbs constituted less than 10% of the composition of diet mixes. Cows #1 and #3 were observed to mouth vetch, reject it and then avoid it in grazing. However, as grasses and other forage became scarce, more Columbia milkvetch was consumed (Tables 4 and 5). Cows #2 and #3 were observed to be actively seeking Columbia milkvetch on days 5 and 6, reaching through the fence to graze plants on the perimeter of the paddock. The average miserotoxin concentration at the time of grazing was about 6%. At this level it would take 1.2 kg dry weight of plant material to acutely poison a cow (Williams et al. 1967, James et al. 1980). No visual effects of poisoning were present during this study. Usage of the grazed milkvetch plants (Table 6) was relatively uniform. Ninety-

Table 6. Average height of 120 marked plants of Columbia milkvetch following heavy grazing of a 37 × 44 m paddock in southern B.C.

Grazing intensity	No. of plants	Height (cm)
All stems grazed	44	2.2
Few stems ungrazed	65	2.6
Two heights	2	7.0 & 2.8
Topped	5	6.0
Ungrazed	1	10.0
Manure covered	3	

one percent were grazed to an average height between 2 and 3 cm, 2% were partially grazed to 2 heights, 4% were topped and 3% were not grazed.

In agreement with our previous study there was a good correlation between the analytical HPLC procedure and the rapid screening method for miserotoxin determination (r=0.99 n =50). In 1987, the average difference ($\bar{x}$) between the quick method and the HPLC procedure was 0.69% miserotoxin and the SD of the difference was 0.39. In the earlier studies, the comparable values were $\bar{x}$ = 0.16 (SD=0.55) for 1986 and $\bar{x}$ = 0.54 (SD=0.77) for 1984. Thus the dispersion about the mean was the smallest in 1987 but the largest in 1984 when the protein precipitation step was not used. The use of the auto-sampler in 1987 was especially advantageous since it greatly improved the efficiency and reproducibility of the HPLC procedure and this may have improved the correlation between the 2 methods.

In 1987 the rate of growth of the milkvetch plants at the grassland site (Fig. 1) closely resembled the pattern that was observed in 1986 (Majak et al. 1988). This could be partly attributed to the

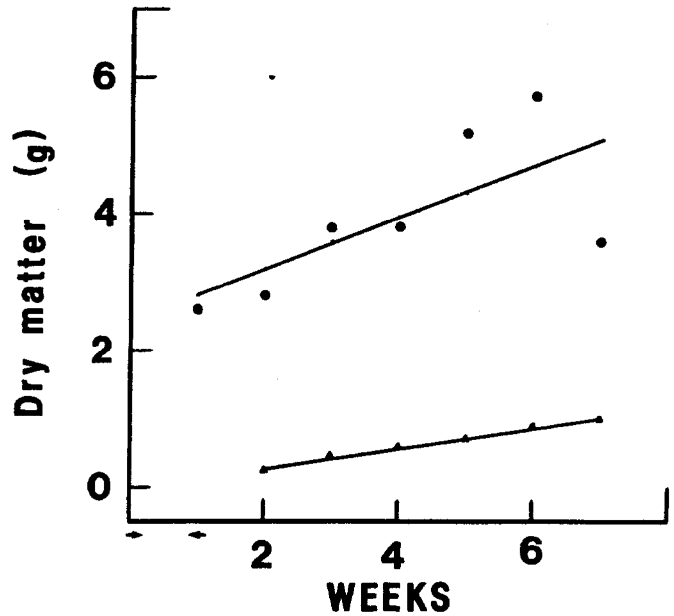

Fig. 1. *Effects of grazing on the average above ground biomass (dry matter) of Columbia milkvetch plants during 1987. Ungrazed plants are indicated with circles and grazed plants with triangles. Arrows indicate the grazing period. SE (dry matter) = 0.56.*

average temperatures for May and June, which were close to normal in both of those years unlike 1984, which had the coldest May on record (Atmospheric Environment Service 1984, 1986, 1987). The phenological developments of the plants in 1986 and 1987 were also similar as the plants progressed from the early bud stage of growth and into the bloom and pod stages during the 6-week study periods.

The analysis of variance revealed the same trends reported previously in the clipping study (Majak et al. 1988). The synthesis and accumulation of miserotoxin followed a pattern similar to the change in the biomass with the significantly higher amount of the toxin (Fig. 2) being present in the largest plants (Fig. 1). The effects of grazing on the dry matter biomass of Columbia milkvetch (Fig. 1) were identical to the effects of clipping (Majak et al. 1988). The growth curves for the clipped plants at the grassland site in 1986 and the grazed plants at the same site in 1987 were superimposable. Both treatments resulted in a marked diminution of Columbia milkvetch dry matter (Fig. 1) and a correspondingly significant decrease in the amount of available toxin per plant (Fig. 2). These combined results verify our previous hypothesis that early grazing can significantly reduce the potential hazard of Columbia milkvetch to livestock.

When the miserotoxin content was expressed as a percentage of the dry matter, ungrazed plants showed a typical decline in toxin concentration with advancing stages of growth (Table 7). It should be emphasized, however, that this decrease in concentration was overshadowed by the larger increase in biomass and the concomitant greater availability of the toxin (Fig. 1 and 2).

Miserotoxin concentrations were also determined in grazed plants where the ungrazed portion of the plant was usually combined with the regrowth material to make a sample of sufficient size for chemical analysis. The miserotoxin concentrations in the total

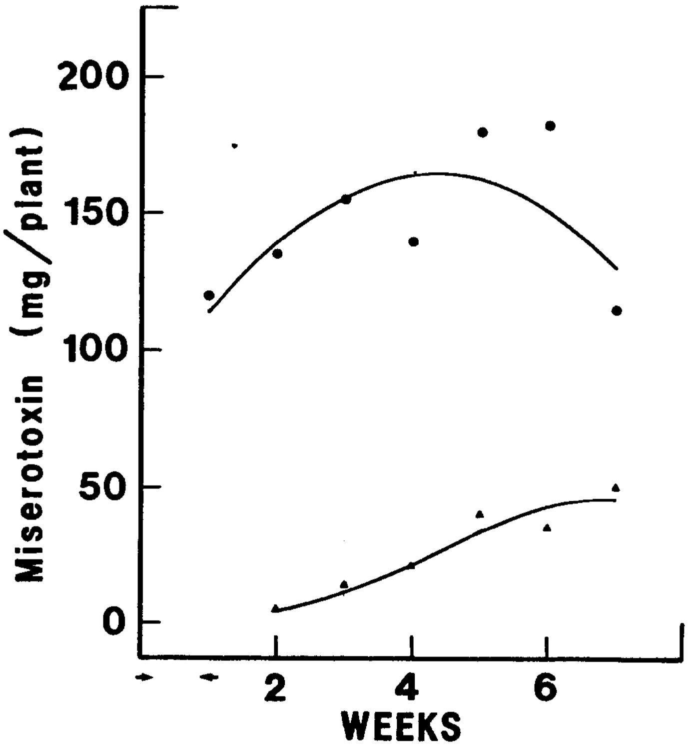

Fig. 2. *Effects of grazing on the average amount of miserotoxin in Columbia milkvetch plants during 1987. Ungrazed plants are indicated with circles and grazed plants with triangles. Arrows indicate the grazing period. SE (miserotoxin) = 0.20 ($\bar{x}$).*

biomass of the grazed plants showed an increase during the study period (Table 7). This increase could be attributed to the increasing proportion of the regrowth biomass and its higher level of the toxin (Table 7). In addition, this trend would be enhanced by the decreasing biomass of the ungrazed portion due to senescence and its lower level of the toxin (Table 7). The miserotoxin levels in the ungrazed biomass appear to be lower than in the controls, but whether this is a physiological response to the effects of grazing is not known. Higher concentrations of miserotoxin in regrowth tissue were also reported earlier (Majak et al. 1988) but the consequences of this should not be misconstrued because the amount of toxin available for consumption is substantially reduced by the effects of grazing (Fig. 2).

Table 7. Average miserotoxin concentrations (%) in grazed and ungrazed Columbia milkvetch plants after the grazing trial at the grassland site in southern B.C., in 1987, data expressed on a dry matter basis.

		Grazed plants		
Date	Ungrazed plants[1]	Regrowth biomass[2]	Ungrazed biomass[2]	Total biomass[1]
	(% miserotoxin)			
12 May	5.89	—	—	—
19 May	5.85	—	—	3.40
26 May	4.96	6.03 (5)	4.50 (4)	3.93
2 June	5.23	7.43 (9)	3.70 (9)	4.54
9 June	4.83	7.49 (14)	4.03 (12)	7.34
16 June	4.31	7.63 (6)	3.53 (4)	7.04
23 June	3.86	6.55 (12)	2.65 (7)	6.09

[1]Each value is the mean of 20 determinations. SE = 0.30.
[2]Number of determinations are indicated in brackets.

Preliminary grazing studies indicate that Columbia milkvetch is neither a highly preferred species nor is it selectively grazed by cattle under good range conditions. Cattle, however, can be forced to eat Columbia milkvetch when other forages are scarce. Caution should be exercised in early grazing systems or in grazing that utilizes the regrowth of milkvetch since anecdotal evidence in southern B.C. indicates that under certain conditions cattle may become addicted to the plant. Caution may also be given to preventing overuse of preferred species in an effort to force cattle to graze Columbia milkvetch. Bluebunch wheatgrass and rough fescue in particular are in a stage of accelerated growth with minimum annual root reserves (McIlvanie 1942) and thus they are at the most vulnerable stage of growth to be defoliated by grazing. Overuse may result in reduced vigor of grasses, deteriorating range condition, and even more weeds in the plant community. Clearly, using early grazing as a tool to manage rangeland infested with Columbia milkvetch warrants further study.

Literature Cited

Atmospheric Environment Service. 1984, 1986, and 1987. Monthly record. Meterological observations in Western Canada. May, June. Environment Canada, Atmos. Environ. Serv. Downsview, Ontario.

Freund, R.J., and R.C. Littell. 1981. SAS for Linear Models, Guide to the ANOVA and GLM Procedures. SAS Institute Inc., Cary, North Carolina.

Gustine, D.L., and B.G. Moyer. 1983. Review of mechanisms of toxicity of 3-nitropropanoic acid in nonruminant animals. p. 736-738. *In:* J.A. Smith and V.W. Hays (eds.). Proceedings XIV Inter. Grassland Congr. Westview Press, Boulder, Colo.

Gould, D.H., M.P. Wilson, and D.W. Hamar. 1985. Brain enzyme and clinical alterations induced in rats and mice by nitroaliphatic toxicants. Toxicol. Lett. 27:83-89.

James, L.F., W.J. Hartley, M.C. Williams, and K.R. Van Kampen. 1980. Field and experimental studies in cattle and sheep poisoned by nitro-bearing *Astragalus* or their toxins. Amer. J. Vet. Res. 41:377-382.

Majak, Wa., M.A. Pass, A.D. Muir, and L.M. Rode. 1984. Absorption of 3-nitro-propanol (miserotoxin aglycone) from the compound stomach of cattle. Toxicol. Lett. 23:9-15.

Majak, W., D.A. Quinton, H.E. Douwes, J.W. Hall, and A.D. Muir. 1988. The effect of clipping on the growth and miserotoxin content of Columbia milkvetch. J. Range Manage. 41:26-29.

McIlvanie, S.K. 1942. Carbohydrate and nitrogen trends in bluebunch wheatgrass *(Agropyron spicatum)* with special reference to grazing influences. J. Plant Physiol. 17:540-557.

Muir, A.D., and W. Majak. 1984. Quantitative determination of 3-nitropropionic acid and 3-nitropropanol in plasma by HPLC. Toxicol. Lett. 20:133-136.

Pass, M.A., A.D. Muir, W. Majak, and G.S. Yost. 1985. Effect of alcohol and aldehyde dehydrogenase inhibitors on the toxicity of 3-nitropropanol in rats. Toxicol, Appl. Pharmacol. 78:310-315.

Reppert, J.N. 1960. Forage preference and grazing habits of cattle at the Eastern Colorado Range Station. J. Range Manage. 13:58-62.

Stermitz, F.R., and G.S. Yost. 1978. Analysis and characterization of nitro compounds from *Astragalus* species. p. 371-378. *In:* R.F. Keeler, K.R. Van Kampen, and L.F. James (eds.). Effects of poisonous plants on livestock. Academic Press, New York.

Williams, M.C., K.R. Van Kampen, and F.A. Norris. 1969. Timber milkvetch poisoning in chickens, rabbits and cattle. Amer. J. Vet. Res. 30:2185-2190.

Williams, M.C., and E. Gomez-Sósa. 1986. Toxic nitro compounds in species of *Astragalus* (Fabaceae) in Argentina. J. Range Manage. 39:341-344.

Effects of short-duration grazing on winter annuals in the Texas Rolling Plains

JEFFREY R. WEIGEL, GUY R. MCPHERSON, AND CARLTON M. BRITTON

Abstract

A study was conducted in the Texas Rolling Plains to test the hypotheses that short-duration grazing increases plant density and diversity in grasslands. Densities of 9 species of winter annual forbs and 2 species of annual grass were compared in short-duration grazed and ungrazed areas for 2 years. Livestock grazing in spring and early summer affected density of 8 winter annuals the following winter. Densities of 2 grasses [little barley (*Hordeum pusillum* Nutt.) and six-weeks fescue (*Vulpia octoflora* [Walt.] Rydb.)] and 3 forbs [common broomweed (*Xanthocephalum dracunculoides* [DC.]), Gordon's bladderpod (*Lesquerella Gordonii* [Gray] Wats.), and Texas filaree (*Erodium texanum* Gray.)] were higher in grazed areas; 3 forbs [bitterweed (*Hymenoxys odorata* DC.), spurge (*Euphorbia* sp.), and woolly plaintain (*Plantago patagonica* Jacq.) were more abundant in exclosures. Richness and diversity of winter annuals generally were not affected by grazing. Increased precipitation during germination and establishment greatly increased the density of winter annuals.

Key Words: plant density, plant diversity, soil strength

Short-duration grazing (SDG) is an intensive, rotational grazing system which uses relatively short grazing periods separated by long rest periods, and high stocking densities to manipulate grazing pressure, forage utilization, and subsequent forage and livestock production (Ralphs et al. 1984). Proponents of SDG have suggested that it closely approximates grazing patterns of native herbivores (Savory and Parsons 1980, Savory 1983, Walter 1984). These authors suggest that dense concentrations of animals provide a beneficial animal impact on soil called 'herd effect'. Herd effect purportedly improves grassland condition by 'chipping' the soil surface, thereby enhancing infiltration (Blackburn 1984, Thurow et al. 1986), herbage production, and seedling emergence.

The objective of this study was to document density of winter annual forb and grass species following SDG during the flowering and seeding period. Density in ungrazed exclosures was also recorded to test the hypotheses that SDG increases density of individual species and SDG increases diversity of annuals in a grassland community.

Materials and Methods

Research was conducted in 1985 and 1986 at the Texas Tech Experimental Ranch 10 km southeast of Justiceburg (Garza County), Texas (101° 11′ W, 32° 58′ N). Study plots were located in a honey mesquite/tobosagrass/alkali sacaton (*Prosopis glandulosa* var. *glandulosa* Torr./*Hilaria mutica* [Buckl.] Benth./*Sporobolus airoides* [Torr.] Torr.) grassland in the Texas Rolling Plains (Gould 1969; nomenclature follows Correll and Johnston 1970). Regional climate is semiarid, with two-thirds of the 490 mm of average annual precipitation falling from May to October. Long-term average precipitation during the fall-winter (September–February) period of peak emergence of annual species is 170 mm (NOAA 1985). Study site soils were nearly level Stamford clays (fine, montmorillonitic, thermic Typic Chromusterts) intermixed with small areas of Vernon clay loams (fine, mixed, thermic Typic Ustochrepts). Stamford soils contain predominantly montmorillonitic clays with high shrink-swell potential (Richardson et al. 1965).

The site was continuously grazed at a moderate intensity by cattle before 1984. It was burned in February 1983 and sprayed with triclopyr (((3,5,6-trichloro-2-pryridinyl)oxy)acetic acid) at a rate of 0.5 kg a.e./ha in July 1983 for control of honey mesquite. At the time of herbicide application, annual and perennial forbs were dormant and thus not affected by treatment. A six-pasture SDG system was established in 1984. Since 1984, pastures have been grazed by livestock seasonally from mid-April to mid-July each year. Fire, herbicide application, and grazing had minimal influence on perennial plant composition. Pastures were characterized by relatively homogeneous stands of tobosagrass and alkali sacaton, under short (1-1.5 m) mesquite plants. Animals were sequentially rotated from pasture to pasture during the grazing season; adjustments in length of grazing and rest periods were based on forage growth and availability (Savory and Parsons 1980, Savory 1983).

Study plots were located in a representative, 14-ha pasture in the six-pasture system. Plots were located in a 2-ha area about 550 m from the single watering point of the 800-m long triangular pasture. The study pasture was grazed by 60 (1985) and 42 (1986) yearling Hereford/Angus crossbred steers for 3 periods each year. Stocking rates were twice (1985) and 1.5 times (1986) those recommended (SCS staff, pers. comm.) for moderate, yearlong-continuous grazing. In both years, the initial 2 grazing periods were 7 days, followed by rest periods of 35 and 21 days in 1985 and 33 and 30 days in 1986. A final grazing period of 3 days in 1985 and 2 days in 1986 occurred before removal of all animals.

A randomized complete block design with 8 blocks was used. Thirty-two, 0.01-m² plots were permanently marked in each block, half in randomly located ungrazed wire-mesh exclosures. A small quadrat size was selected because winter annuals were small and numerous (Kershaw and Looney 1985). Each of 4 exclosures per block contained 4 ungrazed plots; 4 groups of 4 grazed plots were located nearby. Grazed plots were located at least 3 m from exclosures and were marked belowground to avoid increased trampling by animals attracted to exclosure fences or aboveground plot markers. A metal detector was used to locate plots on sampling dates (Weigel and Britton 1986). Blocks were relocated and new plots established before the second grazing season; plots were located in the same 2-ha area each year.

Herbaceous foliar cover of perennial plants was estimated photographically in grazed areas and exclosures after each grazing season. Black-and-white photographs were taken with a 35-mm camera and 50-mm lens from 1.5 m above 16, 0.25-m² plots in each treatment in each block (N = 128/treatment). A dot-grid overlay (50

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dots/grid) was used to measure foliar cover of individual plots.

Soil strength was determined with a proving-ring penetrometer (Soiltest CN-970) after each grazing season. Soil strength is highly correlated with soil bulk density, a measure of soil compaction (Gifford et al. 1977). Eighty measurements per treatment per block were taken in groups of 20 closely spaced (0.5-m^2 area) samples (N=640 measurements per treatment).

Beginning with the first post-grazing seedling emergence event in October 1985, density of all annual species was recorded bimonthly through February 1987, when the onset of a third season of grazing forced termination. Sampling was not conducted during summer when the previous season's plants had senesced and the next season's plants had not yet germinated. Sample dates were classified as either Season 1 (1985–86) or Season 2 (1986–87) based on phenology of species studied. Four and 3 sample dates comprised Seasons 1 and 2, respectively.

Species recorded in at least 5% of plots for any date-treatment combination were analyzed for treatment response (Gauch 1982) using analysis of variance with 8 blocks and 2 treatments. In addition, mean species richness (number of species per quadrat), and mean diversity were estimated for each date and treatment using all species. Diversity was estimated with Simpson's c (which decreases with increasing heterogeneity) and Shannon's H (which increases with increasing heterogeneity) (Greig-Smith 1983). Diversity indices were highly correlated (grazed r=–0.99, ungrazed r=–0.96); only H is presented.

Results

Nine species of winter annual forbs and 2 species of annual grass were analyzed (Table 1). Seven additional species of annual forbs were encountered but not analyzed because of low frequencies (<5%) for each date-treatment combination. Since date × treatment interactions were significant ($P<0.05$) the response of annuals to grazing was compared within dates.

Table 1. Scientific and common names of common annual forbs and grasses in the Texas Rolling Plains, 1985–1987.

Scientific Name	Common Name
Forbs:	
Evax verna Raf.[1]	rabbit tobacco
Xanthocephalum dracunculoides (DC.) Shinners.	common broomweed
Plantago patagonica Jacq.	woolly plantain
Plantago rhodosperma Dcne.	red-seeded plantain
Euphorbia sp.	spurge
Hymenoxys odorata DC.	bitterweed
Astragalus sp.	astragalus
Lesquerella Gordonii (Gray) Wats.	Gordon's bladderpod
Erodium texanum Gray.	Texas filaree
Grasses:	
Hordeum pusillum Nutt.	little barley
Vulpia octoblora Walt.) Rydb.	six-weeks fescue

[1]Nomenclature follows Correll and Johnston 1970.

SDG influenced density of both annual grasses and 6 of 9 forbs during at least 1 sampling date (Fig. 1). Density differences between grazed and ungrazed plots were most prevalent during Season 1, when densities of all species were relatively high. Season 2 was characterized by lower densities and little treatment response. Densities of rabbit's tobacco (*Evax verna* Raf.), red-seeded plantain (*Plantago rhodosperma* Dcne.), and astragalus (*Astragalus* sp.) did not differ ($P>0.10$) in any period (Fig. 1a). Decreased ($P<0.05$) herbaceous cover and increased soil strength was associated with grazed areas (Table 2).

Mean richness varied from 2.1 to 4.1 species/quadrat, and did not differ between treatments on any date. Mean diversity was higher ($P<0.05$) in ungrazed quadrats (H = 0.87) than grazed quadrats (H = 0.81) on 4 February 1986; diversity did not differ ($P>0.10$) between treatments on other dates. Shannon-Weaver's H varied from 0.52 to 1.00.

Table 2. Mean (±S.E.) herbaceous foliar cover and soil strength in grazed areas and exclosures following short-duration grazing in the Texas Rolling Plains.

	Foliar cover		Soil strength	
Season	Grazed	Ungrazed	Grazed	Ungrazed
1	%		MPA	
1	14±1	18±1	0.92±0.01	0.67±0.01
2	20±1	29±2	1.13±0.01	0.85±0.01

Discussion

Above-normal fall precipitation in both seaons provided excellent germination conditions both years. However, densities of most forbs and both grasses were higher in Season 1 regardless of treatment. Lower density of these species in Season 2 may have been related to very low Season 1 winter precipitation and very high Season 2 fall precipitation. Beatley (1974) attributed late winter mortality of Mojave Desert annuals to decreased soil moisture during the critical winter growth period, although some mortality occurred even in years with adequate moisture. Several researchers have demonstrated density-dependent thinning in desert annuals (Fowler 1986). Season 2 fall precipitation occurred early in that period, and was nearly twice normal (Fig. 2). This stimulated vigorous growth of perennial grass dominants, which may have reduced germination and survival of annuals through preemption of soil moisture (Friedman et al. 1977). Thus, below-average precipitation during previous year's flowering and above-average precipitation prior to germination may have reduced current year's densities.

Density differences between years probably resulted from differential precipitation patterns, and not from fire-herbicide treatments. Winter annual densities in this area recover to pretreatment levels within 2 years (Steuter and Wright 1983). Precipitation had a greater impact on densities of winter annual than grazing, which is consistent with other studies (Beatley 1974, Fowler 1986). Despite the overriding influence of precipitation which tended to mask treatment effects, the structure of the winter annual community was effected by SDG.

Little is known about life history characteristics of any of the species studied. The lack of autecological information makes explanation of species' responses highly speculative. Winter annuals usually are regarded as stress-tolerant ruderals capable of exploiting bare and/or trampled areas (Grime 1979). Mechanisms by which plants establish in these areas have been reviewed by Peart (1984) and Booth (1987) in the context of seed morphology and by Evans and Young (1987) in the context of seedbed microenvironment. Five species [little barley, six-weeks fescue (Fig. 1b), common broomweed, Gordon's bladderpod, Texas filaree (Fig. 1c)] exhibited this ability at some time during this study. Decreased herbaceous cover and increased soil strength in grazed areas created favorable microsites for establishment of these species. However, 6 species (all forbs) displayed no response [rabbit's tobacco, astragalus, red-seeded plantain (Fig. 1a)] or had higher densities in quadrats excluded from grazing [spurge, bitterweed, woolly plantain (Fig. 1d)]. These species were not favored by disturbance in the form of SDG, at least in the short term.

Compared to no grazing, the primary effects of SDG are to

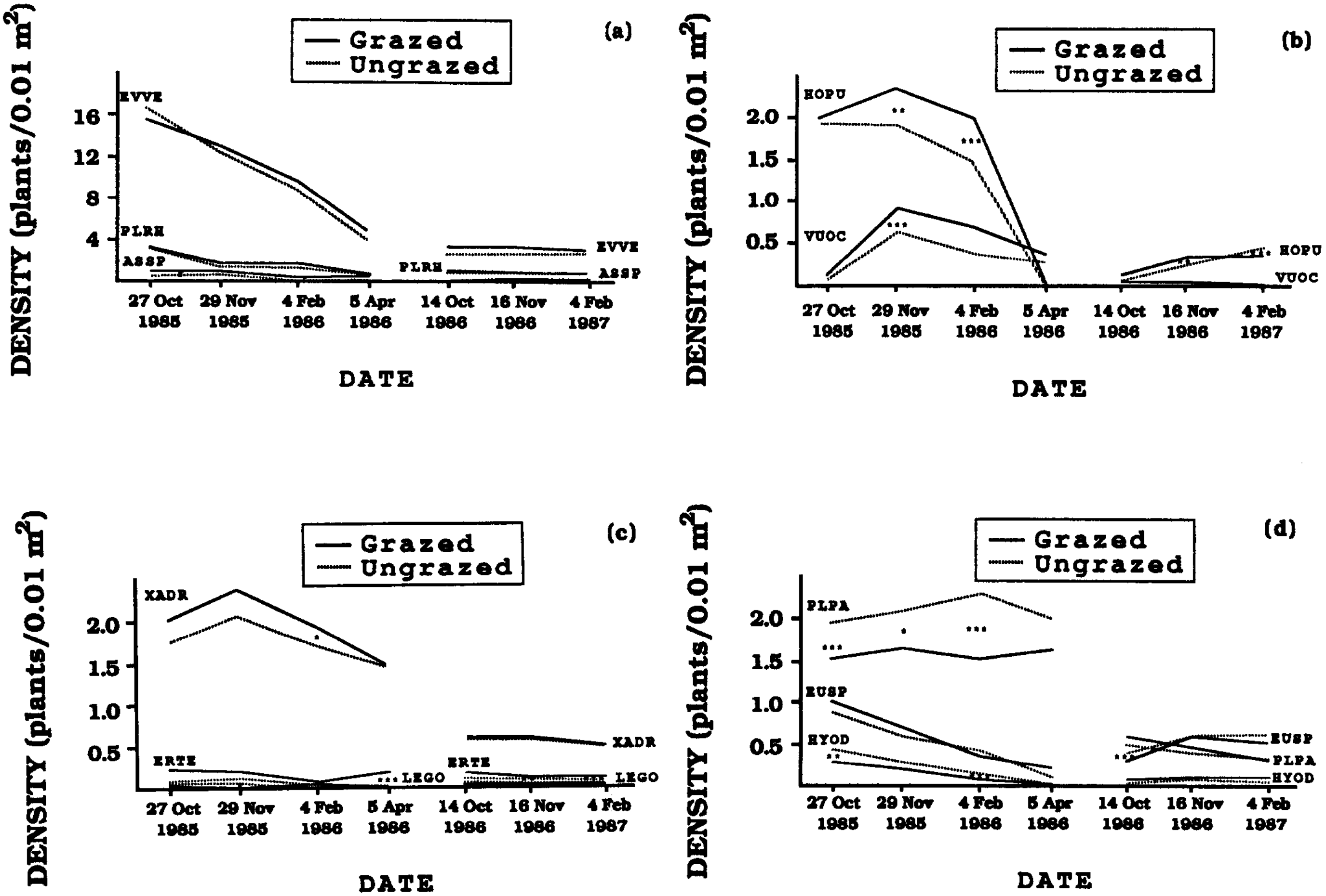

Fig. 1. *Density of winter annuals following short-duration grazing in spring and summer in western Texas. Differences in density between grazed and ungrazed plots are noted by *(P<0.10), **(P<0.05), or ***(P<0.01). (a) Forb species with similar densities in grazed and ungrazed quadrats:* Evax verna *(EVVE), Plantago rhodosperma (PLRH),* Astragalus *sp. (ASSP). (b) Grasses:* Hordeum pusillum *(HOPU),* Vulpia octoflora *(VUOC). (c) Forb species with higher densities in grazed areas on at least one sampling date:* Xanthocephalum dracunculoides *(XADR),* Erodium texanum *(ERTE),* Lesquerella Gordonii *(LEGO). (d) Forb species with higher densities in exclosures on at least one sampling date:* Plantago patagonica *(PLPA),* Euphorbia *sp. (EUSP),* Hymenoxys odorta *(HYOD).*

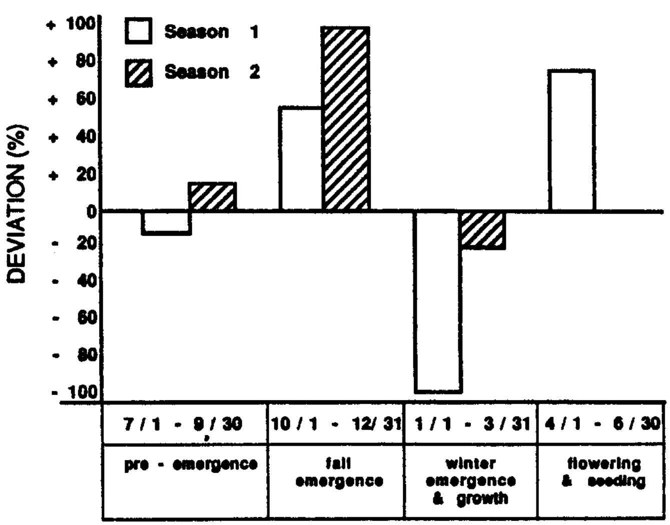

Fig. 2. *Deviations from long-term average precipitation by phenological stage of winter annuals.*

remove vegetation cover and alter soil microtopography. A smooth soil surface devoid of plant cover represents the harshest microenvironment for seedling establishment (Evans and Young 1987). Young et al. (1975) listed 3 adaptations of colonizing species to bare, smooth seedbeds which predominate on grazed sites: (1) rapid germination (e.g., common broomweed); (2) self-burial of seeds (e.g., Texas filaree); and (3) mucilaginous seed coats (e.g., *Plantago* spp.). The response of common broomweed to SDG is consistent with these hypotheses and with the results of other studies on the species (Gordon 1982, Steuter and Wright 1983). Texas filaree density was higher in grazed than ungrazed quadrats, which is also consistent with the hypotheses of Young et al. (1975). However, red-seeded plantain density did not differ between treatments, and woolly plantain density was higher in ungrazed than grazed quadrats. The response of *Plantago* spp. and other winter annuals which did not increase under SDG is not readily explainable by observed grazing-induced changes in light penetration or microtopography. The latter may have been masked by extensive cracking of the Vertisol soils throughout the study site.

Differential seed predation and seedling herbivory by insects and small mammals between grazed and ungrazed areas can contribute significantly to composition of desert annual communities

(Inouye et al. 1980). Different insect communities in exclosures may have resulted from greater aboveground biomass and stratification of herbaceous vegetation. However, seed and vegetation preferences of insects and small mammals have not been reported for the plant species studied. Differential herbivory between species is presented as a potential but untested mechanism affecting community structure.

Competition with perennial plants (especially for light or space) and other winter annuals may have affected density of some species. Mean basal cover of dominant perennials was 8.6% in the study area and was evenly divided between tobosagrass and alkali sacaton in grazed and ungrazed plots (Weigel 1987). Temporal and spatial variability in competitive intensity between species can be quite high (Fowler 1986), and grazing can alter competitive relationships between species (McNaughton 1985, Belsky 1986). Furthermore, germination of winter annuals may be density-dependent, decreasing with increased seedling density (Inouye 1980). For example, invasion of "safe sites" (Harper 1977) in grazed areas by species which germinate early in a season (e.g., Texas filaree, common broomweed) may inhibit subsequent germination, thereby reducing density of late-germinating species. The issues of density-dependent germination and mortality are beyond the scope of the current study.

SDG is capable of altering community structure of winter annuals in the near-term (3 to 9 months after grazing). Directional change to favor some species at the expense of others presumably would continue over time as the latter species became continuously less abundant. The magnitude of the shift in community structure cannot be adequately assessed with a short-term study; further studies addressing the impacts on annual species over longer periods of SDG are needed. Furthermore, basic autecological data (e.g., germination requirements) are needed for most winter annuals encountered in this study.

Literature Cited

Beatley, J.C. 1974. Phenological events and their environmental triggers in Mojave Desert ecosystems. Ecology 55:856-863.

Belsky, A.J. 1986. Does herbivory benefit plants? A review of the evidence. Amer. Natur. 127:870-892.

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. Sci., Westview Press, Boulder, Colo.

Booth, D.T. 1987. Diaspores of rangeland plants, ecology and management. p. 202-211 *In:* G.W. Frasier and R.A. Evans (eds.) Seed and seedbed ecology of rangeland plants. USDA/ARS, Tucson, Ariz.

Correll, D.S., and M.C. Johnston. 1970. Manual of the vascular plants of Texas. Texas Res. Found., Renner, Texas.

Evans, R.A., and J.A. Young. 1987. Seedbed microenvironment, seedling recruitment, and plant establishment on rangelands. p. 212-220 *In:* G.W. Frasier and R.A. Evans (eds.) Seed and seedbed ecology of rangeland plants. USDA/ARS, Tucson, Ariz.

Fowler, N.F. 1986. The role of competition in plant communities in arid and semiarid regions. Annu. Rev. Ecol. and Sys. 17:89-110.

Friedman, J., G. Orshan, and Y. Ziger-Cfir. 1977. Suppresion of annuals by *Artemisia herba-alba* in the Negev Desert of Israel. J. Ecol. 65:413-426.

Gauch, H.G. 1982. Multivariate analysis in community ecology. Cambridge Univ. Press, Cambridge.

Gifford, G.F., R.M. Faust, and G.B. Coltharp. 1977. Measuring soil compaction on rangeland. J. Range Manage. 30:457-460.

Gould, F.W. 1969. Texas plants: a checklist and ecological summary. Texas Agr. Exp. Sta. Rep. MP-585.

Gordon, R.A. 1982. The ecology and control of common broomweed. Ph.D. Diss., Texas Tech Univ., Lubbock, Tex.

Grieg-Smith, P. 1983. Quantitative plant ecology. Third edition. Univ. California Press, Berkeley.

Grime, J.P. 1979. Plant strategies and vegetation processes. John Wiley Publ. Co. Inc. New York.

Harper, J.L. 1977. Population biology of plants. Academic Press, London.

Inouye, R.S. 1980. Density-dependent germination response by seeds of desert annuals. Oecologia 46:235-238.

Inouye, R.S., G.S. Byers, and J.H. Brown. 1980. Effects of predation and competition on survivorship, fecundity, and community structure of desert annuals. Ecology 61:1344-1351.

Kershaw, K.A., and J.H.H. Looney. 1985. Quantitative and dynamic plant ecology. Third edition. Edward Arnold Publ. Ltd., London.

McNaughton, S.J. 1985. Ecology of a grazing ecosystem: the Serengeti. Ecol. Monog. 55:259-294.

National Oceanic and Atmospheric Administration. 1985. Climatological data annual summary-Texas 1984. Vol. 89, No. 13. Asheville, N.C.

Peart, M.H. 1984. The effects of morphology, orientation and position of grass diaspores on seedling survival. J. Ecol. 72:437-453.

Ralphs, M.H., M.M. Kothmann, and L.B. Merrill. 1984. Proper stocking for short duration grazing. Texas Agr. Exp. Sta. Rep. PR-4190.

Richardson, W.E., D.G. Grice, and L.A. Putnam. 1965. Soil survey of Garza County, Texas. USDA Soil Conserv. Serv.

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

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

Steuter, A.A., and H.A. Wright. 1983. Spring burning effects on redberry-mixed grass habitats. J. Range Manage. 36:161-164.

Thurow, T.L., W.H. Blackburn, and C.A. Taylor. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. J. Range Manage. 39:505-509.

Walter, J. 1984. Rangeland revolutionary: an interview with Allen Savory. J. Soil and Water Conserv. 39:235-240.

Weigel, J.R. 1987. Effects of short-duration grazing trampling on seedling emergence and soil strength. M.S. Thesis, Texas Tech Univ., Lubbock, Tex.

Weigel, J.R., and C.M. Britton. 1986. Use of a metal detector to locate permanent plots. J. Range Manage. 39:565.

Young, J.A., R.A. Evans, and B.L. Kay. 1975. Dispersal and germination dynamics of broadleaf filaree, *Erodium botrys* (Cav.) Bertol. Agron. J. 67:54-57.

Cues cattle use to avoid stepping on crested wheatgrass tussocks

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Abstract

This paper tests 2 hypotheses regarding the cues cattle use to avoid stepping on crested wheatgrass (*Agropyron cristatum* (L.) Gaertner) tussocks. The first hypothesis is that cattle are attentive to shade and avoid tussocks by stepping on light areas (soil interstices) and avoiding dark areas (tussocks). In an experiment with 90 Angus heifers placed in a short-duration grazing paddock of 8.5 ha, the animals stepped with equal relative frequency on 28 patches of bare ground, 37 disks painted the shade and color of bare ground, and 37 disks painted to match vegetation over a 24-h period. We therefore reject the shade-cue hypothesis. The second hypothesis is that cattle are attentive to the vegetation itself in their avoidance behavior, and that as they crop the vegetation the frequency of trampling increases. In experiments similar to the first, cattle stepped on 85 intact tussocks 9 times, on 85 clipped (3 to 4 cm above litter) tussocks 28 times, on 85 vegetation-free tussock mounds 107, times and on 35 patches of bare ground 130 times. These differences are statistically significant. The data are consistent with the vegetation-cue hypothesis, except that the cattle also were attentive to the elevated substrate upon which the tussock grew. We conclude that, under the test conditions, hoof action does not have an important impact on crested wheatgrass pastures used for short-duration grazing. The impact could approach importance, however, if the pasture was grazed more heavily and if the vegetation was dry and dusty.

Key Words: short-duration grazing, hoof action, trampling vegetation

Two hypothesized benefits of short-duration grazing are the trampling and mixing of soil and litter (Savory 1978, 1983) and the destruction of standing dead vegetation which deters grazing within caespitose grasses (Willms et al. 1980). In an earlier study, however, we demonstrated that cattle avoid stepping on crested wheatgrass (*Agropyron cristatum* (L.) Gaertner) tussocks and concluded that the abovementioned potential benefits from hoof action are minimal (Balph and Malechek 1985). This conclusion nevertheless might not hold under certain circumstances. For example, as vegetation is eaten or becomes covered with dust, the cue that cattle may use to avoid stepping on tussocks, the green vegetation itself, may disappear. Discovery of the cues cattle use in avoiding tussocks should enable us to predict under what conditions of the environment or grazing animals would trample crested wheatgrass.

This study tests 2 hypotheses regarding the cues cattle use to avoid stepping on tussocks. The first is that the animals are attentive to substrate shade (achromatic variable) and/or color (see Hailman 1977:137-139 for discussion of chromatic variables). The tussocks are dark (green), whereas the spaces between the tussocks are light (beige). If cattle step on light and not dark, they would avoid trampling tussocks. This discrimination task is simple and does not require depth perception, an ability thought to be poorly developed in cattle (Arnold and Dudzinski 1978). The second hypothesis is that cattle are attentive to the tussock as a visual and perhaps tactile stimulus. As tussocks are eaten, error in trampling avoidance should increase.

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Methods

The tests were conducted in 1985 and 1986 at the Tintic pasture research facility, about 10 km southwest of Eureka, Utah. The 8.5-ha paddock was part of a short-duration grazing cell in which 90 Angus heifers were moved from paddock to paddock at 2-day intervals (see Malechek and Dwyer 1983 and Balph and Malechek 1985 for details). The predominant vegetation of the pasture was crested wheatgrass from a seeding established in the early 1960's.

The shade-cue hypothesis was tested by placing 74 disks, cut to a diameter of 20 cm from asphalt shingles, along 2 transects that bisected the paddock (see Balph and Malechek 1985). Thirty-seven of the disks were painted beige to match the soil and the other 37 green to match the vegetation. Thirty-seven patches of bare ground, each 20 cm in diameter, served as controls. The disks and controls were alternated and spaced at approximately equal distances from one another along the entire length of both transects. The cattle were then released into the paddock and the number of hoofprints on the disks and soil locations counted 24 h later by a technician who did not know the hypothesis being tested.

The vegetation-cue hypothesis was tested by locating 50 clusters of 3 tussocks, made equal in diameter, along the same 2 transects. In each cluster, 1 tussock was clipped to the litter and dusted with soil so that the remaining mound had the same color as the surrounding substrate. Another tussock was clipped 3 to 4 cm above the litter, simulating what we thought was the lowest the plants could be grazed by cattle, while the third tussock was left intact with vegetation 15 to 30 cm in height. After the cattle had been in the paddock for 24 h, one of us counted the number of hoofprints on each of the 3 types of tussocks. This test was duplicated the following year except for the inclusion of a control (flat and bare) area the size of a tussock (mean diameter 23.4 cm), randomly located by dropping a coin over the shoulder, near each cluster of tussocks and the use of 35 rather than 50 clusters. Because the soil was dry in 1986 and the hoofprints sometimes indistinct, 2 of us counted hoofprints independently as a check on interobserver reliability.

The data were subjected to chi-square analysis (test for goodness of fit and test of independence).

Results

If the shade-cue hypothesis was correct, we expected very few hoofprints on the dark disks and about as many hoofprints on the light disks as on the control areas of bare ground. There were 50 hoofprints on 37 dark (green) disks, 48 on 37 light (beige) disks, and 48 on 28 of 37 control areas (the data collector was unable to find the remaining 9 control areas). The observed distribution of hoofprints did not differ significantly from chance expectation $\chi^2 = 2.20$, df = 2, $P>0.3$), nor was there any tendency for the cattle to step on dark disks less often than on light disks or bare ground (χ^2 = 0.26, df = 1, P>0.5). These results indicate that cattle do not use shade as a cue to avoid trampling crested wheatgrass tussocks.

If the vegetation-cue hypothesis was correct, we expected the cattle to trample short-clipped tussocks more often than intact tussocks due to the decrease in cue strength. In the first test of this hypothesis with 50 samples per treatment, 5 hoofprints occurred on unclipped tussocks, 13 on short-clipped tussocks, and 58 on totally-clipped tussocks. This outcome was in the predicted direction and differed significantly from what chance would dictate (χ^2 = 64.45, df = 2, P<0.001). Differences between successive treatments compared to chance expectation also were significant or nearly so (χ^2 = 3.56, df = 1, P<0.06 for unclipped versus short-clipped; χ^2 = 28.52, df = 1, P<0.001 for short-clipped versus totally clipped).

Our expectations for the repeat test of the vegetation-cue hypothesis were the same as those for the original test, with the addition that cattle should step on totally clipped tussocks with the same frequency that they stepped on control areas (bare ground). The results in the 35 samples of each treatment were 4 (5, second observer) on unclipped tussocks, 15 (21, second observer) on short-clipped tussocks, 49 (49, second observer) on totally clipped tussocks, and 134 (123, second observer) on control areas. The distribution again was in the predicted direction and deviated significantly from chance expectation (χ^2 = 196.79, df = 3, P<0.001; analysis based on data from the first observer, chosen by tossing a coin). Differences between successive treatments compared to chance expectation were significant in all cases (χ^2 = 6.37, df = 1, P<0.02; χ^2 = 18.06, df = 1, P<0.001; χ^2 = 36.65, df = 1, P<0.001; respectively). The interobserver reliability check showed no significant difference between observers (χ^2 = 1.54, df = 3, P>0.5).

We conclude from these tests that the vegetation-cue hypothesis is correct but incomplete. The cattle seldom stepped on intact tussocks, but when the tussock height was reduced, the trampling frequency increased. When no vegetation was visible, however, the animals still exhibited a strong avoidance of the elevated substrate upon which the tussocks grew, as shown by the significant difference in their response to totally clipped tussocks versus bare ground. This indicates that the mound itself can act as a secondary cue governing hoof placement. These results strengthen the hypothesis advanced earlier that cattle avoid stepping on tussocks because the tussocks present an uneven surface upon which to walk (Balph and Malechek 1985).

Discussion

Animals seek simple, stable cues to guide their behavior. The shade-cue hypothesis at the outset seemed to us to meet these criteria. In retrospect, however, the hypothesis was flawed. We observed after the tests that rain darkened the soil and made the light-dark cues unreliable. It is not surprising, therefore, that the data were inconsistent with the shade-cue hypothesis.

The findings from the vegetation-cue tests indicate that cattle eat the primary cue they rely upon to avoid stepping on tussocks. A key question is: Does the increase in trampling frequency constitute an important hoof-action effect? Our own view is that, under the test conditions, hoof action would not have a major impact on crested wheatgrass pastures used for short-duration grazing. The impact could approach importance, however, if the pasture was grazed more heavily and if the vegetation was dry and dusty. Severe trampling of bunchgrass pastures can, we believe, be expected only near salt or water resources where animal use is exceptionally high and where jostling among animals may prevent them from avoiding tussocks.

Literature Cited

Arnold, G.W., and M.L. Dudzinski. 1978. Ethology of free-ranging domestic animals. Elsevier Publ., Amsterdam.

Balph, D.F., and J.C. Malechek. 1985. Cattle trampling of crested wheatgrass under short-duration grazing. J. Range Manage. 38:226-227.

Hailman, J.P. 1977. Optical signals: Animal communication and light. Indiana Univ. Press, Bloomington.

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

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

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

Willms, W., A.W. Bailey, and A. McLean. 1980. Effect of burning or clipping *Agropyron spicatum* in the autumn on the spring foraging behavior of mule deer and cattle. J. Appl. Ecol. 17:69-84.

Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest

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Abstract

The impacts of intensive vs. extensive silviculture, and moderate continuous livestock grazing vs. no livestock grazing as they relate to infiltration and runoff water quality were evaluated using rainfall simulation. Study sites were located in the Vernon District of the Kisatchie National Forest, Louisiana. Infiltration was greater, and interrill erosion, suspension-solution phase total nitrogen concentrations, and suspension-solution phase total phosphate concentrations were less from areas under extensive silviculture and no livestock grazing than from areas under intensive silviculture and livestock grazing, respectively. Intensive silviculture exposed more bare soil than extensive treatments. Litter cover and litter biomass were significantly reduced by the intensive silvicultural treatment. Livestock grazing also exposed more bare soil mainly resulting from a removal of grass cover and biomass.

Key Words: interrill erosion, nitrogen, phosphorus

Southeastern forests currently produce more than half of the nation's wood supply and are potential major livestock producing areas (Ursic 1975, Grelen 1978). The effects of silvicultural and livestock grazing practices on infiltration, interrill erosion, and runoff water quality are largely undocumented. Such information is needed for state and federal agencies to make sound resource management decisions. Likewise, maintaining site productivity by minimizing interrill erosion and nutrient export is a concern to private and public forest managers.

Intensive forest management practices of tree harvesting, site preparation, and livestock grazing have been identified as potential causes of declining site productivity and nonpoint pollution Bormann et al. 1968, Feller and Kimmins 1984, Patric and Helvey 1986). Natural erosion rates from undisturbed forestlands in the Southeast are low, ranging from a trace to 720 kg ha^{-1} year^{-1} (Schreiber et al. 1980, Yoho 1980, Blackburn et al. 1986). Tree harvesting and site preparation increase the potential for soil erosion and nutrient export by disturbing the protective surface layers of the forest floor, thus reducing infiltration rates and increasing surface runoff (Moehring and Rawls 1970, Hewlett and Troendle 1975, Douglass 1975, Blackburn et al. 1986). For watersheds in northern Mississippi, Beasley (1979) reported first year sediment losses of 12,540 kg ha^{-1} following clearcut harvesting and roller chopping in a watershed in comparison to 620 kg ha^{-1} for an undisturbed watershed. However, sediment losses and concentrations were similar from clearcut harvested and roller chopped, and undisturbed watersheds near Alto, Texas (Blackburn et al. 1986).

Stoeckeler (1959) reported infiltration rates of an ungrazed oak woodland 150 times greater than an adjacent heavily grazed woodland. Infiltration rates of heavily grazed, moderately grazed, and ungrazed longleaf pine (*Pinus palustris*)-bluestem (*Andropogon* spp., *Schizachyrium* spp.) range were reported by Duvall and Linnartz (1967) to be 20, 30, and 46 mm hr^{-1}, respectively. Because of a long history of overgrazing forest, and lack of forest hydrology research applicable to grazing, the conservation-minded public perceives forest grazing as a significant environmental problem (Lee 1980, Johnson 1952, Adams 1975, Blackburn 1984, Patric and Helvey 1986).

The objective of this research was to assess the impact of intensive vs. extensive silvicultural practices, and moderate continuous livestock grazing vs. no livestock grazing on infiltration rates and runoff water quality.

Materials and Methods

Study Area and Treatments

The study area was located 48 km southeast of Leesville, Louisiana on the Fullerton Allotment, Vernon Ranger District, Kisatchie National Forest. Normal annual rainfall is 1,379 mm and the average annual temperature is 18.8° C. The mean frost-free period is 245 days, from the end of March to mid-November. Gentle rolling topography, intersected by numerous drainages, characterize the areas. Elevation ranges from 55 to 135 m above sea level. Vegetation consists mainly of a longleaf pine overstory with a bluestem and panicum (*Panicum* spp., *Diachanthelium* spp.) grass understory. Soils are of the Malbis series, which is a fine-loamy, siliceous, thermic Plinthic Paleudult. Soils are deep and moderately well drained and occur on side slopes and gently sloping ridgetops of less than 5%.

Six study sites (replications) were located within the Fullerton Allotment. Each study site consisted of a fenced exclosure (100 m × 150 m) and an adjacent similar size non-fenced area. The exclosure and the grazed area were partitioned into 10 × 15 m subsections which were randomly assigned a sample date. Two silvicultural management practices, i.e., seedtree harvesting or thinning, were equally represented in the exclosure and adjacent nonfenced area. Each sample date was represented by 6 replications of 4 treatments with 2 subsamples per treatment. Seedtree harvesting was considered an intensive silvicultural practice and involved the removal of all but 4 to 6 m^2 basal area per hectare of seed trees. After harvesting, the areas were site-prepared using a drum chopper or rake harrow (a railroad tie with spikes 8 to 10 cm dragged behind a tractor) and broadcast-burned to remove debris. After pine seedlings were established, all remaining seed trees were harvested. Forest thinning was considered an extensive silvicultural practice with minimal management conducted over a large area. The study sites were thinned to an average basal area of 14 m^2 ha^{-1}, using chain saws and rubber tire skidders. Treatment dates for each study site are summarized in Table 1. Silvicultural study sites were located with seed tree harvest and thinning treatments directly adjacent to each other.

Cattle had free access to the Fullerton Allotment from 1967 to 1977. In 1977 the allotment was cross-fenced into individual range units (RU). Two study sites were located in 3 RU's which contained

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Table 1. Silvicultural treatment schedules for the 6 study sites, Vernon District, Kisatchie National Forest, Louisiana.

Study site	Seedtree harvest	Thinning
1	February 1980	March 1978
2	February 1982	March 1978
3	February 1980	March 1980
4	February 1980	March 1980
5	February 1977	March 1980
6	February 1977	March 1980

535, 511, and 675 ha. Control of animal stocking rates and grazing systems was not initiated on the sites until 1981. From 1967 through 1980, moderate stocking rates averaged 15 ha AU^{-1}. From 1981 through 1985, 2 RU's were grazed continually from 1 March to 15 November and deferred from 16 November to 28 February, and the third RU was continuously grazed yearlong. The yearlong continuously grazed RU was stocked at 13 ha AU^{-1}, and the seasonally grazed RU's were stocked at 15 and 19 ha AU^{-1}, respectively (Pearson et al. 1987). Initially 3 grazing treatments (seasonal continuous grazing, yearlong continuous grazing, and no grazing) were analyzed for statistical differences. Because no significant differences were found between seasonal and yearlong continuous grazing, they were analyzed together as one treatment (continuous grazing) in the final analysis.

Construction of livestock exclosures at each study site was not completed until 1982 just prior to the second sampling period. For this reason both sampling periods in 1982 were treated as grazed conditions. Although the grazing treatments compared were continuous livestock grazing and no livestock grazing, this was not a long-term study and therefore represents a comparison of continuous livestock grazing with the removal of livestock from areas previously grazed.

Methods

Study sites were sampled in June and August/September of 1982–1984, and for a final time in September 1985. A rainfall simulator similar to the one described by Meyer and Harman (1979) was used to determine infiltration and runoff water quality over 1-m^2 plots isolated with metal plot frames. Simulated rainfall had a normal raindrop size distribution from 0 to 6 mm with an average drop diameter of 2.5 mm. Impact energy was 2.75 kJ ha-mm^{-1}. In order to reduce variability attributable to antecedent soil water content, the plots were pre-wet by a sprinkler system that used an agricultural full-cone mist-type nozzle under a plastic cone. An area 1.5 m diameter was prewet with 42 *l* of water at a rate of 190 *l* hr^{-1}. The nozzle tip was located 1.2 m above the soil. The plots were then covered with plastic to reduce evaporation. About 24 hours later, simulated rainfall was applied at a rate of 127 mm hr^{-1} for 30 minutes to insure runoff from all plots. Water used to simulate rainfall was sampled and used to correct nutrient concentrations in runoff samples. Runoff from each plot was regularly pumped into tared containers. At the end of the 30-minute simulated rainfall event, the cumulative runoff was weighed and a 30-minute infiltration rate (mm hr^{-1}) was calculated by determining the difference between applied rainfall and the quantity of runoff. Upon termination of each simulated rainfall event, 1-liter and 0.5-liter subsamples were obtained from a thoroughly agitated collection of runoff. The 1-liter subsamples were filtered through a #1 Whatman filter paper, dried at 105° C for 24 hr, weighed, and converted to sediment loss in kg ha^{-1}. Sediment loss was used as an index of interrill erosion. The unfiltered 0.5-liter water samples were frozen and analyzed, within 2 months, for the suspension-solution phase total nitrogen and total phosphorus using a Technicon Auto Analyzer II. Total nitrogen, which includes organic and ammonium nitrogen, was measured ($\mu g\ l^{-1}$) using the ammonia/salicylate complex method after digestion with a salt/acid catalyst mixture (APHA et al. 1976). Total phosphorus samples were digested using the persulfate digestion method, and concentrations ($\mu g\ l^{-1}$) were determined by the ascorbic acid reduction method (APHA et al. 1976).

For each plot, the foliar cover (%) of grasses, forbs, litter, rock, and bare ground was determined by ocular estimation. Standing grass (live and dead) and standing forbs were clipped and litter was collected from each plot. This material was dried at 60° C, weighed, and reported in kg ha^{-1}. Prior to the start of each simulated rainfall event, 51 mm diameter soil cores were collected adjacent to each runoff plot at 0–50 and 50–100 mm depths for analysis of soil bulk density and moisture (Black 1965). Following each simulated rainfall event, a soil sample of the surface 50 mm was taken from each plot and analyzed for organic carbon content by acid dichromate digestion (Black 1965).

Statistical Analysis

Because no significant interaction was found, treatments were separated and statistical significance pertains individually to either silvicultural or grazing treatment means. Analyses of variance were used to test for significant treatment differences which were separated using Duncan's new multiple range test (Steel and Torrie 1980). Statistical significance was expressed at the 0.05 level.

Results

Silviculture

Silvicultural treatment did not significantly affect vegetative cover or biomass (Table 2). Bare ground (%) was significantly less

Table 2. Vegetation and soil variable means for all sample dates combined, Kisatchie National Forest, Louisiana.

Variable	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
Bare ground (%)	17a*	6b	13a	8b
Grass cover (%)	51a	45a	42b	60a
Forb cover (%)	10a	9a	10a	8a
Litter cover (%)	22b	38a	34a	23b
Woody cover (%)	1a	2a	1a	1a
Grass biomass (kg ha^{-1})	1322a	1229a	1035b	1708a
Forb biomass (kg ha^{-1})	242a	178a	207a	217a
Litter accumulation (kg ha^{-1})	3081b	6805a	5166a	4522a
Soil bulk density 0–50 mm (mg m^{-3})	1.37a	1.33b	1.36a	1.33a
Soil bulk density 50–100 mm (mg m^{-3})	1.45a	1.42a	1.43a	1.44a
Antecedent soil moisture 0–50 mm (%)	17.3a	17.5a	17.2a	17.9a
Antecedent soil moisture 50–100 mm (%)	14.6a	15.3a	14.9a	14.8a
Soil organic matter content (%)	3.7a	3.5a	3.7a	3.4a

*Silviculture or grazing treatment means for each variable followed by the same letter are not significantly different at the 0.05 level.

Table 3. Mean 30 minute infiltration rate (kg ha^{-1}) by sample date and for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	43.9a*	48.0a	46.0	——[1]
Sept. 1982	47.7a	49.3a	48.5	——
June 1983	44.4a	58.4a	47.4a	55.4a
Aug. 1983	37.4a	41.4a	39.6a	39.1a
June 1984	45.6a	54.0a	45.0a	54.6a
Aug. 1984	35.4a	50.8a	42.7a	43.4a
Sept. 1985	50.4a	58.4a	45.8b	63.1a
Combined mean	43.5b	51.5a	45.4b	51.1a

*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.
[1]No sample date treatment mean.

Table 5. Mean suspension-solution phase total nitrogen concentrations ($\mu g l^{-1}$) by sample date and for all sample dates combined. Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	——[1]	——	——	——
Sept. 1982	980a*	1227a	1103	——
June 1983	1204a	1640a	1519a	1325a
Aug. 1983	3112a	2227a	2767a	2616a
June 1984	1691a	1558a	1677a	1571a
Aug. 1984	2775a	1327b	2401a	1632b
Sept. 1985	1243a	694a	1123a	813a
Combined mean	1777a	1403b	1643a	1514b

[1]No sample date treatment mean.
*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.

on extensive treatments than on intensive treatments where harvesting and site preparation exposed areas of bare soil. While grass, forb, and woody cover were similar for both treatments, litter cover and accumulation were significantly greater on extensive treatments than on intensive treatments.

Measured soil variables were similar for both silvicultural treatments, with the exception of surface soil bulk density, which was significantly greater for intensive silvicultural treatments than for extensive treatments.

There was a nonsignificant trend for infiltration rates and runoff water quality to decline for both silvicultural treatments as the season progressed from late spring to fall. Infiltration rates were statistically similar between treatments for all individual sampling dates, but were significantly greater from extensive treatments than from intensive treatments when all sample dates were combined (Table 3).

Interrill erosion as well as total nitrogen and phosphorus concentrations in runoff were significantly greater from intensive silvicultural treatments than from extensive silvicultural treatments for the August 1984 sampling date and for all sample dates combined (Tables 4, 5, and 6).

Livestock Grazing

Surface soil cover and biomass revealed some differences between grazing treatments (Table 2). As would be expected, cover and biomass of grass were significantly greater on treatments with no livestock grazing than on treatments with grazing. Bare ground and litter cover were significantly greater on grazed areas than on areas excluded from grazing.

All measured soil variables were similar for both grazed and ungrazed treatments (Table 2). As with the silvicultural treatments, infiltration rates and runoff water quality from grazing treatments displayed a nonsignificant trend of decreasing infiltration and runoff water quality as the seasons progressed from late spring to fall. Mean infiltration rates were significantly greater on treatments excluded from livestock grazing than on grazed treatments for the September 1985 sample date and for all sample dates combined (Table 3). Sediment production, as a measure of interrill erosion, was significantly greater from livestock grazing treatments than from treatments with no livestock grazing for the August 1983 and September 1985 sampling dates, and for all sample dates combined. Total nitrogen concentration was greater from the grazed treatments than from the treatments without grazing for the August 1984 sampling date and for all dates combined (Table 5). Concentrations of total phosphorus were low and similar from both grazing treatments at each sampling date and for all dates combined (Table 6).

Discussion and Conclusions

Nitrogen and phosphorus are often closely associated with sediments (Schreiber et al. 1980, Duffy et al. 1978); therefore, it follows that runoff concentrations of total nitrogen and phosphorus would exhibit a similar trend to interrill erosion or sediment loss. A small watershed study near Alto, Texas, reported similar stormflow water quality from undistrubed watersheds and watersheds that had been clearcut harvested and site prepared by roller chopping (Blackburn et al. 1986). Another small watershed study near Broaddus, Texas, reported only minimal impact on sediment loss and stormflow from continuous livestock grazing when compared to no livestock grazing (Blackburn et al. 1987).

The primary potential impacts on infiltration and runoff water

Table 4. Mean interrill erosion (kg ha^{-1}) by sample date and for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	49.9a*	54.2a	52.0	——[1]
Sept. 1982	312.4a	274.4a	293.4	——
June 1983	72.5a	82.5a	86.4a	68.6a
Aug. 1983	223.2a	159.6a	244.9a	137.0b
June 1984	47.9a	69.2a	63.4a	53.7a
Aug. 1984	209.3a	108.5b	139.7a	178.1a
Sept. 1985	208.8a	68.5a	200.0a	83.5b
Combined mean	158.7a	115.1b	155.6a	104.1b

*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.
[1]No sample date treatment mean.

Table 6. Mean suspension-solution phase total phosphate concentrations ($\mu g l^{-1}$) by sample date for all sample dates combined, Kisatchie National Forest, Louisiana.

Sample date	Intensive silviculture	Extensive silviculture	Livestock grazing	No livestock grazing
June 1982	——[1]	——	——	——
Sept. 1982	402a*	424a	413	——
June 1983	136a	140a	148a	128a
Aug. 1983	166a	172a	176a	163a
June 1984	136a	98a	117a	116a
Aug. 1984	233a	136b	178a	196a
Sept. 1985	189a	111a	177a	123a
Combined mean	209a	178b	229a	144a

[1]No sample date treatment mean.
*Silviculture or grazing treatment means by sample date and combined across all sample dates, followed by the same letter, are not significantly different at the 0.05 level.

quality attributable to silviculture or grazing treatment are predominately related to the removal of protective vegetation and disturbances of the surface soil.

Surface cover and bulk density were influenced most by the silvicultural treatments. Intensive silvicultural treatments exposed greater amounts of bare soil than the extensive treatment, causing the sites to be more vulnerable to the detrimental influences of raindrop impact and overland flow. Litter cover and accumulation were the only cover variables that were significantly influenced by the intensive silvicultural treatments and were probably most important. Surface soil bulk density was only slightly greater on intensively managed silvicultural treatments than on extensively managed areas; however, differences were significant. The greater surface soil bulk density and percent bare ground on intensive silvicultural treatments are probably related to harvesting and site preparation practices.

Grass cover and biomass were significantly different between treatments, and were most influenced by grazing treatments. Although litter cover was significantly different between grazing treatments, this difference was probably due mostly to the indirect reduction of grasses by cattle grazing, thus exposing additional litter. The reduction of grass cover and grass biomass by livestock grazing exposed greater amounts of bare soil to the detrimental influences of raindrop impact and overland flow. Livestock grazing did not greatly influence soil conditions since all of the soil variables measured were found to be similar for treatments with or without livestock grazing.

Under the prevailing climatic, soil, and vegetative conditions of the study area, the impacts of applied silvicultural and grazing practices on infiltration and runoff water quality, although significant, should not present a problem to management or site productivity.

Literature Cited

Adams, S.M. 1975. Sheep and cattle grazing in forests: A review. J. Appl. Ecol. 12:143-152.

American Public Health Association, American Water Works Association, Water Pollution Control Federation. 1976. Standard methods for the examination of water and wastewater. 14th ed. Amer. Public Health Assoc., Washington, D.C.

Beasley, R.S. 1979. Intensive site preparation and sediment losses on steep watersheds in the Gulf Coastal Plain. Soil Sci. Soc. Amer. J. 43:412-417.

Black, C.A. 1965. Methods of soil analysis. Amer. Soc. Agron. Ser. No. 9, Madison, Wisc.

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

Blackburn, W.H., J.C. Wood, and M.G. DeHaven. 1986. Storm flow and sediment losses from site-prepared forestland in East Texas. Water Resour. Res. 22:776-778.

Blackburn, W.H., J.C. Wood, H.A. Pearson, and R.W. Knight. 1987. Storm flow and sediment loss from intensively managed forest watersheds in East Texas, p. 233-243. *In:* Proc. of Southern Evaluation Project Workshop, May 26-27, Longbeach, Miss. USDA Forest Serv. Gen. Tech. Rep. S0-68. New Orleans, La.

Bormann, R.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clearcutting of a forest ecosystem. Sci. 159:882-884.

Douglass, J.E. 1975. Southeast forest and the problem of non-point sources of water pollution, p. 29-44. *In:* P.M. Ashton and R.C. Underwood (eds.), Proc. Southeastern Regional Conf. Virginia Water Resour. Res. Center, Blacksburg, Va.

Duffy, P.D., J.D. Schreiber, D.C. McClurkin, and L.L. McDowell. 1978. Aqueous- and sediment-phase phosphorus yields from five southern pine watersheds. J. Environ. Qual. 7:45-50.

Duvall, V.L., and N.E. Linnartz. 1967. Influences of grazing and fire on vegetation and soil of longleaf pine-bluestem range. J. Range Manage. 20:241-247.

Feller, M.C., and J.P. Kimmins. 1984. Effects of clearcutting and slash burning on streamwater chemistry and watershed nutrient budgets in southwestern British Columbia. Water Resour. Res. 20:29-40.

Grelen, H.E. 1978. Forest grazing in the South. J. Range Manage. 31:244-250.

Hewlett, J.D., and C.A. Troendle. 1975. Nonpoint and diffused water sources: a variable source area problem, p. 21-46. *In:* Proc. of Watershed Management Symp. Irrig. and Drain., Amer. Soc. Civil Engin., Logan, Utah.

Johnson, E.A. 1952. Effect of farm woodland grazing on watershed values in the southern Appalachian mountains. J. Forest. 50:109-113.

Lee, R. 1980. Forest hydrology. Columbia Univ. Press, New York.

Meyer, L.D., and W.C. Harmon. 1979. Multiple intensity rainfall simulator for erosion research on row sideslopes. Trans. Amer. Soc. Agr. Eng. 22:100-103.

Moehring, D.M., and I.W. Rawls. 1970. Detrimental effects of wet weather logging. J. Forest. 68:166-167.

Patric, J.H., and J.D. Helvey. 1986. Some effects of grazing on soil and water in the eastern forest. USDA Forest Serv. Gen. Tech. Rep. NE-115. Broomall, Penn.

Pearson, H.A., H.E. Grelen, B.R. Parresol, and V.L. Wright. 1987. Detailed description of the longleaf-slash pine type, Vernon District, Kisatchie National Forest, La., p. 107-115. *In:* H.A. Pearson, F.E. Smeins and R.E. Thill (eds.), Proc. of Southern Evaluation Project Workshop, May 26-27, Longbeach, Miss. USDA Forest Serv. Gen. Tech. Rep. S0-68. New Orleans, La.

Schreiber, J.D., P.D. Duffy, and D.C. McClurkin. 1980. Aqueous- and sediment-phase nitrogen yields from five southern pine watersheds. Soil Sci. Soc. Amer. J. 44:401-407.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. McGraw-Hill, New York.

Stoeckler, J.H. 1959. Trampling by livestock drastically reduces infiltration rate of soil in oak and pine woods in southwestern Wisconsin. USDA For. Serv., Lake State Forest. Exp. Sta. Tech. Note 556.

Ursic, S.J. 1975. Harvesting southern forests: A threat to water quality? p. 145-151. *In:* P.M. Ashton and R.C. Underwood (eds.), Proc. of Southeastern Reg. Conf. Virginia Water Resour. Res. Cen. Blacksburg, Va.

Yoho, N.S. 1980. Forest management and sediment production in the South—a review. Southern J. Appl. Forest. 4:27-36.

Infiltration and sediment production as affected by soil surface conditions in a shrubland of Patagonia, Argentina

CÉSAR M. ROSTAGNO

Abstract

Infiltration and sediment production of eroded and uneroded shrub interspace soils were evaluated in December 1986 in a severely grazed, arid range site in northeastern Patagonia. A rainfall simulator and small plots were used to collect the data. A desert pavement embedded in a vesicular crust characterized the surface soil of the eroded areas that occupy the lowest position in the microtopographic pattern. A granular, fine, and weak structured A horizon characterized the soil of uneroded areas. Slopes were similar for the eroded and uneroded areas. Surface soil bulk density, electrical conductivity, clay and organic matter content were significantly greater for the eroded than for the uneroded soils. Litter cover was significantly higher for the uneroded soils. Plant cover, although higher for the uneroded areas, was low (<5%) for both eroded and uneroded areas.

Mean infiltration rate at the end of 35 min, with the soil initially dry, was 0.8 and 6.1 cm/hr for the eroded and uneroded soils, respectively. For the soil initially at field capacity, infiltration decreased to 0.6 cm/hr and 4.1 cm/hr. Soil losses were higher from the eroded areas (606 kg/ha and 687 kg/ha) than for the uneroded areas (291 kg/ha and 556 kg/ha) when the soils were initially dry and at field capacity, respectively. Regression analysis indicated infiltration rate was positively related to litter cover and negatively related to gravel cover, whereas sediment production was negatively related to bulk density, plant, and gravel cover characteristics of the site.

Key Words: soil erosion, desert pavement, soil crust, Torriorthent, rangeland hydrology

Infiltration is the term applied to the process of water entry into the soil. The rate of this process, relative to the rate of water supply, determines how much water will enter the root zone, and how much, if any, will run off (Hillel 1982). Hence, the rate of infiltration affects not only the water budget of plant communities but also the amount of surface runoff and the attendant danger of erosion. Livestock grazing has the potential to alter soil surface hydrological properties (Blackburn et al. 1982). In shrub-dominated communities, shrub interspace areas are more sensitive to deterioration than canopy-covered areas (Beeskow et al. 1987). In arid and semiarid areas with sparse vegetation, the development of vesicular horizons tends to increase with the removal of herbaceous vegetation from shrub interspaces through overgrazing (Volk and Gyeger 1970). Vesicular horizons are usually accompanied by crust or desert pavement development (Evenari et al. 1974).

In various semiarid rangelands in Nevada the occurrence and morphology of vesicular horizons are negatively correlated with infiltration rate and positively correlated with sediment production (Blackburn 1975). As water moves more rapidly over a smooth, crusted surface with vesicular pores and lower infiltration, the potential for runoff and sediment production increases. This type of soil surface is often associated with early-seral range condition (Eckert et al. 1986). In the study site, crusted and paved areas produced by water removal of the surface soil and exposure of the subsoil occupy part of the shrub interspace areas, being more frequent in severely degraded sites. The objective of this study was to compare infiltration rate and sediment production of eroded and uneroded shrub interspace soils of an arid range site that had a history of overgrazing in northeastern Patagonia, and then to evaluate edaphic and vegetation variables as they influence these parameters. It is postulated that eroded soils present hyrological properties less favorable than uneroded ones, consequently, the aridity of the site will increase as the proportion of eroded areas increases.

Study Area

The study site is located in a closed basin of northeastern Patagonia, 15 km southwest of Puerto Madryn, Chubut (42° 46′ S, 65° 00′ W). Average annual precipitation for the site is 170 mm and highly variable. The coefficient of variation for annual precipitation is 40% (Barros and Rivero 1982). Mean annual temperature is 13.5° C.

Soils of the study site belong to the sandy, mixed, thermic family of typic Torriorthent derived from a 1-m alluvium layer underlain by a compacted, cinereous substratum. The elevation is 75 m with a slope of 4%. Vegetation of this range site is a shrubby steppe predominated by quilembai (*Chuquiraga avellanedae* Lorentz.). Additional shrubs are jarilla (*Larrea divaricata* Cav.), piquillin (*Condalia microphylla* Speg.), and yaoyin (*Lycium chilense* Miers ex Bertero). Grasses on this study site include pasto hilo (*Poa lanuginosa* Poiret ap Lamarck), *Poa ligularis* Nees ap Steudel, *Stipa speciosa* Trinius and Ruprecht, and *Stipa neaei* Nees ex Steudel.

Shrubs are distributed as discrete clumps or individuals which cover 29% of the surface. Shrub interspace areas comprise the remaining 71%. In the shrub interspace areas, 2 types of soil surfaces are well differentiated:

i) The first, similar to that occurring beneath shrub clumps, is characterized by a granular, fine, weak structured A horizon. This soil surface type occupies the higher positions in the microtopographic pattern and is referred to as the uneroded condition (Fig. 1 A).

ii) The second one is characterized by a well-developed desert pavement embedded in a vesicular crust (Fig. 1 B). This soil surface type is referred to as the eroded surface condition and develops when the subsoil is exposed following removal of the topsoil by erosion. The position each surface type occupies in the microtopographic pattern is shown in Fig. 1 C.

The study area was intensively grazed in the past. However, for the past 5 years, all livestock have been excluded from the area.

Methods

A mobile, drip-type rainfall simulator similar to that described by Blackburn et al. (1974) was used to simulate rainfall on eight

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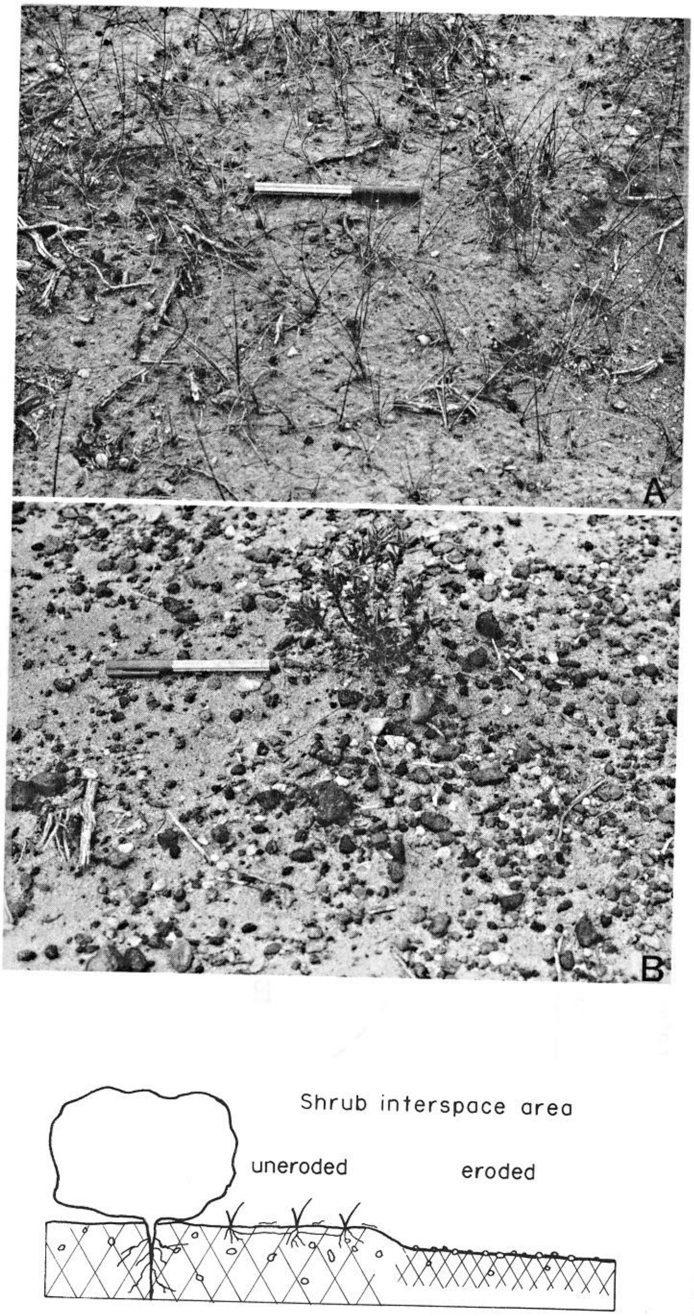

C

Fig. 1. *Uneroded (A) and eroded (B) soil surface conditions that alternate in the shrub interspace area, and their positions in the microtopographic pattern (C).*

0.25-m² (62.5 cm × 40 cm) plots randomly located in each surface condition within a previously mapped quadrat of 30 × 40 m. Simulated rainfall was applied for 35 min to 2 antecedent moisture conditions: (1) soil surface horizon initially air dry and (2) soil surface horizon near field capacity (24 hr after the dry run). Both conditions occur during the warm season when high intensity rainfall occurs. Rainfall application rate was 68 mm/hr. Data of Trelew station, 40 km south of the study area, indicate that a rainfall of this duration and intensity has a recurrence interval of 50 years (Vicenty et al. 1984). Drop diameter of the simulated rainfall was 2.5 mm. Falling 2.1 m, water drops of this size reach a velocity of 5.35 m/sec or 72% of the terminal velocity of natural rainfall drops of this diameter (Epema and Riezebos 1983).

Runoff was collected at 5-min intervals during the 35-min simulated rainfall events. Infiltration was defined as the difference between total water applied during a given time period and total runoff during the same period. Initiation of runoff was defined as the time when measurable (i.e., approximately 20 cc runoff in 30 seconds) runoff occurred from the plot (Devaurs and Gifford 1984). Sediment production was determined from the total runoff collected during each time interval by passing the sample through a Pt 325 sieve (45 um mesh). Sediment passing the sieve was determined for a sub-sample. This determination showed less variation than when taking an aliquot of the whole sediments. The 2 subfractions were dried at 105° C for 24 hr, weighed, converted to sediment yield (kg/ha) and used as an index of erosion.

Immediately before each simulated rainfall, a soil sample of the 0 to 5 cm depth was collected on areas adjacent to each plot for determination of organic carbon content by the Walkley-Black method (Allison 1965) and electrical conductivity of the saturation extract (U.S. Salinity Laboratory Staff 1954). Bulk density was determined by the excavation method (Blake 1965) and textural composition by the pipette method (Day 1965). Vegetation, litter, and gravel cover were visually estimated in each sample plot.

Significant differences between hydrological attributes on the two soil surface conditions were determined using Student's *t*-test. Variables associated with infiltration rate and sediment production were determined by means of forward stepwise multiple regression procedures using the Statistical Analysis System. Significant differences are at $P \leq 0.05$.

Results and Discussion

Soils and Vegetation

Selected soil and vegetation variables for the 2 soil surface conditions are given in Table 1. Eroded soils had higher density

Table 1. Mean soil and vegetation values for uneroded and eroded soil surface conditions ($\bar{x} \pm$ 1SD) in northeastern Patagonia, Argentina.

Variable	Soil Surface Condition			
	Uneroded		Eroded	
Bulk density (g/cc)	1.34	(0.09)	1.55	(0.15)
Sand (%)	77.14	(1.60)	70.80	(3.90)
Clay (%)	6.50	(1.70)	10.70	(2.60)
Organic matter (%)	1.19	(0.17)	1.56	(0.28)
Electrical conductivity (mmhos/cm)	0.22	(0.01)	3.50	(4.30)
Gravel cover (%)	3.00	(2.10)	60.00	(8.00)
Litter cover (%)	19.00	(12.10)	4.50	(0.41)
Plant cover (%)	4.50	(1.50)	0.75	(1.29)

and electrical conductivity, and a finer texture than the uneroded soils. Percent organic matter was low in both eroded and uneroded soils, but highest on the eroded soils. This can be attributed to the higher clay content of eroded soils as more organic matter can be adsorbed on fine than on coarse-textured soils (Dregne 1976). Organic matter and clay content were positively related ($r = 0.71$). Gravel cover was substantially higher on eroded soils. Gravel concentration on the soil surface reflects the amount of topsoil eroded. On the eroded soils, gravels are embedded in the vesicular crust, but on the uneroded soils, gravel lies on the surface or is immersed in loose, fine materials.

Litter cover was higher and more viable on the uneroded soils. Vegetation cover was low for both soil surface conditions, although it was significantly higher on uneroded soils. On the study site, the dominant species associated with the uneroded soils was pasto hilo, a rhizomatous plant that grows on loose, sandy soils (Bertiller et al. 1981). This species is absent from the eroded soils.

Infiltration Rate

Under dry antecedent moisture conditions, mean infiltration rate was substantially greater ($P \leq 0.05$) and less variable for the uneroded than for the eroded soils (Fig. 2A, Table 2). The mean

Table 2. Mean infiltration rates at the end of the 35 min simulated rainfall event and time to runoff under dry and field capacity antecedent moisture conditions for uneroded and eroded soil surface conditions ($\bar{x} \pm$ 1SD) in northeastern Patagonia, Argentina.

Soil Surface Condition	Mean Infiltration Rate cm/hr		Time To Runoff min	
	Dry	Field capacity	Dry	Field capacity
Uneroded	6.1 (0.67)	4.1 (1.31)	16.8 (2.35)	6.5 (2.34)
Eroded	0.8 (0.47)	0.6 (0.08)	3.5 (1.32)	3.2 (0.48)

infiltration rate under field capacity antecedent moisture conditions for the uneroded soils was significantly greater ($P \leq 0.05$), and more variable than for the eroded soils (Fig. 2B).

Stepwise regression analysis was used to identify the variables associated with infiltration rate for both soil surface conditions combined. For the soils initially at field capacity the following equation was obtained:

Mean infiltration rate after 35 min = 2.79 + 0.050 (litter cover) −0.039 (gravel cover) R=0.94

Litter and gravel cover were the variables that most effectively predicted infiltration rate. Besides its direct effect on the infiltration process, litter cover integrates other variables related to it. Thus, litter cover was positively related to sand content (r = 0.68) and negatively related to bulk density (r = 0.57). Sand content was higher and bulk density was lower in the uneroded than in the eroded soils. In contrast, gravel cover, that was negatively related to infiltration rate (r = 0.94), was positively related to clay content (r = 0.82) and bulk density (r = 0.67). Desert pavement was closely related to the surface soil crust. The crust, considered to negatively affect infiltration rate (McIntyre 1958), was only present on the eroded areas. Thus, the gravel cover variable integrated the surface soil characteristics negatively related to infiltration rate. Blackburn (1975) found, on a big sagebrush community, that infiltration rate of dune interspace areas was 3–4 times lower than that of coppice dunes. Coppice dune and dune interspace areas exhibited soil surface horizon properties similar to the uneroded and eroded soils in this study respectively.

For the eroded soils differences between infiltration rate, for the 2 antecedent moisture conditions were not significantly different ($P \leq 0.05$) (Table 2). However, for the uneroded soils, infiltration rate was significantly greater ($P \leq 0.05$) for the soils initially dry than for the soils at field capacity.

Rainfall duration necessary to produce runoff was significantly greater ($P \leq 0.05$) for uneroded than for eroded soils (Table 2). Similar time-to-runoff was found for crusted and uncrusted soils of an open chenopod shrubland of southern Australia (Graetz and Tongway 1986) as well as in laboratory experiments (Cai et al. 1985, De Ploey and Bryan 1985), although slope and rainfall intensity were different.

Runoff and Sediment Production

Runoff and sediment production were significantly greater ($P \leq 0.05$) from the eroded than from the uneroded soils for dry antecedent moisture condition only (Table 3). For the initially dry soil, sediment production from the eroded soils was twice that of uneroded soils. However, an 18-fold difference in total runoff

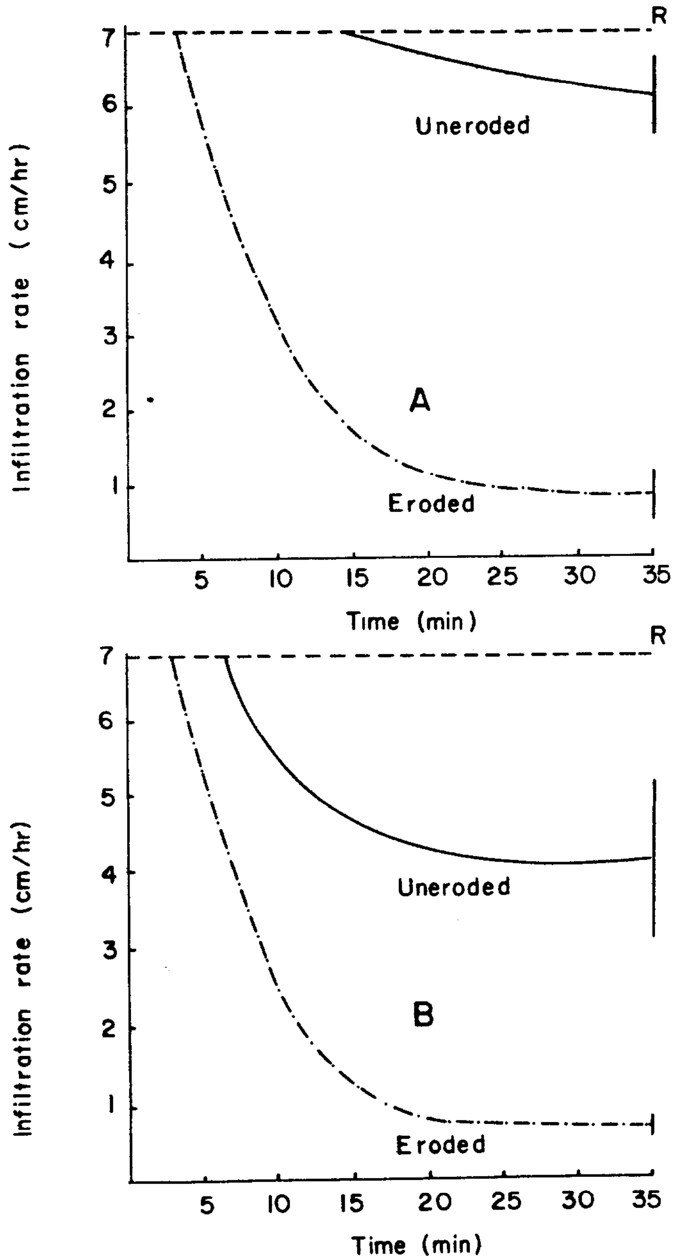

Fig. 2. *Infiltration rates under dry (A) and field capacity (B) antecedent soil moisture for uneroded and eroded soil surface conditions. Vertical lines represent 95% confidence interval for mean infiltration rates after 35 min. R is applied rainfall intensity. Each curve is hand drawn using the mean values from 8 plots.*

Table 3. Mean sediment production and runoff under dry and field capacity antecedent moisture conditions for uneroded and eroded soil surface conditions ($\bar{x} \pm$ 1SD) in northeastern Patagonia, Argentina.

Soil Surface Condition	Sediment Production (kg/ha)		Runoff (% of applied rainfall)	
	Dry	Field capacity	Dry	Field capacity
Uneroded	292 (121)	556 (195)	4 (3)	32 (12)
Eroded	616 (192)	667 (343)	71 (3)	75 (1)

existed between the 2 soil conditions, (i.e., 4% and 71% for the uneroded and eroded soils, respectively). Assuming that the rate of sediment production under similar slopes is a function of excess overland flow (Thornes 1985), the relatively small differences in sediment production compared to the great differences in runoff production may be accounted for by the protective effect of the cover of gravel on the eroded soils and the resistance of the crust.

Sediment production was significantly greater ($P \leq 0.05$) from uneroded soils initially at field capacity than from uneroded soil initially dry (Table 3). Differences in sediment production and runoff from the eroded soils for the 2 antecedent moisture conditions were not significant ($P \geq 0.05$).

When the combined data for the 2 surface conditions were used in the regression analysis, no variables met the 0.05 significance level for entry into the model. The stepwise multiple regression generated the following model for the uneroded soils with the soil initially at field capacity:

Mean sediment production after 35 min = 2758 − 1486.4 (bulk density) − 49.6 (plant cover) R^2=0.95

The model for the eroded soils with the soil initially at field capacity was:

Mean sediment production after 35 min = 3625.5 − 1186 (bulk density) − 20.1 (gravel cover) R^2 = 0.65

For the 2 soil conditions, bulk density was the strongest predictor of sediment production. Bulk density may influence sediment production by affecting soil detachment, with the soils more compacted being less detachable. Plant cover was the second strongest variable associated with sediment production for the uneroded soils. Although the influence of plant cover on sediment production is well understood (Thurow et al. 1986, Bedunah and Sosebee 1986), its effect on the study site is not clear since the low plant cover present on the uneroded areas may contribute little to soil loss control. For the eroded soils, gravel cover was the second most important variable predicting sediment production. Simanton et al. (1984) found that erosion ratios from macroplots with rock fragments decreased exponentially with the increase in percent rock cover. The influence of soil crusts on erosion is not well understood. Although, the resulting increased runoff due to low infiltration rates of the eroded soils enhanced erosive capacity (Bryan and De Ploey 1983), it is possible that this is more than offset by the increased erosion resistance of the crusted surface.

Conclusions

Topsoil erosion, the main degradation process affecting the soils of the study area, occurs in discrete patches in the shrub interspace areas. This process has generated 2 soil surface conditions that differ greatly in term of pedological as well as hydrological properties. The main difference between the 2 conditions with direct consequences on biological productivity was the reduced infiltration rate of the eroded soils. Results indicate that eroded soils provide less opportunity for soil water storage, producing most of the runoff generated from the site. This tends to accentuate the biological patchiness that characterizes more arid ecosystems, reducing also the ecosystem potential for production.

Differences in sediment production from the 2 soil surface conditions were not as high as expected considering the differences in runoff produced. The erosion process on the eroded soils seems to be reduced by soil compaction and the formation of a desert pavement that attenuates raindrop impact, thus reducing soil detachment.

Literature Cited

Allison, L.E. 1965. Organic carbon, p. 1367-1378. *In:* C.A. Black (ed). Methods of Soil Analysis. Monogr. Ser. Part 2, No. 9 Amer. Soc. Agron., Madison, Wis.

Barros, V., and M.M. Rivero. 1982. Mapa de probabilidad de precipitacion de la Provincia del Chubut. Contribución No. 54. Centro Nacional Patagónico, Puerto Madryn, Chubut, Argentina.

Bedunah, D.J., and R.E. Sosebee. 1986. Influence of mesquite control on soil erosion on a depleted range site. J. Soil Water Conserv. 41:131-135.

Beeskow, A.M., H.F. Del Valle, and C.M. Rostagno. 1987. Los Sistemas fisiográficos de la región arida y semiarida de la provincia del Chubut, Argentina. SECYT Delegación Regional Patagonia, S.C. de Bariloche, Rio Negro, Argentina.

Bertiller, M.B., A.M. Beeskow, and M.P. Irisarri. 1981. Caracteres fisonómicos y floristicos de la vegetación del Chubut. 2. La Peninsula Valdes y el Istmo Ameghino. Contribución No. 41, Centro Nacional Patagónico, Puerto Madryn, Chubut, Argentina.

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.

Blackburn, W.H., R.W. Knight, and M.K. Wood. 1982. Impact of grazing on watersheds: A state of knowledge. Texas Agr. Exp. Sta. MP-1496.

Blake, B.R. 1965. Bulk density, p. 374-390. *In:* C.A. Black (ed). Methods of soil analysis. Monogr. Ser. Part 1, No. 9, Amer. Soc. Agron., Madison, Wis.

Bryan, R.B., and J. De Ploey. 1983. Comparability of soil erosion measurements with different laboratory rainfall simulators. Cantena Supplement 4:34-56.

Cai, Q.G., S.H. Luk, H. Chen, and Y.Z. Chen. 1985. Effect of surface crusting on water erosion: laboratory experiments on loess soils, China, p. 99-106. *In:* Proc. Symp. on Assessment of Soil Surface Sealing and Crusting. State University of Ghent. Ghent, Belgium.

Day, P.R. 1965. Particle fractionation and particle-size analysis, p. 545-567. *In:* C.A. Black (ed). Methods of Soil Analysis. Monogr. Ser. Part 1, No. 9, Amer. Soc. Agron., Madison, Wis.

De Ploey, J., and R.B. Bryan. 1985. Time to runoff as a function of slope angle, p. 106-119. *In:* Proc. Symp. on Assessment of Soil Surface Sealing and Crusting. State University of Ghent, Belgium.

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

Dregne, H.E. 1976. Soils of arid regions. Elsevier Sci. Pub. Co., New York.

Eckert, R.E., F.F. Peterson, and J.T. Belton. 1986. Relation between ecological range condition and proportion of soil-surface types. J. Range Manage. 39:409-413.

Epema, G.F., and H.T. Riezebos. 1983. Fall velocity of water drops at different heights as a factor influencing erosivity of simulated rain. Catena Supplement 4:1-18.

Evenari, M., D.H. Yaalon, and Y. Gutterman. 1974. Note on the soils with vesicular structure in deserts. Z. Geomorphol. N.F. 18:162-172.

Graetz, R.D., and D.J. Tomgway. 1986. Influence of grazing management on vegetation, soil structure, and nutrient distribution and the infiltration of applied rainfall in a semiarid chenopod shrubland. Australian J. Ecol. 11:347-360.

Hillel, D. 1982. Introduction to soil physics. Academic Press. New York.

McIntyre, D.S. 1958. Permeability measurements of soil crusts formed by raindrop. Soil Sci. 85:185-189.

Simanton, J.R., E. Rawitz, and E.D. Shirley. 1984. Effects of rock fragments on erosion of semiarid rangelands soils, p. 65-72. *In:* J.D. Nichols, P.L. Brown, and W.J. Grant (eds). Erosion and productivity of soils containing rock fragments. Soil Sci. Soc. Amer. Spec. Pub. 13.

Thornes, J.B. 1985. The ecology of erosion. Geography 70:222-238.

Thurow, T.L., W.H. Blackburn, and C.A. Taylor, Jr. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. J. Range Manage. 39:505-508.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Agr. Handb. 80, USDA, U.S. Government Printing Office, Washington, D.C.

Vicenty, O.A., J.J. Serra, and A.D. Gabetta. 1984. Estudio de las precipitaciones en la ciudad de Trelew, Chubut. MESOP, RAWSON, Chubut, Argentina.

Volk, O.H., and E. Geyger. 1970. Schaumboden als Urache der Vegetationslosigkeit in arid Gebieten. Z. Geomorph. N.F. 14:79-95.

Matric potential of clay loam soils on arid rangelands in southern New Mexico

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Abstract

The matric potential of soil water is presented for 6 clay loam sites on floodplains of arid rangelands. Gypsum resistance blocks impregnated with plaster of paris were placed at 6 soil depths to 122 cm. At 4 locations, blocks were placed inside and outside a buried sheet metal cylinder so that estimates could be obtained of matric potential due to precipitation and due to precipitation plus run-in. The average annual precipitation during the approximate 20-year study period was 242 mm, slightly above the long-time average. Haplargids dominated by tobosa [*Hilaria mutica* (Buckl.)Benth.] had a greater probability of the matric potential ≥-1.5 MPa (wet soil) than the Calciorthids dominated by burrograss (*Scleropogon brevifolius* Phil.). The probability of matric potential ≥-1.5 MPa (wet soil) was as great or greater in winter as during the summer growing season. The factors affecting matric potential were amount and nature of precipitation, amount of run-in water, soil and vegetation type, position on the landscape, and microrelief.

Key Words: soil matric potential, precipitation, probabilities, soil texture

Forage production on arid rangelands is highly dependent on available soil water. Soil water deficits can cause large reductions in forage production. However, there is little information in scientific literature of field measurements of soil water on arid rangelands.

Herbel and Gibbens (1987) measured the matric potential of 11 coarse-textured sites in southern New Mexico for nearly 20 years. During the cool part of the year, December–April, the probability of soil matric potential ≥-1.5 MPa (wet) was 69% at the 10-cm depth, 83% of the 69% was ≥-0.1 MPa (readily available). The probability of wet soils during the summer rainy season, July–September, was 53% at the 10-cm depth, 73% of which was readily available. When the matric potential was ≤-1.5 MPa (dry), it took at least 13 mm precipitation in a single day to change to wet soils at the 10-cm depth.

Tromble (1982) studied the volume of soil water on a fine-loamy, mixed, thermic, Typic Haplargid of the Dona Ana series with a 1% slope about 10 km from our study sites. Soil water content during the summer thunderstorm period averaged 13.5% for 2 years at depths of 30–180 cm, but it was about 35% where water was ponded behind dikes 15 cm high. This indicates slow infiltration on this bare area with a slight slope. Overland flow was initiated with as little as 5 mm of rainfall.

As much as 93% of the annual precipitation is lost by evaporation on sites dominated by creosotebush [*Larrea tridentata* (Sesse & Mocino ex DC.) Coville] in the Sonoran Desert (Sammis and Gay 1979). On a site dominated by creosotebush in the Chihuahuan Desert, Schlesinger et al. (1987) estimated that 72% of precipitation was removed by transpiration. This suggests a tremendous variation in soil water losses due to evaporation and due to transpiration. The latter authors also suggested that plant uptake of water from the lower soil profile greatly affects calcium carbonate (caliche) deposition in desert soils.

On loamy sands and sandy loams of the Jornada Experimental Range, factors affecting soil matric potential were precipitation amount, surface soil characteristics, topography, subsurface conditions, and season of the year (Herbel and Gibbens 1987). Information on soil water is needed to understand forage dynamics on flood plains of arid rangelands. This paper presents information on the soil matric potential of clay loams at several sites receiving run-in water from adjacent slopes. These data are unique because soil water potential was determined for nearly 20 years, and we attempted to determine soil water due to precipitation and due to precipitation plus run-in. It is the first attempt to quantify these measurements on clay loam soils on arid rangelands.

Materials and Methods

Description of the Study Area

This study was conducted on the Jornada Experimental Range about 40 km north of Las Cruces, New Mexico. Most of the Jornada is in a closed intermountain basin with a level to gently undulating topography. The average annual precipitation is 228 mm with 129 mm occurring during the July through September growing season. Most summer rainfall occurs as intensive thunderstorms. Conversely, winter precipitation from frontal storms is gentle. Description of other climatic features can be found in Herbel and Gibbens (1987).

Five locations, 6 sites, designated V, W, X, Y_2, Y_3, and Z, were sampled during the study. Table 1 shows the soil and the dominant plants at the 6 sampling sites and Table 2 shows the textural class and soil horizon for the depths where matric potentials were determined (Bulloch and Neher 1980, Herbel and Gile 1973). Both Sites V and Y_2 occur on the toeslopes at the edge of the basin floor. The slope is about 0.5% and the vegetation is a dense stand of tobosa [*Hilaria mutica* (Buckl.) Benth.]. Toeslopes, such as V and Y_2, may contribute some runoff water to the basin floor from a high-intensity storm, they also receive considerable run-in from the adjacent steeper slopes. Average annual tobosa production at Y_2 for 4 years was 3,005 kg/ha (Herbel 1963). Site Y_3 is an inclusion of Reagan soil 4 m in diameter, dominated by burrograss (*Scleropogon brevifolius* Phil.), located 5 m from Site Y_2. Locations W and X occur on the relatively level basin floor. Run-in water from

Table 1. Soils and dominant vegetation of 6 sites on the Jornada Experimental Range.

Site	Soil classification	Soil series	Dominant vegetation
V, W, Y_2	Ustollic Haplargid, fine, mixed, thermic	Stellar	Tobosa
X Y_3	Ustollic Calciorthid, fine-silty, mixed, thermic	Reagan	Burrograss
Z	Typic Calciorthid, fine-loamy, mixed, thermic	Algerita	Tobosa-burrograss

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Table 2. Soil texture (horizon) for the study depths at six sites at the Jornada Experimental Range.

Site	Depth (cm)					
	10	25	41	61	91	122
V	cl(A)	cl(Bt1)	cl(Bt1)	cl(Bt2)	c(Bk)	c(2Bt)
W	c(Btl)	cl(Bt2)	cl(Bt2)	c(Btk)	cl(Bk1)	cl(Bk2)
X	sicl(AB)	cl(BA)	sicl(Bk1)	cl(Bk2)	cl(Bk3)	cl(Btkb)
Y_2	cl(BAt)	c(Bt1)	c(Bt1)	c(Bt2)	sicl(Bk)	cl(Bky)
Y_3	sicl(A)	sicl(Bw1)	cl(Bw2)	sicl(Bk)	sicl(Bk)	cl(2Bt)
Z	fsl(A)	cl(BA1)	scl(BA2)	sicl(Bk1)	sicl(Bk3)	sl(2Bky2)

Abbreviations used in describing soil textures: c = clay, l = loam, si = silty, s = sandy.

the adjacent slopes does not stand on the area, but drains slowly to a playa about 2 km distant. The vegetation at Location W is tobosa and the average 1957–77 production was 1,662 kg/ha (Herbel and Gibbens 1981). The tobosa at W is sparser than at V and Y_2. Location X is about 75 m from W and dominated by burrograss that averaged 950 kg/ha 1957–77. Location Z is in a small playa at the end of a drainageway that begins on the slopes of mountains about 16 km distant. The playa is flooded about twice every 3 years. The vegetation is a mixture of tobosa and burrograss that averaged 1,710 kg/ha 1957–77 (Herbel and Gibbens 1981).

The soils at V, W, and Y were formed in fan-piedmont sediments derived from monzonite, rhyolite, and andesite; at X, the soil was formed in basin floor sediments derived primarily from sedimentary rocks with lesser amounts from igneous rocks; and at Z, the soil was formed in alluvium from sedimentary and igneous rocks resting on gypsum of lacustrine origin (Herbel and Gile 1973). The surface was Pleistocene age (Gile and Hawley 1968, Hawley and Gile 1966).

Measurement Techniques

Gypsum resistance blocks impregnated with plaster of paris were placed at depths of 10, 25, 41, 61, 91, and 122 cm. At 4 locations (W, X, Y, and Z) blocks were placed inside and outside a sheet-metal cylinder. The cylinder was 3 m in diameter, was buried 15 cm in the soil, and extended 15 cm above the soil surface. The blocks inside the cylinder provided estimates of the matric potential due to precipitation while those outside the cylinder provided estimates of the matric potential due to precipitation plus run in. The subscript numbers 0 and 1 identify sites inside the cylinder and the subscript numbers 2 and 3 identify sites outside the cylinder. At Site Y_2, 2 sets of blocks were inside the cylinder, identified as Y_0 and Y_1. At this site, the cylinder did not completely block run-in water because water that accumulated in a depression outside the cylinder was able to infiltrate and move laterally through natural soil pipes or tubes to the Bt1 horizon. The matric potential at the location was also measured in a relatively small inclusion of burrograss outside the cylinder in an otherwise thick stand of tobosa (Site Y_3).

All sampling sites were located within livestock exclosures. Matric potential measurements were recorded with an ohmmeter 1 to 3 times per week when the soil was wet during the summer. Measurements were recorded monthly during the remainder of the year when there were fewer changes in soil water status. Blocks were calibrated in medium-textured soil by determining their resistance in a pressure plate extractor (Taylor et al. 1961). Only blocks with similar response curves were used. Occasionally, blocks were replaced because of rodent damage to wires. No deterioration of the gypsum medium occurred in these aridisols. No change in calibration of the blocks was observed. All resistance readings were corrected to 15.6° C using soil temperatures recorded with thermistors at several soil depths at 4 locations when matric potential was measured. Precipitation was recorded at each study site in a standard U.S. Weather Bureau rain gauge modified to reduce evaporation loss (Gomm 1961).

The soils in this study were nonsaline as determined by a method developed by the U.S. Salinity Laboratory (1954). Therefore, the measurement of the soil water was assumed to be a measure of the matric potential. Each resistance reading was translated to MPa. For days when the resistance was not measured, matric potential was determined by (1) previous determinations of matric potential at that depth, (2) current precipitation, (3) matric potential at other depths at that location, and (4) previous precipitation events at that location. All the daily determinations were grouped into matric potentials of 0 to –0.1 MPa (readily available), –0.1 to –1.5 MPa, and <–1.5 MPa(dry).

Resource availability dictated the establishment of sampling sites. Blocks were installed at the 10-, 25-, and 41-cm depths at Sites V, W_2, X_2, and Z_2 in July 1957; and at Site Y_2 in July 1958. The remainder of the blocks were installed in August 1959. Resistance readings were terminated 31 Dec. 1976. No readings were obtained 1 Aug. through 31 Dec. 1972 because of a meter failure.

Soil matric potential was determined for each day. Probabilities were calculated by determining the percentage of days in each month at each study site at each depth that had matric potentials (1) >–0.1 MPa, (2) between –0.1 and –1.5 MPa, and (3)<–1.5 MPa, and then averaging these percentages for the entire study period. For the probability of wet soils, ≥–1.5 MPa, we combined (1) and (2). Thus, for purposes of this paper, a matric potential of ≥–1.5 MPa is considered a wet soil with water available to plants. A metric potential of ≥–0.1 MPa shows the soil very wet with water readily available to plants while soil water with a matric potential <–1.5 MPa is considered dry soil. Some plants use soil water <–1.5 MPa. This broad interpretation minimizes the effect of hysteresis of the blocks.

Table 3. Average monthly precipitation (mm) at 3 locations, 1957–76, on the Jornada Experimental Range.

Month	Location		
	V	W	Z
	mm		
Jan.	13	11	10
Feb.	7	6	7
Mar.	8	8	6
Apr.	3	3	3
May	5	4	3
June	16	14	16
July	60	50	46
Aug.	58	58	41
Sep.	44	40	47
Oct.	25	17	19
Nov.	12	11	10
Dec.	16	14	16
Total	267	236	224

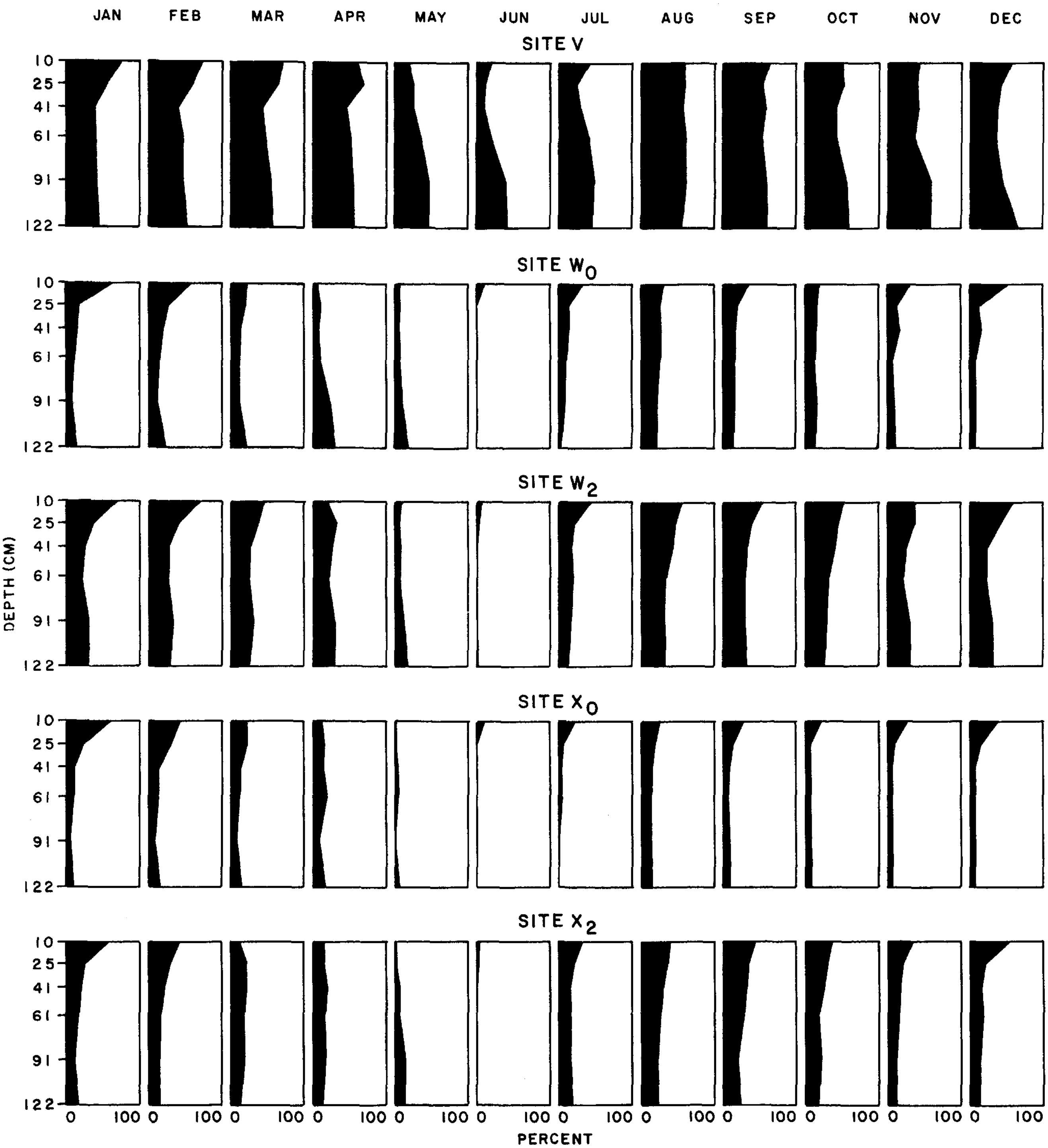

Fig. 1. *Monthly probability (%) of the matric potential ≥−1.5 MPa (wet soils) for 6 depths at Locations, V, W, and X.*

Results and Discussion

The average annual precipitation for Locations V, W, and Z was 267, 236, and 224 mm, respectively, and the average rainfall for July–Sep. was 162, 148, and 134 mm (Table 3). The precipitation for V and Y, and for W and X, is similar because they are close to each other. Inspection of daily precipitation and matric potential revealed, when the soil was dry, it took at least 20 mm precipitation in a single day to change a wet soil at the 10-cm depth, particularly in the warm days of June–Aug. Correlations between precipitation, all daily events or daily events ≥20 mm, and matric potentials at the various locations were low ($r \leq 0.32$).

Soil Matric Potentials

Location V

Figure 1 shows the monthly probabilities of wet soil for all study depths of V, W, and X. The annual probabilities of wet soil for V ranged from 39–53%. Except for May, July, and August, the lowest probabilities of wet soil were at the 41- and 61-cm soil depths. Evapotranspiration did not seem to have a large effect on the matric potential at the 91- and 122-cm depths. As soil temperature declined, there apparently was an increase in the probabilities

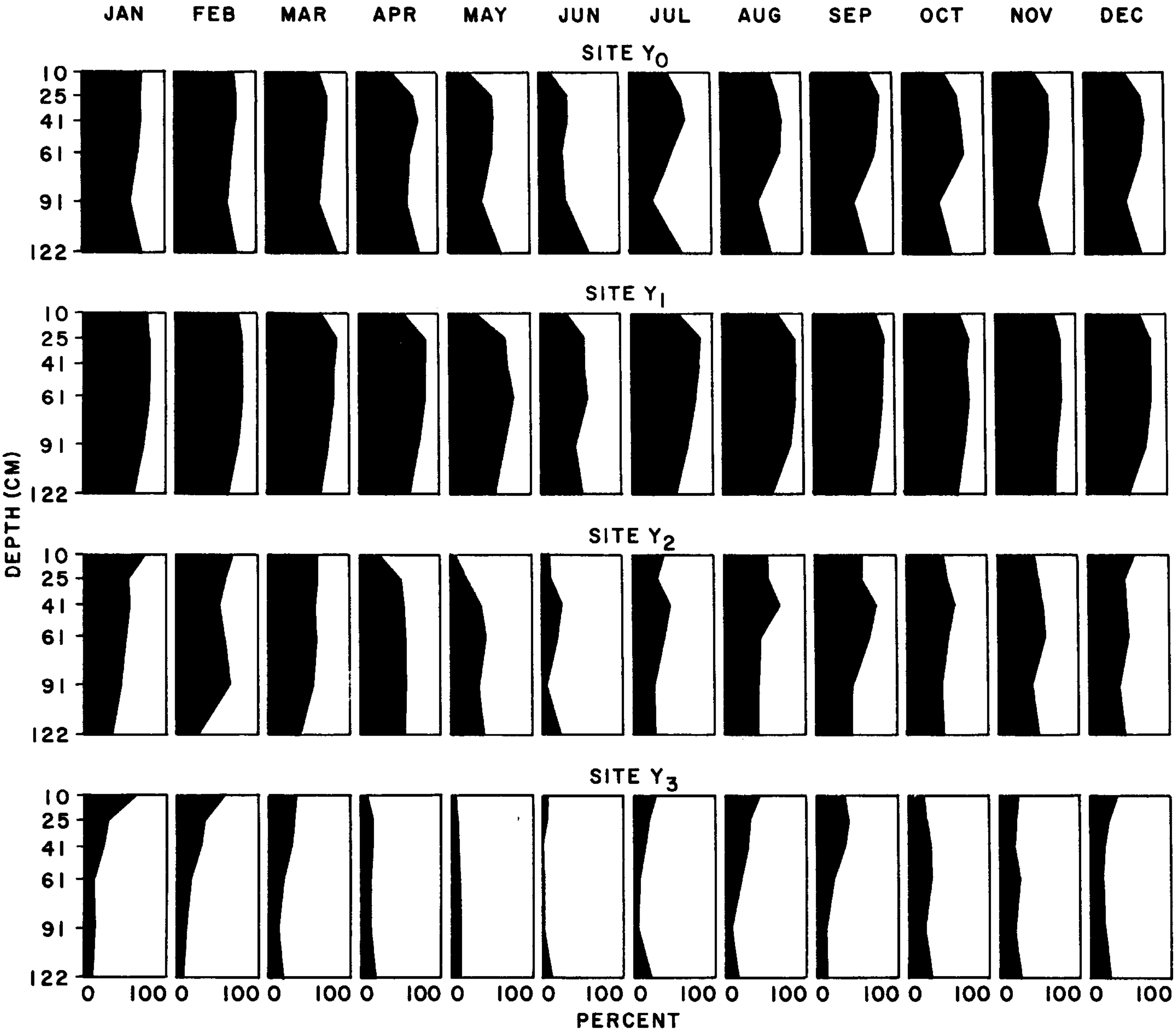

Fig. 2. *Monthly probability (%) of the matric potential ≥-1.5 MPa (wet soils) for 6 depths at Location Y.*

of wet soil at the 122-cm depth from the calcium carbonate (caliche) underlying this soil (Hennessy et al. 1983, Taylor 1962). In the A horizon at the 10-cm depth, the probabilities of wet soil were lowest in May and June while the highest was Jan.–Mar. The lowest probabilities of wet soil at the other depths was in June. During summer, when average precipitation is the highest, the average probability of wet soil at the 10-cm depth was highest in September. The average lowest probabilities during summer were at the Bt1 horizon at the 25- and 41-cm depths. During Nov.–Apr., average lowest probabilities of wet soil were at the 41- and 61-cm depths.

Location W

The annual probability of wet soil for W_0 averaged 10–30% for the 6 soil depths where matric potentials were determined, whereas at W_2 the annual average was 21–43% (Fig. 1). In the Bt1 horizon at the 10-cm depth, the average annual probability of wet soil was 43% greater at W_2 than at W_0; at deeper depths, it was about 100% greater. Probabilities of wet soil at a depth of 10 cm at W_0 during Dec.–Feb. were 57%, and 33% during July–Sep. At W_2, the probabilities of wet soil at the 10-cm depth were 65% during Dec.–Feb., and 51% during July–Sep. At W_0, the probabilities of wet soil were at least 100% greater at the 122-cm depth than at the 91-cm depth for Jan.–Mar. and May. During Apr., the probabilities of wet soil at both the 91- and 122-cm depths were >100% more than at the 61-cm depth. These differences were not apparent at W_2. At both sites, the probabilities of wet soil were considerably higher during Dec.–Feb., July, and Sep. at the 10-cm depth then at the remaining soil depths.

Location X

The probability of wet soil was at least 100% greater at each depth for the average of July–Dec. at X_2 than at X_0, while it was similar for Jan.–June (Fig. 1). The highest probabilities for each month at X_0 and X_2 occurred in the AB horizon at the 10-cm depth, except for Mar.–May. At X_2, the probabilities of wet soil at the 10-cm depth were 50% during Dec.–Feb., and 38% during July–Sep. The same probabilities at the 25-cm depth were 25% and 30%. At X_0, the probabilities of wet soil were at least 100% greater during Jan.–May at the 122-cm depth than at the 91-cm depth. These pronounced differences did not occur at X_2. At both sites, the probabilities of wet soil were higher during June–Feb. at the 10-cm

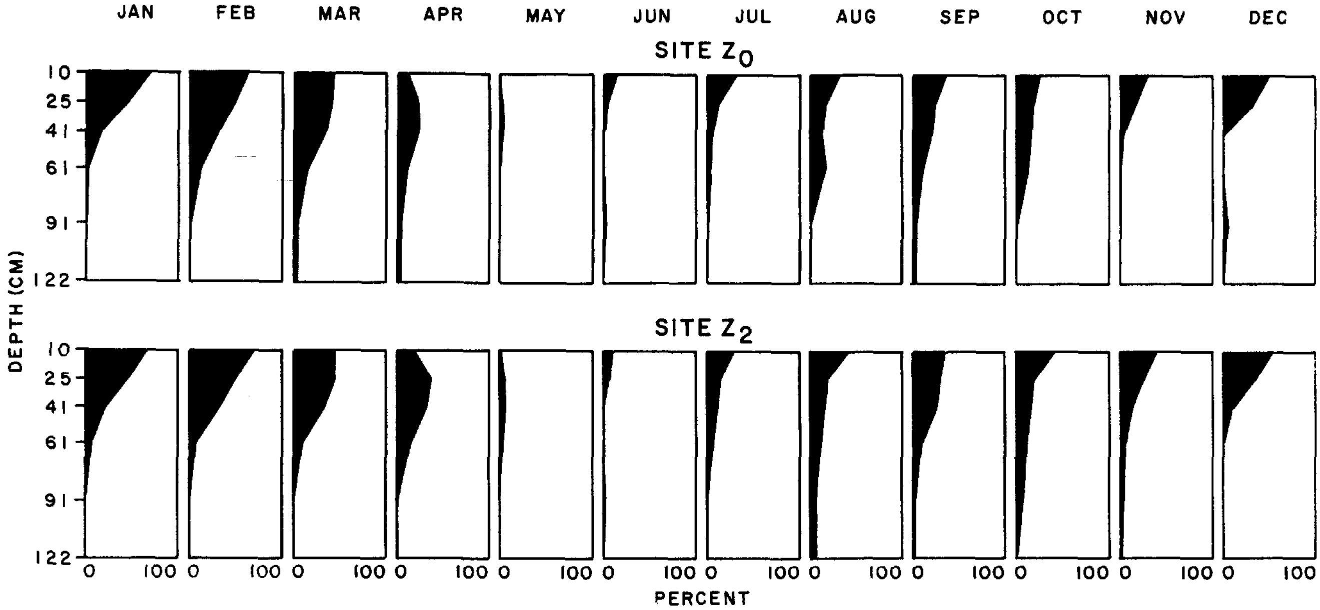

Fig. 3. *Monthly probability (%) of the matric potential ≥-1.5 MPa (wet soils) for 6 depths at Location Z.*

depth than the other soil depths.

Location Y.

The annual probabilities of wet soil for the 6 soil depths averaged 51–70% at Y_0, 61–81% at Y_1, 39–53% at Y_2, and 12–31% at Y_3 (Fig. 2). The probabilities for July–Sep. were 42–76% at Y_0, 61–88% at Y_1, 37–63% at Y_2, and 9–36% at Y_3, while for Nov.–Apr. they were 59–75% at Y_0, 63–82% at Y_1, 42–56% at Y_2, and 14–37% at Y_3. Although surface runoff was prevented inside the sheet metal cylinder at Y_0 and Y_1, the probability of wet soil was higher at Y_0 and Y_1 than at Y_2. The probabilities at the 25- to 91-cm soil depths were 4–6% higher during July–Sep. than Nov.–Apr. at Y_1 whereas at Y_0 the probabilities for the 2 periods were similar at all depths sampled. At Y_0, every month had a higher probability of wet soil at the 122-cm depth than the 91-cm depth, but at Y_1, most months had a higher probability at the 91-cm depth than at the 122-cm depth. At Y_2, with the exception of the 41-cm depth, the probability of wet soil was higher during Nov.–Apr. than July–Sep.

Location Z

At the A horizon at the 10-cm depth, the average probability for wet soil at Z_2 was 37% greater for Nov.–Apr. than for July–Sep. (Fig. 3). Also at the 10-cm depth, the probabilities for July–Sep. were 9% higher at Z_2 than at Z_0; for Nov.–Apr. it was 12%. The highest probabilities for each month at Z_0 and Z_2 occurred at the 10-cm depth, except for Mar.–May.

Soil Matric Potential >-0.1 MPa

Table 4 shows the percentage of wet soil that is readily available for V, Y_0, Y_1, and Y_2; for Y_3, W_2, X_2, and Z_2; and for W_0, X_0, and Z_0. A greater percentage of soil water was readily available at the tobosa-dominated sites near slopes providing run-in water (V, Y_0, Y_1, Y_2) than at the other sites, with the exception of the 122-cm depth during July–Mar. Generally, the burrograss-dominated site at Y_3, and the other sites receiving less run-in (W_2, X_2, Z_2) were intermediate in the percentage of soil water that was readily available. During Apr.–June, when the soil was in a drying trend, more of the matric potential ≥-1.5 MPa was between -1.5 and -0.1 MPa, except for soil depths between 25 and 91 cm at V, Y_0, Y_1, and Y_2.

Variability Among Years

Figure 4 shows the percentage of days during 3-month periods with matric potential >-1.5 MPa (wet) for the 6 soil depths and precipitation for 5 years (1963, 1965, 1969, 1970, and 1975) at Location V. These data are typical of those obtained at other locations, and illustrate the variability among years.

Total precipitation for 1963 was 252 mm (average during study period = 267 mm). The precipitation during this year can be characterized as a dry winter and spring, wet summer, and dry fall. The

Table 4. The average probabilities of soil matric potential ≥-0.1 MPa (readily available soil water) as a percentage of matric potential ≥-1.5 MPa (wet soils) for the sample sites, Jornada Experimental Range. Subscripts 0 and 1 denote sites within metal cylinders, subscripts 2 and 3 outside cylinders.

	July through March			April through June		
	sites					
	V, Y_0, Y_1, Y_2,	Y_3, W_2, X_2, Z_2	W_0, X_0, Z_0	V, Y_0, Y_1, Y_2	Y_3, W_2, X_2, Z_2	W_0, X_0, Z_0
Depth (cm)	%					
10	66	57	48	35	32	21
25	79	67	57	67	22	20
41	78	65	50	71	21	13
61	70	58	47	61	25	23
91	57	47	50	66	21	9
122	29	41	40	27	20	12

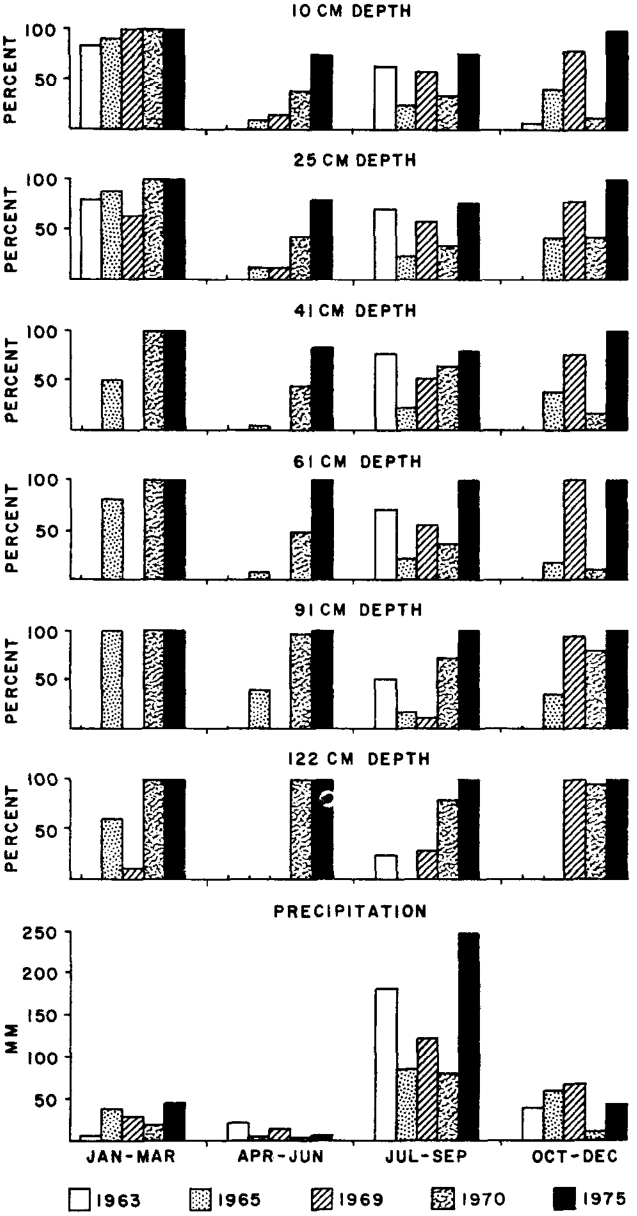

Fig. 4. *Percentage of days with matric potential ≥-1.5 MPa (wet soils) and precipitation (mm) for 5 years at Location V.*

precipitation during Jan.-Mar. was only 9 mm, but the probability of wet soil was 83% at the 10-cm depth and 80% at the 25-cm depth from precipitation in fall 1962. Rainfall during July-Sep. was 181 mm (average = 162 mm). The probability of wet soil was above average during the summer growing season, but was very low in spring and fall.

The year 1965 had 187 mm precipitation at Location V. The winter was wet with 143% of average precipitation and the probability of wet soil averaged 79% at the 6 soil depths. Precipitation during summer was only 52% of average, and the probability of wet soil was 18-26% at the 10- through 91-cm depths. The soil at the 122-cm depth was always dry. Although precipitation during fall was 13% above average, probability of wet soil was only 30% at the 6 soil depths.

Precipitation during 1969 was 88% of average. The probability of wet soil during winter was relatively high at the 10- and 25-cm depths, but decreased rapidly in April. Rainfall in summer was 75% of average, but the probability of wet soil was more than 50% at the 10-through 61-cm soil depths. Precipitation for Oct.-Dec. was 128% of average and the probability of wet soil averaged 88%.

The year 1970 can be characterized as a dry year, but the probability of wet soil at all soil depths was relatively high during Jan.-June, and was high at the 91- and 122-cm depths the entire year. Rainfall was 51% and 19% of average during July-Sep. and Oct.-Dec., respectively, and the probability of wet soil for the 6 depths averaged 54 and 44%, respectively.

The probability of wet soil was considerably above average at all 6 depths for the entire year in 1975. Precipitation was above average in winter and summer, but 25 and 81% of average in spring and fall, respectively. Primarily because of the high summer rainfall, total precipitation for 1975 was 341 mm or 28% above average.

Conclusions

Much of the rainfall in the warm season in this arid region falls during torrential thunderstorms, and runoff occurs on slopes. This provides additional soil water to sites below the slopes as evidenced by Y_0, Y_1, W_2 X_2, and Z_2. A depression and soil tubes provided additional run-in water to Y_0 and Y_1 compared to Y_2. Stellar soils dominated by tobosa (Locations W and Y_2) had a greater probability of the matric potential ≥-1.5 MPa (wet soil) than the Reagan soils dominated by burrograss at the same relative position on the landscape (W vs X, Y_2 vs Y_3). The matric potential was reduced when a drainageway was a considerable distance from piedmont slopes that had runoff water (Z_2 vs. V or Y_2). Infiltration rates at X were reduced by the presence of silty, platy structure, 3 mm thick, at the soil surface. This decreased soil water also contributed to a higher calcium content in the Reagan than the Stellar soils.

Most of the precipitation during the cool season is gentle and light. Most of the winter soil water is from rainfall and run-in during late summer and fall. Apparently, there was some upward movement of soil water in late winter from the caliche layer below our deepest observation to the 122-cm depth. This was particularly evident in observations at W_0, X_0, and Y_0.

Most of the soil water that remains from winter is evaporated during the normally dry spring periods. Therefore, most burrograss and tobosa production must occur during summer when conditions are favorable for plant growth. This study showed that daily precipitation <20 mm did not contribute to soil water of dry soils at the 10-cm depth.

The probability of wet soil was as great or greater in winter as during the summer growing seasons. This indicates a potential for cool-season plants on these floodplains dominated by tobosa and burrograss. Unpublished information by the authors indicates disturbance (e.g., plowing) of these sites resulted in a dense stand of russianthistle (*Salsola iberica* Sennen & Pau.). Russianthistle, an annual forb, can be established on moisture available in late winter, and the young plants provide nutritious livestock forage in early spring when nutrients are in short supply.

The severe drought of 1951-56 did not reduce the burrograss and tobosa cover on these sites as it did black grama [*Bouteloua eriopoda* (Torr.) Torr.] on coarse-textured soils (Herbel et al. 1972). Apparently, soil water is sufficient during droughty years to reduce mortality of burrograss and tobosa, but production is dramatically reduced by dry weather (Herbel and Gibbens 1981).

Nature and amount of precipitation, amount of run-in water, soil and vegetation type, position on the landscape, and microrelief are variable and have a marked effect on the matric potential of soil water. Precipitation values alone can be misleading when evaluating matric potential. The extreme variability of the matric potential results in a highly variable forage crop. The variability encountered can only be accommodated by highly flexible management strategies.

Literature Cited

Bulloch, H.E., Jr., and R.E. Neher. 1980. Soil survey of Dona Ana County area of New Mexico. Soil Conserv. Serv., USDA, Washington, D.C.

Gile, L.H., and J.W. Hawley. 1968. Age and comparative development of desert soils at the Gardner Spring radiocarbon site, New Mexico. Soil Sci. Soc. Amer. Proc. 32:709-716.

Gomm, F.B. 1961. A modification of the standard Weather Bureau rain gauge for summer and winter use. Bull., Amer. Meteorol. Soc. 42:311-313.

Hawley, J.W., and L.H. Gile. 1966. Landscape evolution and soil genesis in the Rio Grande Region, southern New Mexico. Guidebook, 11th Annu. Field Conf., Rocky Mountain Sect., Friends of the Pleistocene, University Park, N. Mex.

Hennessy, J.T., R.P. Gibbens, J.M. Tromble, and M. Cardenas. 1983. Water properties of caliche. J. Range Manage. 36:723-726.

Herbel, C.H. 1963. Fertilizing tobosa on flood plains in the semidesert grassland. J. Range Manage. 16:133-138.

Herbel, C.H., F.N. Ares, and R.A. Wright. 1972. Drought effects on a semidesert range. Ecology 53:1084-1093.

Herbel, C.H., and R.P. Gibbens. 1981. Drought and grazing management decisions, p. 187-192. *In:* Proc., 1981 Int. Rancher's Roundup, Del Rio, Texas, (eds. L.D. White and A.H. Hoermann), Tex. Agr. Ext. Serv., College Station.

Herbel, C.H., and R.P. Gibbens. 1987. Soil water regimes of loamy sands and sandy loams on arid rangelands in southern New Mexico. J. Soil and Water Conserv. 42:442-447.

Herbel, C.H., and L.H. Gile. 1973. Field moisture regimes and morphology of some arid-land soils in New Mexico, p. 119-152. *In:* Field Soil Water Regime, (eds. R.R. Bruce, K.W. Flach, and H.M. Taylor), Soil Sci. Soc. Amer. Spec. Pub. 5, Madison, Wisc.

Sammis, T.W., and L.W. Gay. 1979. Evapotranspiration from an arid zone plant community. J. Arid Environ. 2:313-321.

Schlesinger, W.H., P.J. Fonteyn, and G.M. Marion. 1987. Soil moisture content and plant transpiration in the Chihuahuan Desert of New Mexico. J. Arid Environ. 12:119-126.

Taylor, S.A. 1962. The influence of temperature upon the transfer of water in soil systems. Overdruk Uit de Mededelingen van de Landbouwhogeschool en de Opzoekingsstations van de steat te Gent 27:535-551.

Taylor, S.A., D.D. Evans, and W.D. Kemper. 1961. Evaluating soil water. Utah Agr. Exp. Sta. Bull. 426.

Tromble, J.M. 1982. Waterponding for increasing soil water on arid rangelands. J. Range Manage. 35:601-603.

U.S. Salinity Laboratory Staff. 1954. Methods for soil characterization, p. 83-126. *In:* L.A. Richards (ed.) Diagnosis and improvement of saline and alkali soils. USDA Handb. 60, Washington, D.C.

Growth patterns of yearling steers determined from daily live weights

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Abstract

Growth patterns for free-ranging yearling steers were quantified from daily live weights obtained with automatic scales which animals entered to obtain drinking water. Forty steers were monitored during each summer grazing period of 1986 and 1987. Frequency of watering and, thus, weighing on the automatic scales averaged 2.4 times/day. Significant ($P<0.01$) quadratic relationships between live weight and Julian date were obtained. In 1986, predicted live weight of the steers peaked in late July to early August and then decreased through to the end of the grazing period in September. Live weight of the steers in 1987 followed a similar pattern although the late summer decrease was not as great as in 1986. When animals were periodically weighed using manual procedures, a lower rate of gain was measured in the second half than in the first half of the summer grazing period every year from 1983 through 1987. However, we were unable to specifically identify when these weight changes occurred until the automatic scales were used in 1986 and 1987. The automatic weighing equipment documented substantial within-day live weight variability among steers. This variability changed over the grazing period on a day-to-day basis. Within-day variability must be considered when establishing manual weighing schedules with conventional equipment. Live weight data in conjunction with other measurements will permit development of a more comprehensive animal-plant-climate model.

Key Words: automated weighing equipment, sampling methods, growth models

Growth and productivity of free-ranging herbivores is assessed most often by periodically weighing animals at various time intervals. However, length of interval between weighings can affect interpretive conclusions about temporal changes in live weight gains because it dictates the number of data points available for analyses. For example, rate of gain of yearling animals has been observed to consistently decline over a growing season in conjunction with declines in forage quality (Hart et al. 1983, Jung et al. 1985, Volesky 1986). Although this gradual decline in rate of gain over time is described generally as a quadratic relationship, the relationship has never been very precisely defined because of our inability to obtain daily live weight data without excessive animal handling.

Another major problem affecting interpretive conclusions based on temporal changes or differences in animals weights is rumen fill (Hart 1987). In early studies, variations in weights due to temporal variation in amount of rumen fill were minimized by using average live weights taken 2 or 3 days in succession to estimate daily gain (Lush and Black 1927). Later studies showed, however, that statistical variation was often reduced more by increasing numbers of animals per treatment and weighing them once rather than having fewer animals and weighing them on successive days (Johnson and Laycock 1963, Hughes 1976). More recently, employment of overnight shrinks as a means to reduce the effects of rumen fill on live weights has been used (Hughes 1976). However, weight loss during a period of shrink has been shown to not be consistent within a year. Anderson and Tietjen (1982) and Heitschmidt (1982) concluded length of shrink, forage, and environmental conditions must be similar in order to standardize the measurement of range cow weights.

In an attempt to better quantify seasonal live weight gains of cattle, an automatic scale which delivers water to the animal while it is on the scale was developed to weigh individual animals each time they watered (Anderson 1981, Adams et al. 1987). The purpose of this paper is to describe live weight patterns of free-ranging yearling steers using daily live weights obtained from this newly developed scale system (Adams et al. 1987). Results are described in reference to potential usefulness and applicability to a comprehensive animal-plant-climate model.

Material and Methods

The research was conducted during 1986 and 1987 at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, Montana. Long-term annual precipitation at Miles City averaged 35 cm from 1936 to 1987. Annual precipitation was 41 cm in 1986 and 31 cm in 1987. The study was made on 8 pastures each of which was approximately 12 ha in size. These pastures were established in 1982 on a fair to poor condition range site. Vegetation in the pastures in 1982 was a mixture of western wheatgrass (*Pascopyrum smithii* (Rydb.) Love), Sandberg bluegrass (*Poa sandbergii* Vasey), blue grama (*Bouteloua gracilis* H.B.K. Lag. ex Griffiths), cheatgrass (*Bromus tectorum* L.), and big sagebrush (*Artemisia tridentata* Pursh.). In 1982, 6 of the 8 pastures were treated with a prototype Range Improvement Machine (RIM) (Erickson and Currie 1985) or a combination of treatments using the RIM, nitrogen fertilizer, legume interseeding, or brush control. Further descriptions of the RIM and pasture treatments are given by Currie and Volesky (1987).

Each year, a minimum total of 40 cross-bred yearling steers were assigned to the 8 different pastures. During the 1986 trial (9 June – 10 September) 5 yearling steers continuously grazed 6 of the pastures whereas 10 steers alternately grazed 2 of the pastures. During the 1987 trial (1 June to 1 September), the initial number of steers per pasture was the same as in 1986. However, numbers were varied later in the grazing period as put-and-take animals were used to equalize grazing pressure among experimental pastures. Average initial weights of the steers were 338 and 319 kg in 1986 and 1987, respectively.

Seven automatic scale units were used in the study. All units were designed so animals had to enter individually to gain access to drinking water. An individual's live weight was continuously recorded for as long as the animal was in the unit. Weights were averaged every 3 seconds and stored in computer Random Access Memory (RAM) for daily transmission via radio signal to storage in a central computer located approximately 10 km away. Quantity

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of water consumed, expressed as a weight, served as a cross-check for changes in animal live weight from the time an animal first entered the scale to when it left. A more detailed description of the system and its peripherals is given by Adams et al. (1987).

All steers underwent a 2- to 3-week training period with the scales in drylot prior to starting the grazing trials. Animals which were reluctant or refused to enter the scales for water during this period were culled. For comparative purposes, all steers were also manually weighed on a 'conventional' scale at the beginning, mid-point, and end of each grazing period. The conventional scale was a chute suspended from electronic load-cells with an electronic read-out. Linear and nonlinear regression analyses were used to evaluate and quantify daily live weight changes in relation to Julian date. The minimum daily live weight recorded for each individual animal was used in the regression analyses.

Results and Discussion

Steer Activities

Most animals learned relatively quickly how to use the scale units as their sole source for drinking water. Less than 5% of the steers were culled each year for lack of adaptation or problems with disposition which interfered with use of the scales. Electrical and mechanical performance of the scale equipment was generally trouble free during the 2-year study. Free-water that had ponded in some of the experimental pastures after heavy rainstorms limited the use of the scales by animals for short periods each year.

Frequency of watering and thus use of the automatic scales averaged 2.4 times/day during the 2-year study. Animals entered the scales to drink water during all hours of the day or night. There were, however, 3 distinct time blocks that accounted for 44% of all observations (Fig. 1). They were 0700 to 0800 (15%), 1100 to 1200

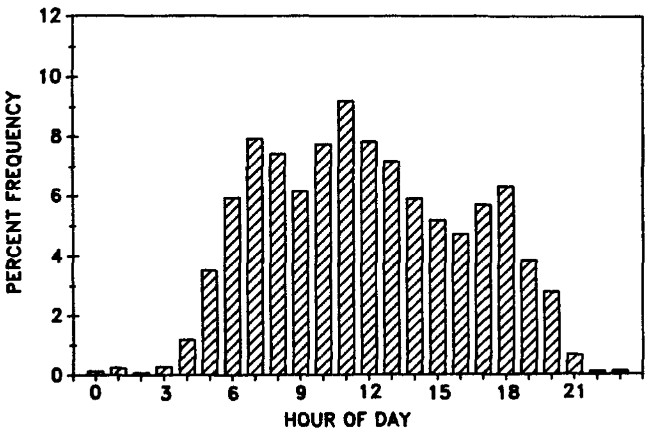

Fig. 1. *Percent frequency of automatic scale unit use by hour of day (MST) during 1986 and 1987 summer grazing periods.*

(17%), and 1700 to 1800 (12%) hr MST. These periods of scale use varied slightly over the summer with the corresponding changes in time of sunrise and sunset and other environmental conditions.

Steers were observed to have less grazing activity and rested more near the scale units with the warmer mid-day and afternoon temperatures of late July and August. Also, the steers used in 1986 tended to be more active in the early morning hours compared to those used in 1987. They used the scales more often from 0500 to 0600 hr. This was possibily related to differences in environmental factors in the 2 years. Our pastures were, however, relatively small (12 ha), and the observed behavior and patterns of use might have been different on larger pastures. Such effects will receive further scrutiny as additional data become available.

Live Weight Gains

Minimum estimates of live weight generally occurred before noon for all animals and was the first record stored before any water consumption took place. Minimum daily live weights had less day-to-day variation than weights based on averages of all weights recorded or the maximum daily live weights. Hughes and Harker (1950) reported that weighing after a 16-hour fast resulted in the lowest day-to-day variation in live weight, but weighing 3 hours after sunrise was almost as good.

In 1986, the linear relationship between live weight and Julian date was significant ($P<0.01$) (Fig. 2). The quadratic fit was also significant and the R^2 value was increased from 0.59 to 0.88. A plateau in live weight occurred on day 215 (3 August) and then a marked decrease began about 10 days later and continued through the remainder of the grazing period. The amount of live weight loss from the peak live weight to the end of the grazing period averaged 8.3 kg.

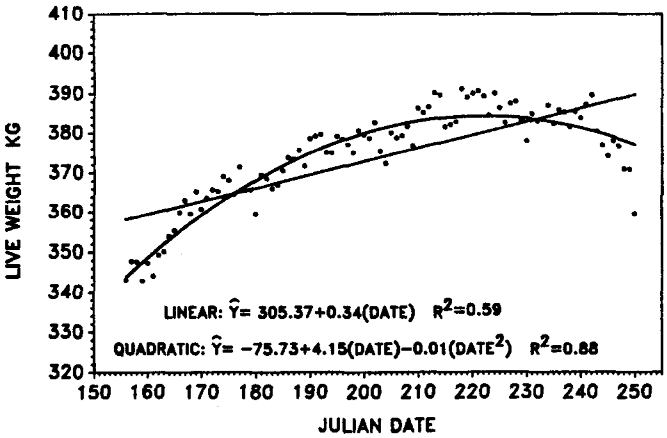

Fig. 2. *Linear and quadratic relationships of mean minimum daily live weight and Julian date for 40 yearling steers, 1986.*

Linear and quadratic relationships based on the 1987 data were also significant ($P<0.01$) (Fig. 3). The R^2 value was increased from 0.80 to 0.90 using the quadratic model. Predicted live weights of the 1987 steers based on the quadratic fit plateaued on about day 225 (12 August) followed by a slight decrease at the end of the grazing period. The amount of live weight loss from the peak live weight to the end of the grazing period averaged only 1.4 kg.

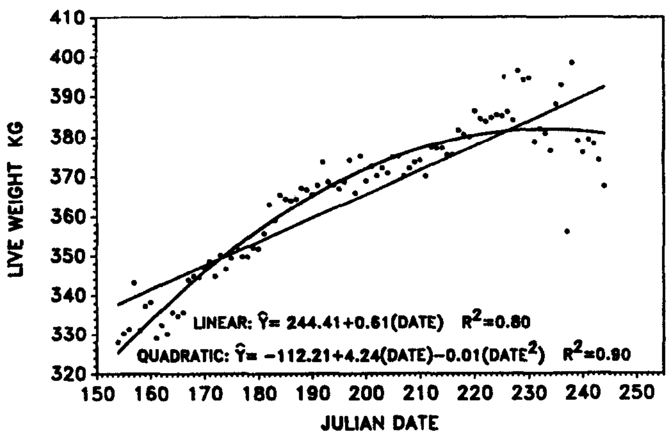

Fig. 3. *Linear and quadratic relationships of mean minimum daily live weight and Julian date for 40 yearling steers 1987.*

Differences in grazing pressure between years was probably the major factor causing differences in live weight gains. Although total growing season precipitation was similar in both years, mid growing season (July) precipitation was 82% greater in 1987 compared to 1986. As a result, we assume both quantity and quality of forage during the latter portion of the 1987 growing season was greater than in 1986; thus, live weight gains were greater in 1987 than 1986 (Figs. 2 & 3).

Daily Variability

The automatic weighing of steers showed that within-day variability of live weight was substantial. For example, typical fluctuations in daily live weight of steer 62-002 are shown in Figure 4. The average range (high minus low) of daily live weight for this steer was 22.4 kg. The maximum range was 40 kg and occurred on day 173 (22 June). This 40-kg change in live weight was associated with a total water intake of 34.5 liters or 34.5 kg in weight of water consumed over 4 drinking events throughout the day plus an unknown amount of forage intake minus defecation and urination loss. The greatest daily range in live weight occurred between days 166 and 196 (15 June to 15 July) and averaged 25.3 kg during this period. In contrast, the range in August was 19.4 kg. It is hypothesized that the greater daily live weight range during mid-June to mid-July was due to a more rapid passage of forage and fluids from the rumen. Fluid and particulate passage rates from the rumen are greater for immature than mature forages (Galyean 1987). This period was also the time of the greatest rate of daily gain. Dry matter content of the forage available in August was substantially higher and rate of daily gain very low.

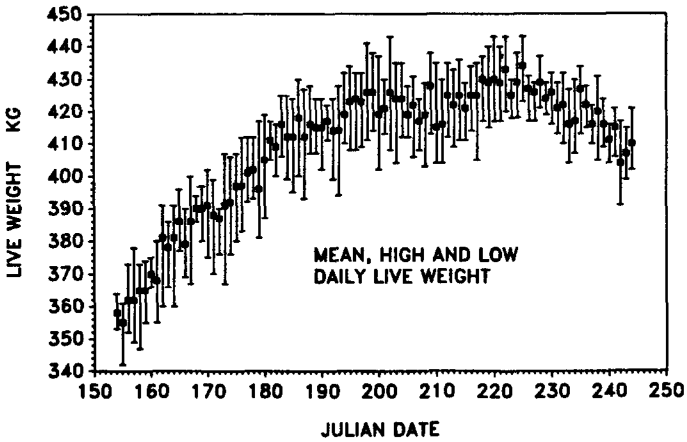

Fig. 4. *Fluctuations in daily live weight of a free-ranging yearling steer (No. 62-002), 1987.*

As depicted in Figure 4, the minimum daily live weight of steer 62-002 was recorded during the first drinking event of the day 81% of the time. The first drinking event generally occurred before 1000 hr. The mean daily live weight, calculated from all high and low weights recorded, tended to be closer to the highest weight because of the influence of grazing fill and previous water intake as the animal entered the scale for water later in the day.

Observed variability of within-day live weight also showed the need for caution when establishing weighing schedules with conventional equipment. Hart (1987) reported variations in live weight of grazing animals appear to be cyclic and related to grazing patterns. Our data would indicate patterns of water consumption are also important.

Conventional vs. Automatic Scale Weighing

Comparisons of steer live weights taken manually on a conventional electronic scale and those recorded on the same day by the automatic scales are given in Table 1. Correlations of live weights from the 2 different weighing systems was very high with correlation coefficients *(r)* of 0.85 and 0.87 in 1986 and 1987, respectively.

Table 1. Comparison of steer mean live weights (kg) ± standard error (SE) determined using automatic and conventional scales during July, 1986 and 1987.[1]

Date	Automatic scale		Conventional scale
	Minimum	Maximum	
25 July 1986	372 ± 13	383 ± 14	392 ± 18
17 July 1987	368 ± 9	380 ± 9	376 ± 9

[1]Conventional scale live weights were taken between 0900 and 1100 hr (MST).

Average live weight measurements from conventional weighing, however, were 20 and 8 kg higher than daily minimums from the automatic scales during 1986 and 1987, respectively. This is as would be expected because conventional scale weights were taken between 0900 and 1100 hr and all steers would have had the opportunity to graze and/or consume water prior to the time of being conventionally weighed. This is in agreement with the findings of Heitschmidt (1982), who reported early morning live weights of mature range cows to be about 2.5% less than late morning live weights. The maximum automatic scale live weight was 9 kg less than the conventional scale live weight in 1986 and 4 kg greater in 1987.

Calculated average daily gain (ADG) based on the conventional scale weights showed marked differences between the first and second half of the grazing seasons in both 1986 and 1987 and reflected a pattern of animal performance measured since the study was started in 1983 (Table 2). Second half ADG calculated from the conventional scale live weights were -0.36 and 0.13 kg/d in 1986 and 1987, respectively. A similar trend of reduced weights in the second half of the season were also measured in 1983, 1984, and 1985. Thus, these data indicated that rates of gain based on a relatively long weighing interval mask the true picture, as interpreted from the daily live weights measured by the automatic scales (Fig. 2 and 3). These differences in ADG between periods can also be calculated and interpreted from the predicted growth curve lines generated with the daily live weight data from the automatic scales. More importantly, however, the automatic scales allows one to define a growth curve line and discern the specific days when the live weight changes begin to plateau and decline, or correspondingly, when the ADG is at or below zero.

Table 2. Average daily gains (kg/d) of yearling steers during the first half, second half, and entire grazing period.

Year[1]	First half	Second half	Entire period
1983	1.06	0.23	0.65
1984	1.44	0.34	0.89
1985	1.02	0.54	0.78
1986	1.13	-0.36	0.39
1987	1.27	0.13	0.70
Mean	1.18	0.18	0.68

[1]1983 and 1987 grazing period length = 90 days.
1984 grazing period length = 60 days.
1985 grazing period length = 40 days.
1986 grazing period length = 96 days.

Management Implications

Daily live weight estimates obtained by the use of automatic scales allowed development of more precise growth patterns for free-ranging yearling steers than can be obtained by conventional weighing methods. The regression lines developed allowed us to specifically identify points in time when live weight was leveling out, increasing or decreasing. From a livestock management perspective for yearling steers, these weight estimates defined when a decision should be made. It suggested this may be the time when the producer should provide supplemental feed or remove the animals from pasture and place them in a feedlot. Otherwise decreasing weight gain performance can be expected. With the rather narrow margin profit or loss margin frequently encountered by livestock producers, this decision can have a significant impact on relative success of a livestock operation.

From a research perspective, the potential within-day variability of live weight re-emphasizes the need for caution when interpreting infrequent live weight data, especially in light of the temporal pattern associated with events such as drinking. Also, data obtained by the use of the automatic scales and complemented with appropriate climatic and forage quality and quantity data will allow development of comprehensive models to quantitatively describe growth of free-ranging animals under a variety of conditions.

Literature Cited

Adams, D.C., P.O. Currie, B.W. Knapp, T. Mauney, and D. Richardson. 1987. An automated range-animal data acquisition system. J. Range Manage. 40:256-258.

Anderson, D.M., J.A. Landt, and P.H. Salazar. 1981. Electronic weighing, identification and subdermal body temperature sensing of range livestock. p. 373-382. *In:* J.L. Wheeler and R.D. Mochrie (eds.), Forage Evaluation: Concepts and Techniques, CSIRO and Amer. Forage and Grassl. Counc., Melbourne, Australia.

Anderson, D.M., and G. Tietjen. 1982. Drylot shrink of cattle grazing semidesert rangeland during February, May, July and October. Proc. Western Section, Amer. Soc. Anim. Sci. 33:242-245.

Currie, P.O., and J.D. Volesky. 1987. Effects of multiple range renovation practices on forage production and animal performance. Fort Keogh Livestock and Range Research Station Field Day, Miles City, Mont., 14 Sept., 1987 p. 3-7.

Erickson, L.R., and P.O. Currie. 1985. Rangeland improvement machine for multiple renovation practices on semi-arid rangelands. Trans. Amer Soc. Agr. Eng. 28:94-96.

Galyean, M.L. 1987. Factors influencing digesta flow in grazing ruminants. p. 77-89. *In:* Proc., Grazing Livestock Nutrition Conference, 23–24 July, 1987, Jackson, Wyo.

Hart, R.H., and J.W. Waggoner, D.H. Clark, C.C. Kaltenbach, J.A. Hager, and M.B. Marshall. 1983. Beef cattle performance on crested wheatgrass plus native range vs. native range alone. J. Range Manage. 36:38-40.

Hart, R.H. 1987. Monitoring changes in animal weights. p. 37-39, *In:* Monitoring Animal Performance and Production Symp. Proc., 12 Feb., 1987, Boise, Ida., Soc. Range Manage., Denver, Colo.

Heitschmidt, R.K. 1982. Diurnal variation in weight and rates of shrink of range cows and calves. J. Range Manage. 35:717-720.

Hughes, J.G. 1976. Short-term variation in animal live weight and reduction of its effect on weighing. Anim. Breeding Abstr. 44:111-118.

Hughes, J.G., and K.W. Harker. 1950. The technique of weighing bullocks on summer grass. J. Agr. Sci. 40:403-409.

Johnson, W.M., and W.A. Laycock. 1963. Kind, number and selection of livestock for grazing studies, and animal measurement most suited for evaluating results. p. 137-142. *In:* Range Research Methods. USDA Misc. Pub. 940.

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

Lush, J.L., and W.H. Black. 1927. How much accuracy is gained by weighing cattle three days instead of one at the beginning and end of the feeding experiment. Proc. Amer. Soc. Anim. Prod. 1925-1926:206-210.

Volesky, J.D. 1986. A comparison of high-performance short-duration and repeated-seasonal grazing systems. Ph.D. Diss., S. Dakota State Univ., Brookings.

An improved harness for securing fecal collection bags to grazing cattle

D.R. TOLLESON AND L.L. ERLINGER

Abstract

An improved bovine fecal collection harness is described. The harness is durable, adjustable, and comfortable to the animal. The harness has a wide variety of experimental applications.

Key Words: fecal collection, sampling, measurements

Measurement of fecal output of grazing cattle is often accomplished by fitting an animal with a fecal collection bag held in place by a harness (Garrigus and Rusk 1939). Modifications to the original concept have resulted in numerous designs for harnesses and fecal bags. Cammell (1977) described a double-girth harness using adjustable straps between the front and rear girths. The harness of Mitchell (1977) was constructed of an X-shaped, web-belt material and designed as an inexpensive collection apparatus for sheep. Other modifications include the addition of a urine collection bag for grazing cows and heifers (Lesperance and Bohman 1961, Stillwell et al. 1983). In spite of the numerous designs available, the basic construction material has continued to be some type of rot-proof canvas webbing.

Workers at the South Central Family Farm Research Center (SCFFRC) in Booneville, Arkansas, have used the standard harness in forage intake and digestibility studies involving cattle with a wide range of frame scores (Erlinger and Tolleson 1988). However, this type of harness proved to be unsatisfactory under SCFFRC pasture and experimental conditions for several reasons. The entire weight of the fecal collection bag is supported by a 20.3 × 25.4 cm (8 × 10 in) canvas apparatus, therefore pressure on the animal is concentrated in a small area. The canvas apparatus frequently rips upon contact with fences and trees. Spring-steel snaps which open by downward pressure catch on corral panels as the animal moves about in confined quarters. Friction type buckles on the harness are difficult to adjust and the web-belt material of the straps often rubs and irritates the cattle. Feces is sometimes lost because of torn or improperly adjusted harnesses, and some cattle react adversely to the harness and bag despite prior acclimation to

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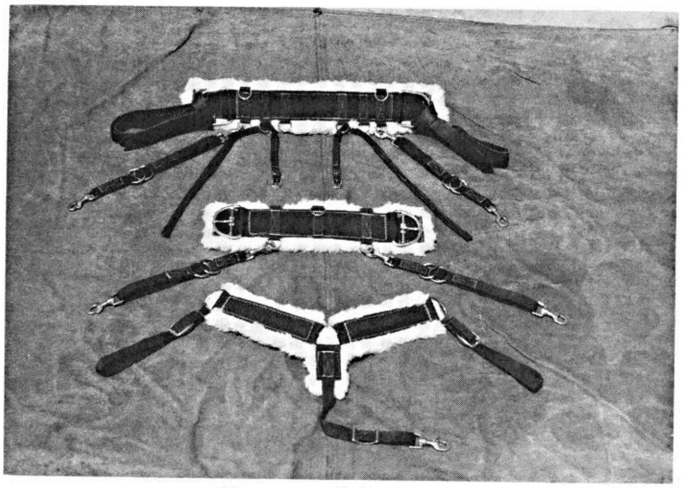

Fig. 1. *The harness consists of (top to bottom): 1) Upper girth with latigos, top and side adjustable straps, 2) Lower girth with bottom adjustable straps, and 3) Breast collar with collar-to-upper-girth straps and the brisket strap.*

a "practice" harness. Because of these problems, a harness that is more durable in pasture situations, easily adjusts to different sizes of cattle, and perhaps most importantly, is more comfortable to the animals themselves, was developed.

Materials and Methods

Materials used in the construction of the harness include nylon straps, leather latigo straps, synthetic fleece, and stainless steel hardware. Figure 1 illustrates the component parts of the harness, and Figure 2 diagrams the placement of each component on the animal including attachment of the fecal collection bag. The harness consists of an upper and lower girth, latigos to connect the girths, a breast collar, and 3 pair of adjustable straps (top, side, and bottom) that connect to the fecal collection bag. Specifications of each component for various size animals are given in Table 1.

The upper girth (Fig. 1) is a 7.6 cm (3 in) wide, fleece-lined nylon strap. There is a 7.6 cm (3 in) D ring at each end of the girth. Leather latigo straps 162.5 cm long × 3.8 cm wide (64 × 1 1/2 in) are attached to each large D ring. There are 8 small, 2.54 cm (1 in) D rings, 6 pointing toward the rear of the animal and 2 pointing forward. The adjustable straps attach to the posterior D rings, and the breast collar attaches to the anterior D rings. Most of the weight of the collection bag is borne by the upper girth. Therefore, the upper girth is designed to distribute weight over a large area and is more comfortable to the animal than was the previous model.

The lower girth (Fig. 1) is similar to the upper one except it has a 7.6 cm (3 in) double-bar cinch buckle on each end and contains only 3 small D rings. One D ring points forward for attachment to the breast collar strap that lies between the animal's front legs; the 2 D rings face toward the rear to connect to the adjustable straps which lie along the ventral side of the animal between the rear legs to the collection bag. The upper and lower girths are pulled securely around the animal by the latigo straps. In contrast to the web-belt material, the padding in the girths offers protection against chafing during the normal movement of the animal.

The breast collar (Fig. 1) is constructed of 5.1 cm (2 in) or 7.6 cm (3 in) wide for larger animals, fleece-lined nylon straps. A D ring of corresponding size is located at each end of the breast collar and in the center of the collar where the 10 cm (4 in) long drop strap is located. The breast collar is positioned under the animal's neck (Fig. 2) and attaches to the upper girth on both sides with 2.54 cm (1 in) nylon straps adjustable through the use of 2.54 cm (1 in) double-bar buckles. In the center of the breast collar is a 50.8 cm long × 2.54 cm (20 × 1 in) adjustable strap which lies between the animal's front legs and attaches to the center D ring on the lower girth by means of a 2.54 cm (1 in) trigger snap. The breast collar keeps the entire harness, and thus the collection bag, in the proper position.

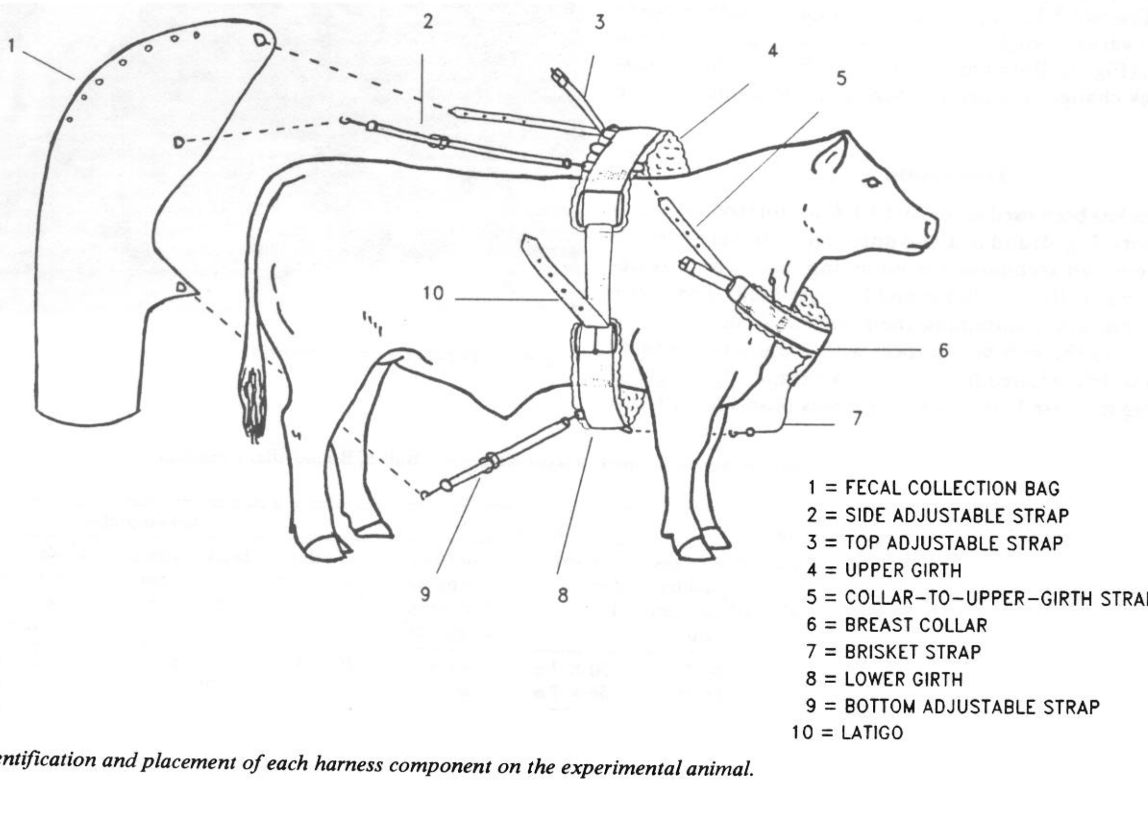

Fig. 2. *Identification and placement of each harness component on the experimental animal.*

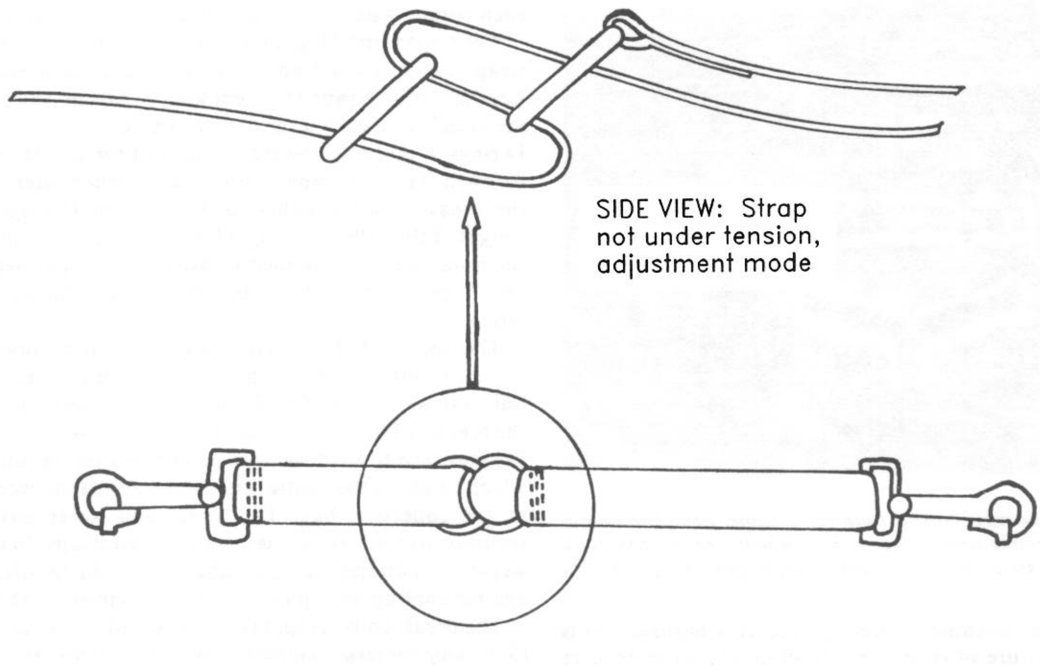

Fig. 3. *Side and bottom adjustable girth strap demonstrating the principle of the non-slip adjustment rings.*

Two types of nylon straps are used to connect the harness to the fecal collection bag. The top adjustable straps on the upper girth (Fig. 1) are similar to a dog collar. Constructed of 1.6 cm (5/8 in) nylon and a corresponding size double-bar buckle, these straps are placed through the small D rings on the harness and the collection bag and then buckled to proper length. The other type strap (Fig. 3) connects the collection bag to the sides and bottom of the harness. This is a 2.54 cm (1 in) double strap with 2.54 cm (1 in) trigger snaps on each end. The two 3.2 cm (1 1/4 in) metal rings allow the strap to be adjusted to various lengths (Table 1) as long as the strap is not under tension (Fig. 3). Both types of straps utilized in this harness allow for quick change of collection bags and easy adjustments in the field.

Discussion

This harness has been used at the SCFFRC for total collection of feces from steers (Fig. 4) and to avoid unrecoverable weight loss in a weigh-graze-weigh technique for obtaining bite size measurements on pastured heifers (Tolleson and Erlinger 1989). The device does an excellent job maintaining the position of the collection bag. Compared to the web-belt harness with friction type adjustment buckles which required frequent retightening as the weight of feces in the bag increased, no bag slippage was observed with this

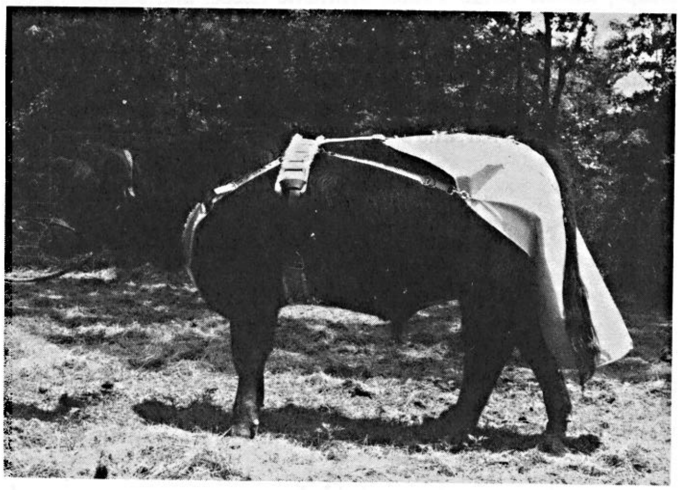

Fig. 4. *Steer fitted with the harness.*

Table 1. Specifications of harness components for various size cattle used in fecal collection studies, Booneville, Arkansas.

Animal size		Upper girth			Lower girth		Breast collar		
Weight, kg	Hip height, cm	Girth dimensions LXW, cm	Side straps adjustment range cm[a]	Top straps (dog collar), adjustment cm	Girth dimensions LXW, cm	Bottom straps, adjustment range, range, cm[a,b]	Collar dimensions LXW, cm[c]	Brisket strap, adjustment range, cm	Collar-to-upper girth straps, adjustment range, cm
170–270	95–110	60 × 7.6	46–66	20–30	50 × 7.6	40–56	50 × 5.1	25–40	15–25
230–330	110–125	60 × 7.6	46–66	25–30	56 × 7.6	40–62	66 × 5.1	25–40	20–30
330–430	125–135	60 × 7.6	60–95	30–50	62 × 7.6	56–86	80 × 7.6	25–40	20–30

[a]Adjustment range includes snap on each end.
[b]For extremely long-body cattle in the 330–430 kg weight range a strap adjustable to 115 cm is required.
[c]Breast collar has a 10 cm drop on center D ring for attachment of brisket strap.

harness when the bags were emptied twice daily. The bag can actually be secured so tightly that defecation will become difficult, and the animal will be observed straining as if constipated. Caution must therefore be taken not to adjust the harness too tightly. The harness needs to be secure enough only to prevent slippage; i.e., the girth need not be as tight as that on a saddle. When the harness is properly adjusted, animal comfort appears to be quite satisfactory.

The nylon material is available in several colors which can aid identification of grazing animals in large pastures. The materials can be obtained from and constructed by shops involved in manufacturing tack for the equine industry. Cost of the harness is reasonable. A conventional harness complete with collection bag has been selling for $80–90 per set with itemized costs being equally divided between the harness and bag when purchased separately. Cost of the harness described herein was approximately $10 higher than that of the conventional harness.

Maintenance is relatively easy. Cleanup between collection periods can be accomplished with a water hose. Both the nylon and fleece materials are machine washable, and a thorough cleaning in this manner is recommended prior to storage of the harness between experiments. The leather latigos should be conditioned with an appropriate oil.

In summary, this harness is durable, adjustable, comfortable to the animal and can be adapted to a wide variety of experimental applications. The harness should be compatible with any of the commonly used fecal collection bags.

Literature Cited

Cammell, S.B. 1977. Equipment and techniques used for research into the intake and digestion of forages by sheep and calves. Grassland Research Institute Tech. Rep. 24. pp 37-40.

Erlinger, L.L., and D.R. Tolleson. 1988. Factors associated with grazing behavior in cattle: The effects of frame size and rate of maturity. J. Anim. Sci. (Suppl. 1) 66:50 (Abstr.).

Garrigus, W.P., and H.P. Rusk. 1939. Some effects of the species and stage of maturity of plants on the forage consumption of grazing steers of various weights. Ill. Agr. Exp. Sta. Bull. 454.

Lesprance, A.L., and V.R. Bohman. 1961. Apparatus for collecting excreta from grazing cattle. J. Anim. Sci. 20:503-505.

Mitchell, A.R. 1977. An inexpensive metabolic harness for female sheep. British Vet. J. 133:483-485.

Stillwell, M.A., R. Senft, and L.R. Rittenhouse. 1983. Total urine collection from free-grazing heifers. J. Range Manage. 36:798-799.

Tolleson, D.R., and L.L. Erlinger. 1989. Effects of bite size and biting rate measurements on estimated intake of grazing heifers. J. Anim. Sci. (Suppl. 1) 67:50 (Abstr.).

Winter forb control for increased grass yield on sandy rangeland

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Abstract

Four separate studies evaluated several herbicides for reducing competition from overwintering weeds on sandy rangeland in west Texas. Air temperature was 10° C with soil moisture adequate for plant growth at herbicide application (0.28 kg ae/ha) on 14 March 1985. Trichlopyr ([3,5,6-trichloro-2-pyridinyl)oxy]acetic acid); 2,4-D [(2,4-dichlorophenoxy)acetic acid]; and dicamba (3,6-dichloro-2-methoxybenzoic acid) plus 2,4-D were ineffective, while picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid); picloram plus 2,4-D; and dicamba alone adequately controlled western ragweed (*Ambrosia psilostachya* DC.), the major targeted weed. These treatments were repeated on 4 April 1986 when air temperature was 24° C but with dry surface soils. Results were similar to those of 1985, except trichlopyr also controlled western ragweed under the warmer temperature. In another study, various rates of picloram and trichlopyr aerially applied 5 April 1986 showed that 0.07 kg ae/ha of picloram or 0.28 kg ae/ha of trichlopyr reduced ($P<0.05$) western ragweed with a corresponding increase in grass production. Picloram more effectively controlled targeted forbs while trichlopyr suppressed sand shinnery oak (*Quercus havardii* Rydb.) more effectively. Two companion studies also evaluated picloram and picloram plus 2,4-D. In one study 0.28 kg ae/ha of picloram was applied to sand shinnery oak range on 11 March 1985. Grass yield increased from 359 kg/ha in untreated plots to 1,222 kg/ha in treated plots. Grass yield in treated areas remained greater ($P<0.05$) for 3 growing seasons post-treatment. Sand shinnery oak plants at the bud burst stage were top-killed by picloram. On 14 March 1985 picloram (0.056 kg ae/ha) plus 2,4-D (0.224 kg ae/ha) was applied to sand shinnery oak rangeland. This treatment reduced forb production with a corresponding increase in grass production the year of application ($P<0.05$), but effects did not persist into the second growing season. Picloram plus 2,4-D did not suppress sand shinnery oak.

Key Words: herbicides, sand shinnery oak, *Quercus havardii* Rydb.

Winter forbs on sandy rangeland occur at sufficient densities some years to suppress grass growth the following summer. Dense populations of undesirable winter forbs result from favorable environment for germination and stand establishment rather than removal of competing vegetation by excessive grazing (Sosebee 1983, Hylton and Bement 1961). However, declines in grass cover or vigor do encourage dense stands of weedy forbs when combined with favorable weather conditions. Summer drought in 1983 in west Texas followed by high October rainfall resulted in sufficient growth by perennial grasses to deplete their root and crown energy reserves before a killing frost. Three weeks of record cold in December weakened or killed these plants and only 1 or 2 tillers per plant grew from surviving grasses the following spring. Although 1984 was a drought year (NOAA 1984) and neither grasses nor forbs thrived, favorable 1984–85 fall and winter precipitation and temperatures resulted in large populations of winter and annual and biennial forbs.

Because winter forbs can drastically suppress growth of vigorous warm-season perennial grasses in west Texas (Sosebee 1979, Ueckert 1979), we anticipated that weakened grasses faced potentially severe competition during spring and summer 1985 from the dense stands of establishing winter forbs. The objectives of this study were: (1) to evaluate several herbicides for reducing competiton from overwintering undesirable forbs; (2) to compare grass response following herbicidal treatments; and (3) to determine whether herbicidal control benefited perennial grasses through the second year after treatment.

Study Area and Methods

The study was conducted from 1985–1987 on the Post-Montgomery Estate and Middleton Ranches located 15 and 20 km northeast of Post, Texas, respectively. Average annual precipitation is 480 mm, approximately 75% occurring from May through October (Richardson et al. 1965). Soils on study sites are mostly Brownfield fine sand, a loamy, mixed thermic Arenic Aridic Paleustalf (Richardson et al. 1965). Vegetation was dominated by sand shinnery oak (*Quercus havardii* Rydb.) and fringed signalgrass (*Brachiaria ciliatissima* [Buckl.] Chase). Other common species included sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), hooded windmill grass (*Chloris cucullata* Bisch.), purple threeawn (*Aristida purpurea* (Nutt.), fall witchgrass (*Leptoloma cognatum* [Schult.] Chase), sand paspalum (*Paspalum setaceum* (Michx.), western ragweed (*Ambrosia psilostachya* DC.), and erect dayflower (*Commelina erecta* L.).

The study consisted of 4 separate experiments: (1) use of picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) to control winter-growing weedy forbs; (2) use of picloram plus 2,4-D [(2,4-dichlorophenoxy)acetic acid] to control winter-growing weedy forbs; (3) a herbicide comparison repeated over 2 years to evaluate cost-effective methods for controlling winter-growing weedy forbs; and (4) a herbicide rate comparison using trichlopyr ([3,5,6-trichloro-2-pyridinyl)oxy]acetic acid] and picloram to suppress sand shinnery oak and winter-growing weedy forbs.

Study 1

Sixty-five ha of sand shinnery oak rangeland were evaluated for forb response with and without picloram herbicide during 1985–1987. Picloram at 0.28 kg ae/ha was applied to 32.5 ha on 11 March 1985. The remaining 32.5 ha were in four 8.1-ha untreated plots on each side of the treated plot. Herbicide was applied from a sprayer mounted in a pickup truck using a boomless nozzle with a cluster of 5 spray jets. Swath width was 13 m. Air temperature reached a maximum of 26° C during application. Soil moisture was not sampled but precipitation from October to March exceeded 254 mm, which provided adequate soil moisture for plant

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growth. Forbs were in the early vegetative stage when herbicide was applied. A few sand shinnery oak plants were breaking bud, with most plants apparently fully dormant. Grass and forb yield was determined in July 1985, 1986, and 1987 by clipping 35 randomly located 0.4-m^2 quadrats in both treated and untreated plots. The treated plot was grazed by cattle during the study, so quadrats were located inside cages. The adjacent untreated plots were ungrazed during the growing season so cages were not used in the untreated plots. Site constraints prohibited true random location of treatments. Therefore, the error term in the analysis of variance was the nested variation of the randomized quadrats within the study area (Dunn and Clark 1974).

Study 2

On 14 March 1985 picloram plus 2,4-D (4 parts 2,4-D and 1 part picloram) at 0.28 kg ae/ha was applied to two 0.4-ha plots. Two untreated 0.4-ha plots interspersed between the treated plots served as the control. In addition, a 0.2-ha buffer was left untreated between all treatment plots so that spray drift would not influence subsequent vegetation sampling. Air temperature remained about 10° C during herbicide application. Above-average winter rainfall had provided adequate moisture in the top 60 cm of soil for plant growth. All sand shinnery oak plants appeared dormant when herbicide was applied but forbs were in early vegetative stage. Grass and forb standing crop was clipped within ten 0.4-m^2 quadrats in each of the four 0.4-ha plots in July 1985 and 1986.

Study 3

On 14 March 1985 we applied 2,4-D; a mixture of 3 parts 2,4-D and 1 part dicamba (3,6-dichloro-2-methoxybenzoic acid); trichlopyr; dicamba; picloram; and picloram plus 2,4-D (4 parts 2,4-D and 1 part picloram) each at 0.28 kg ae/ha to sand shinnery oak rangeland. Also, 2,4-D was applied at 0.56 kg ae/ha. Experimental design was completely random with 3 replications. Each plot was 0.4 ha. Including 3 untreated plots, there were 24 plots within the study area on the Post-Montgomery Estate Ranch. Herbicides were ground applied as in Studies 1 and 2. A 9-m wide buffer strip was left untreated between all plots. Sand shinnery oak appeared totally dormant when herbicides were applied. Oak plants were sparse because the site had been treated with tebuthiuron (*N*[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea) in 1981. Forbs were in early vegetative growth stages. Treatment plots were unfenced and grazed by cattle, so species frequency was used to evaluate plant response. Air temperature was about 10° C during herbicide application. Soil moisture in the top 60 cm was adequate for plant growth.

The study was repeated in 1986 on the adjacent Middleton Ranch, where treatment plots were fenced, using the same herbicides and rates as in 1985. In addition, dichlorprop [-2(2,4-dichlorophenoxy)propanoic acid] at 0.28 kg ae/ha was also applied. Herbicides were applied on 4 April 1986 with air temperature about 24° C. However, soil moisture was only the top 30 cm and only 4.1% in the second 30 cm; little forb growth was occurring due to insufficient moisture. Sand shinnery oak had been suppressed by tebuthiuron application in 1983. Remaining oak plants were all in early vegetative stage (miniature leaves). Western ragweed was the only herbaceous plant of sufficient density to warrant control. Its new shoots were about 2.5 cm tall. Treatment plots were 0.2 ha arranged in a completely random design.

Plant response was evaluated with forty 0.25-m^2 frequency quadrats per plot in July 1985 for the Post-Montgomery Estate plots. These plots were resampled in July 1986 with twenty 0.25-m^2 frequency quadrats per plot. The 1986 herbicide applications on the Middleton Ranch were sampled with twenty 0.25-m^2 frequency quadrats per plot in July 1986. Also, five 0.4-m^2 quadrats were clipped in each of the Middleton Ranch plots in July 1986 to evaluate impact of weed control on forage yield.

Study 4

McIlvain and Armstrong (1974) used ultra-low rates of 2,4,5-T to suppress sand shinnery oak and give grasses a competitive edge at low cost. This study was designed to evaluate alternatives to 2,4,5-T and to examine the oak suppression potential of picloram. On 5 April 1986 picloram at 0.07, 0.14, and 0.28 kg ae/ha; trichlopyr at 0.28 and 0.56 kg ae/ha; and a mixture of picloram and trichlopyr each at 0.28 kg ae/ha were applied aerially on 6-ha plots on the Middleton Ranch. The entire east half of the treated area had been treated with tebuthiuron in 1983 and the west half had no previous herbicide treatment. However, forb response did not differ ($P<0.05$) between east and west portions so values were pooled in analyses. Experimental design was a randomized block with 2 complete blocks. Untreated plots in each block were 12 ha instead of 6 ha to facilitate subsequent vegetation sampling away from any herbicide drift. Air temperature was 24° C when herbicides were applied and soil moisture was low as described in Study 3. All sand shinnery oak plants had produced at least miniature leaves and western ragweed was about 2.5 cm tall. Herbage yield was obtained in July 1986 by clipping ten 0.4-m^2 quadrats per herbicide plot. Western ragweed control was evaluated with twenty 0.25-m^2 frequency quadrats per plot in December 1986. We also determined sand shinnery oak mortality by dead-alive analysis in December from forty 0.25-m^2 quadrats per treatment plot. Oak plants in a quadrat were considered either all dead or all alive if any part of the plant was alive. Other weeds did not occur commonly enough for statistical evaluation.

Data Analysis

Statistical analyses for Studies 1 through 4 were one- and two-way analyses of variance. Frequency data were analyzed by chi square as well as by analyses of variance after arc sine transformation (Steel and Torrie 1980); untransformed data are presented. Percent mortality of sand shinnery oak was arc sine transformed (Sokal and Rohlf 1981) prior to analysis of variance. Chi square analyses and analyses of variances yielded similar results; tables presented use analysis of variance format. Mean separation was by Fisher's protected LSD test.

Results and Discussion

Study 1

Picloram at 0.28 kg ae/ha on 11 March 1985 suppressed broadleaved forbs that had germinated. Surprisingly, sand shinnery oak plants that were at the bud burst stage were also top-killed. The

Table 1. Herbaceous standing crop in July 1985, 1986, and 1987 following ground application of picloram (0.28 kg ae/ha) to sand shinnery oak rangeland on the Post-Montgomery Estate Ranch near Post, Texas on 11 March 1985.

Sampling date	Vegetation component	Standing crop	
		Treated	Control
		(kg/ha)	
1985	Grass	1222a[1]	359b
	Forbs	62a	359b
1986	Grass	1104a	527b
	Forbs	56a	118a
1987	Grass	1642a	807b
	Forbs	336a	471b

[1]Numbers in the same row followed by the same letter are not significantly different ($P<0.05$).

Table 2. Herbaceous standing crop in July 1985 and 1986 following ground application of picloram plus 2,4-D (0.056 + 0.224 kg ae/ha) to sand shinnery oak rangeland on the Post-Montgomery Estate Ranch near Post, Texas on 14 March 1985.

Sampling date	Vegetation component	Standing crop	
		Treated	Control
		(kg/ha)	
1985	Grass	1939a[1]	572b
	Forbs	202a	790b
1986	Grass	1216a	1076a
	Forbs	56a	106a

[1]Numbers in the same row followed by the same letter are not significantly different ($P<0.05$).

desirable, summer-growing velvet bundleflower (*Desmanthus velutinus* Scheele) and erect dayflower appeared unharmed by the herbicide. These species had not emerged at the time of application. By early July, grass yield increased ($P<0.01$) from 359 kg/ha in untreated plots to 1,222 kg/ha in treated plots (Table 1). Forb yield was 62 kg/ha where treated with picloram compared to 359 kg/ha without the herbicide. The fact that total herbaceous yield was 1,284 kg/ha in treated plots and only 717 kg/ha in untreated plots (Table 1) is assumed due to sand shinnery oak suppression.

Winter and spring of 1985–86 produced few forbs, and there was no difference in 1986 forb yield between treatments. However, 1986 grass yield in treated plots was twice that in untreated plots (Table 1). We attribute this to reduced competition from early growing forbs and sand shinnery oak. By 1987, visual differences between picloram-treated (in 1985) and untreated plots had largely dissipated. Nevertheless, grass production in treated plots was still considerably greater and forb production less ($P<0.05$) than in untreated plots (Table 1).

Study 2

Unlike the picloram treatment in Study 1, picloram plus 2,4-D did not suppress sand shinnery oak. It did reduce ($P<0.05$) forb production the year of treatment by 588 kg/ha (Table 2), and increased grass standing crop by 1,367 kg/ha. However, there was no carry-over effect into 1986 as with the picloram-treated pastures (Table 2). This study was not designed to compare picloram vs. picloram plus 2,4-D. However, Studies 1 and 2 were adjacent to each other, so we suspect the lack of carry-over effect with the picloram plus 2,4-D was due to its lack of effectiveness on sand shinnery oak.

Table 3. Frequency of western ragweed in 0.25-m² quadrats following herbicide treatments to sand shinnery oak rangeland on the Post-Montgomery Estate Ranch on 14 March 1985 and evaluated in July 1985 and 1986. The study was repeated on the Middleton Ranch on 4 April 1986 and evaluated in July 1986.

Treatment	Rate	Western ragweed frequency		
		Post-Montgomery Estate Ranch		Middleton Ranch
		1985	1986	1986
	(kg ae/ha)	(%)		
Control	0.00	60a[1]	45ab	50a
2,4-D	0.28	58a	53ab	50a
2,4-D	0.56	65a	60a	42ab
Dicamba + 2,4-D	0.07 + 0.21	67a	33abc	37abc
Trichlopyr	0.28	80a	48ab	12c
Dicamba	0.28	27b	32abc	5c
Picloram + 2,4-D	0.056 + 0.224	23b	10bc	7c
Picloram	0.28	2c	0c	15c
Dichlorprop	0.28	—	—	30abc

[1]Numbers in the same column followed by the same letter are not significantly different ($P<0.05$).

Table 4. Herbaceous standing crop in July 1986 following ground herbicide application on 4 April 1986 to sand shinnery oak rangeland on the Middleton Ranch near Post, Texas.

Herbicide	Rate	Standing crop	
		Grass	Forbs
	(kg ae/ha)	(kg/ha)	
Control	0.00	802a[1]	353a
2,4-D	0.28	1267ab	196abc
2,4-D	0.56	1127ab	291ab
Dichlorprop	0.28	1496ab	129bc
Dicamba + 2,4-D	0.07 + 0.21	1435ab	185abc
Trichlopyr	0.28	1900b	73c
Dicamba	0.28	1317ab	45c
Picloram + 2,4-D	0.056 + 0.224	1872b	95bc
Picloram	0.28	1379ab	45c

[1]Numbers in the same column followed by the same letter are not significantly different ($P<0.05$).

Study 3

Targeted annual weeds were camphor weed (*Heterotheca latifolia* Buckl.) annual buckwheat (*Eriogonum annuum* Nutt.), yellow woollywhite (*Hymenopappus flavescens* Gray), and spectacle pod (*Dithyrea wislizenii* Engelm). Western ragweed was the most common perennial weed. Under the cool environment at the time of application in 1985, 2,4-D; 2,4-D plus dicamba; and trichlopyr were ineffective. Only picloram achieved greater than 90% control of targeted weeds ($P<0.05$). Picloram plus 2,4-D and dicamba alone also had less ragweed ($P<0.05$) than in the other treatments (Table 3). In 1986 no western ragweed was found on the Post-Montgomery Estate Ranch plots treated with picloram. Because of the dry conditions in the winter of 1985–86, few annuals germinated.

In 1986 on the Middleton Ranch plots, dry soil prevented germination of annuals so western ragweed was the only species targeted for herbicidal control. Since Ueckert et al. (1980) found poor response from 2,4-D when applied during cold air temperatures, we applied the 1986 treatments on 4 April 1986 when air temperature was 24° C. The surface 30 cm of soil had only 1.0% water and the second 30 cm had 4.1%, thus little water was available for seedling growth. There is evidence that dry soils prevent or reduce 2,4-D effectiveness as well as low air temperature (Hormay et al. 1962, Jones et al. 1982, Mayeux and Scifres 1981, Sperry and Sultemeir 1965). This was apparent for our 2,4-D applications as no visible difference existed between 2,4-D and control plots. Also,

Table 5. Vegetation response to various herbicide treatments applied aerially to 6-ha plots on 5 April 1986 to sand shinnery oak rangeland on the Middleton Ranch near Post, Texas. Standing crop was evaluated in July 1986 and western ragweed frequency (0.25-m² quadrats) and sand shinnery oak mortality was evaluated in December 1986.

Herbicide	Rate	Standing crop		Western ragweed frequency	Shinnery oak mortality
		Grass	Forbs		
	(kg ae/ha)	(kg/ha)		(%)	
Control	0.00	1065a[1]	695a	36a	5a
Picloram	0.07	1407abc	118b	11b	13ab
Picloram	0.14	1872c	90b	4b	2a
Picloram	0.28	1474abc	17b	3b	2a
Trichlopyr	0.28	1244ab	196b	10b	62c
Trichlopyr	0.56	1749bc	67b	6b	48c
Picloram + Trichlopyr	0.28+0.28	1937c	50b	3b	43bc

[1]Numbers in the same column followed by the same letter are not significantly different ($P<0.05$).

the 2,4-D plus dicamba treatment appeared little better than the control under these conditions. Picloram, picloram plus 2,4-D, and dicamba most effectively suppressed western ragweed (Table 3). Trichlopyr, which was ineffective when applied during cold air temperatures in 1985, effectively controlled western ragweed in 1986 when applied during warm air temperatures. Grass yields were also highest in the trichlopyr and picloram plus 2,4-D treatments (Table 4). Picloram and dicamba, which gave best weed control (Table 3), provided no more grass than the 2,4-D plots.

Study 4

In Study 1, picloram applied at 0.28 kg ae/ha in 1985 to sand shinnery oak controlled those plants just breaking bud. However, in this study trichlopyr controlled more oak than picloram (Table 5). All herbicides reduced western ragweed ($P<0.05$) compared to unsprayed plots. Also, forb yields were reduced ($P<0.05$) by all herbicide treatments. Grass yields were generally the reverse of forb yields (Table 5).

Conclusions

Many ranchers have successfully used tebuthiuron to control sand shinnery oak on rangeland. However, weedy forb competition often limited post-treatment grass yields far below expectations. Winter weather unfavorable for forb germination makes it unnecessary to consider control efforts most years. But results of this study indicate that even modest weed infestations on sandy rangeland reduce usable forage 560–785 kg/ha. Herbicidal control is warranted in those years favorable for winter weed germination. Our data indicate picloram or dicamba at 0.28 kg ae/ha are usually effective. However, they may cost more than can be recovered in extra benefits if weeds are suppressed for only 1 year. To reduce costs, chemical companies producing these herbicides often combine them with 2,4-D. Our results showed that picloram plus 2,4-D worked reasonably well but we suspect that its effectiveness was due to the picloram alone because of the ineffectiveness of 2,4-D during cool, dry growing conditions. We believe 2,4-D is the most cost-effective alternative under ideal growing conditions of readily available soil moisture and air temperature over 21° C at time of application. If these conditions cannot be met then we suggest using picloram, dicamba, or picloram plus 2,4-D. Trichlopyr was effective if air temperature was over 21° C, even on dry soil. It also suppressed sand shinnery oak more than did picloram.

In 1985 annual and perennial weeds were a problem; by controlling them with picloram we increased grass yield 860 kg/ha. Few annual weeds germinated in 1986, but perennial weeds (mostly western ragweed) produced from 350–795 kg/ha. Grass production increased up to 800 kg/ha if either annual or perennial weedy forbs were controlled. Picloram at 0.28 kg ae/ha allowed increased grass production for 3 years, whereas picloram plus 2,4-D reduced broad-leaved herbaceous weeds sufficiently to increase grass production for 1 year. Since picloram killed sand shinnery oak shoots that were just breaking dormancy, further investigation of this response is warranted.

How many winter weeds should be present before considering control? We found that undesirable annual weeds either were numerous (i.e., all quadrats examined contained seedlings) or they were scarce with few quadrats having seedlings. Herbicidal control would not be needed in the latter case. However, control would be desirable if 1/3–1/2 of the 0.25-m² quadrats examined contained targeted weeds. Fortunately 2 common desirable forbs, erect dayflower and velvet bundleflower, were unharmed by early spring-applied herbicides. They began growth late enough to escape harm.

Literature Cited

Dunn, O.J., and V.A. Clark. 1974. Applied statistics: analysis of variance and regression. John Wiley and Sons, New York.

Hormay, A.L., F.J. Alberico, and P.B. Lord. 1962. Experiences with 2,4-D spraying on the Lassen National Forest. J. Range Manage. 15:325-328.

Hylton, L.O., Jr., and R.E. Bement. 1961. Effects of environment on germination and occurrence of six weeks fescue. J. Range Manage. 14:257-261.

Jones, R.D., Ueckert, J.T. Nelson, and J.R. Cox. 1982. Threadleaf groundsel and forage response to herbicides in the Davis Mountains. Texas Agr. Exp. Sta. Bull. 1422.

Mayeux, H.S., and C.J. Scifres. 1981. Drummond's goldenweed and its control with herbicides. J. Range Manage. 34:98-101.

McIlvain, E.H., and C.G. Armstrong. 1974. Brush and weed suppression with mistblowers. *In:* Proc. Agr. Chem. Conf. Oklahoma City, Okla.

National Oceanic and Atmospheric Administration. 1984. Texas climatological data. U.S. Dep. Comm. Nat. Climate Cent., Asheville, N.C.

Richardson, W.E., D.G. Grice, and L.A. Putnam. 1965. Soil survey of Garza County, Texas. USDA-SCS.

Sokal, R.R., and F.J. Rohl. 1981. Biometry—the principles and practices of statistics in biological research (2nd ed.) W.H. Freeman and Co., San Francisco.

Sosebee, R.E. 1983. Physiological, phenological, and environmental considerations in brush and weed control, p. 27-43. *In:* Proc. Brush Management Symposium (ed. K.C. McDaniel), Soc. Range Manage. Annual Meeting. Albuquerque, N.M.

Sosebee, R.E., W.E. Boyd, and C.S. Brumley. 1979. Broom snakeweed control with tebuthiuron. J. Range Manage. 32:179-182.

Sperry, O.E., and G.W. Sultemeir. 1965. Bitterweed...its control in relation to soil moisture. Sheep and Goat Raiser 2:122-127.

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

Ueckert, D.N. 1979. Broom snakeweed: effect on shortgrass forage production and soil water depletion. J. Range Manage. 32:216-220.

Ueckert, D.N., C.J. Scifres, S.C. Whisenant, and J.L. Mutz. 1980. Control of bitterweed with herbicides. J. Range Manage. 33:465-469.

Root-feeding insects of *Senecio riddellii* in Eastern New Mexico and Northwestern Texas

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Abstract

Five insect species were reared from roots of Riddle's groundsel (*Senecio riddellii* Torrey & Gray). *Phaneta offectalis* (Hulst) (Lepidoptera: Tortricidae), *Cylindrocopturus armatus* Champion (Coleoptera: Curculionidae), and *Cochylis felix* Walsingham (Lepidoptera: Cochylidae) were the most abundant, while only one individual each of the 2 other species, *Smicronyx intricatus* Casey (Coleoptera: Curculionidae) and an undescribed moth (Lepidoptera: Gelechiidae), was reared. A survey conducted in southeastern New Mexico and northwestern Texas indicated that infestation of Riddle's groundsel by *P. offectalis* is widespread. Riddle's groundsel is a new host record for these 5 insect species, and these insects are naturally occurring exploiters of this rangeland weed.

Key Words: biological control, rangeland, Riddle's groundsel, toxic plant, weed

Riddle's groundsel (*Senecio riddellii* Torrey & Gray) is a prevalent, toxic plant that occurs from South Dakota south to Texas and west to Arizona (Barkley 1978). Species of the genus *Senecio* are known to contain hepatotoxic pyrrolizidine alkaloids (Johnson et al. 1985a) and are considered to be noxious rangeland weeds. Plants containing these alkaloids cause considerable loss to the livestock industry (Mathews 1933, Johnson et al. 1985b, Seaman and Walker 1985). Cattle and horses are most often affected, although other animals are also susceptible (Bull et al. 1968). Toxicity of species of *Senecio* and associated poisonings of humans and livestock recently have been reviewed by Cheeke and Shull (1985).

Blatchley and Leng (1916) reported the weevil *Hyperodes echinatus* Dietz to reproduce in the roots of *Senecio*. Research has also been conducted to identify naturally occurring biological control agents of threadleaf groundsel (*S. longilobus* Benth.) (Linsley and Cazier 1962) and tansy ragwort (*S. jacobaea* L.) (Cameron 1935; Linsley and Cazier 1962; Frick 1964, 1972; Frick and Hawkes 1970) in the western United States. To augment naturally occurring biological control, the cinnabar moth (*Tyria jacobeae* [L.]) (Lepidoptera: Arctiidae) was imported and has been successful in reducing populations of tansy ragwort in the western United States (Frick and Holloway 1964) and Canada (Harris et al. 1975).

Riddle's groundsel occurs in sandy, open areas and is a common component of rangeland communities. With the exception of research on fungal pathogens (Alber et al. 1986), no information is available on biological control agents of Riddle's groundsel. Presented here are data on the identity and prevalence of indigenous, root-feeding insects in Riddle's groundsel in eastern New Mexico and northwestern Texas.

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Materials and Methods

This project was conducted from July through October 1986 in eastern New Mexico and northwestern Texas. A study site approximately 16 km south of Hobbs, Lea Co., New Mexico, contained a dense population of Riddle's groundsel, and many plants appeared chlorotic with dying branches. On 17 July, taproots from approximately 50 plants were brought to the laboratory, kept moist, and placed in a screened rearing container to allow emergence of adult insects.

On 17 and 18 July 1986, the presence of root-feeding larvae in Riddle's groundsel was evaluated in 4 eastern and southeastern New Mexico counties (Chaves, Eddy, Lea, and Roosevelt) and 2 adjacent Texas counties (Andrews and Winkler). Plants were examined at 34 locations along major highways by dissecting roots immediately in the field to determine if root-feeding larvae were present.

On 29 July, 89 plants at the study site near Hobbs were selected randomly and brought to the laboratory. Roots of these plants were carefully dissected and examined for the presence of root-feeding insects. Several larvae of each species and all pupae were reared through adult emergence. All remaining larvae were placed in Kahle's fixative for 3 hr and transferred to 70% ethyl alcohol. The number of larvae and pupae per root for each species was recorded, and mean and standard error were calculated.

Results and Discussion

Five species of root-feeding insects occurred in Riddle's groundsel in eastern New Mexico. These included 2 species of weevils, *Cylindrocopturus armatus* Champion and *Smicronyx intricatus* Casey (Coleoptera: Curculionidae), and 3 species of moths, *Cochylis felix* Walsingham (Lepidoptera: Cochylidae), *Phaneta offectalis* (Hulst) (Lepidoptera: Tortricidae), and an undescribed species (Lepidoptera: Gelechiidae). Riddle's groundsel is a new host record for each species.

Many (>40 each) adult *C. armatus, C. felix,* and *P. offectalis* emerged from the field-collected root material kept in the laboratory. Only one individual each of *S. intricatus* and the undescribed moth emerged.

Known host plants for members of *Phaneta* are predominantly in the family Compositae, and *P. offectalis* has been recorded to feed on *Artemisia* (Heinrich 1923) and loco-weed (MacKay 1959). Anderson (1962) reported the biology of the weevil *S. intricatus* to be entirely unknown; however, a series was collected in New Mexico from *Solidago* and is in the U.S. National Museum (USNM) (D.M. Anderson, pers. comm.). The undescribed moth is a species related to *"Anacampsis" conclusella* (Chambers) (R.W. Hodges, pers. comm.).

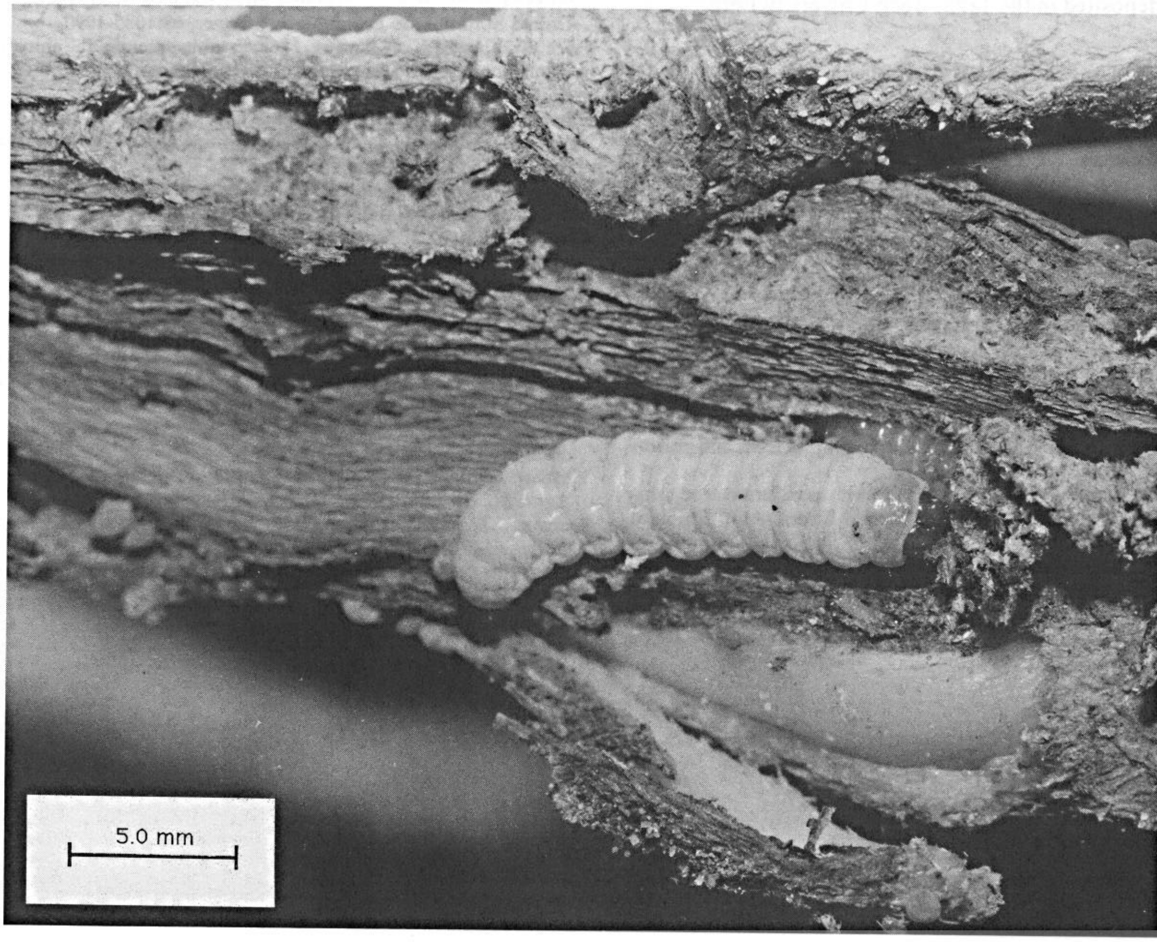

Fig. 1. *Larval* Phaneta offectalis *in taproot of Riddle's groundsel,* Senecio riddellii. *Root was cut open to expose larva and feeding tunnel.*

We found *P. offectalis* larvae in all counties and 30 of the 34 localities sampled, from south of Jal in the southeastern corner of New Mexico, north to Portales, west to 48 km east of Roswell, and east to 19 km north of Andrews, Texas. The 4 localities in which we did not find *P. offectalis* were not extremities of the range examined, but rather isolated areas of nonoccurrence within the observed range.

Of the 89 randomly selected plants returned to the laboratory, many appeared to be heavily stressed (i.e., chlorotic, wilted, or dead branches). Twenty-two of these 89 plants (24.7%) harbored none of the root-feeding insects, and had significantly lower wet weights than the 67 plants with root-feeding insects ($t = 2.89$; $df = 87$; $p < 0.01$). Larger, older plants may be more frequently attacked simply because they have been exposed to the insects longer. The extent to which root-feeding larve contributed to the plant stress is unknown; however, the moth *P. offectalis* and the weevil *C. armatus* were the most commonly encountered (Table 1) and largest-sized larvae in these roots. The larvae of *C. felix* were less common (Table 1). Additionally, because *C. felix* larvae were less frequently encountered and considerably smaller than *P. offectalis,* the impact of their feeding activity on the roots may not be significant. Four adult *Bracon* sp. (Hymenoptera: Braconidae) emerged from one pupa of *C. felix*. This parasitoid was unidentifiable to species because of the need for taxonomic revision (P.M. Marsh, pers. comm.).

Other insects also observed in roots of Riddle's groundsel included termites (Isoptera: Rhinotermitidae), larvae of checkered beetles (Coleoptera: Cleridae), which are predaceous, and larvae of root gnats (Diptera: Sciaridae), which may be fungivorous. However, because these insects do not feed on live roots they probably did not impact the vigor of Riddle's groundsel populations. Of the species observed, because of high frequency of occurrence and large size, *P. offectalis* may have the greatest impact on the growth and vigor of Riddle's groundsel.

Table 1. Occurrence of three species of root-feeding insect larvae in Riddle's groundsel *(Senecio riddellii)* in eastern New Mexico (89 plants examined).

Species	% Plants Infested[a]	$\overline{X} \pm$ SE per infested plant
Phaneta offectalis (Hulst)	59.6	4.3 ± 0.5
Cylindrocopturus armatus Champion	46.1	2.0 ± 0.3
Cochylis felix Walsingham	29.2	1.8 ± 0.3

[a]24.7% of the plants observed harbored none of these three species.

These data should lead to other investigations through which additional natural control agents might be detected. In addition, further research is needed to determine the population dynamics of each species and the extent that root feeding by these species individually and collectively affects the vigor of Riddle's groundsel.

The specimens of the undescribed moth (Gelechiidae) and *S. intricatus* were retained by the Biosystematics and Beneficial Insects Institute/Plant Sciences Institute (BBII) and are housed at the USNM. Voucher specimens of *C. armatus*, *C. felix*, and *P. offectalis* are deposited in the Texas Tech University Entomological Collection.

Literature Cited

Alber, G., G. Defago, H. Kern, and L. Sedlar. 1986. Host range of *Puccinia expansa* Link (=*P. glomerata* Grev.), a possible fungal biocontrol agent against *Senecio* weeds. Weed Res., UK 26:69-74.

Anderson, D.M. 1962. The weevil genus Smicronyx in America north of Mexico (Coleoptera: Curculionidae). Proc. U.S. Nat. Mus. 113:185-372.

Barkley, T.M. 1978. Senecio. *In:* Rogerson, C.T. ed. North American flora, series II, part 10.

Blatchley, W.S., and C.W. Leng. 1916. Rhynchophora or weevils of north eastern America. Nature Pub. Co., Indianapolis.

Bull, L.B., C.C.J. Culvenor, and A.T. Dick. 1968. The pyrrolizidine alkaloids: their chemistry, pathogenicity and other biological properties. North-Holland Pub. Co., Amsterdam.

Cameron, E. 1935. A study of the natural control of ragwort (*Senecio jacobaea* L.). J. Ecol. 23:265-322.

Cheeke, P.R., and L.R. Shull. 1985. Natural toxicants in feeds and poisonous plants. Avi Pub. Co., Westport, Conn.

Frick, K.E. 1964. Some endemic insects that feed upon introduced tansy ragwort *(Senecio jacobaea)* in western United States. Ann. Entomol. Soc. Amer. 57:707-710.

Frick, K.E. 1972. Third list of insects that feed upon tansy ragwort, *Senecio jacobaea,* in the western United States. Ann. Entomol. Soc. Amer. 65:629-631.

Frick, K.E., and R.B. Hawkes. 1970. Additional insects that feed upon tansy ragwort, *Senecio jacobaea,* an introduced weedy plant, in western United States. Ann. Entomol. Soc. Amer. 63:1085-1090.

Frick, K.E., and J.K. Holloway. 1964. Establishment of the cinnabar moth, *Tyria jacobaeae,* on tansy ragwort in the western United States. J. Econ. Entomol. 57:152-154.

Harris, P.A., A.T.S Wilkinson, M.E. Neary, and L.S. Thompson. 1975. *Senecio jacobeae* L., tansy ragwort (Compositae). Commonw. Inst. Biol. Control Tech. Commun. 4:97-104.

Heinrich, C. 1923. Revision of the North American moths of the subfamily Eucosminae of the family Olethreutidae. Bull. U.S. Nat. Mus. 123:1-298.

Johnson, A.E., R.J. Molyneux, and G.B. Merrill. 1985a. Chemistry of toxic range plants. Variation in pyrrolizidine alkaloid content of *Senecio, Amsinckia,* and *Crotalaria* species. J. Agr. Food Chem. 33:50-55.

Johnson, A.E., R.J. Molyneux, and L.D. Stuart. 1985b. Toxicity of Riddle's groundsel *(Senecio riddellii)* to cattle. Amer. J. Vet. Res. 46:577-582.

Linsley, E.G., and M.A. Cazier. 1962. A note on the attraction of *Stenaspis solitaria* (Say) and other insects to *Senecio longilobus,* a range plant highly toxic to livestock. Can. Entomol. 94:745-748.

MacKay, M.R. 1959. Larvae of the North American Olethreutidae (Lepidoptera). Can. Entomol. Suppl. 10.

Mathews, F.P. 1933. Poisoning of cattle by species of groundsel. Texas Agr. Exp. Sta. Bull. 481:1-20.

Seaman, J.T., and K.H. Walker. 1985. Pyrrolizidine alkaloid poisoning of cattle and horses in New South Wales. Plant Toxicology. Proc. Australia-U.S.A. Poisonous Plants Symposium, Brisbane, Australia, May 14–18, 1984, p. 235-246.

Control of huisache and honey mesquite with a carpeted roller herbicide applicator

RODNEY W. BOVEY AND ROBERT E. MEYER

Abstract

Several herbicides were evaluated for control of honey mesquite (*Prosopis glandulosa* Torr.) and huisache [*Acacia farnesiana* (L.) Willd.] using a tractor-mounted carpeted roller. Foliar sprays of picloram + 2,4,5-T at 0.28 + 0.28 and 0.56 + 0.56 kg/ha were included for comparison. When applied by carpeted roller, picloram at 60 g/L killed about 40% of the honey mesquite plants whereas 120 g/L killed 63 to 83% of the plants after 2 years. Clopyralid at 60 or 120 g/L killed 65% or more of the plants. Mixtures of picloram + clopyralid (1:1) at 30 + 30 g/L killed 53 to 73%, whereas, 60 + 60 g/L killed 83 to 98% of the honey mesquite. Clopyralid + triclopyr (1:1) 30 + 30 g/L killed 48 to 58% of the plants, while 60 + 60 g/L killed 80 to 85%. Picloram + 2,4,5-T (1:1) applied by the carpeted roller was usually more effective than foliar sprays of picloram + 2,4,5-T. For huisache, picloram, clopyralid, or picloram + clopyalid at a total of 60 or 120 g/L killed 60% or more of the plants after 1 year. Picloram + clopyralid at 60 + 60 g/L applied in 1983 and 1984 killed 92% or more of the huisache. Picloram + 2,4,5-T at 60 + 60 g/L killed 73 to 83%, but foliar sprays of picloram + 2,4,5-T were sometimes ineffectve. Glyphosate, dicamba, triclopyr and 2,4,5-T applied alone reduced the canopy of honey mesquite and huisache but usually killed few plants. Honey mesquite was controlled from spring applications, whereas, summer and fall treatments controlled huisache.

Key Words: picloram, clopyralid, triclopyr, dicamba, glyphosate, 2,4,5-T, canopy reduction, mortality

Herbicide foliar sprays are usually superior to soil treatments for control of honey mesquite (*Prosopis glandulosa* Torr.) and huisache [*Acacia farnesiana* (L.) Willd.] (Bovey and Meyer 1978, Bovey and Meyer 1981). Since these species sometimes occur on grazing lands in crop areas, foliar sprays of herbicide cannot be used because of possible damage from spray drift. These species are also rapid and persistent invaders of improved pastures such as bermudagrass [(*(Cynodon dactylon* L.) Pers.], and herbicide foliar sprays on the forage may be undesirable because of injury or herbicide residues.

A carpeted roller for conrol of small shrubs and honey mesquite has been developed (Mayeux and Crane 1984, 1985). The roller consisted of a polyvinyl chloride (PVC) cylinder covered with common household carpet. Acceptable control of honey mesquite was obtained with picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) or clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) when wiped onto the foliage under favorable growing conditions. Solutions containing 120 g/L of herbicide were sometmes only slightly more effective than solutions containing 30 g/L active ingredient of herbicides. In dense stands of honey mesquite, Mayeux (1987a) found that picloram, but not 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid], was effective at 60 g/L from August and September treatments as well as June applications. Clopyralid or clopyralid + picloram was also effective in spring or fall. In honey mesquite, rates of application of herbicide applied with the carpeted roller at concentrations of 30, 60, and 120 g/L averaged about 0.2, 0.6 and 1.25 kg ae/ha, respectively (Mayeux 1987b). Height of plants had no influence on volume of solution applied, but volume required to treat a given area increased with mesquite density. Active ingredient of herbicide applied to individual plants (0.3 to 3 g/shrub) decreased in a curvilinear manner with increasing stand density, suggesting that the carpeted roller is most effective in treating sparse stands. Waddington and Bittman (1987) attempted to control dense regrowth of aspen poplar (*Populus tremuloides* Michx.) and willows (*Salix* spp.) by passing a roller applicator several times in different directions using 2,4-D [(2,4-dichlorophenoxy)acetic acid], 2,4-D + picloram or glyphosate [*N*-(phosphonomethyl)glycine]. Control of regrowth was in proportion to the number of passes made.

Information concerning the use of the carpeted roller to control huisache is limited. Preliminary data from greenhouse-grown plants indicated that picloram and clopyralid were more effective than triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid or dicamba (3,6-dichloro-2-methyoxybenzoic acid) (Bovey et al. 1981) and that the use of a surfactant (0.5% v/v) in the treating solution significantly increased canopy reduction and mortality, especially at lower concentrations of herbicide (Mayeux and Bovey 1988). Scifres et al. (1988) recently indicated that picloram, clopyralid and equal-ratio mixtures of these herbicides reduced the live canopy of huisache by 90% or more by 2 years after treatment, but the least concentration that provided acceptable control was not indicated. None of the investigations mentioned compared a standard herbicide foliar treatment with the carpeted roller applicator.

The primary objective of this study was to evaluate the effectiveness of the carpeted roller applicator with a standard foliar herbicide application for control of honey mesquite and huisache, to identify effective herbicides and rates for acceptable control, and to evaluate certain herbicide mixtures and carriers in east central Texas. Summer and fall applications were also made on huisache to determine if fall application could be used to control huisache.

Materials and Methods

Dense stands of honey mesquite or huisache 1 to 2 m tall were treated. Multistemmed honey mesquite occurred on a Wilson clay loam (Vertic Ochraqualfs) while huisache occurred on a Bleiblerville clay (Udic Pellusterts) near Bryan and Washington, Texas, respectively. The plants consisted of vigorous regrowth from mechanical brush control several years before. Herbicides applied were the isopropylamine salt of glyphosate, the dimethylamine salt of dicamba, the propylene glycol butyl ether ester of 2,4,5-T, the butoxyethyl ester of triclopyr, the potassium salt of picloram, the triisopropanolamine salt of picloram + the propylene glycol butyl ether ester of 2,4,5-T (1:1), the monoethanolamine salt of clopyralid, the ethyl ester of benazolin (4-chloro-2-oxo-3(2*H*)-benzothiazoleacetic acid), and certain combinations of these formulations.

Herbicides were applied at total concentrations of 60 or 120 g/L,

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unless stated otherwise, with a carpeted roller mounted in place of a bulldozer blade on the front of a small tracklayer tractor. The roller was a 2.4-m-long by 21-cm-diameter aluminum cylinder rotated at 45–50 rpm by a hydraulic motor in reverse direction of the forward motion of the tractor. Rotating the roller maximized application of herbicide on brush and minimized dripping. Herbicide solutions were supplied to the roller from a spray boom and spraying system on the tractor. Nine Teejet flat fan nozzles, Tip No. 9505 (Spraying Systems Co., North Ave., Wheaton, Ill. 60188), spread 27 cm apart and 29 cm above the roller were activated periodically to keep the carpet saturated. The roller was covered with common household nylon carpet with a dense mat of medium nap length. The carpet was secured to the roller by either steel bands or rubber stretch bands.

Height of the roller could be adjusted hydraulically during operation depending upon the height of the brush. Generally the roller was operated about 30 to 60 cm above ground, bending the plants over to maximize herbicide wiping. Different carpets were marked and attached for each herbicide or herbicide mixture. A standard spray treatment was included for comparison. Sprays of picloram + 2,4,5-T in 1:1 ratio mixture was applied at a total of 0.56 or 1.1 kg/ha in 187 L/ha of water with either a compressed air, hand-carried, 3 nozzle boom sprayer or a 9 nozzle tractor mounted sprayer. Sprays were applied at the same time as the carpeted roller treatments.

Herbicides were applied to honey mesquite on 6 July 1983, 15 June 1984, and 12 June 1985. Treatments on huisache were made on 26 July and 7 December 1982, 20 October 1983, 15 July 1985, and 14 July 1986. All experiments were randomized complete block designs with 2 replications. Plot size was 15 by 45 m. Treatments were evaluated by visually estimating percent canopy reduction and mortality of 20 plants in each replicate 1 to 2 years after treatment. Plants with 100% canopy reduction and no live tissue or resprouts were considered dead. Data were subjected to analysis of variance, and means were compared by the least significant difference at the 5% level. Data were also analyzed as arcsine-transformed values (Steel and Torrie 1980), but there was no meaningful difference between the 2 analyses.

Results and Discussion

Huisache

Glyphosate, dicamba, triclopyr, and 2,4-5-T were essentially ineffective for killing huisache when applied either in July or December 1982 (Table 1). Herbicide 2,4,5-T at 240 g/L killed 38% of the plants in the December application, but picloram at 120 g/L or picloram + 2,4,5-T at 60 + 60 g/L killed 78% or more of the plants. Picloram and picloram + 2,4,5-T killed 60 to 80% of the plants from June and December applications. Foliar sprays of picloram + 2,4,5-T at 0.56 + 0.56 kg/ha killed 60% of the huisache plants in the July application but killed no plants when applied in December 1982. Possibly the huisache was approaching dormancy in December since extensive natural defoliation had occurred before treatment, and fewer leaves were available for herbicide absorption from foliar sprays than in July. Rainfall, however, was more favorable before and after treatment in December than July 1982 (Table 2).

Table 1. Response of huisache near Washington, Texas, to herbicides by 2 August 1983 after application by a carpeted roller on two dates in 1982.

		Date applied			
		26 July 1982		7 December 1982	
Herbicide(s)	Rate	Canopy reduction	Dead plants	Canopy reduction	Dead plants
	(g/L a.e.)	(%)			
Glyphosate	180	32	5	40	0
Dicamba	240	29	0	34	2
Triclopyr	240	57	25	52	5
2,4,5-T	240	60	10	74	38
Picloram	120	84	60	92	80
Picloram+ 2,4,5-T	60+60	84	75	92	78
Picloram + 2,4,5-T	0.56+0.56[1] kg/ha	83	60	8	0
Untreated		6	0	4	0
LSD (5%) for canopy reduction = 22; for dead plants = 32					

[1]Applied by hand boom sprayer.

Table 2. Rainfall 1 or 2 months before or after herbicide treatment near the experimental sites.[1]

	Months				Total for year and departure from the long-term mean
	Before		After		
Species	1	2	1	2	
	(cm)				
Huisache					
26 Jul 1982	5.3	7.7	1.4	5.7	93.5 –6.7
7 Dec 1982	14.3	33.6	5.8	14.8	93.5 –6.7
20 Oct 1983	6.2	13.7	8.5	18.2	137.9 38.0
15 Jul 1985	12.0	14.3	6.3	3.8	103.6 3.7
14 July 1986	2.6	22.2	1.7	15.4	109.4 9.5
Honey mesquite					
6 Jul 1983	6.8	35.8	5.5	19.5	122.3 23.1
15 Jun 1984	18.4	18.4	6.3	12.8	97.6 –1.7
12 Jun 1985	4.8	15.1	7.4	13.2	96.9 –2.4

[1]Rainfall amounts from *Climatological Data,* U.S. Dep. Commerce Nat. Climatic Center, Fed Bldg., Asheville, NC, as collected at Washington, Texas (huisache) and at College Station, Texas (honey mesquite).

Foliar sprays of picloram + 2,4,5-T at 0.56 + 0.56 kg/ha were effective when applied in October 1983, reducing the canopy by 90% and killing 82% of the huisache (Table 3). Sprays of picloram + 2,4,5-T at 0.28 + 0.28 kg/ha only reduced the canopy 60% and killed 48% of the huisache. Carpeted roller treatments that reduced the canopy by 92% or more and killed more than 88% of the plants included clopyralid and picloram + clopyralid at a total of 60 and 120 g/L herbicide.

Picloram + clopyalid at 30 + 30 g/L + 20 g/L benazolin was no more effective than picloram + clopyralid alone at the same rate (Table 3). However, picloram + 2,4,5-T at 30 + 30 g/L in a 1:4 (v/v) diesel oil:water carrier was as effective as picloram + 2,4,5-T at 60 + 60 g/L in water carrier. Picloram alone at 60 and 120 g/L killed 75 and 82% of the plants, respectively. Glyphosate, dicamba and 2,4,5-T applied alone were ineffective, whereas triclopyr at 60 or 120 g/L, picloram + dicamba, or picloram + 2,4,5-T at 30 + 30 g/L was intermediate in effect, killing about 40 to 55% of the plants. Rainfall was favorable before and after treatment (Table 2). These data agree with greenhouse investigations using a model carpeted roller that indicated that picloram, clopyralid, or mixtures of picloram + clopyralid were the most effective of several herbicides evaluated against juvenile huisache (Mayeux and Bovey 1988).

Fall applications of foliar sprays of picloram + 2,4,5-T are some-

Table 3. Response of huisache near Washington, Texas, to herbicides by 19 July 1984 after application by a carpeted roller on 20 October 1983.

Herbicide(s)	Rate	Huisache control: Canopy reduction	Huisache control: Dead plants
	(g/L a.e.)	(%)	
Glyphosate	60	19	5
Dicamba	60	12	0
Dicamba	120	30	0
Triclopyr	60	56	40
Triclopyr	120	71	50
2,4,5-T	60	36	18
Picloram	60	82	75
Picloram	120	86	82
Clopyralid	60	97	92
Clopyralid	120	92	88
Picloram + 2,4,5-T	30+30	58	42
Picloram + 2,4,5-T	60+60	86	85
Picloram + 2,4,5-T	0.28+0.28 kg/ha[1]	60	48
Picloram + 2,4,5-T	0.56+0.56 kg/ha[1]	90	82
Picloram + 2,4,5-T	30+30[2]	92	85
Picloram + clopyralid	30+30	96	95
Picloram + clopyralid	60+60	99	98
Picloram + clopyralid	30+30[3]	93	90
Picloram + dicamba	30+30	68	55
Untreated	—	10	0
LSD (5%) for column		27	30

[1]Applied by hand boom sprayer.
[2]1:4 (v/v) diesel oil:water carrier.
[3]Treating solution contained 20 g/L a.e. benazolin [4-chloro-2-oxo-3(2*H*)-benzo-thiazole acetic acid].

times more effective on huisache than spring or summer applications (Bovey et al. 1972). Also, foliar sprays of picloram at 2.2 kg/ha or picloram + 2,4,5-T at 1.1 + 1.1 kg/ha is sometimes required to provide huisache mortality exceeding 80% (Bovey et al. 1970). In this study foliar sprays of 0.56 + 0.56 kg/ha of picloram + 2,4,5-T killed 47 and 3% huisache in 1985 and 1986, respectively (Table 4). Picloram + 2,4,5-T spray at 0.28 + 0.28 kg/ha was ineffective. Rainfall was limited 1 and 2 months after treatment in 1985 and 1 month before and after treatment in 1986. Reduced plant growth from drought probably reduced transport and activity of the foliar applied herbicides.

Application of clopyralid, picloram, picloram + 2,4,5-T, picloram + clopyralid or picloram + dicamba with the carpeted roller killed a high percentage of huisache plants in 1985 where adequate rainfall preceded treatment (Table 4). Picloram + clopyralid and picloram + dicamba were particularly effective, killing 95% or more of the huisache plants. Glyphosate, dicamba, triclopyr and 2,4,5-T reduced the canopy as much as 85% but killed only 35% or less of the plants. Treatments applied in 1986 generally killed fewer plants than in 1985 where rainfall was limited for a long period of time before and after treatment.

Honey mesquite

In actual field use, foliar sprays of picloram + 2,4,5-T have been applied at recommended rates of 0.28 + 0.28 kg/ha to 0.56 + 0.56 kg/ha (Bovey and Meyer 1981). In this study, these herbicides caused 31 and 73% canopy reduction and killed 3 and 48% of the plants, respectively, by 2 years after treatment (Table 5). Mortality of honey mesquite was about as expected for foliar sprays of picloram + 2,4,5-T at these rates in east Texas. Canopy reduction and mortality of picloram + 2,4,5-T applied by the carpeted roller were similar to foliar sprays. Picloram + 2,4,5-T at 30 + 30 g/L applied in a 1:4 (v/v) diesel oil:water carrier appeared superior to water carrier alone after 1 year but was no different by the second year (1985) after application. Carpeted wiper treatments that killed 78% or more of the plants included picloram at 120 g/L, clopyralid

Table 4. Response of huisache near Washington, Texas, to herbicides by 13 May 1986 and 5 May 1987 after application by a carpeted roller on 15 July 1985 and 14 July 1986, respectively.

Herbicide(s)	Rate	15 July 1985: Canopy reduction	15 July 1985: Dead plants	14 July 1986: Canopy reduction	14 July 1986: Dead plants
	(g/L a.e.)	(%)			
Glyphosate	60	58	10	57	13
Dicamba	60	78	20	67	15
Dicamba	120	80	23	80	20
Triclopyr	60	64	5	63	13
Triclopyr	120	76	33	78	25
2,4,5-T	60	85	35	67	10
Picloram	60	96	88	97	85
Picloram	120	97	93	89	68
Clopyralid	60	93	85	65	20
Clopyralid	120	90	88	99	90
Picloram + 2,4,5-T	30+30	96	70	89	63
Picloram + 2,4,5-T	60+60	98	83	96	73
Picloram + 2,4,5-T	0.28+0.28 kg/ha[1]	62	5	29	0
Picloram + 2,4,5-T	0.56+0.56 kg/ha[1]	70	47	37	3
Picloram + 2,4,5-T	30+30[2]	94	85	91	70
Picloram + clopyralid	30+30	100	98	89	60
Picloram + clopyalid	60+60	100	98	97	80
Picloram + clopyralid	30+30[3]	100	98	92	58
Picloram + dicamba	30+30	94	95	80	38
Untreated	—	2	0	6	0
LSD (5%) for column		14	15	14	22

[1]Applied by hand boom sprayer.
[2]1:4 (v/v) diesel oil: water carrier.
[3]Treating solution contained 20 g/L a.e. benazolin [4-chloro-2-oxo-3(2*H*)-benzo-thiazole acetic acid].

at 60 and 120 g/L, and picloram + clopyralid at 60 + 60 g/L. Picloram + clopyralid at 30 + 30 g/L + 20 g/L benazolin killed 80% of the honey mesquite but was no different than the same treatment without benazolin. All of these carpeted roller treatments were superior to foliar sprays of picloram + 2,4,5-T. Glyphosate, dicamba, triclopyr and 2,4,5-T applied by the carpeted roller killed only 15% or less of the plants. Canopy reduction and mortality evaluations were similar whether taken 1 or 2 years after treatment although some treatments showed more regrowth by the second year.

Foliar sprays of picloram + 2,4,5-T were ineffective in killing honey mesquite by 1 or 2 years after spraying when applied in June 1984 (Table 6). The reasons for poor results is not clear; timing of treatment and rainfall amounts (Table 2) were satisfactory. Canopy reduction and mortality from picloram + 2,4,5-T applied by carpeted roller were superior to foliar sprays of picloram + 2,4,5-T as were picloram, clopyralid or mixtures of picloram + clopyalid. Picloram + clopyralid at 60 + 60 g/L killed 98% of the plants. Clopyralid + triclopyr at 30 + 30 or 60 + 60 g/L killed 58 and 80% of the plants after 2 years, respectively. Sprays of clopyralid + picloram or clopyralid + triclopyr are highly effective on honey mesquite at 0.28 + 0.28 kg/ha and 0.56 + 0.56 kg/ha (Bovey and Meyer 1985). In this study, picloram + dicamba at 30 + 30 or 60 + 60 g/L killed about the same percentage of plants as picloram alone at 60 g/L (35 to 60%). Glyphosate, dicamba, triclopyr and 2,4,5-T killed

Table 5. Response of honey mesquite near Bryan, Texas, to herbicides by 7 August 1984 and 6 August 1985 after application by a carpeted roller on 6 July 1983.

Herbicide(s)	Rate	Date evaluated 1984 Canopy reduction	Dead plants	1985 Canopy reduction	Dead plants
	(g/L a.e.)	(%)			
Glyphosate	60	38	5	22	0
Glyphosate	120	55	8	30	3
Dicamba	60	48	3	30	5
Dicamba	120	71	10	30	8
Triclopyr	60	53	5	24	0
Triclopyr	120	65	3	25	0
2,4,5-T	60	58	15	39	10
2,4,5-T	120	63	0	36	0
Picloram	60	75	43	66	40
Picloram	120	97	83	93	78
Clopyralid	60	99	95	99	98
Clopyralid	120	98	80	90	78
Picloram + 2,4,5-T	30+30	84	30	58	23
Picloram + 2,4,5-T	60+60	89	50	68	35
Picloram + 2,4,5-T	0.28+0.28 kg/ha[1]	68	20	31	3
Picloram + 2,4,5-T	0.56+0.56 kg/ha[1]	88	40	73	48
Picloram + 2,4,5-T	30+30[2]	94	78	69	45
Picloram + clopyralid	30+30	96	73	87	73
Picloram + clopyralid	60+60	98	85	90	83
Picloram + clopyralid	30+30[3]	98	83	94	80
Untreated	——	3	0	2	0
LSD (5%) for column		14	24	20	24

[1]Applied by hand boom sprayer.
[2]1:4 (v/v) diesel oil:water carrier.
[3]Treating solution contained 20 g/L a.e. benazolin [4-chloro-2-oxo-3(2*H*)-benzothiazole acetic acid].

Table 6. Response of honey mesquite near Bryan, Texas, to herbicides by 6 August 1985 and 25 June 1986 after application by a carpeted roller on 15 June 1984.

Herbicide(s)	Rate	Date applied 1985 Canopy reduction	Dead plants	1986 Canopy reduction	Dead plants
	(g/L a.e.)	(%)			
Glyphosate	60	55	8	33	5
Glyphosate	120	77	35	35	8
Dicamba	60	61	15	61	35
Dicamba	120	86	43	46	13
Triclopyr	60	78	10	47	5
Triclopyr	120	95	60	67	33
2,4,5-T	60	65	5	50	18
2,4,5-T	120	85	40	55	10
Picloram	60	90	60	71	43
Picloram	120	98	93	93	83
Clopyralid	60	92	78	81	65
Clopyralid	120	99	90	91	83
Picloram + 2,4,5-T	30+30	87	60	66	43
Picloram + 2,4,5-T	60+60	97	80	80	53
Picloram + 2,4,5-T	0.28+0.28 kg/ha[1]	53	3	30	3
Piclorm + 2,4,5-T	0.56+0.56 kg/ha[1]	64	3	35	8
Picloram + 2,4,5-T	30+30[2]	88	55	76	50
Picloram + clopyralid	30+30	96	83	97	58
Picloram + clopyralid	60+60	100	100	99	98
Picloram + clopyralid	30+30[3]	97	88	83	63
Picloram + dicamba	30+30	88	60	64	35
Picloram + dicamba	60+60	89	60	71	50
Clopyralid + triclopyr	30+30	96	75	83	58
Clopyralid + triclopyr	60+60	95	73	93	80
Untreated	——	4	0	4	0
LSD (5%) for column		9	17	18	26

[1]Applied by hand boom sprayer.
[2]1:4 (v/v) diesel oil:water carrier.
[3]Treating solution contained 20 g/L a.e. benazolin [4-chloro-2-oxo-3(2*H*)-benzothiazole acetic acid].

35% of the plants or less by 2 years after treatment.

Carpeted roller treatments of picloram, clopyralid, picloram + clopyralid, picloram + dicamba and clopyralid + triclopyr were superior to foliar sprays of picloram + 2,4,5-T (Table 7). Carpeted roller treatments of picloram + 2,4,5-T at 60 + 60 g/L killed more honey mesquite than foliar sprays of picloram + 2,4,5-T. Picloram + 2,4,5-T at 30 + 30 g/L also killed more plants thay sprays of picloram + 2,4,5-T at 0.28 + 0.28 kg/ha. Treatments that killed over 80% of the plants included clopyralid at 60 g/L, picloram + clopyralid at 60 + 60 g/L, picloram + clopyralid + benazolin at 30 + 30 + 20 g/L, respectively, and clopyralid + triclopyr at 60 + 60 g/L. Ineffective treatments were glyphosate, dicamba, triclopyr and 2,4,5-T. Honey mesquite mortality from foliar sprays of picloram + 2,4,5-T was within the expected range (Bovey and Meyer 1981). Rainfall amounts were low 1 month before treatment (Table 2).

Mayeux (1987b) indicated that rates of application of herbicide applied to honey mesquite with the carpeted roller at concentrations of 30, 60, and 120 g/L averaged about 0.2, 0.6, and 1.25 kg a.e./ha. Based on this criterion, foliar sprays of picloram + 2,4,5-T at 0.28 + 0.28 and 0.56 + 0.56 kg/ha for a total of 0.56 and 1.1 kg/ha would be comparable to 60 and 120 g/L applied by the carpeted roller on a herbicide/ha basis. Amount of herbicide used and cost/ha should be comparable. The carpeted roller treatments, however, were usually more effective than the herbicide sprays on both huisache and honey mesquite. This is probably due to a greater concentration of herbicide being applied to each plant by the carpeted roller.

These studies demonstrate that picloram or clopyralid at rates of 60 or 120 g/L or 1:1 mixtures of picloram + clopyralid or picloram + 2,4,5-T applied by the carpet roller are highly effective for reducing the canopy and causing high mortality of huisache from summer and fall treatments. Picloram + 2,4,5-T applied by the carpeted roller was sometimes more effective than sprays of the same mixture. Picloram, clopyralid, or 1:1 mixtures either of picloram + clopyralid or clopyralid + triclopyr were most effective for control honey mesquite applied in June or July. Small, dense, (<2 m tall) honey mesquite and/or huisache and associated weeds can be controlled using the carpeted roller near sensitive crops and domestic areas, thus minimizing herbicide residues to non-target, hay or grazing areas before the species become too large and unmanageable.

Table 7. Response of honey mesquite near Bryan, Texas, to herbicides by 23 June 1986 after application by a carpeted roller on 12 June 1985.

Herbicide(s)	Rate	Honey mesquite control	
		Canopy reduction	Dead plants
	(g/L a.e.)	--------(%)--------	
Glyphosate	60	52	13
Glyphosate	120	51	5
Dicamba	60	52	3
Dicamba	120	57	10
Triclopyr	60	42	0
Triclopyr	120	68	13
2,4,5-T	60	74	10
2,4,5-T	120	57	3
Picloram	60	75	40
Picloram	120	93	63
Clopyralid	60	95	83
Picloram + 2,4,5-T	30+30	72	28
Picloram + 2,4,5-T	60+60	85	48
Picloram + 2,4,5-T	0.28+0.28 kg/ha[1]	24	3
Picloram + 2,4,5-T	0.56+0.56 kg/ha[1]	65	23
Picloram + 2,4,5-T	30+30[2]	68	10
Picloram + clopyralid	30+30	93	73
Picloram + clopyralid	60+60	98	90
Picloram + clopyralid	30+30[3]	96	88
Picloram + dicamba	30+30	84	48
Picloram + dicamba	30+30	87	60
Clopyralid + triclopyr	30+30	86	48
Clopyralid + triclopyr	60+60	98	85
Untreated	——	6	0
LSD (5%) for column		12	16

[1]Applied by hand boom sprayer.
[2]1:4 (v/v) diesel oil:water carrier.
[3]Treating solution contained 20 g/L a.e. benazolin [4-chloro-2-oxo-3(2*H*)-benzothiazole acetic acid] and 1% (v/v) surfactant (trimethyl nonylpoly ethoxyethanol).

Literature Cited

Bovey, R.W., J.R. Baur, and H.L. Morton. 1970. Control of huisache and associated woody species in south Texas. J. Range Manage. 20:577-580.

Bovey, R.W., R.H. Haas, and R.E. Meyer. 1972. Daily and seasonal response of huisache and Macartney rose to herbicides. Weed Sci. 20:577-580.

Bovey, R.W., and R.E. Meyer. 1978. Control of huisache with soil applied herbicides. J. Range Manage. 31:179-182.

Bovey, R.W., and R.E. Meyer. 1981. The response of honey mesquite to herbicides. Texas Agr. Exp. Sta. B-1363.

Bovey, R.W., R.E. Meyer, and J.R. Baur. 1981. Potential herbicides for brush control. J. Range Manage. 34:144-148.

Bovey, R.W., and R.E. Meyer. 1985. Herbicide mixtures for control of honey mesquite *(Prosopis glandulosa).* Weed Sci. 33:349-352.

Mayeux, H.S., Jr., and R.A. Crane. 1984. Application of herbicides on rangeland with a carpeted roller: Control of goldenweeds (*Isocoma* spp.) and false broomweed *(Ericamera austrotexana).* Weed Sci. 32:845-849.

Mayeux, H.S., Jr., and R.A. Crane. 1985. Applications of herbicides on rangelands with a carpeted roller: Evaluation of four herbicides for control of honey mesquite. J. Range Manage. 38:238-241.

Mayeux, H.S., Jr. 1987a. Applications of herbicides on rangelands with a carpeted roller: Timing of treatment in dense stands of honey mesquite. J. Range Manage. 40:348-352.

Mayeux, H.S., Jr. 1987b. Application of herbicides on rangelands with a carpeted roller: Shrub density influences volume, dosage, and rate. Weed Sci. 35:444-448.

Mayeux, H.S., Jr., and R.W. Bovey. 1988. Effectiveness of herbicides applied with a model carpeted roller to huisache *(Acacia farnesiana)* seedlings in the glasshouse. Weed Technol. 3:232-237.

Scifres, C.J. R.A. Crane, B.H. Koerth, and R.C. Flinn. 1988. Roller application of clopyralid for huisache *(Acacia farnesiana)* control. Weed Technol. 2:317-322.

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

Waddington, J., and S. Bittman. 1987. Effect of number of passes with a roller-applicator using dilute herbicide solutions on control of brush regrowth in northeastern Saskatchewan. Can. J. Plant Sci. 67:845-848.

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Effect of fertilization date and litter removal on grassland forage production

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Abstract

The effects of application dates of urea fertilizer and dormant-season removal of litter were examined on a bluebunch wheatgrass (*Pseudoroegneria spicatum* [Pursh] A. Lõve subsp. *spicata*)-Sandberg's bluegrass (*Poa sandbergii* Vasey) site in southern British Columbia. Forest grade urea, applied at 100 kg N/ha, increased the yield of both spring (53%) and summer (73%) forage compared to the unfertilized control. Spring forage production was not affected by the application date of urea. Summer forage yields, however, were 20% higher when urea was applied on snow-free (October and March) compared to snow-covered ground (November, January, and February). Dormant-season removal of litter reduced spring forage yields by different amounts ($P<0.05$) in 1984 (29%) and 1981 (25%). Albiet a small difference, this suggests that removal of litter may interact with annual weather conditions and confound measurements of absolute spring herbage yields in a long-term study. In contrast, dormant-season removal of litter reduced summer forage production consistently by 23% in both 1981 and 1984. This technique might therefore be used to reduce clipping time for summer plots in fertilizer trials. If absolute estimates of above ground herbage production are required, control plots should be clipped each year to account for the losses in yields induced by dormant-season removal of litter.

Key Words: urea, bluebunch wheatgrass, nitrogen, precipitation, cool season grasses, clipping

Fertilization research on British Columbia (B.C.) grasslands has focused primarily on application rates, site specific response, and residual effects of N fertilizers (Mason and Miltimore 1959, Kilcher et al. 1965, Hubbard and Mason 1967, Mason and Miltimore 1969, Mason and Miltimore 1972). In Oregon, Sneva (1973) reported equal response for fall, winter, and spring applications of urea and ammonium nitrate on standard crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult) and Siberian wheatgrass (*Agropyron sibiricum* (L.) Beauv.). Similarly, Hull (1963) found no significant difference in pubescent wheatgrass (*Thinopyrum intermedium* subsp. *barbulatum* [Schur]) yields between spring and fall applications of ammonium nitrate on high elevation ranges in northeastern Utah. No information is available on the effect of different dates of fertilizer application on grasslands in B.C.

Separating litter from the current annual growth in a clipping study can be tedious and time consuming. In order to reduce clipping time, some researchers have removed the standing dead phytomass from bunchgrasses before spring growth commences by mowing the experimental site during the dormant period (Mason and Miltimore 1964, Wilson et al. 1966).

The removal of standing litter after plant senescence reduces plant growth in the following year, and consequently, may itself be considered a treatment. For example, Sauer (1978) found that bluebunch wheatgrass (*Pseudoroegneria spicatum* [Pursh] A. Love subsp. *spicata*) yields were reduced by 28% when quiescent plants were clipped to the crowns in January. In a second study, bluebunch wheatgrass biomass was reduced 42% the following season when plants were clipped in September (McShane and Sauer 1985). Similarly, Willms et al. (1986) showed that rough fescue (*Festuca scabrella* Torr. var. *major* Vasey) yields on a Mixed Prairie site in southern Alberta were reduced by 25% after litter was removed during fall before winter dormancy.

True estimates of above-ground biomass only can be determined if the reductions in yields resulting from litter removal is consistent across all levels of other experimental treatments and can be accounted for in the experiment. The purposes of this research were to determine (1) the appropriate season and date to fertilize mid-elevation grassland sites in B.C., (2) the effects of applying urea on snow compared to bare ground and (3) the effects of dormant-season removal of litter, combined with other treatments, on subsequent spring and maximum (summer) above-ground herbage production.

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Study Area and Methods

The study site is located 6 km north of Kamloops, B.C. (50° 44′ N, 120° 24′ W), in a bluebunch wheatgrass-Sandberg's bluegrass (*Poa sandbergii* Vasey) habitat type (Tisdale 1947, Table 1). The

Table 1. Mean percent frequency (per 20 × 50 cm plot) of plant species found on the study site.

Species	Frequency (%)
Grasses	
Pseudoroegneria spicatum	36.8
Koeleria cristata	7.5
Poa sandbergii	18.4
Festuca scabrella	1.0
Forbs	
Achillea millefolium	3.0
Antennaria parvifolia	1.4
Antennaria dimorpha	3.1
Arabis holboellii	T
Astragalus collinus	0.5
Crepis atrabarba	T
Draba nervosa	2.2
Draba verna	0.5
Erigeron filifolius	T
Erigeron spp.	1.8
Fritillaria pudica	T
Lomatium macrocarpum	T
Microseris gracilis	0.7
Taraxacum officinale	T
Tragopogon dubius	T
Shrubs	
Artemisia frigida	0.7
Artemisia tridentata	T
Eriogonum heracleoides	T
Others	
Rock	T
Soil	20.7

T = Trace (less than 0.5% frequency).

Table 2. Soil conditions during fertilizer application and precipitation and temperatures for the week following fertilization.

Application date	Soil surface Conditions	Precipitation Rain	Snow	Total	Temperature
	1980–81	(mm)	(cm)	(mm)	° C
Oct.	Moist, free water	1.2	0.0	1.2	6.2
Nov.	20 cm snow, frozen	0.0	31.6	21.8	–6.8
Jan.	2 cm snow, frozen	Tr	1.1	1.1	–1.7
Feb.	7 cm snow, frozen	1.8	4.2	5.0	7.3
Mar.	moist, frozen	Tr	0.0	Tr	7.1
	1983–84				
Oct.	moist, free water	2.3	0.0	2.3	9.5
Nov.	7 cm snow, frozen	0.0	1.0	0.8	–5.3
Jan.	20 cm snow, frozen	3.0	2.0	4.9	0.7
Feb.	21 cm snow, frozen	0.0	0.0	0.0	6.4
Mar.	moist, free water	7.3	Tr	7.3	10.5

Tr = Trace

aspect at the site is northwest with a 3–5% slope and the elevation is approximately 750 m. The soil is an Orthic Dark Brown Chernozem (Typic Haploboroll) of aeolean origin with a fine sandy loam texture (pH 5.8 (0.01 M $CaCl_2$), organic matter 2%, Bray P 23 ppm). Mean annual precipitation at Kamloops is 256 mm with peaks in June–August and December–January (Atmospheric Environment Service 1984). The area has been moderately grazed by cattle using a deferred rest rotation system for the past 10 years, but the specific study site was ungrazed during the study because of restricted access.

Four blocks were layed out parallel to slope contours. Each block was divided in half (whole-plots) to accommodate the 2 years in the experiment. Factorial combinations of 2 treatments, FERTILIZATION and LITTER REMOVAL were randomly applied to 2 × 2 m plots within each whole-plot. The FERTILIZATION treatment consisted of a single application of 100 Kg N/ha of forest grade urea (45-0-0-0) at 5 dates and a control. Application dates of the fertilizer treatment in 1980–81 were 23 October, 28 November, 5 January, 12 February, and 19 March. In 1983–84, the fertilizer treatment was applied on 27 October, 29 November, 6 January, 16 February, and 21 March. Fertilizer was hand applied to bare ground in October and March, and onto snow in November, January and February in each year (Table 2).

Table 3. Comparisons of forage production means using orthogonal contrasts.

Comparison	Spring harvest		Summer harvest	
Main effects	kg/ha			
Fertilized vs. Unfertilized	270	176 *	1401	809 *
1981 vs. 1984	128	381 *	1470	1130 *
Fertilized on Snow vs. Bare Ground	264	280	1302	1551 *
Fertilized FALL[1] vs. SPRING[2] (Season)	263	187	1460	1362
Litter Removal vs. NO Removal	214	297 *	1133	1470 *
Interactions				
Year × Litter Removal	*		NS	
Year × Fertilized	*		NS	
Year × Snow-Covered	NS		NS	
Year × Season-of-N-Application	*		NS	
Litter Removal × Fertilized	NS		NS	
Litter Removal × Snow Covered	NS		NS	
Litter Removal × Season-of-N-Application	NS		NS	

*Means significantly different at $P<0.05$.
[1]FALL = October and November
[2]SPRING = February and March

The LITTER REMOVAL treatment was applied to one-half of the fertilized plots and the remaining plots were left untreated. Litter removal took place in mid-October of 1980 and 1983 following senescence of bluebunch wheatgrass. Plots were hand clipped and the harvested material was spread over each of the 2- × 2-m plots. Spring and summer forage production data were collected each year by clipping a 1- × 1-m area located centrally within each plot.

Spring forage production was determined by clipping one-half of the total number of plots annually on 22 April 1981 and 16 May 1984 when bluebunch wheatgrass tillers reached 20 cm. These dates correspond to the recommended height required for spring grazing in the Kamloops area (McLean and Marchand 1968). In order to determine maximum forage production, the remaining plots were harvested in August following seed set of bluebunch wheatgrass. Plants were clipped to a 5-cm stubble height and the litter was discarded where applicable. Herbage samples were oven dried at 70° C for 48 h and weighed.

The experimental design was a randomized complete block with a split-plot in time. Spring and summer forage production were analyzed separately with analysis of variance using SAS PROC GLM (SAS 1979). Means were tested for differences using orthogonal contrasts at $P<0.05$.

Results and Discussion

Spring Harvest

Averaged over both years, urea fertilization increased ($P<0.05$) spring forage production by 53% compared to the unfertilized control. Yields in 1984, were nearly triple those in 1981 (Table 3) reflecting the higher spring precipitation in 1984 (Table 4). A significant Year by Fertilized interaction (Table 3) showed that herbage responded substantially more to fertilizer in 1984 than 1981. Indeed, yields on fertilized plots increased by 69% in 1984 but only 19% in 1981 compared to the unfertilized controls.

Dormant-season removal of litter produced different effects on spring forage production in 1981 compared to 1984 as indicated by the significant Year by Litter Removal interaction in Table 3. In 1984 this treatment reduced spring forage yields by 29% compared to 25% in 1981. These results suggest that the removal of standing litter of bluebunch wheatgrass when the plant is senescent may interact with annual weather conditions and confound measurements of absolute herbage yields in a long-term study. Additionally, these yield reductions may be further exacerbated if the treatment is repeated on the same plants over a number of years.

A significant Year by Season-of-N-Application interaction (Table 3) indicates that spring forage yields responded differently to the season of fertilizer application in each year. In 1981, forage production was 33% higher when urea was applied in FALL (October and November) as compared to SPRING (February and March). In 1984, however, this trend was reversed with SPRING fertilizer application yielding 28% more forage production than

Table 4. March to July precipitation (mm) and mean temperatures (° C) during 1981, 1984 and 85 year average for Kamloops, B.C.

Date	1981	1984	85 Year average
		(mm)	
Mar.–Apr.	22	37	20
May–July	126	72	70
Total	148	109	90
		(° C)	
Mar.–Apr.	8	8	6
May–July	17	17	18

Table 5. Mean herbage yields (kg/ha) from spring and summer harvested plots as affected by date of N fertilization and litter removal treatment.

Date Fertilized	Spring harvest litter removed	Spring harvest untreated	Summer harvest litter removed	Summer harvest untreated
	kg/ha			
Control	153	199	681	938
October	215	325	1196	1825
November	191	338	1263	1579
January	169	291	1202	1521
February	306	299	1024	1242
March	247	340	1432	1752
$\bar{x}$	214	299	1133	1476

Table 6. Mean herbage yields (kg/ha) of spring and summer harvested plots as affected by date of N application.

Date Fertilized	Spring harvest 1981	Spring harvest 1984	Spring harvest Mean	Summer harvest 1981	Summer harvest 1984	Summer harvest Mean
	kg/ha					
Control	110	242	176 b	993	625	809 c
Oct.	156	392	266 a	1805	1216	1511 a
Nov.	141	362	259 a	1517	1289	1410 ab
Jan.	138	323	230 ab	1548	1176	1362 ab
Feb.	114	491	303 a	1164	1102	1133 b
Mar.	110	477	294 a	1790	1393	1592 a

Means in the same column followed by a different letter are significantly different ($P<0.05$) with Duncan's Multiple Range test.

FALL. No differences ($P>0.05$) were found in spring forage production among individual urea application dates (Table 6) possibly because the fertilizer was not fully depleted by the time the plots were harvested. There was no significant Litter Removal by Fertilized interaction (Table 3) indicating that fall litter removal affected both the fertilized and unfertilized plots equally.

Summer Harvest

Fertilization increased the average yield of summer forage by 73% compared to the control (Table 3). In contrast to spring forage, mean forage production at the end of the growing season was lower in 1984 than in 1981 (Table 6) corresponding to drier growing conditions during May–July in 1984 (Table 4).

Although there was no difference in forage production between FALL and SPRING N application dates, herbage yields were nearly 20% higher when urea was applied on bare ground compared to snow (Table 3). Moreover, an insignificant Year by Snow-Covered interaction (Table 3) indicates that the response was consistent between years. In agreement with our results, Campbell et al. (1986) concluded that N efficiency was lowest when ammonium nitrate and urea were applied to 6 dryland grass species on snow-covered soils in Saskatchewan. Losses, however, appeared to be greatest on the plots fertilized with ammonium nitrate compared to urea. Our results, however, do not agree with Sneva (1973) who found that forage yields were unaffected when urea was applied to deep snow compared to bare soil on rangeland. Wullstein and Gilmour (1964) attributed losses of N, applied on deep snow, to gaseous processes presumably resulting from the dissociation of urea in the snow to ammonia and the rapid evaporation of the snow to the air. Once urea penetrates the soil, however, losses of ammonia are reduced (Tisdale and Nelson 1975).

The specific mechanism for N losses in this study are not known but likely relate to rapid snow-melt on the site. For example, mean summer forage production was lower ($P<0.05$) for the February application date than for October and March (Table 6). Most of this difference, however, occurred in 1981 when there was a sudden increase in average daily maximum temperatures from -1.4° C for the 5-day period before application to 13.8° C for the 5-day period after application. Nitrogen was likely lost by volatilization during this period.

Summer forage production was reduced by 23% following dormant-season litter removal (Table 5). These losses probably resulted from changes in the microenvironment on the plots rather than from direct effects of plant defoliation because the litter removal treatment was applied when plants were senescent. Estimates of snow cover taken in late January 1981 indicated that the percent cover of snow on the plots where litter was removed (34%) was lower ($P<0.05$) than on the untreated plots (47%). This loss of snow cover may have increased frost damage to plants and reduced soil moisture recharge on these plots for spring growth compared to those plots with greater snow cover. Ndawula-Senyimba et al. (1971) found that simulated rainwater penetrated deeper into the soil profile beneath intact bluebunch wheatgrass plants than beneath plants which had been clipped. They attributed the difference to the funnelling effect of the aerial plant parts which directed rainfall into the rooting zone.

Although dormant-season removal of litter reduced summer forage yields, there was no interaction with any other factor. Therefore, true above-ground herbage production can be determined by adjusting treatment means to account for the losses from the litter removal treatment. This technique has the potential to halve the cost of clipping experimental plots which require litter to be sorted from current year's production. For example, an average of 7 min was required to harvest a plot which had been treated with litter removal compared to 15 min to harvest an untreated plot.

Conclusions

Spring forage production was unaffected regardless of whether urea was applied on snow or bare ground but summer yields were reduced when urea was applied on snow. Therefore, in order to maximize returns from fertilization, we recommended that urea be applied only on bare soils.

Autumn litter removal, following plant dormancy, reduced both spring and summer yields. Therefore, preharvesting plots in fall to clear litter is not recommended in studies where spring yields are required and particularly where absolute values of above-ground biomass are required.

Even though summer forage yields were reduced by the fall litter removal, there was no further change in the effect when these plots were fertilized. Therefore, in fertilizer trials at least, this technique may be used to reduce harvesting time of the plots in the next growing season. Corrections will be required, however, to account for losses resulting from the fall litter removal if absolute standing crop is required in the study.

Literature Cited

Atmosphric Environment Service. 1984. Annual meteorological summary, Environment Canada. Downsview, Ontario.

Campbell, C.A., A.J. Leyshon, H. Ukrainetz, and R.P. Zentner. 1986. Time of application and source of nitrogen fertilizer on yield, quality, nitrogen recovery, and net returns for dryland forage grasses. Can. J. Plant Sci. 66:915-931.

Hubbard, W.A., and J.L. Mason. 1967. Residual effects of ammonium nitrate and ammonium phosphate on some native ranges of British Columbia. J. Range Manage. 20:1-5.

Hull, A.C. Jr. 1963. Fertilization of seeded grasses on mountainous rangelands in northeastern Utah and southeastern Idaho. J. Range Manage. 16:306-310.

Kilcher, M.R., S. Smoliak, W.A. Hubbard, A. Johnston, A.T.H. Gross, and E.V. McCurdy. 1965. Effects of inorganic nitrogen and phosphorus fertilizers on selected sites of native grassland in Western Canada. Can. J. Plant Sci. 45:229-237.

McShane, M.C., and R.H. Sauer. 1985. Comparison of experimental fall burning and clipping on bluebunch wheatgrass. Northwest Sci. 59:313-318.

McLean, A., and L. Marchand. 1968. Grassland ranges in the southern interior of British Columbia. Can. Dep. Agr. Pub. No. 1319. Ottawa, Ontario.

Mason, J.L., and J.E. Miltimore. 1959. Increase in yield and protein content of native bluebunch wheatgrass from nitrogen fertilization. Can. J. Plant Sci. 39:501-504.

Mason, J.L., and J.E. Miltimore. 1964. Effect of nitrogen content of beardless wheatgrass on yield response to nitrogen fertilization. J. Range Manage. 17:145-147.

Mason, J.L., and J.E. Miltimore. 1969. Yield increases from nitrogen on native range in southern British Columbia. J. Range Manage. 22:128-131.

Mason, J.L., and J.E. Miltimore. 1972. Ten year yield response of beardless wheatgrass from a single nitrogen application. J. Range Manage. 25:269-272.

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.

SAS Institute, Inc. SAS User's Guide 1979 Edition. Cary, NC., 1979.

Sauer, R.H. 1978. Effect of removal of standing dead material on growth of *Agropyron spicatum*. J. Range Manage. 78:121-122.

Sneva, F.A. 1973. Wheatgrass response to seasonal applications of two nitrogen sources. J. Range Manage. 26:137-139.

Tisdale, E.W. 1947. The grasslands of the southern interior of British Columbia. Ecology 28:346-382.

Tisdale, S.L., and W.L. Nelson. 1975. Soil fertility and fertilizers. Macmillan Publishing Co., Inc. New York.

Willms, W.D., S. Smoliak, and A.W. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-540.

Wilson, A.M., G.A. Harris, and D.H. Gates. 1966. Fertilization of mixed cheatgrass-bluebunch wheatgrass stands. J. Range Manage. 19:134-137.

Wullstein, LeRoy H., and C.M. Gilmour. 1964. Gaseous nitrogen losses and range fertilization. J. Range Manage. 17:203.

Correlation of steer average daily gain with diet quality and forage phenology in an improved annual grassland

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Abstract

Management of legume-improved annual range forage is made difficult by the rapid declines in nutritive quality and animal gains as the plants mature. An improved ability to predict occurrence of the critical spring grazing period (CSGP) when these declines begin would help in making livestock management decisions. Objectives of this study were to construct a model to describe seasonal changes in steer average daily gain (ADG); to observe changes in nitrogen concentration ([N]) and in vitro organic matter digestibility (IVOMD) related to time of season and ADG; and to relate the phenological progress of maturation of rose clover (*Trifolium hirtum* L.) to ADG, [N], and IVOMD. Data from 5 years of a grazing experiment were used to construct the ADG model, which consisted of 3 season-related zones which were described by a series of linear and quadratic functions. Data for [N] and IVOMD from 2 spring seasons of sampling with esophageally fistulated steers, and from 1 season of hand-cut sampling of rose clover and other plant species from annual range were related to the CSGP. Nitrogen content of the forage was a more useful predictor of rapid ADG change during the CSGP than was IVOMD. The CSGP midpoint coincided with an approximately 0.5:0.5 mixture of 2 well-defined maturation stages of rose clover.

Key Words: esophageal fistula samples, organic matter digestibility, nitrogen content, phenological development, *Trifolium subterraneum, T. hirtum, Erodium* sp.

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Annual range forage is commonly grazed with stocker steers on California's annual rangelands (Oltjen et al. 1982, Wolters and Eberlein 1985). Annual legumes frequently have been introduced to improve yield and nutritional quality of the forage. Despite this, the characteristic changes in nutritional quality of the grass-legume-forb community with advance in maturity can lead to rapid and sharp declines in average daily gain (ADG) (Raguse et al. 1984, 1988). This is the spring "critical period" in grazing management as applied to improved annual grasslands.

Determination of an appropriate ending date for the grazing season has both biological and economic value (Vantassell et al. 1987). Indicator plant species and their developmental growth stages are potentially useful in this regard.

Objectives of this study were to construct a general, descriptive model from seasonal changes in steer ADG observed over 5 consecutive grazing seasons, to describe related changes in the nutritive value of the currently grazed forage at the time of seasonal decline in ADG, and to relate phenological changes in maturing rose clover to this critical period of the grazing season.

Materials and Methods

The study was conducted at the University of California's Sierra Foothill Range Field Station, Browns Valley, Yuba Co., Calif., a location representative of the lower-foothill oak woodland zone of the northern Sierra Nevada mountains. The field site was approximately 330 m elevation at 39° 14′N, 121° 18′W. Herbaceous vegetation, which is almost completely annual, is a variable mixture of grasses, legumes and other forbs. The soils are fine to fine-loamy, mixed, thermic Mollic Haploxeralfs or Typic Rhodoxeralfs (Alfisols).

The research plots consisted of 16 13.2-ha pastures in an area which previously had been control burned to remove woody vegetation (1966), re-seeded with the annual legumes subterranean clover (*Trifolium subterraneum* L.) and rose clover (1971 to 1974), and used in various grazing management studies since 1968. Botanical composition measurements documented existence of a stable annual plant community (Raguse et al. 1988).

In 1982 a 3-yr range fertilization experiment was initiated, using the 16 pastures as 2 replicates of 7 fertilization treatments (each replicate of the control consisted of 2 pastures) in a randomized complete block design. Beginning mid- to late November, each field was uniformly stocked with steers (initial weight approximately 215 kg) at an average of 2.5 ha $steer^{-1}$. Two subsequent increases in stocking rates within each season were based on forage levels measured along permanent transects in each field. The stocking rate increases were made to reduce within-season differences in forage allowance and to maintain it at comparable levels across fertilizer treatments. No animals were removed before the end of the grazing season. Grazing was terminated when forage quality declined to a point where approximately zero gain could be estimated from previous weighings. Other details of experimental procedures were given in Raguse et al. (1984, 1988).

Part of the work reported here was done during the 1983–84 grazing season. Forage samples were collected using esophageally-fistulated steers or were hand-cut where the steers were grazing. Samples were taken from 12 April to 1 June 1984 from 2 replicate pastures of the control and the following 3 fertilization treatments:

90 kg ha^{-1} N;
0 kg ha^{-1} N, 67 kg ha^{-1} P, 74 kg ha^{-1} S;
90 kg ha^{-1} N, 34 kg ha^{-1} P, 37 kg ha^{-1} S

Fistula-collected samples were taken as follows. The 2 steers were released into a sample field the day before sampling. About 1 hour after dawn on the following morning, they were harnessed for sampling using solid bottom collection harnesses. Ordinarily, 16 samples were collected per field, or 8 samples per steer. Sampling time averaged from 40 minutes to 1 hour. The samples were placed in plastic bags, labeled, and stored in a freezer until processed. After sample collection the steers were immediately moved to the next field where they remained overnight to become accustomed to the field and the steers in it.

Hand-cut samples of rose clover, subclover (*Trifolium subterraneum* L.), filaree (*Erodium botrys* L. and *E. cicutarium* L.), and a mixture of the principal forage grasses (primarily *Bromus, Festuca, Avena,* and *Hordeum* species) were taken from 16 April to 12 May 1984. Samples of the 4 species or species groups were chosen to represent forage that was being grazed. Three samples of each category were taken near the location of fistula sampling in each replicate pasture. The samples were dried to constant weight in a forced air oven at 57° C, ground through a 1-mm screen, and stored until analyzed.

Because fistula-collected samples were taken only from 1 pasture a day and hand-cut sampling was coordinated on the same day, 1 replicate of the 4 fertilizer treatments was sampled in sequence, usually in 4 consecutive days. This was followed by sampling of the second replicate, whereupon the full sampling schedule was

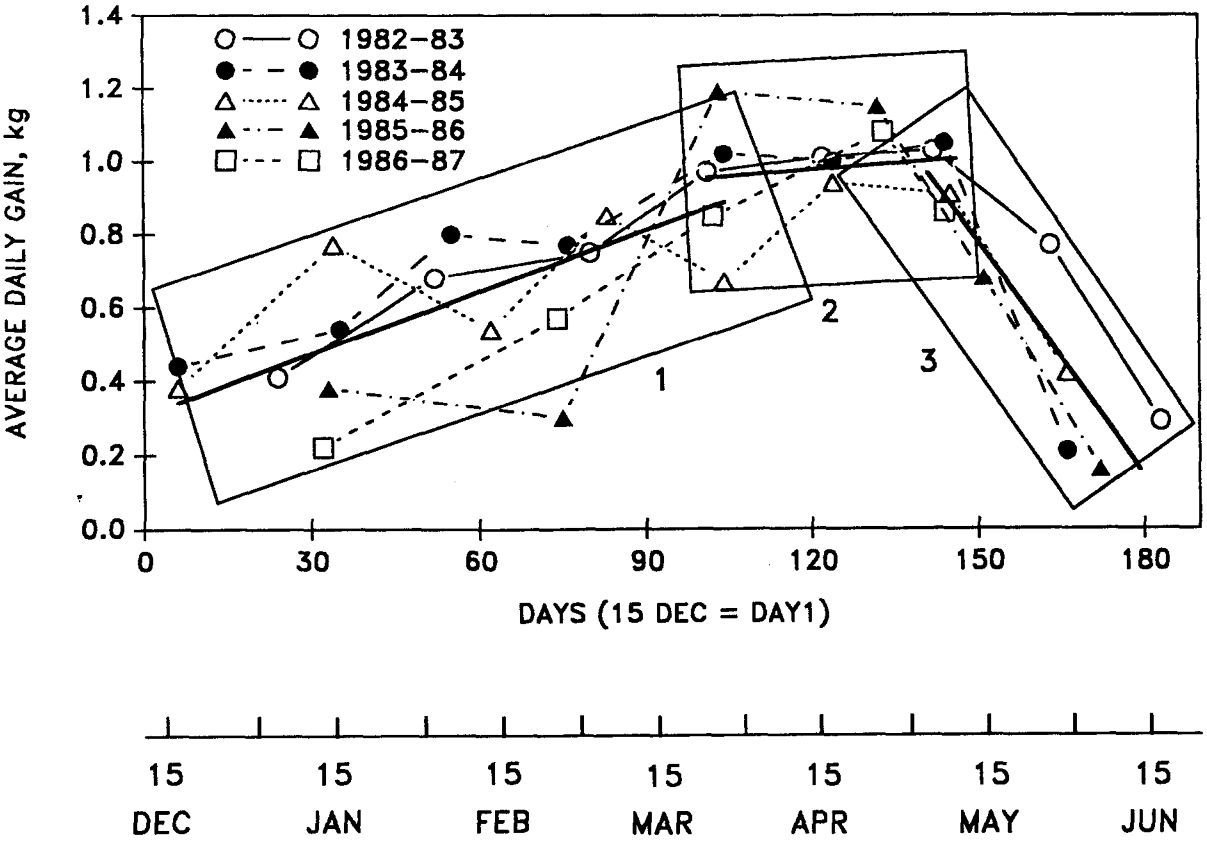

Fig. 1. *Average daily gains (ADG) over 5 consecutive grazing seasons, showing 3 within-season zones and the spring critical grazing period. Each point is the mean of 2 field replicates of 6 fertilizer treatments and a control (the latter used the mean of 2 fields as a replicate) (n = 16). See Table 1 for equations.*

Table 1. Relationship of average daily gains (ADG) of steers and of fistula-collected forage sample concentrations of nitrogen ([N]) and in vitro organic matter digestibility (IVOMD) to time of season on improved annual range pastures.

Parameter	Year(s)	Equation	r^2/R^2	Equation No.
		Fig. 1		
ADG, Zone 1 (1 Dec. to 1 Apr.)	$\bar{x}$, 1983–87	ADG = 0.307 + 0.0056X[1]	0.52*	1
ADG, Zone 2 15 Mar. to 10 May)	$\bar{x}$, 1983–87	ADG = 0.943 + 0.0013X	0.02	2
ADG, Zone (1 May to 15 June)	$\bar{x}$, 1983–87	ADG = 1.05 – 0.021X	0.79**	3
		Fig. 2		
ADG, 15 Mar. to 15 June	$\bar{x}$, 1983–87	$ADG = 0.803 + 0.15X - 0.00026X^2$	0.74**	4
		Fig. 3		
ADG, 15 Mar. to 15 June	$\bar{x}$, 1983–84	$ADG = 0.880 + 0.12X - 0.00021X^2$	0.78**	5
[N], 15 Mar. to 15 June	1983	[N] = 3.22 – 0.022X	0.80**	6
IVOMD, 15 Mar. to 15 June	1983	$IVOMD = 71.2 + 0.021X - 0.0026X^2$	0.93**	7
[N], 15 Mar. to 1 June	1984	[N] = 2.66 – 0.017X	0.89**	8
IVOMD, 15 Mar. to 1 June	1984	$IVOMD = 38.3 + 0.173X - 0.0026X^2$	0.58*	9

*,**Regressions significant at $P<0.05$ and 0.01, respectively.
[1]X = Days following calendar date indicated.

repeated. For purposes of data analysis and presentation, fertilizer treatment samples were combined and reported on the mid-point dates of each sampling interval: 12, 18, and 25 April and 4, 10, 16, and 30 May. Hand-cut sampling of subterranean clover and filaree was discontinued after 5 May because their availability had declined so that they were no longer an important part of the diet and it was not practical to collect samples of sufficient size for laboratory analysis.

The average botanical composition for the 8 pastures sampled (step-point cover, 16 March) was: rose clover, 14%, CV=41%; subterranean clover, 20%, CV=15%; filaree, 19%, CV=39%; and forage grasses, 35%, CV=13%. The remaining 12% of cover was composed of miscellaneous species of variable proportions and minor amounts.

As the plant samples were taken, the average phenological stage of development of rose clover was recorded using the following five-stage system.

0: Plants vegetative
1: Plants green, each having one or more visibly developing heads, heads green.
2: Plants green, with at least one-half of the heads in flower (flower color apparent).
3: Plants beginning to dry, flower color disappeared (petals dried) on at least one-half of the heads.
4: Plants completely dry, no green color remaining.

Hand-clipped plant samples and samples collected using esophageally fistulated steers were analyzed for nitrogen concentration [N] and organic matter (A.O.A.C. 1975). In vitro digestibility of organic matter (IVOMD) was measured by the two-stage procedure of Tilley and Terry (1963).

The 3-year study reported by Raguse et al. (1988) was extended by 2 additional grazing seasons (1985–86 and 1986–87) to further assess within-season forage-animal relationships. Experimental conditions were the same as in the first 3 years except that only animal weight, forage level (kg ha^{-1}), and botanical composition data were collected. Only the ADG data are reported in this paper.

Data were analyzed using analysis of variance. Linear and nonlinear regression procedures were used to determine significance ($P<0.05$) of trends in ADG, [N], and IVOMD over time.

Results and Discussion

Although [N] and IVOMD in the sampled forage in 1982–83 were influenced by fertilizer treatment (Raguse et al. 1988), this was much less so in 1983–84. By the fourth year (1985–86), differences in animal gain per unit area due to fertilizer treatments no longer were significant ($P>0.05$). In order to simplify presentation of results from the current study, all data for ADG, [N], and IVOMD will be combined over fertilizer treatments.

Figure 1 presents annual means (each data point is the mean of the 16 fields) for 5 grazing seasons for each weigh date for which ADG could be calculated. The data set can be divided into 3 zones, each reducible to a summary linear regression. In the first zone, ADG is characterized by generally rising values (Table 1, Equation 1). Lower ADG values than at the preceding weigh date seldom occurred and were followed by obvious compensatory gain. The second zone represents attainment of the maximum seasonal animal performance possible under the various constraints of the system (Equation 2). Its duration and peak ADG are the integrated result of animal, plant, soil, and weather-year conditions. The third zone begins abruptly and is related to maturation of the annual plant species, with the concomitant loss of nutritional quality (Equation 3). Frequently associated with the transition from zone 2 to zone 3 are important changes in plant species acceptability, which lead to differential, or patchy, grazing and large changes in grazing pressure as it is related to individual plant species.

The 3 linear regressions of Figure 1 converge near 1 May. We will define this date as the mid-point of a month-long "critical spring grazing period (CSGP)", a period of time during which management decisions relative to end-of-season must be made. As defined, the CSGP coincides with the end of zone 2, immediately prior to the period of rapidly declining ADG.

In Figure 2 we have isolated the 20 data points of zones 2 and 3 for the 5-year period. Each point represents a total of 16 pastures with a sample size of 15 to 25 animals per pasture. All 20 points of zones 2 and 3 from 1983–1987 fit a quadratic function (Table 1, Equation 4, n=20, $r^2=0.74$; and Fig. 2). This simple but plausible mathematical model for describing seasonal changes in ADG can be constructed given a representative sampling of variation within the grazing season and across years (Fig. 1). This analysis then provides the basis for a quantitative description of the transition between the CSGP and the subsequent precipitous decline in ADG (Fig. 2, Table 1).

The equation which describes the combined 1983 and 1984 ADG data from zones 2 and 3 (Table 1, Equation 5, n=9, $r^2=0.78$; and Fig. 3) is quite similar to the 5-year summary equation and the maxima

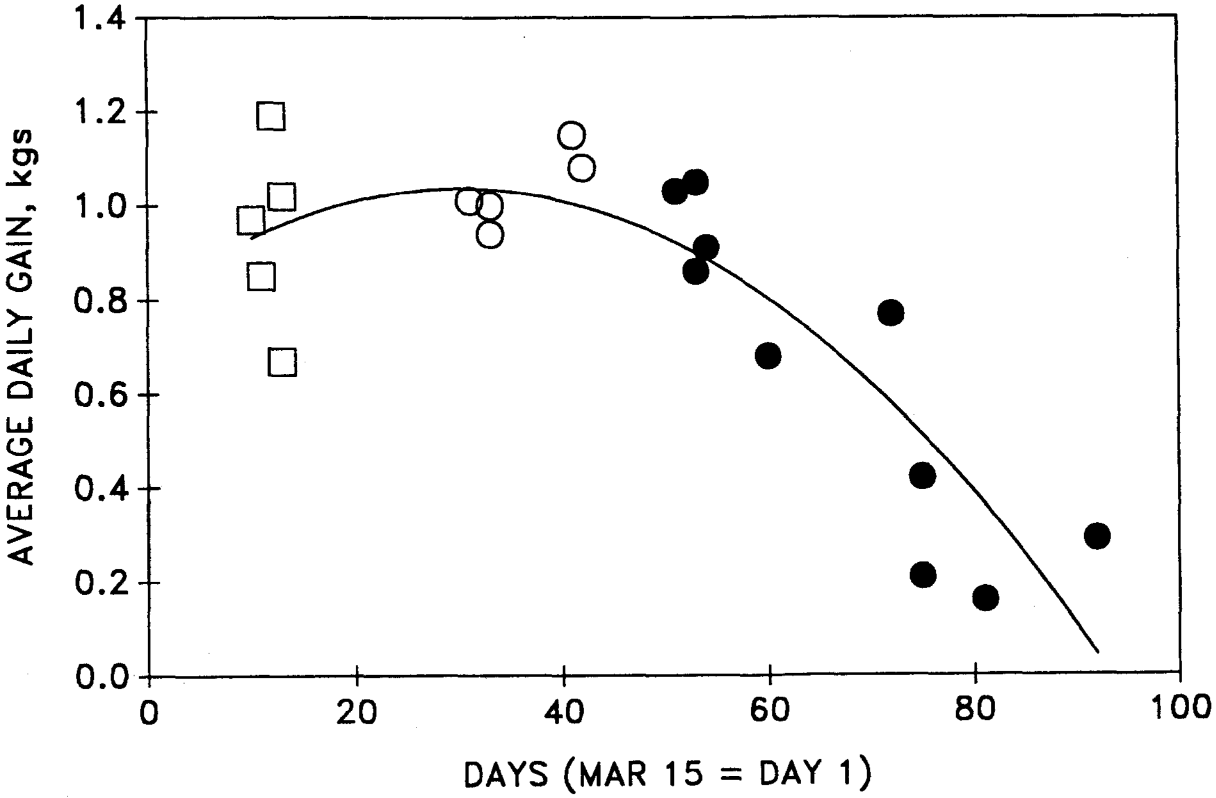

Fig. 2. *Transition of ADG from zone 2 (open symbols) to zone 3 (closed symbols), 1983-87. See Table 1, equation No. 4.*

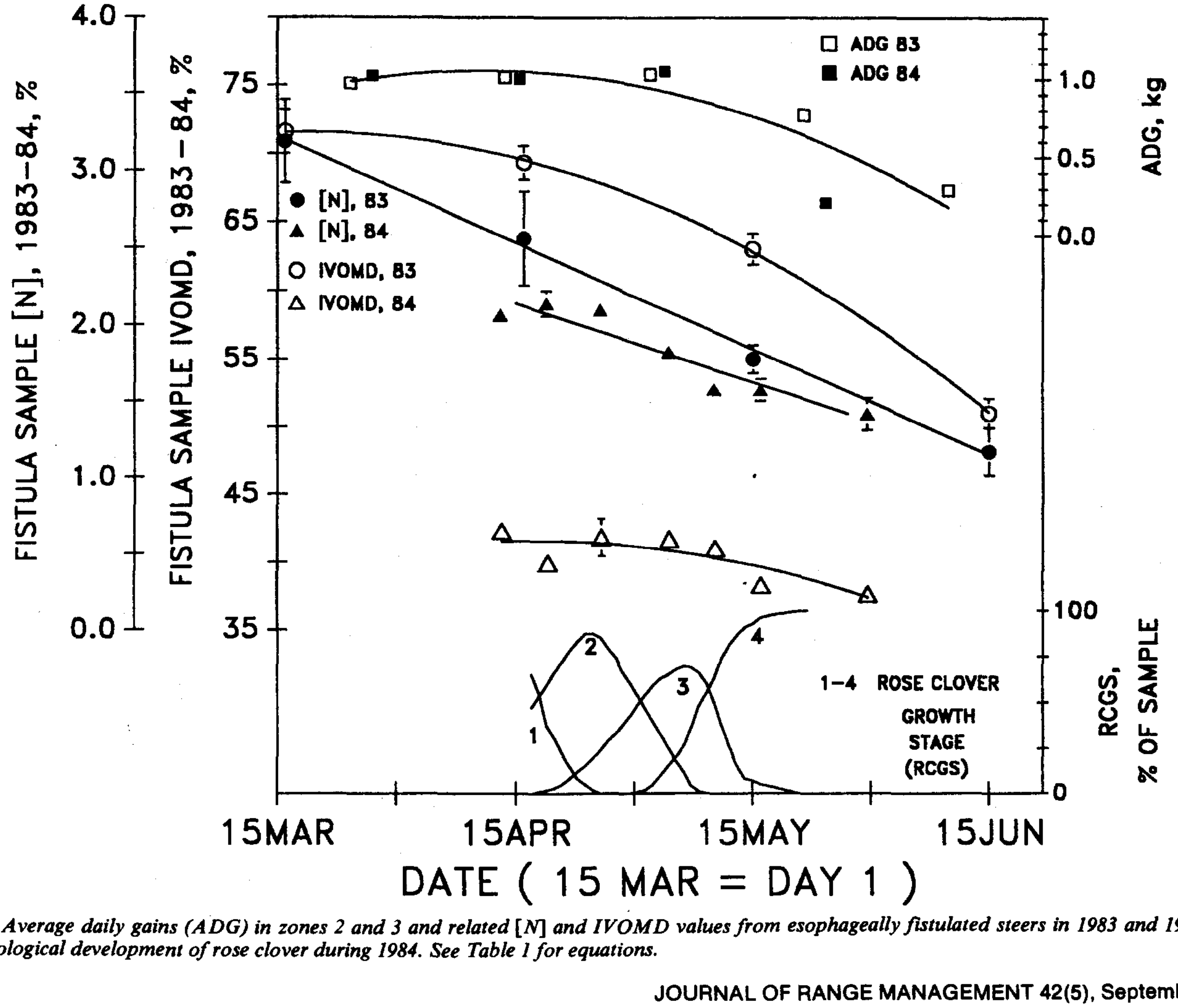

Fig. 3. *Average daily gains (ADG) in zones 2 and 3 and related [N] and IVOMD values from esophageally fistulated steers in 1983 and 1984, and phenological development of rose clover during 1984. See Table 1 for equations.*

of both curves fall on 13 April. The remainder of Figure 3 presents [N] and IVOMD from esophageally collected samples for both years, and the sequence of phenological stages for rose clover in 1984. Regression equations describing the time-related trends of [N] and IVOMD are given in Table 1. Although the time interval covered by analyses for [N] and IVOMD was shorter in 1984 than in 1983, the closer spacing of sample dates permitted a more precise description of the decline. They also were well located with respect to the (later) defined CSGP. Peak IVOMD values, calculated from the first derivatives of Equations 7 and 9, occurred on 19 March 1983 and 17 April 1984. Values for [N] were comparable for the 2 years (Eq. 6, 8). And, despite the disparity between absolute values for IVOMD for the 2 years, the pattern and rate of decline (1 May values were 94% and 104% of 15 March values for 1983 and 1984, respectively) was similar (Eq. 7, 9). Diet samples in 1983 and 1984 were collected by different samplers. Hart et al. (1983) have reported that years accounted for a significant fraction of the variation in IVDMD determined on esophageally fistulated cattle collected diet samples, while values for crude protein agreed well. The closeness of ADG values for April and May of 1983 and 1984 (Fig. 3) is evidence that dietary quality and availability were similar for the 2 years. However, neither [N] nor IVOMD demonstrated changes abrupt and consistent enough to serve alone as reliable predictors of the ADG decline. Moreover, sampling and sample processing costs together with laboratory turnaround time would normally discourage their use as real-time management decision aids.

A potentially useful predictor of impending ADG decline is the phenological maturation of an appropriate indicator plant. In Figure 3, changes in the development of rose clover are related to the previously described changes in ADG, [N] and IVOMD. Rose clover exhibits several desirable characteristics for an indicator species. It is now almost ubiquitously distributed in annual range communities, has a determinate pattern of inflorescence development, demonstrates a nearly time-linear sequence of the chosen phenological stages ($Y = 1.245 + 0.0985X$ $r^2 = 0.95$, where Y = average stage of development and X = the number of days from 18 April under 1984 growth conditions), and has distinctly different maturation stages which are readily identifiable. For the environmental conditions represented by the study, the estimated peak ADG (near 1 May) occurred when the number of rose clover plants at stage 2 was declining while those at stage 3 were still increasing. Only minor variations in stage sequence were observed in relation to fertilizer treatments. Variations due to site differences were more apparent, but these could be used to advantage in differential management of rangeland units where important microclimatic-edaphic differences exist, e.g., as for north- and south-facing slopes.

Limited resources precluded more extensive analysis of hand-cut plant samples. However, all samples analyzed were collected within the CSGP. Samples collected near the time of disappearance of subterranean clover and filaree (midpoint = 4 May) showed [N] of grass and filaree to be similar (1.4 and 1.3%, respectively), as were rose and subterranean clovers (2.1 and 2.3%, respectively). Differences in [N] between the 2 groups were significant ($P<0.01$). The IVOMD values of rose and subterranean clover and filaree (49, 52, and 49%, respectively) were similar, but IVOMD of the grasses was only 41%. These average group differences also were significant ($P<0.05$).

The plant species composition of steer diets was not measured, but as availability of earlier-maturing and nutritious species (e.g., subterranean clover) declined, it is likely that change in species composition of the diet was a significant factor in initiating the ADG decline (Ridley et al. 1986). The principal remaining plants were the mixture of annual grasses and rose clover. The quality of these continued to decline. For example, over the 18-day period from 24 April to 12 May, IVOMD of hand-cut samples of grasses and rose clover declined at the following rates (Y = IVOMD, X = days from 24 April):

$$Y_{grasses} = 47.5 - 0.337X,\ r^2 = 0.99,\ P = 0.062$$

$$Y_{rose\ clover} = 53.6 - 0.267X,\ r^2 = 0.56,\ P = 0.26$$

the [N] of grasses also declined similarly, as

$$Y_{grasses} = 1.76 - 0.019X,\ r^2 = 0.82,\ P = 0.094$$

but [N] of rose clover did not change

$$Y_{rose\ clover} = 2.08 - 0.000024X,\ r^2 = 0.01,\ NS$$

Interpretation and Application

The rose clover phenology data from 1983–84 indicate that one should expect to find roughly equal amounts of stages 1 and 2 (with 1 decreasing and 2 increasing) and very little of stage 3 at the beginning of the CSGP. At the CSGP midpoint, roughly equal amounts of stages 2 and 3 will be present with stage 4 beginning to appear. Finding stage 3 rapidly disappearing and stage 4 predominating would indicate that the CSGP is ending and ADG is already declining.

If the equations for IVOMD and [N] are used to estimate their values at the 1 May CSGP midpoint, 1983 predicted values were approximately 67 and 2.2%, and 1984 values were approximately 41 and 1.9%, respectively.

It appeared that [N] was a more reliable indicator of steer diet quality decline than was IVOMD. A working hypothesis for use of [N] data to predict the CSGP midpoint would be to find [N] at 2% following a 30% decline over the previous 6-week period. Ridley et al. (1986) concluded that N content was particularly important as a determinant of nutritive value as plants approached maturity; they also reported significant differences in the N balance of sheep diets where either subterranean clover or rose clover were fed in spring or late spring. Our results suggest that, with good judgement, careful observation, and a few years experience, the combination of well-timed recording of seasonal weight gains, keeping track of key species (especially subterranean clover) availability, and following phenological development of an appropriate indicator species can aid a range manager in determining when to end the grazing season. Plant sample analysis for [N], if available and affordable, would provide additional information of value.

Finally, it is worth noting that the coherence and uniformity of the 5-year set of ADG was somewhat unexpected. There were important differences in weather-year characteristics, soil fertility, and species composition and availability during this time. Despite this, and under the grazing management employed (Raguse et al. 1988), the within-season pattern of ADG obviously provided a valuable reference based against which forage quality measures could be evaluated. It is also a measure which is feasible for many, if not most, ranch or grazing managers to employ.

In Memoriam

This paper is dedicated to the memory of Virginia ("Ginny") Landry, whose hard work and cheerful outlook contributed an important dimension to this study.

Literature Cited

Association of Official Agricultural Chemists. 1975. Official methods of analysis, 12th ed. Association of Official Agricultural Chemists, Washington, DC.

Hart, R.H., O.M. Abdalla, D.H. Clark, M.B. Marshall, M. H. Hamid, J.A. Hager, and J.W. Waggoner, Jr. 1983. Quality of forage and cattle diets on the Wyoming High Plains. J. Range Manage. 36:46-51.

Oltjen, J.W., A.C. Bywater, C.R. Benson, and J.W. Clawson. 1982. An analysis of the California beef cattle industry. Univ. California Div. Agr. Sci. Spec. Pub. 2181.

Raguse, C.A., J.L. Hull, M.B. Jones, J.G. Morris, M.R. George, and K.D. Olson. 1984. Range fertilization in the Sierra Nevada foothills. California Agr. 38:4-6.

Raguse, C.A., K.L. Taggard, J.L. Hull, J.G. Morris, M.R. George, and L.C. Larsen. 1988. Conversion of fertilized annual range forage to beef cattle liveweight gain. Agron. J. 80:591-598.

Ridley, P.E.R., H.L. Davies, and I.N. Southey. 1986. The nutritive values of subterranean clover (*Trifolium subterraneum* L.), rose clover (*Trifolium hirtum* All.) and soft brome grass (*Bromus mollis* L.). Aust. J. of Exp. Agr. 26:665-668.

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

Vantassell, L.W., R.K. Heitschmidt, and J.R. Connor. 1987. Modelling variation in range calf growth under conditions of environmental uncertainty. J. Range Manage. 40:310-314.

Wolters, G.L., and G.P. Eberlein. 1986. Sulfur or sulfur plus nitrogen increases beef production on California annual range. J. Range Manage. 39:125-128.

Viewpoint: Do your digits betray you or does rounding raise your reputation?

J.L. WHEELER, L.H. PRASETYO, AND H.I. DAVIES

A quick glance at a person's fingers and fingernails may reveal a lot about them. The transverse Beau's line on fingernails can indicate if, and roughly when, an acute illness has occurred. Heavy smokers and nervous nail biters instantly disclose their habits.

The digits presented by an author in a paper may be similarly revealing. Reporting means with an excessive number of digits (e.g., an animal's weight as 351.3 kg) has 6 disadvantages for other people and brings 4 unwanted consequences for the author(s) in return for 1 dubious advantage. The practice has declined since Van Dyne's (1969) plea in this journal but as a quick look at recent issues of this and other scientific journals will show, it is still prevalent. Our viewpoint, prompted by the cogent articles in the September 1988 issue of the *Journal of Range Management* on writing for the benefit of readers, draws attention to the disadvantages for authors as well as for editors, printers, and readers, of failure to consider carefully the number of significant figures to be used in presenting data.

The disadvantages for other people of using excessive digits are that it:

1) takes longer to read tables;
2) makes treatment effects harder to grasp;
3) prevents rapid mental comparisons;
4) discourages readers from (fully) perusing tables;
5) costs more to type, print, and check; and
6) may prevent a table fitting across a page.

Unwelcome consequences for authors are that it:

1) warns readers that the data have not been thoughtfully considered;
2) raises a suspicion that the author(s) do not understand their own work;
3) increases the chance that readers will not take in the desired message; and
4) may imply that the author(s) disparage the reader's intelligence.

The only possible advantage for authors that we can see is that they may delude undiscriminating or ingenuous readers into thinking that their work was more detailed, precise, or "scientific" than it really was.

We suggest that adherence to the following principles, drawn from the literature cited, will do much to ensure that tables present clear, easily grasped information.

1) Tabulated figures must reflect closely the precision of the original observations.
2) Consider bias and other sources of inaccuracy.
3) Round means to a number place indicated by taking a quarter of the standard error of the mean, e.g.,
   SE = 400; 400/4 = 100; round to nearest 100
   SE = 8.55; 8.55/4 = 2; round to nearest integer.
4) Never use more than 2 or 3 significant figures unless there is a specific need, for example, write 2.34, 234, 2340 or 2300.

Round values even more if the data are to be used in slides during a lecture; where feasible use graphical presentation in talks.

Note also, that a correlation coefficient $r = .8861$ or .886 accounts for within 1% of the same percentage of the variance, as $r = .89$.

Tables can frequently be made clearer, more informative and more attractive by providing a least significant difference rather than by using a range test and its fringe of superscripts (Carmer and Walker 1982).

Table 1. Examples of Superfluous Digits and Appropriate Rounding.

	Published	SE/4	Round to
Live weight gain (g/d)	78.5–114.1	1.4	78–114
Milk yield (kg/301 d)	2401–2617	34‡	2400–2620
Wool growth (g/d)	9.96–10.53	0.38–0.50	10.0–10.5
Green forage production (kg/ha)	1633–3259	93‡	1600–3300
Dry matter intake (g/d)	488.9	17.4	490
Volatile fatty acid concentration (mM/l)	88.9	2.9	89

‡Calculated from SD or LSD.

Some examples of the use of excessive digits and their suggested rounding are given in Table 1. These examples are taken from recent published conference proceedings in animal science but others may readily be found in current range science and agronomy publications.

In our view, writing with the interests of readers in mind implies also a careful consideration of all the means presented and a rigorous exclusion of unnecessary digits.

Further Reading

Carmer, S.G., and Walker, W.M. 1982. Baby bear's dilemma: a statistical tale. Agron. J. 74:122-24.

Cochran, W.G., and Cox, G.R. 1957. Experimental designs (2nd Ed.) Wiley, New York p61.

Little, T.M., and Hills, F.J. 1978. Agricultural experimentation (1st Ed.) Wiley, New York p41.

Terman, G.L. 1978. Comments on significant figures in relation to experimental errors. Agron. J. 70:519-20.

Van Dyne, G.M. 1969. A plea for fewer but more-significant digits. J. Range Manage. 22:52-4.

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SMART: a Simple Model to Assess Range Technology

RICHARD H. HART

Abstract

A model, more detailed than a set of stocking rate response curves but less detailed than large process models such as SPUR, was needed to evaluate the short-term effect of grazing management practices on range herbage growth and livestock production. SMART (Simple Model to Assess Range Technology) simulates the effects of stocking rate and rotation on herbage production and steer performance. Herbage growth rate is a quadratic function of herbage biomass and is adjusted for seasonal differences. Herbage intake increases with herbage biomass and digestibility and animal weight. Animal gain increases logarithmically with digestible dry matter intake and decreases with animal weight. Output of these simulations confirms that early removal of steers from pasture in autumn will increase net returns, and that short-duration rotation grazing will produce little increase in gains or returns over those achieved under season-long grazing. Development of the SMART model revealed deficiencies in our understanding of the factors controlling herbage intake.

Key Words: herbage production, modelling, grazing systems, steer performance

Many process models of grazing ecosystems have been developed in the past 20 years (Goodall 1979). SPUR (Simulation of Production and Utilization of Rangelands; Wight 1987b) and other models of this sort tend to be mathematically complex and extremely detailed. Such detail often is not needed, wanted, or understood by stockmen or by researchers conducting grazing studies.

A simpler approach to modeling was suggested by Noy-Meir (1978), based on his earlier work with predator-prey graphs (Noy-Meir 1975). He plotted herbage growth and consumption as functions of herbage biomass, and drew conclusions about the productivity and stability of grazing systems as influenced by the balance between the two processes. His models are concerned with long-term equilibria in which animal numbers are controlled by forage availability, and have several deficiencies when applied to a single grazing season on rangeland. The models assume that herbage growth rate is a constant quadratic function of herbage biomass throughout the season, with growth stopping abruptly on a fixed date. They also assume that consumption of green biomass by each animal is a constant function of total green biomass throughout the season, without regard to changes in digestibility, animal weight, or stage of production (i.e., pregnancy or lactation). In the original model (Noy-Meir 1975), herbage consumption was a Michaelis or logarithmic function of biomass; the later version assumed a discontinuous or ramp function (Noy-Meir 1978). Stable equilibrium points were proposed when consumption and growth were equal and when a decrease in herbage biomass caused an increase in growth.

Under some conditions, a sudden collapse in gains was predicted, with gain per unit area falling abruptly from near maximum to less than zero with a very small increase in stocking rate (SR). The data of Bement (1974) and Hart et al. (1988b), in which SR greatly exceeded that at maximum gain per unit area and in one case was so high that cattle lost weight, showed no such sudden decrease in gain. Experimental evidence indicates a "plateau" of constant gain per animal at grazing pressures below some critical level, and a linear decline in gain as grazing pressure increases past this level (Hart 1978). Any model must account for these responses.

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Assumptions, Development and Validation of SMART

SMART assumes that herbage growth rate is a quadratic function of herbage biomass (both measured as dry matter), but that growth rate at any given level of biomass declines as the growing season advances, rather than holding constant. In some climates and ecosystems, growth rate increases in the fall and continues at a low rate through the winter; SMART could be modified accordingly for such ecosystems. Digestibility of diets also decreases as the season advances; again, this may not be true of all ecosystems. Intake of digestible dry matter (DDM) increases linearly as the standing crop of DDM increases, until maximum intake is achieved. The rate of increase becomes smaller as animal weight increases. Maximum intake of dry matter increases as animal weight and rumen capacity increase, but decreases as digestibility and the ease of meeting energy demand increase. Animal gain is a logarithmic function of animal weight times DDM intake, after an allowance for maintenance is deducted from intake; this is a simplification of the more complex function used by NRC-NAS (1984).

Parameters for the functions were calculated from published and unpublished data. The herbage growth function was fit to 1982 data of Test (1984); he measured herbage production and steer gains on blue grama-western wheatgrass range near Cheyenne, Wyoming. This function predicts net herbage biomass growth, or total growth minus losses from weathering, trampling, and rodent and insect grazers. A net loss in biomass in autumn is predicted and has been shown to occur. Dry matter digestibility of diet declines linearly during the season but at changing rates as the botanical composition of the diet changes (Hart et al. 1983).

DDM intake was fit to data of Zoby and Holmes (1983) from heavier cattle and from data of Test (1984) at the end of the grazing season, when nutrient availability and/or density limited intake. Test (1984) did not measure intake, but calculated intake from his data on standing crop inside and outside of exclosures which were moved every two weeks. Maximum intake was fit to Test's (1984) data in mid-season and to Zoby and Holmes' (1983) data from lighter cattle; it was assumed that intake was not limited by DDM availability in either case. Fit of data to a discontinuous function with a ceiling on intake was much superior to fit to Michaelis, logarithmic, inverse, or other continuous functions. Daily intake calculated from the data of Allden and Whittaker (1970) relating grazing time and rate of intake to herbage availability demonstrated this response. The upper limit is fixed by rumen capacity and rate of passage. Difference equations and symbols used are listed in Table 1.

The single-paddock version of SMART requires 46 lines when coded in BASIC 3.11; the multi-paddock version requires 56 lines. Coding may be obtained from the author.

SMART requires input of initial values of SR, animal weight, and herbage biomass; the day grazing begins and ends; and a growth factor (the value .000001 in the first equation of Table 1) by

Table 1. Equations and symbols used in SMART.

Equations
$G = (72000\ V - 36\ V^2 - 263\ VT + 0.128\ V^2T)\ .000001$
$D_{(T<188)} = 108.1 - 0.25\ T$
$D_{(T>187,\ <218)} = 92.75 - 0.167\ T$
$D_{(T>217)} = 110.85 - 0.25\ T$
$I_{DDM} = (0.029 - 0.000039\ W)\ (DV/100)$
$I_{DM\ max} = 0.051\ W - 0.00037\ DW$
$L = (3.12 - 0.45\ \text{in}\ W)\ (I_{DDM} - 0.042\ W^{.75})$
Symbols
G = Herbage growth rate, kg dry matter/ha/day
V = Herbage standing crop, kg dry matter/ha
T = Day of year (Julian date)
D = Dry matter digestibility, %
I_{DDM} = Intake of digestible dry matter, kg/animal/day
$I_{DM\ max}$ = Maximum intake of dry matter, kg/animal/day
L = Gain per animal, kg/day
W = Animal weight, kg

which growth rate is adjusted to achieve the desired value for peak standing crop in an exclosure. SMART then operates on a daily time step. First, herbage growth is calculated for grazed and ungrazed stands (the latter simulates the exclosure) and added to the biomass of each, and dry matter digestibility is calculated. Next, digestible, total and maximum dry matter intake per animal are calculated; if the calculated dry matter intake exceeds maximum intake, total and digestible dry matter intake are reduced accordingly. Then gain per animal is calculated and animal weight and gain per hectare are incremented. Finally, dry matter intake per hectare is calculated from intake per animal and stocking rate, and deducted from herbage biomass. The effect of herbage biomass on herbage growth and intake as digestibility decreases and animal weight increases are shown in Figure 1.

As now coded, SMART prints at daily or longer pre-selected intervals the Julian date, standing crop and growth rate in each paddock, the paddock being grazed, dry matter digestibility, dry matter intake per steer, daily gain, and steer weight. At the end of the grazing season it prints peak exclosure standing crop and total dry matter consumption from each paddock, average daily gain and gain per ha for the season, and the SR and growth factor originally specified.

SMART was validated using 1983 data from Test (1984) and 1984 data from Hart (1988a) collected at Cheyenne. Biomass predicted by the model was greater than that in the field in 1983 and less in 1984 (Fig. 2) but by only a small margin, and seasonal

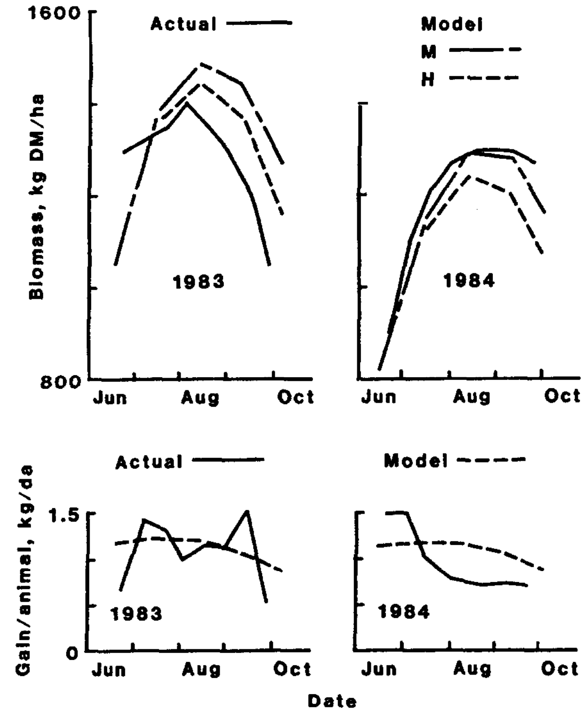

Fig. 2. *Validation of herbage biomass and animal gain simulations of SMART; M = moderate stocking, H = heavy stocking.*

patterns were the same in the model and in the field. However, as indicated by the name, SMART is designed not to simulate forage growth in response to environment, but to evaluate the impact of grazing technology on animal intake and gains, and the feedback of intake to forage growth. SMART predicted actual gains very closely but without the fluctuations between weigh dates observed when animals are weighed frequently.

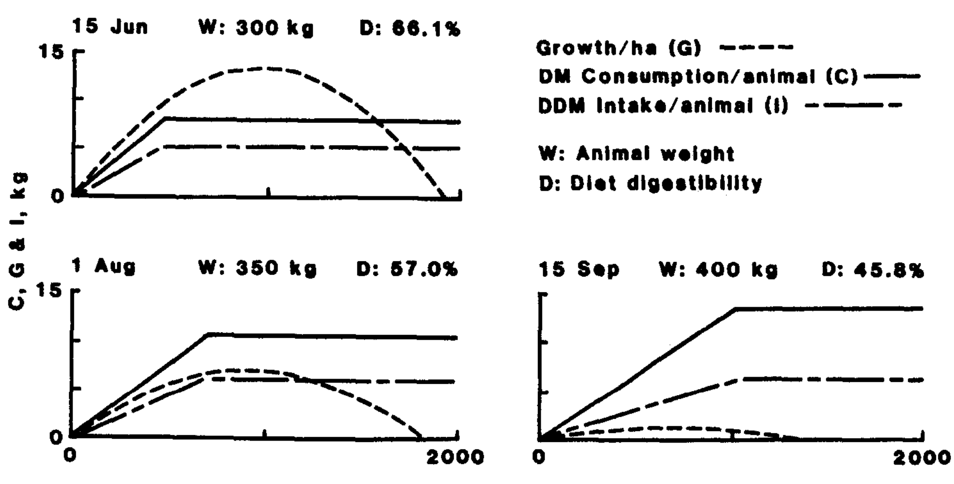

Fig. 1. *Response of herbage growth to herbage biomass and date, and of herbage intake to herbage biomass and digestibility and animal weight; SMART simulations.*

Applications of SMART to Management and Research

SMART was run over a range of SR for grazing seasons beginning 1 or 15 June and ending 15 September or 15 October and assuming forage production of 1,326 kg/ha. Over each season, the response of gain per animal followed the standard SR curves (Fig. 3), indicating the model is a useful approximation of reality. No large drop in gains was predicted at high SR. This conforms to reality on range, where grazing seldom begins until a reserve of forage has been produced, and forage intake by grazing animals declines gradually, not abruptly, as forage supply decreases.

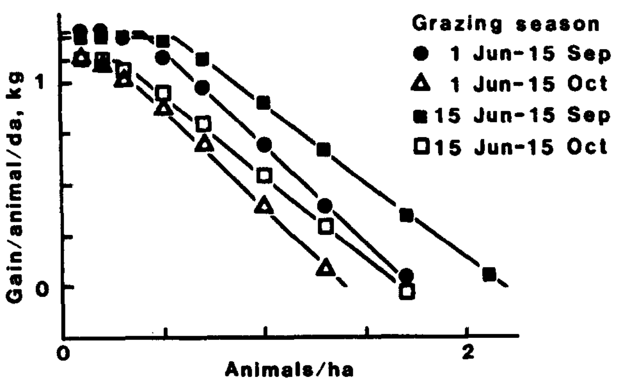

Fig. 3. *Effect of stocking rate on gain per animal over 4 grazing schedules: SMART simulations.*

Stocking rate response curves can be used by a livestock producer to make simple pencil-and-paper calculations of the most profitable SR under his range and economic conditions (Hart 1978 and Hart et al. 1988a). Equations for the stocking rate-gain curves of Figure 3 are given in Table 2, with SR converted from head/ha to steer days/ha. The optimum or most profitable SR is calculated from the equation

Table 2. Average daily gain (ADG) above critical grazing pressure, optimum stocking, rate, and ADG and net return at optimum stocking rate for four grazing seasons (SMART simulation).

Grazing season	ADG (H = steer da/ha)	Optimum H	--At optimum H-- ADG, kg	Return/ ha
1 Jun - 15 Sep	1.61 - 0.00870 H	66.8	1.03	$61.75
1 Jun - 15 Oct	1.33 - 0.00693 H	63.8	0.89	44.79
15 Jun - 15 Sep	1.65 - 0.00830 H	72.2	1.05	68.80
15 Jun - 15 Oct	1.33 - 0.00648 H	67.8	0.89	47.34

$$H = (Pa - C)/(2Pb),$$

in which H = optimum SR, P = selling price in dollars per kg, C = carrying cost per head per day, and values of a and b are taken from the equations in Table 2. These equations also are used to calculate ADG at the optimum SR. Net return/ha to land, labor and management or R is calculated by the equation

$$R = (Pa - C)H - PbH^2.$$

Average selling price in September and October of 1987 was $1.59/kg and carrying costs in 1987 were estimated at $0.71/head/-day (Hart et al. 1988a). Gains and returns estimated from SMART simulations were much higher when steers were removed from pasture 15 September rather than waiting until 15 October. As forage biomass and quality declined in late September and early October, intake and steer gains also declined while carrying costs remained the same, reducing net returns.

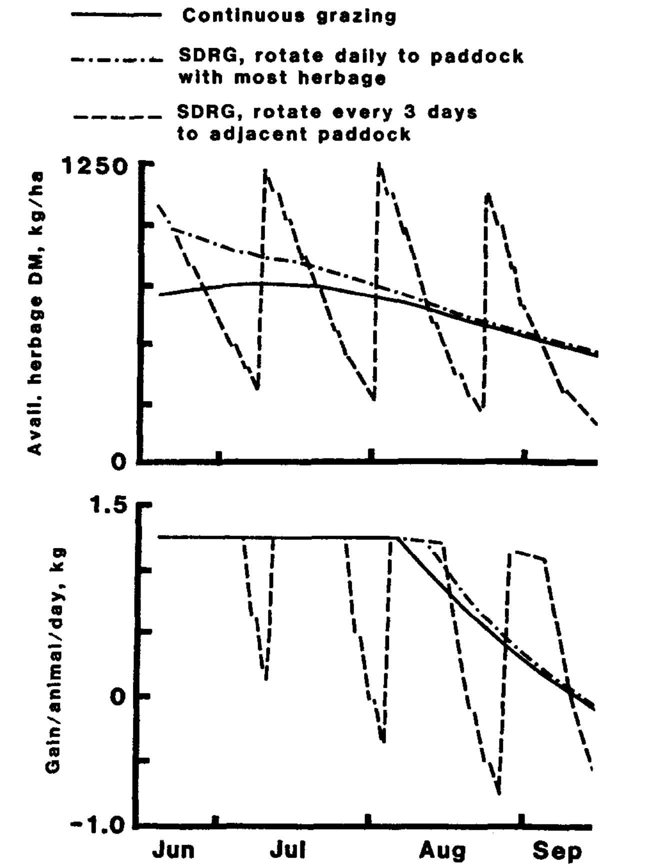

Fig. 4. *Herbage availability and animal gain under continuous grazing and 8-paddock short-duration rotational grazing (SDRG) with cattle moved daily to the paddock with greatest herbage standing crop or every 3 days to the adjacent paddock; SMART simulations.*

SMART provides information about the operation of rotation grazing systems. This model was used to simulate rotation patterns in an 8-paddock rotational grazing system, in which growth rate in the paddocks ranged from one-third less than the mean growth rate to one-third more. When steers were rotated daily to the paddock with the greatest herbage biomass, simulated gain per steer for the season was 4% greater than that simulated under continuous season-long grazing. But when steers were rotated through the paddocks in order every 3 days, without regard to herbage biomass, available forage and animal gain varied greatly from paddock to paddock and day to day, and total gain was 20% less than under season-long grazing (Fig. 4). These responses are confirmed by Hart et al. (1988a), who reported that gains under 8-paddock short duration rotation grazing were not significantly different from gains under season-long grazing when rotation was based on herbage biomass and assumed growth rate, but were 16% less when animals were rotated according to a set schedule.

The most significant effect of chemical and mechanical treatments on range is an increase in forage production. SMART can simulate this increase and estimate its impact on livestock gains, providing a basis for economic evaluation of proposed treatments.

The herbage growth and digestibility equations of SMART may be modified to match the average response of range and pasture types other than blue grama-western wheatgrass range. Most of the necessary data probably has been published, or languishes in researchers' files awaiting application. Temperature, solar radiation, and precipitation parameters may be added as driving variables for herbage growth and digestibility. The ERHYM model provides an example (Wight 1987a). No attempt was made to simulate growth of individual plant species. Caughley (1982) has stated that the dynamics of a system made up of several plant species can often be summarized by a one-species model. However, a multi-species model is necessary if succession is to be simulated, or if shifts of plant species in the diet cause significant changes in diet quality.

The intake and gain equations may be modified to fit other species and classes of livestock, on other forage types. For example, intake on improved pastures in humid areas is much less than that on rangeland with the same standing crop of digestible biomass (Hodgson and Wilkinson 1968, Jamieson and Hodgson 1979).

The SR response curves developed from SMART indicate appropriate SR to include in grazing trials. There is little value to grazing trials in which all SR are below the critical SR, and all gains are equal. As a result of our work with this model, we increased SR on a grazing systems and stocking rate study by 25% (Hart et al. 1988a).

The curves also provide a format for quantifying and reporting results of grazing trials. Too many publications conclude, after 10 to 40 years of research, only that "moderate" stocking produced more gain per hectare than "heavy" stocking; a very small return of information for an enormous investment in land, time, and money. Response curves developed from such data sets would be valuable guides to stockmen operating on many types of range and pasture.

Finally, development of models such as SMART stimulate the formulation of researchable hypotheses and the identification of data needed to enlarge our understanding of the operation of plant-animal systems. Our search for data to paramaterize and validate SMART revealed the shortage of range data relating herbage intake to standing crop of forage; digestibility or other measure of forage quality; and animal species, class, weight, and condition. Estimating intake of grazing animals is always difficult, but especially under range conditions where a large area per animal is needed and difficulties in handling animals are increased proportionately.

Literature Cited

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

Bement, R.E. 1974. Strategies used in managing blue-grama range on the Central Great Plains. p. 108-120 *In:* Kreitlow, K.W., and R.H. Hart (eds.) Plant morphogenesis as the basis for scientific management of range resources. USDA Misc. Pub. 1271.

Caughley, G. 1982. Vegetation complexity and the dynamics of modelled grazing systems. Oecol. 54:309-312.

Goodall, D.W. 1979. The modeling of arid ecosystem dynamics. p. 385-409. *In:* Goodall, D.W., and R.A. Perry (eds.) Arid-land ecosystems: structure, functioning and management, vol. 2. Cambridge Univ. Press, Cambridge.

Hart, R.H. 1978. Stocking rate theory and its application to grazing on rangelands. p. 547-550 *In:* Hyder, D.N. (ed.) Proc. 1st Internat. Range. Cong. Soc. Range Manage., Denver, Colo.

Hart, R.H., O.M. Abdalla, D.H. Clark, M.B. Marshall, M.H. Hamid, J.A. Hager, and J.W. Waggoner, Jr. 1983. Quality of forage and cattle diets on the Wyoming High Plains. J. Range Manage. 36:46-54.

Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988a. Cattle, vegetation and economic responses to grazing systems and grazing pressure. J. Range Manage. 41:282-286.

Hart, R.H., J.W. Waggoner, Jr., T.G. Dunn, C.C. Kaltenbach, and L.D. Adams. 1988b. Optimal stocking rate for cow-calf enterprises on native range and complementary improved pastures. J. Range Manage. 41:435-441.

Hodgson, J., and J.M. Wilkerson. 1968. The influence of the quantity of herbage offered and its digestibility on the amount eaten by grazing cattle. J. Brit. Grassl. Soc. 23:75-81.

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

Noy-Meir, I. 1975. Stability of grazing systems: an application of predator-prey graphs. J. Ecol. 63:459-481.

Noy-Meir, I. 1978. Grazing and production in seasonal pastures: analysis of a simple model. J. Appl. Ecol. 15:809-820.

NRC-NAS. 1984. Nutrient requirements of beef cattle, 6th rev. ed. Nat. Acad. Press, Washington, DC.

Test, P.S. 1984. Vegetation and livestock response to three grazing systems—continuous, rotationally deferred and short-duration rotation. Ph.D. Diss., Univ. Wyoming, Laramie. Diss. Abstr. 8508879.

Wight, J.R. 1987a. ERHYM-II: Model description and user guide for the BASIC version. USDA-ARS Publ. ARS-59.

Wight, J.R. (project coord.) 1987b. SPUR—Simulation of Production and Utilization of Rangelands: documentation and user guide. USDA, ARS Publ. ARS-63.

Zoby, J.L.F., and W. Holmes. 1983. The influence of size of animal and stocking rate on the herbage intake and grazing behaviour of cattle. J. Agr. Sci. 100:139-148.

Justification for grazing intensity experiments: economic analysis

DAVID I. BRANSBY

Abstract

Economic arguments in favor of grazing intensity trials are provided by economic analysis of grazing intensity results from Coastal, Callie and experimental hybrid S-16 bermudagrass (*Cynodon dactylon* L. Pers), and by emphasizing the biological and economic differences among cultivars. Cattle buying prices of $1.20, $1.30, and $1.40/kg and price margins (selling price minus buying price) from -$0.20 to $0.20 were considered on a return/ha and /animal basis, assuming land or capital to buy animals to be limiting, respectively. When price margin was -$0.20, the stocking rate at which profit/ha was maximized ranged from 4.19 to 5.85 animals/ha, while profit/animal was maximized between 4.77 and 6.89 animals/ha. Corresponding ranges in average weight of herbage present/ha which maximized profit/ha and /animal were 2.83 to 3.60 Mg and 2.34 to 3.72 Mg. For a price margin of $0.20, profit/ha and /animal were maximized at stocking rates of 7.36 to 9.86 and 4.14 to 5.83 animals/ha respectively, with corresponding levels of herbage present/ha in the ranges 0.33 to 1.79 Mg and 2.73 to 4.06 Mg. Relative differences in profit/ha and /animal among cultivars did not correspond to differences in gain/ha and /animal. Economic comparison of the cultivars considered in this study would have had little relevance if only one grazing intensity had been used in the field trial. Only grazing trials with several grazing intensities per treatment can allow for the determination of economic optimum grazing intensities in respect of a wide range in economic conditions.

Key Words: profit/ha, profit/animal, price margin/kg, *Cynodon dactylon*, stocking rate, herbage present

If forage-animal research data are intended to benefit the producer, their "final use value" is determined largely by economic analysis (Jacobs 1974, Cook and Stubbendieck 1986, Workman 1986). However, economic analyses of grazing data are seldom published. Consequently, it is difficult for grazing researchers to adequately appreciate the economic implications of their research. This being the case, grazing researchers face the danger of becoming pre-occupied with biological details and losing sight of the research needs of producers. Furthermore, a narrow biological emphasis increases vulnerability to the development of preconceptions. For example, Blaser et al. (1974) contended that "Establishing goals of animal production, as within narrow limits of daily gains per head that are economically feasible, the grazing pressure to obtain such goals becomes fixed and supercedes stocking rates". Inherent in this statement are the apparent implications that (a) daily gain/head is of greater importance than other biological parameters such as gain/ha, and (b) economic feasibility is confined to narrow limits in grazing intensity. Yet neither of these suggestions was verified.

The economic goal for most pasture-based livestock enterprises is to maximize total net return. If land is the most limiting factor of production this goal will be realized by maximizing return/ha. Previous economic analyses of grazing intensity data have mostly considered land to be limiting, and have therefore concentrated on the relation between profit/ha and stocking rate (Hildreth and Riewe 1963, Hart 1972, McCartor and Rouquette 1977, Hart 1978, Riewe 1981, Quigley et al. 1984, Bransby 1985). Some of these studies have been subject to several limitations. Firstly, stocking rate provides no information about the pasture. Consequently, little is known about what pasture condition (forage availability, species composition, etc.) is associated with the stocking rate which maximizes total net return. Secondly, responses of income, expenditure and profit in relation to production variables and cattle prices are often not clear. Finally, even though land is almost always the most limiting production factor under rangeland conditions (Workman 1986) and frequently for improved pastures too, other factors such as operating capital may be more limiting in some cases, particularly on improved pastures which have high carrying capacities and other annual inputs such as fertilizer. Under these conditions maximization of total net return may be realized at a completely different stocking rate to that which maximizes profit/ha.

The general aim of this paper is to emphasize the need for grazing intensity trials by means of economic arguments. More specifically, the objectives are (a) to examine the responses of income, expenditure and profit to stocking rate and pasture condition, as indicated by average herbage present, (b) to emphasize the differences between biological and economic responses to grazing intensity considering land or animals to be limiting, and (c) to highlight general implications for commercial pasture-livestock systems and future grazing research. Data from three bermudagrasses (*Cynodon dactylon* L. Pers.) grazed by steers are considered.

Methods

The analysis in this study made use of the production functions developed for Coastal, Callie and experimental hybrid S-16 bermudagrass in a companion paper which also described the experimental procedure for data collection in more detail (Bransby et al. 1988). These 3 cultivars were chosen for economic analysis due to their distinctly contrasting biological responses to grazing intensity. Each cultivar was continuously grazed at 4 grazing pressures under variable stocking (put-and-take) with steers for an average of 151 days over 3 consecutive years. While it is recognized that data from put-and-take trials are not ideally suited to economic analysis, when a number of grazing intensities were examined by both put-and-take and set stocked procedures the general nature of grazing intensity relationships was similar (Burns et al. 1970, Marten and Jordan 1972). Consequently, it was considered that these data serve as an adequate example for the following analysis. Furthermore, it was assumed in the analytical procedure which follows, that animals were bought at the start of the grazing period and sold at the end of the period, or alternatively, that a value/kg could be assigned to animals at the start (buying price) and end (selling price) of the grazing period. In order to broaden the scope of conclusions drawn from this study, buying prices of $1.20, $1.30, and $.140/kg, and price margins (selling price minus buying price) of -$0.20 to $0.20/kg were considered. It must be emphasized that these values are not important in the context of this study, except in the sense that they serve as examples to illustrate important principles. However, they corresponded closely to the 1985 figures

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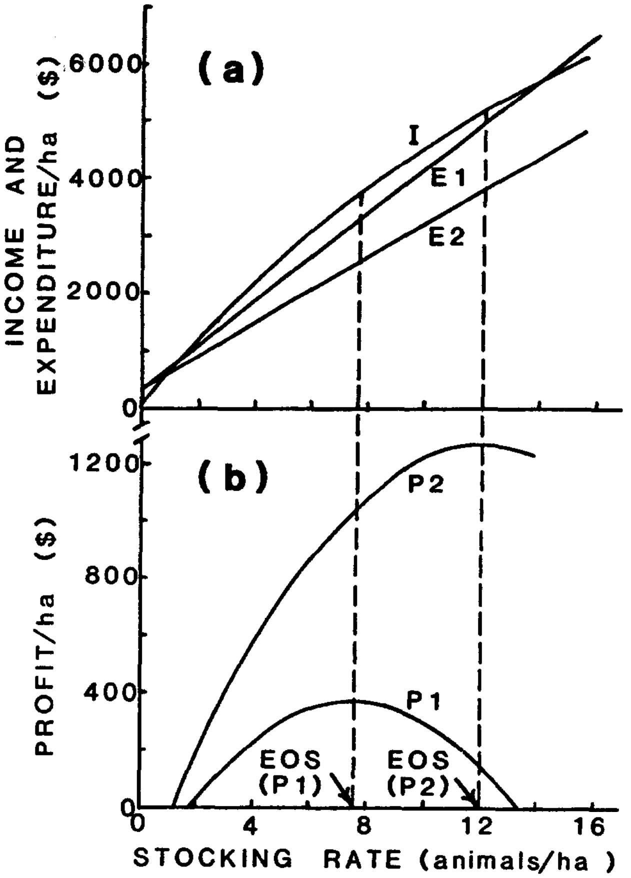

Fig. 1. *(a) Relationships between income/ha (I) and stocking rate for Coastal with selling price/kg set at $1.60, and between expenditure/ha and stocking rate with buying price set at $1.60 (E1) and $1.20 (E2). (b) Relationships between profit/ha and stocking rate for Coastal with selling price set at $1.60/kg and buying price at $1.60 (P1) or $1.20 (P2). (EOS = stocking rate rate which maximized profit).*

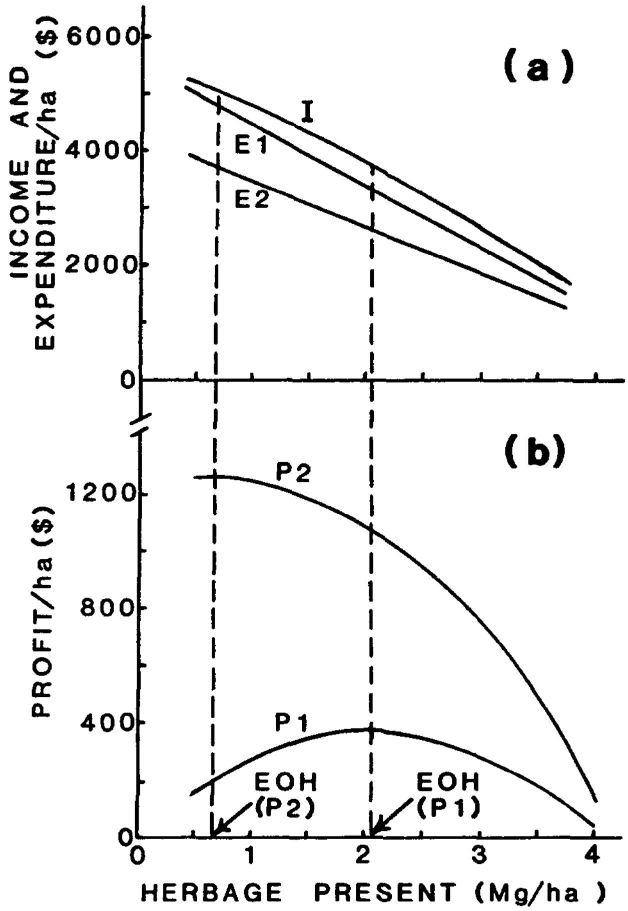

Fig. 2. *(a) Relationships between income/ha (I) and herbage present for Coastal with selling price/kg set at $1.60, and between expenditure/ha and herbage present with buying price set at $1.60 (E1) and $1.20 (E2). (b) Relationships between profit/ha and stocking rate for herbage present for Coastal with selling price set at $1.60/kg and buying price at $1.60 (P1) or $1.20 (P2). (EOH = level of herbage present which maximized profit).*

reported by Hart et al. (1988). Although the advantage of including time as a variable in economic analyses is recognized, time was considered to be fixed in this study.

Profit/ha (P) was determined by subtracting expenditure/ha (E) from income/ha (I):

$$P = I - E \quad [1]$$

Income/ha was calculated by multiplying the sum of the initial mass of animals/ha (W) and gain/ha (G) by the selling price/kg (n):

$$I = n(W + G) \quad [2]$$

For each of the 3 bermudagrasses, gain/ha/day was related to stocking rate (S) by means by quadratic functions (Bransby et al. 1988). In general terms, therefore, gain/ha (G) for a 151-day grazing period can be expressed as follows:

$$G = (b_0S - b_1S^2) \times 151 \quad [3]$$

Initial mass of animals/ha is the product of stocking rate and the initial mass of each animal (219 kg). Consequently, from equations 2 and 3, income can be expressed in terms of stocking rate:

$$I = n[219S + (b_0S - b_1S^2) \times 151]$$
$$= nS(219 + 151b_0 - 151b_1S) \quad [4]$$

Expenditure/ha consisted of animal costs/ha (A) and pasture costs/ha (Q):

$$E = A + Q \quad [5]$$

Animal costs/head included the purchase price of each animal (219m, where m is the purchase price/kg), interest on this purchase price at 13% for 151 days ($0.13 \times 151/365 \times 219m = 11.78m$) and additional costs such as labor, veterinary and feed expenses ($20/head). Animal costs/ha could therefore be obtained by multiplying the sum of these values by stocking rate:

$$A = (219m + 11.78m + 20)S$$
$$= 230.78mS + 20S \quad [6]$$

Pasture costs/ha were estimated to be $356, including $250 for fertilizer and its application, $36 for limited supplementary irrigation and $70 for land lease. These values will clearly vary widely as production and environmental conditions change. From equations 5 and 6,

$$E = 230.78mS + 20S + 356 \quad [7]$$

and from equations 1, 4 and 7,

$$P = nS(219 + 151b_0 - 151b_1S)$$
$$-(230.78mS + 20S + 356) \quad [8]$$

Herbage present is expressed as average weight of above ground herbage/ha obtained from 4-weekly estimates made throughout the grazing periods in each grazed field. Linear equations relating stocking rate to herbage present were also developed for each of the 3 bermudagrasses (Bransby et al. 1988). Consequently

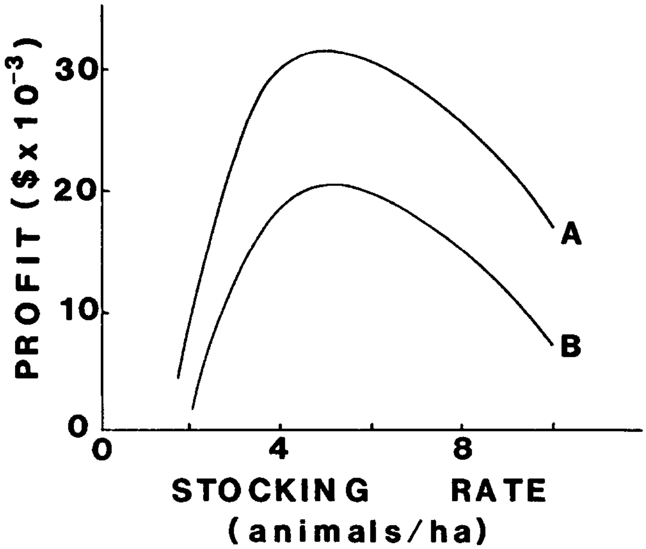

Fig. 3. *(a) Relationships between total net profit and stocking rate for 200 ha of Callie bermudagrass with operating capital limited to $150,000 and buying and selling prices of (A) $1.40 and $.130 or (B) $1.20 and $1.40/kg, respectively.*

$$S = b_0' - b_1'H \quad [9]$$

and by substituting this function for stocking rate in equations 4 and 7 it was possible to express income and expenditure, respectively, in terms of herbage present:

$$I = n(b_0' - b_1'H\,[219 + 151b_0 - 151b_1(b_0' - b_1'H)] \quad [10]$$

and

$$E = (230.78m + 20)\,(b_0' - b_1'H) + 356 \quad [11]$$

The difference between functions 10 and 11 represents profit/ha, expressed in terms of herbage present.

Income/animal (Ia) and expenditure/animal (Ea) were obtained by dividing the functions in equations 4 and 7 respectively, by stocking rate:

$$Ia = n(219 + 151b_0 - 151b_1S) \quad [12]$$

and

$$Ea = 230.78m + 20 + 356/S \quad [13]$$

Profit/animal was obtained from equations 12 and 13. The stocking rate or level of herbage present which maximized profit was obtained by setting the first derivative of the profit function to zero and solving. The values derived by this procedure were then substituted back into the profit equations to obtain the corresponding maximum profit.

Results and Discussion

Economic Functions

In order to understand the response of profit to a change in the level of a production variable (stocking rate or herbage present) or buying and selling price, it is necessary to carefully examine the response of income and expenditure functions to such changes.

The first example considered here assumes land to be limiting and therefore makes use of a per ha analysis. For Coastal bermudagrass expenditure/ha increased linearly with an increase in stocking rate, and the slope of the function increased with an increase in buying price of animals (equation 7 and Fig. 1a). When stocking rate was zero, expenditure consisted of pasture costs only

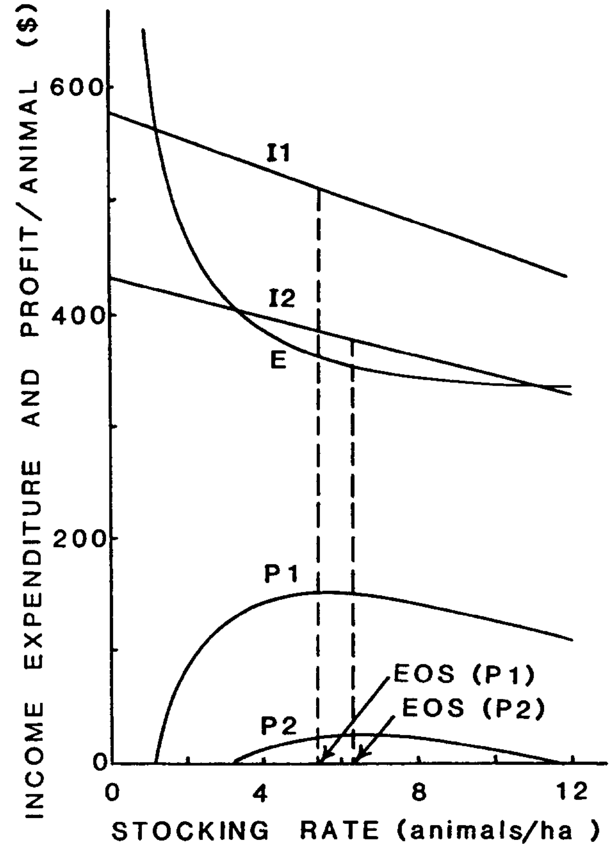

Fig. 4. *Relationships between income, expenditure and profit/animal for Coastal (I1; income with selling price set at $1.60/kg: I2; income with selling price set at $1.20: E; expenditure with buying price set at $1.20: P1 = I1 - E and P2 = I2 - E: EOS = stocking rate which maximized profit).*

($356/ha). Income functions started at the origin and also increased with stocking rate. However, since they were derived from the quadratic gain/ha function (equation 3), they were non-linear and their position relative to the expenditure function changed with the nature of the gain/ha function and selling price. Profit/ha was represented by the difference between the income and expenditure/ha functions, and was influenced by the price margin/kg, the level of buying and selling price within a given margin, and the parameters of the gain/ha function. However, because of the gentle slope of the quadratic relationship between profit/ha and stocking rate in the region of maximization, profit/-ha remained close to maximum within a relatively large range in stocking rate (Fig. 1b); e.g., when buying and selling price were both $1.60/kg, estimated profit/ha from Coastal bermudagrass was 90% or more of maximum between stocking rates at 6.0 and 9.3 animals/ha. In other words, within this range profit/ha was well buffered against changes in stocking rate.

Because of the negative linear relationship between herbage present and stocking rate, changes in income, expenditure and profit/ha as herbage present increased were similar to those observed as stocking rate increased, but trends were reversed (Fig. 2a). A low level of herbage present represented a high stocking rate with corresponding high expenditure and income, while the converse applied to high levels of herbage present. Income/ha decreased as herbage present increased. The parameters of this function were dependent on the relationships between gain/ha and stocking rate, and between stocking rate and herbage present (equations 9 and 10). Consequently, profit/ha was related to herbage present by means of a quadratic function (Fig. 2b).

Table 1. Stocking rates which maximized profit/animal (economic optimum stocking rate for profit/animal , EOSa) and/ha (EOSh) for three bermudagrasses, allowing for different buying prices and price margins/kg.

		Price margin ($)									
		-0.2		-0.1		0.0		0.1		0.2	
Cultivar	Buying price	EOSa	EOSh	EOSa	EOSh	EOSa	EOSh	EOSa	EOSh	EOSa	EOSh
	$	animals ha^{-1}									
	1.2	6.89	4.21	6.57	6.01	6.29	7.51	6.05	8.78	5.83	9.86
Coastal	1.3	6.57	4.61	6.29	6.23	6.05	7.60	5.83	8.77	5.63	9.78
	1.4	6.29	4.95	6.05	6.42	5.83	7.67	5.63	8.76	5.45	9.72
	1.2	5.62	5.37	5.36	6.58	5.14	7.59	4.94	8.41	4.75	9.14
Callie	1.3	5.36	5.65	5.14	6.70	4.94	7.62	4.75	8.41	4.59	9.09
	1.4	5.14	5.85	4.94	6.84	4.75	7.68	4.59	8.41	4.45	9.03
	1.2	5.23	4.19	4.99	5.21	4.77	6.09	4.59	6.83	4.42	7.44
S-16	1.3	4.99	4.41	4.77	5.35	4.59	6.15	4.42	6.82	4.27	7.41
	1.4	4.77	4.61	4.59	5.44	4.42	6.18	4.27	6.82	4.14	7.36

In contrast to situations in which land is the most limiting factor, another scenario of interest is where funds to meet production costs are most limiting. For example, a producer may own 200 ha of Callie bermudagrass but may need to borrow funds to implement a stocker program. A production loan of no more than $150,000 may be available. If (a) expected buying and selling prices of cattle are assumed to be $1.40 and $1.30/kg respectively, (b) values of b_0 and b_1 in equation 3 for Callie are 1.32 and 0.075 (Bransby et al. 1988) (c) the aim is to maximize net return, and (d) initial weight of cattle is 219 kg, total profit (P_t) is the difference between total income (I_t) and expenditure (E_t):

$$P_t = I_t - E_t$$

Total income is the product of income/ha (I) and the number of hectares to be fertilized and grazed, which may not include all available land. The number of hectares to be fertilized and grazed is total expenditure divided by expenditure/ha. Hence,

$$I_t = I \times (150{,}000/E), \text{ and}$$

$$P_t = I \times (150{,}000/E) - 150{,}000$$

For Callie bermudagrass and the stated cattle prices, income/ha is related to stocking rate as follows:

$$I = 1.3\,[219S + (151 \times 1.32S - 151 \times 0.075\,S^2)] = 544S - 14.7S^2$$

Expenditure/ha is a linear function of stocking rate:

$$E = 356 + 20S + (219 \times 1.4S) + (12 \times 1.4S) = 356 + 343S$$

Total profit can now be expressed in terms of stocking rate:

$$P_t = (544S - 14.7S^2)\,[150{,}000/(356 + 343S)] - 150{,}000$$

This function is maximized at a stocking rate of 5.25 animals/ha (Fig. 3) which is close to that which maximizes profit/animal (4.94 animals/ha), but quite different from that which maximizes profit/ha (6.84 animals/ha). If buying and selling prices for this scenario were $1.2 and $1.4 respectively, total profit would be maximized at a slightly lower stocking rate (5.22 animals/ha). For this price margin the stocking rate which maximized profit/animal changed only slightly (4.75 animals/ha), but that which maximized profit/ha increased sharply (9.14 animals/ha). These trends clearly indicate that the stocking rate which maximized profit for this scenario responded to changes in cattle prices in a similar way to that which maximized profit/animal, and responded in quite a different manner to that which maximized profit/ha. Consequently, in the discussion which follows, profit/animal is considered to be a generalization for scenarios of this nature.

Income/animal decreased linearly as stocking rate increased (Fig. 4) due to the corresponding linear decrease in ADG (Bransby et al. 1988). The parameters of this function were dependent on both the selling price and the relationship between ADG and stocking rate (equation 12). On the other hand, expenditure/animal was negatively related to stocking rate with a decreasing rate of change per unit increase in stocking rate. This was due to a fixed level of pasture costs/ha being spread over more animals as stocking rate increased. The shape of this curve remained fixed for a given level of pasture costs, while its elevation increased with an increase in animal costs (including buying price). Despite the high sensitivity of ADG to changes in stocking rate, the difference in the income and expenditure/animal functions again constituted relatively little change in profit/animal over a fairly large range in stocking rate (Fig. 4). The profit function shown here also suggests that maximum profit/animal is achieved at a higher stocking rate than maximum gain/animal. The trends in Figure 4 were also reversed when income, expenditure and profit/animal were expressed in terms of herbage present instead of stocking rate, but are not shown.

Economic Optimum Grazing Intensities

Grazing intensity can be expressed in terms of the animal (as stocking rate) or in terms of the pasture (as level of herbage present). According to economic theory (Bishop and Toussaint 1956, Doll and Orazem 1978, Workman and Fowler 1986, Torell and Hart 1988) profit is maximized (or loss minimized) at the level of production where the slope of the income function is equal to that of the expenditure function. This principle is clearly illustrated in the cases discussed above for profit/ha and /animal in respect of stocking rate, and for profit/ha in respect of herbage present. The advantage of the functional approach to economic analysis is that profit for different treatments can be compared at any specified level of production in question (in this case grazing intensity), or in terms of maximum profit for each treatment, even though this may occur at different levels of production.

The economic optimum stocking rates for conditions considered in this study fell within the limits of the experimental data (Bransby et al. 1988). As price margin increased, the stocking rate at which profit/ha was maximized increased, while that which maximized profit/animal decreased. However, the stocking rate which maximized profit/animal was less sensitive to changes in price margin than the stocking rate which maximized profit/ha (Table 1). This difference in response is related to the different nature of corresponding income and expenditure functions, and the way each changes with price margin (Fig. 1 and 4). The stocking rates which

Table 2. Levels of herbage present which maximized profit/animal (economic optimum herbage present for profit/animal, EOSa) and/ha (EOSh) for three bermudagrasses, allowing for different buying prices and price margins/kg.

		Price margin ($)									
		−0.2		−0.1		0.0		0.1		0.2	
Cultivar	Buying price	EOHa	EOHh	EOHa	EOHh	EOHa	EOHh	EOHa	EOHh	EOHa	EOHh
	$	Mg ha^{-1}									
	1.2	2.34	3.32	2.46	2.66	2.56	2.11	2.65	1.65	2.73	1.25
Coastal	1.3	2.46	3.17	2.56	2.58	2.65	2.08	2.73	1.65	2.80	1.28
	1.4	2.56	3.05	2.65	2.51	2.73	2.05	2.80	1.66	2.87	1.30
	1.2	3.48	3.60	3.61	3.00	3.72	2.50	3.82	2.10	3.91	1.74
Callie	1.3	3.61	3.47	3.72	2.95	3.82	2.49	3.91	2.10	3.99	1.76
	1.4	3.72	3.37	3.82	2.88	3.91	2.46	3.99	2.10	4.06	1.79
	1.2	2.28	3.20	2.50	2.30	2.69	1.52	2.85	0.87	3.00	0.33
S-16	1.3	2.50	3.01	2.69	2.17	2.85	1.47	3.00	0.88	3.13	0.35
	1.4	2.69	2.83	2.85	2.10	3.00	1.44	3.13	0.88	3.25	0.40

maximized gain/ha were 9.4, 8.9, and 7.2 animals/ha for Coastal, Callie, and S-16, respectively. It is clear, therefore, that the stocking rate which maximized profit/animal remained well below these values for all price margins considered, and so did the stocking rate at which profit/ha was maximized, except when price margin was $0.20. It is also interesting to note that, except for buying prices of $1.30 and $1.40, stocking rates which maximized profit/ha at a negative price margin of $0.20 on Callie were slightly lower than those at which profit/animal was maximized. Intuitively, such a result would not seem likely, because gain/animal is maximized at a lower stocking rate than gain/ha. In general, however, profit/ha and /animal were maximized at similar stocking rates when price margin was negative, while at positive price margins stocking rates which maximize profit/ha and /animal were quite different.

The stocking rate which maximized profit/ha was relatively stable as buying and selling price changed with the price margin of $0.10 (Table 2). However, for high price margins this value decreased with an increase in buying and selling price. This is in agreement with the observations of Riewe (1981) but not with those of McCartor and Rouquette (1977), who suggested that increases in stocking rate may be justified as absolute values of buying and selling prices increase. The stocking rate which maximized profit/animal decreased slightly as buying and selling price increased within all price margins. Differences between cultivars in stocking rates which maximized profit/animal were relatively small, but the stocking rates which maximized profit/ha reflected similar differences between cultivars as for stocking rates which maximized gain/ha (9.4, 8.9, and 7.1 animals/ha for Coastal, Callie and S-16 bermudagrass respectively).

Because of the negative linear relation between stocking rate and herbage present (Bransby et al. 1988), all the trends in economic optimum stocking rates were reversed for economic optimum levels of herbage present (Table 2). The level of herbage present which maximized profit/animal showed relatively little change within and between price margins for each cultivar. On the other hand, the level of herbage present which maximized profit/ha at a negative price margin of $0.20 was 1.7 to 9.7 times higher than that which maximized profit/ha at a positive price margin of $0.20, depending mainly on cultivar. It is important to note that for a price margin of $0.20 the level of herbage present which maximized profit/ha on S-16 was between 0.3 and 0.4 Mg/ha. However, production under such a high grazing intensity is unlikely to be sustainable, and Hart et al. (1988) discuss implications of this relative to range conditions. This example therefore demonstates the importance of examining profit in relation to the condition of the pasture and not only in relation to stocking rate. Furthermore, these data refute the suggestion of Blaser et al. (1974) that there is a single optimum grazing pressure that has universal application.

Maximum Profit

The maximum profit/ha and /animal corresponding with the stocking rates and levels of herbage present in Tables 1 and 2 respectively, appear in Table 3. These values clearly depend on the various costs outlined in the procedure, and the independent variables in equations 8, 12, and 13. Maximum profit increased with an increase in price margin because of the corresponding relative increase in selling price of both the initial weight of the animal and

Table 3. Expected maximum profit/animal (Pa max) and/ha (Phmax) for three bermudagrasses, allowing for different buying prices and price margins/kg.

		Price margin ($)									
		−0.2		−0.1		0.0		0.1		0.2	
Cultivar	Buying price	Pa max	Ph max	Pa max	Ph max	Pa max	Ph max	Pa max	Ph max	Pa max	Ph max
		$									
	1.2	−40	−224	−9	−59	22	151	53	395	85	664
Coastal	1.3	−32	−181	−1	−7	30	206	62	451	93	720
	1.4	−24	−136	7	45	39	262	70	507	106	777
	1.2	−6	−31	30	181	66	422	102	678	138	961
Callie	1.3	7	40	42	251	79	493	115	759	152	1039
	1.4	19	106	56	328	92	574	129	839	165	1111
	1.2	−27	−127	6	32	41	223	76	433	110	650
S-16	1.3	−17	−78	18	91	53	284	87	488	122	715
	1.4	−5	−24	29	145	64	339	99	551	134	769

the weight gained during the season. For the costs used in this study it is important to note that when price margin was negative, maximum profit was mostly low or negative, despite relatively high gain/animal obtained at a low stocking rate. For example, each animal on Coastal gained 108 kg during the season at an economic optimum stocking rate of only 4.2 animals/ha, but despite this, a loss of $244/ha was expected for a negative price margin of $0.20. Consequently, at negative price margins only Callie, which demonstrated both high inferred quality and carrying capacity (Bransby et al. 1988), was able to produce sizeable profits. However, when price margin dropped to -$0.20, even this cultivar produced low or negative profit.

As buying and selling prices increased within each price margin, maximum profit increased. This is primarily due to the corresponding increase in selling price of the animal gain which occurred during the season. In general, cultivars were ranked in the same order for maximum profit/animal and /ha as for maximum gain/ha. However, there were some exceptions to this: e.g., maximum profit/ha for Coastal bermudagrass was 2% higher than S-16 at a price margin of $0.20 and a buying price of $1.20/kg, while the corresponding profit/animal for Coastal was 23% lower than for S-16. This is due to a cultivar × stocking rate interaction (Bransby et al. 1988). In addition, the relative difference between maximum profit for the different cultivars varied with price margin: e.g., for a buying price of $1.20 and a price margin of $0.20, maximum profit/ha for S-16 was 2% lower than for Coastal, but when price margin was zero it was 32% higher than for Coastal. Finally, the relative difference in maximum profit/ha between cultivars was greater than the difference in maximum gain/ha: e.g., maximum gain/ha for Callie was 30 and 33% greater than that for S-16 and Coastal respectively (Bransby et al. 1988), while the corresponding differences in maximum profit/ha for a buying and selling price of $1.20 (zero price margin) was 89 and 179%. Consequently, relatively small differences in animal production were translated into large differences in profit due to much of the income being required to cover expenditure. This means that resolution of statistical tests for treatment differences in animal gain needs to be considerably higher than that desired or specified for treatment differences in profit. For example, if treatment differences in profit of 20 to 30% are intended to be statistically detectable, resolution of statistical tests for animal gain may have to be such that differences of 5 to 10% are detectable.

Conclusions

Information presented in this study allowed certain important conclusions to be drawn.

(1) Examination of the behavior of income and expenditure functions provided greater insight into the response of profit to both economic and biological variables, compared to similar previously published studies.

(2) Relative economic differences between cultivars were much larger than biological differences, thus emphasizing the need for economic evaluation.

(3) The optimum economic grazing intensity varied widely, depending on the most limiting factor and price differential. The contention that a universal economic optimum level of herbage present exists is therefore not correct. In fact, under certain conditions it may pay in the short term to overgraze, but this strategy will not sustain production in the long term.

(4) If the 3 cultivars considered in this study had been evaluated at only one grazing intensity, economic analysis would have had narrow application. However, if a negative price margin was expected to apply, then a trial conducted at a single relatively low grazing intensity may be justified, because profit/animal and /ha are both maximized at low stocking rates under these conditions. Conversely, if a positive price margin was expected, a grazing trial that made use of only one grazing intensity should have employed a high stocking rate if profit/ha was of interest, and a low stocking rate if profit/animal was of interest.

(5) From an economic standpoint, grazing trials which include only one grazing intensity suffer from the following weaknesses: they may allow for consideration of only one limiting factor and a narrow range in price margins; predictions of price margins face the risk of being wrong; and price margins can change with time and location. Consequently, only grazing trials which include several grazing intensities per treatment can allow for the determination of economic optimum grazing intensities over a wide range of economic conditions.

Literature Cited

Bishop, C.E., and W.D. Toussaint. 1956. Introduction to agricultural economic analysis. John Wiley & Sons, Inc., New York.

Blaser, R.E., E. John, and R.C. Hammes. 1974. Evaluation of forage and animal research. p. 1-26. *In:* R.W. van Keuren (ed.) Systems analysis in forage crops production and utilization. Crop Sci. Soc. Amer., Madison, Wisconsin.

Bransby, D.I. 1985. A model for predicting long term economic optimum stocking rates for beef cattle grazing dryland pastures. J. Grassl. Soc. So. Afr. 2:18-20.

Bransby, D.I., B.E. Conrad, H.M. Dicks, and J.W. Drane. 1988. Justification for grazing intensity experiments: analysing and interpreting grazing data. J. Range Manage. 41:274-279.

Burns, J.C., R.D. Mochrie, H.D. Gross, H.L. Lucas, and R. Teichman. 1970. Comparison of set-stocked and put-and-take systems with growing heifers grazing Coastal bermudagrass (Cynodon dactylon L. Pers) p. 904-909. *In:* N.J.J. Norman (ed.) Proc. 11th Inter. Grassl. Congr. Univ. Queensland Press, Brisbane.

Cook, C.W., and J. Stubbendieck. (eds.). 1986. Economic Research in Range Management. *In:* Range Research: basic problems and techniques. Soc. Range Manage., Denver, Colo.

Doll, J.P., and F.O. Orazem. 1978. Production economics. Grid Inc., Columbus, Ohio.

Hart, R.H. 1972. Forage yield, stocking rate, and beef gains on pasture. Herbage Abstracts 42:345-353.

Hart, R.H. 1978. Stocking rate theory and its application to grazing of rangelands. Proc. 1st Int. Rangeland Cong. Denver, USA. 547-550.

Hart, R.H., M.J. Samuel, P.S. Test, and M.S. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. J. Range Manage. 41:282-286.

Hildreth, R.J., and M.E. Riewe. 1963. Grazing production curves. II. Determining the economic optimum stocking rate. Agron. J. 55:370-372.

Jacobs, V.E. 1974. Needed: A systems outlook in forage-animal research. p. 33-48. *In:* R.W. van Keuren (ed.) Systems analysis in forage crops production and utilization. Crop Sci. Soc. Amer. Madison, Wisc.

Marten, G.C., and R.M. Jordan. 1972. Put-and-take vs fixed stocking for defining three grazing levels by lambs on alfalfa-orchardgrass. Agron. J. 64:69-72.

McCartor, M.M., and F.M. Rouquette. 1977. Grazing pressure and animal performance from pearl millet. Agron. J. 69:983-987.

Pearson, H.A. 1973. Calculating grazing intensity for maximum profit on ponderosa pine range in northern Arizona. J. Range Manage. 26:277-279.

Quigley, T.M., J.M. Skovlin, and J.P. Workman. 1984. An economic analysis of two systems and three levels of grazing on ponderosa pine-bunchgrass range. J. Range Manage. 37:309-312.

Riewe, M.E. 1981. The economics of grazing. *In:* J.L. Wheeler and R.D. Mochrie (ed.) Forage evaluation: concepts and techniques. American Forage and Grassland Council, USA and CSIRO, Australia.

Torell, L.A., and R.H. Hart. 1988. Economic considerations for efficient rangeland use. p. 71-76 *In:* R.S. White and R.E. Short (eds.). Proc. Symp. Achieving Efficient Use of Rangeland Resources. Montana State Univ. Agr. Exp. Sta. and USDA-ARS Bozeman and Miles City, Montana.

Workman, J.P. 1986. Range economics. MacMillan Publishing Co. New York, NY.

Workman, J.P., and J.M. Fowler. 1986. Optimum stocking rate-biology vs. economics. p. 101-102. *In:* Joss, P.J., P.W. Lynch, and O.B. Williams (eds.) Rangelands: A resource under seige. Proc. Second Internat. Rangeland Congress, Australian Acad. Sci., Canberra.

Mineral dynamics in beef cattle diets from a southern mixed-grass prairie

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Abstract

Acute and chronic dietary deficiencies in macro and micro minerals have significant impacts on production efficiency on rangelands throughout the world. However, limited information is available on the mineral quality of diets primarily because salivary and soil mineral contamination of esophageal extrusa precludes quantitative recovery of dietary minerals. Mineral profiles of diets can be estimated indirectly, however, if forage species composition of diets and mineral concentrations of selected forages are known. The objective of this study was to utilize this approach to estimate seasonal dynamics of phosphorus (P), calcium (Ca), potassium (K), and magnesium (Mg) in cattle diets' relative requirements. Two diet selection scenarios were developed: the first, maximum mineral intake, assumed cattle consumed only live plant tissue of a forage if it was available; the second, considered minimum mineral intake, assumed cattle consumed live and dead tissue in direct proportion to their availability. Calculated concentrations of P and Ca in diets showed P concentrations were below and Ca concentrations were above their respective requirements for spring calving cows regardless of selection scenario or season of the year. However, K and Mg concentrations varied as a function of selection scenario and season of year and ranged from adequate during periods of rapid vegetation growth to marginally inadequate during periods of water (drought) or temperature (winter) induced dormancy.

Key Words: phosphorus, potassium, calcium, magnesium, diet quality

Livestock production from rangeland is a function primarily of the quantity and quality of forage consumed and subsequent efficiency of conversion into animal fiber. While deficiencies or imbalances in dietary protein and energy and their effects on range livestock production are well established, less is known about the temporal and spatial distribution of acute and chronic mineral deficiencies on most rangelands. Realistic estimates of dietary mineral status are essential for development of mineral supplementation programs. Although numerous studies have focused on quantifying relationships between forage nitrogen, fiber, and energy profiles and associated diets, few have attempted to quantify mineral profiles of diets (Kalmbacher et al. 1984). This information void exists because esophageal extrusa is generally considered sufficiently adulterated by salivary and soil minerals (Little 1975, Kirby and Stuth 1980) to preclude quantitative recovery of dietary minerals. Hand squeezing (Lesperance et al. 1974) and rinsing extrusa (Hart 1983) with distilled water are generally unacceptable alternatives because leaching of soluble fractions from the forage and differential removal of salivary minerals may occur. Hence, although the mineral dynamics in available forage are quantifiable (Rauzi et al. 1969, Everitt et al. 1980, Huston et al. 1981, Kalmbacher 1983, Green et al. 1987), the absolute concentrations of minerals in the diets of grazing animals cannot be assayed using esophageal extrusa. However, concentrations of dietary minerals can be estimated indirectly if mineral concentrations in the forages consumed are known. The objective of this note is to utilize this technique to ascertain the probable maximum and minimum concentrations of phosphorus (P), calcium (Ca), potassium (K), and magnesium (Mg) in cattle diets relative to the NRC (1984) requirements for spring calving cows.

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Materials and Methods

Research was conducted at the Texas Experimental Ranch located on the eastern edge of the Rolling Plains Resource Region. The study was one of a series of studies designed to examine the effects of a 16-paddock, 1-herd rotational grazing treatment on quantity and quality of forage produced and consumed.

Quantity of forage produced was estimated by clipping aboveground standing crop in 4 paddocks immediately before and after each grazing period during the 2-year study period. Standing crop was clipped by species and/or functional group. Species/functional groups were annual grasses, Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.), sideoats grama (*Bouteloua curtipendula* Michx.), other warm-season grasses, and forbs. Following drying and weighing, subsamples were separated by hand into live and dead tissue for laboratory analyses of mineral concentrations. For a detailed description of field sampling procedures and associated results, see Heitschmidt et al. (1987a, 1987b, and 1987c). For a detailed description of laboratory procedures and study results relative to mineral concentrations in the various forage species/-functional groups, see Greene et al. (1987).

On 8 dates over the 2-year period, diet samples were collected in the same paddocks as forage samples, utilizing 3–6 esophageally fistulated Hereford-Angus × Jersey cross bred steers per paddock. Botanical composition of diets was determined by species/functional group using the microscopic frequency technique as described by Kothmann (1968). For a detailed description of sampling procedures and study results, see Walker et al. (1989).

Mineral concentration in diets within date were estimated utilizing the forage mineral concentrations from Greene et al. (1987) and the botanical composition of diet data summarized by Walker et al. (1989). Because esophageal extrusa was not separated into physiologic age of tissue (live vs. dead) by species or functional group, mineral concentrations in diets were estimated in 2 scenarios. First, it was assumed that selection for live tissue was nonexistent. In this instance, whole-plant mineral concentrations (Greene et al. 1987) were multiplied by estimates of diet composition by species/functional group. Products were then summed across species. For example, in October 1982, estimated diet composition was 13% Texas wintergrass, 1% annual grasses, 19% sideoats grama, 55% other warm season grasses, and 12% forbs. Estimated whole plant P concentrations for the 5 species/functional groups were 0.056, 0.040, and 0.046, 0.058, and 0.46%, respectively. Thus, estimated percentage concentration of P in the diet was 0.054%. For the second method, concentrations of minerals in the diet were calculated in the same manner except it was assumed diets con-

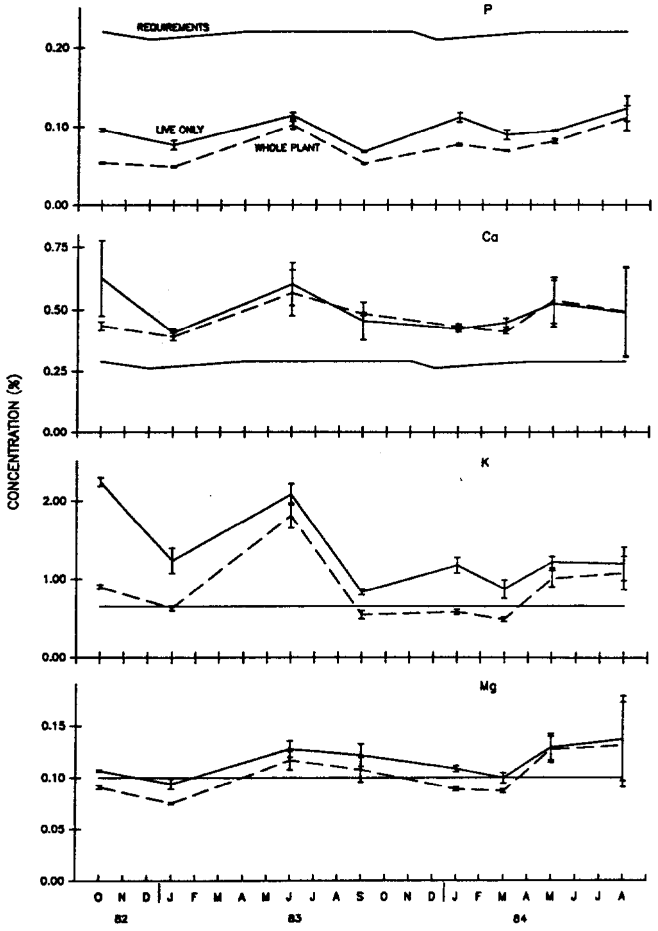

Fig. 1. *Estimated mineral concentrations (%) in diets of beef cattle grazing north Texas native rangeland on 8 dates over a 2-year period. Mineral concentrations in diets are based on botanical composition (Walker et al. 1989) and forage mineral concentration data (Greene et al. 1987). "Live only" and "whole plant" estimates represent concentrations based on assumption that cows either selectively consumed only live tissue or nonselectively consumed only whole plants. Nutrient requirements are based on NRC (1984) recommendations.*

sisted of only live tissue if available. Thus, it can be assumed the 2 methods provide estimates of minimum and maximum mineral concentrations in the diets.

Many sources of variation exist in estimating the nutrient content of livestock diets. Animal variation (sample units) in terms of selectivity for particular plants and plant parts, the variation in availability of these food items among pastures (experimental units), and variation in composition among samples of live portions and whole plants are primary sources of variation. The first 2 sources are addressed by Walker et al. (1989), and the third by Greene et al. (1987). Our results are presented in terms of potential variation in selectivity (live tisue only or maximum selectivity vs. whole plant or minimum selectivity). The maximum-minimum approach allows biological interpretable upper and lower limits to be placed upon the estimated concentration of a mineral in the diet. The variance of these limits can only be approximated from the variances and the distributions (if known) of the plant and animal parameters from which they are calculated. The standard deviations presented in Figure 1 arise from the variance in species composition of diets among paddocks within scenarios and trials (n=4).

Results and Conclusions

Estimated P concentrations in the diets showed a critical need for P supplementation yearlong, regardless of diet selected relative to live/dead tissue composition. This deficiency was directly attributed to low P concentrations in all available forages. The maximum concentration of P in any species/functional group during the study was 0.212% (forbs–Jan. 1983, Greene et al. 1987).

Estimated Ca concentrations in diets indicated Ca requirements for cows with average milking ability (5.0 kg milk/d) were exceeded throughout the study period. The abundance of Ca in the diets, regardless of method of calculation, reflected the effect of consistently high Ca concentrations in all available forages. The lowest concentration of Ca found in any forage during the study was 0.22% (warm-season grasses–Sept. 1983, Greene et al. 1987). The data did not show, however, that Ca supplementation would be appropriate during the first 4 months postpartum if cows of superior milking ability (10 kg milk/d) were grazing these forages. During this period, NRC (1984) recommendations for diet Ca concentrations for 400 kg cows is 0.49%.

Potassium concentrations in diets met requirements if it was assumed only live tissue was consumed. However, whole-plant diet calculations indicated minor deficiencies could occur during periods of extended dormancy. This deficiency resulted because K concentrations in live tissue averaged across species/functional group were about 3.5 times as much as concentrations in dead tissue (Greene et al. 1987).

Trends in Mg concentrations in diets were similar to K trends, but when Mg concentrations exceeded requirements the excess was smaller. This is cause for concern because the NRC (1984) requirements of 0.10% Mg in the diet is probably a minimum. O'Kelly and Fontenot (1969, 1973) have reported that magnesium requirements of cows double from late gestation to early parturition (0.1 vs. 0.2%).

Based upon the results of this study and NRC (1984) nutrient requirements for beef cows, we conclude mineral concentrations in these diets did: (1) not meet P requirements; (2) meet Ca requirements; (3) generally meet K requirements for nonlactating cows except during periods of dormancy; and (4) generally meet Mg requirements for nonlactating cows except during periods of dormancy. The described approach allows for biologically realistic bounds to be placed upon the dietary mineral status of free-ranging livestock facilitates the formulation of complete mineral supplements, and interpretation of mineral supplementation experiments on rangeland.

Literature Cited

Everitt, J.H., M.A. Alaniz, A.H. Gerbermann, and H.W. Gausman. 1980. Nutrient content of native grasses on sandy and red sandy loam range sites in south Texas. USDA-SEA Agr. Res. Results. Southern Ser. No. 7.

Greene, L.W., W.E. Pinchak, and R.K. Heitschmidt. 1987. Sesaonal dynamics of minerals in forages at the Texas Experimental Ranch. J. Range Manage. 40:502-506.

Hart, R.H. 1983. Correcting for salivary contamination of esophageal fistula samples. J. Range Manage. 36:119-120.

Heitschmidt, R.K., S.L. Dowhower, and J.W. Walker. 1987a. 14-vs. 42-paddock rotation grazing: aboveground biomass dynamics, forage production, and harvest efficiency in a rotational grazing treatment. J. Range Manage. 40:216-223.

Heitschmidt, R.K., S.L. Dowhower, and J.W. Walker. 1987b. 14-vs. 42-paddock rotation grazing: forage quality. J. Range Manage. 40:315-317.

Heitschmidt, R.K., S.L. Dowhower, and J.W. Walker. 1987c. Some effects of a rotational grazing treatment on quantity and qualify of available forage and amount of ground litter. J. Range Manage. 40:318-321.

Huston, J.E., B.S. Rector, L.B. Merrill, and B.S. Engdahl. 1981. Nutritional value of range plants in the Edwards plateau regions of Texas. Texas Agr. Exp. Sta. Full. No. 1357.

Kalmbacher, R.S. 1983. Distribution of dry matter and chemical constituents in plant parts of four Florida native grasses. J. Range Manage. 36:298.

Kalmbacher, R.S., K.R. Long, and F.G. Martin. 1984. Seasonal mineral concentration in diets of esophageally fistulated steers on three range areas. J. Range Manage. 37:36-39

Kirby, D.R., and J.W. Stuth. 1980. Soil ingestion rates following brush management in central Texas. J. Range Manage. 33:207-209.

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

Lesperance, A.N., D.C. Clanton, A.B. Nelson, and C.B. Theurer. 1974. Factors affecting the apparent chemical composition of fistula samples. Nevada Agr. Exp. Sta. Pub. T18.

Little, D.A. 1975. Studies on cattle with oesophageal fistulae. Comparison of concentrations of mineral nutrients in feeds ina associated boluses. Australian J. Exp. Exp. Agr. Anim. Husb. 15:437.

National Research Committee. 1984. Nutrient requirements of beef cattle. National Academy Press. Washington, D.C.

O'Kelly, R.E., and J.P. Fontenot. 1969. Effects of feeding different magnesium levels to drylot-fed lactating beef cows. J. Anim. Sci. 29:959-963

O'Kelly, R.E., and J.P. Fontenot. 1973. Effects of feeding different magnesium levels to drylot-fed gestating beef cows. J. Anim. Sci. 36:994-999

Rauzi, F., L.I. Painter, and A.K. Dobrenz. 1969. Mineral and protein contents of bluegrama and western wheatgrass. J. Range Manage. 22:47-48

Walker, J.W., R.K. Heitschmidt, E.A. deMoraes, M.M. Kothmann, and S.L. Dowhower. 1989. Quality and botanical composition of cattle diets under rotational and continuous grazing treatments. J. Range Manage. (In Press).

Technical Notes

A pocket computer program for collecting forage selection frequency data in the field

RICHARD P. CINCOTTA

Abstract

An algorithm was developed to conduct bite-count sampling employing a programmable pocket computer. The BASIC program was successfully employed to collect forage selection data on rangeland livestock at a remote field site in Tibet. The program features techniques that are applicable to developing programs for sustained frequency data collection using similar battery-powered computers. Pocket computers have been demonstrated to be powerful field tools, and their potential promises to increase as new units become available with larger memories and added features.

Key Words: pocket computer, bite-count technique, livestock forage selection

In 1987, I was asked by a team of anthropologists to determine the botanical composition and quality of summer diets of yak, goats, and sheep in a high altitude Tibetan pastoral ecosystem. The bite-count technique (Wallmo and Neff 1970, Hobbs et al. 1979) was chosen for these purposes over the use of an esophageal cannula, thus avoiding surgery on indigenous stock that might have been culturally unacceptable to local pastoralists. I also decided to minimize the amount of labor involved in the bite-count technique by using a relatively inexpensive, battery-powered, programmable pocket computer, which could be easily used on foot or on horse at the remote field site. The objective of this article is to present the algorithm[2], and the programming techniques that permitted successful data collection. Secondly, I will touch on the present state of the art in pocket computing and its future for field researchers.

Materials and Methods

Computer

The pocket computer that I used for frequency data collection was the Sharp[1] EL-5400, which measures 170 mm × 72 mm × 9.5 mm, weighs about 125 g., and features a single row, 16-character liquid crystal display. This computer is driven by a 4 bit microprocessor, contains 17.4 kbytes of system ROM (including BASIC interpreter), and 1962 bytes of RAM (including 208 bytes of fixed memory area and 1462 bytes of "user RAM"). RAM is nonvolatile, i.e., when the processor is powered off, memory-resident programs and data are preserved.

Sharp, Tandy, and Hewlett-Packard market a range of flat, battery-powered computers that can be described as pocket computers, but vary widely in size of RAM, keyboard functions, display screen, and price (from about $60 to $130). Present limitations in the size of RAM (even new models with 8 kbytes RAM) make these computers suitable primarily for data collection where only summary data are stored. Applications that require the collection of many individually stored data are impractical with pocket computers similar to the EL-5400. In most models, data can be uploaded for storage on an audio cassette recorder or output to a special attachable printer. However, presently there is no commercially available communications interface for uploading to microcomputers.

Data Collection

A researcher using the bite-count technique records the particular plant species, plant part (leaf, stem, inflorescence, seeds, whole plant), and condition (green, dry) that an herbivore selects during a predetermined foraging bout (Hobbs et al. 1979). If forage samples are needed for laboratory analysis, vegetation can be plucked either simultaneously (Hobbs et al. 1979) or directly following a "foraging bout" (Coppock et al. 1986), though the simultaneous hand plucking of samples is more likely to produce a sample similar to dietary forage (Van Soest 1982).

During the Tibetan research, summer forage selection was assessed over 1 month from a regularly rotating schedule that comprised fifteen 30-minute foraging bouts per livestock species. One livestock species was sampled during each bout by recording the selections of 3 individuals, one at a time, during consecutive 10 minute periods. Between 400 and 700 bites of forage were recorded during each bout. At the end of each session, the observer recorded the date, time, livestock species, location, vegetation type, relative frequency of each item, and total bite count in a field notebook. Following a bout, 100 g live weight duplicates of forage, in the proportions selected during the bout, were hand plucked and bagged at the site of grazing. Bite weight samples were collected and bite rates were estimated to facilitate the computation of dry-matter basis botanical composition of the diet (Baker and Hobbs 1982).

Throughout this research it was necessary to count bites at distances between 5 and 10 m. using 8x binoculars, especially with skittish sheep and goats that were foraging on small alpine-desert plants. This situation may commonly arise when working among pastoralist societies where herders propel stones to herd small stock. If data were collected unassisted under these conditions, an audio recorder and microphone would have been necessary, since the attention and hands of the observer were occupied using the binoculars. In this field situation, however, the observer was assisted by a field technician who input data on the pocket computer as the observer called out item numbers.

Program

A program for collecting bite-count data, e.g. BITECOUNT (Fig. 1), must store and display on command (1) the sum of bites, (2) the count of bites (absolute frequency) for each item selected, (3) and the proportion (relative frequency) attributed to each item. To use the program, BITECOUNT, names of dietary items must be coded, as positive integers (1,2,...,M; where the constant, M, is the maximum; M can be changed by editing the program), prior to sampling. A list of codes may be written on a file card that is weather-proofed with transparent tape and clipped to the observer's

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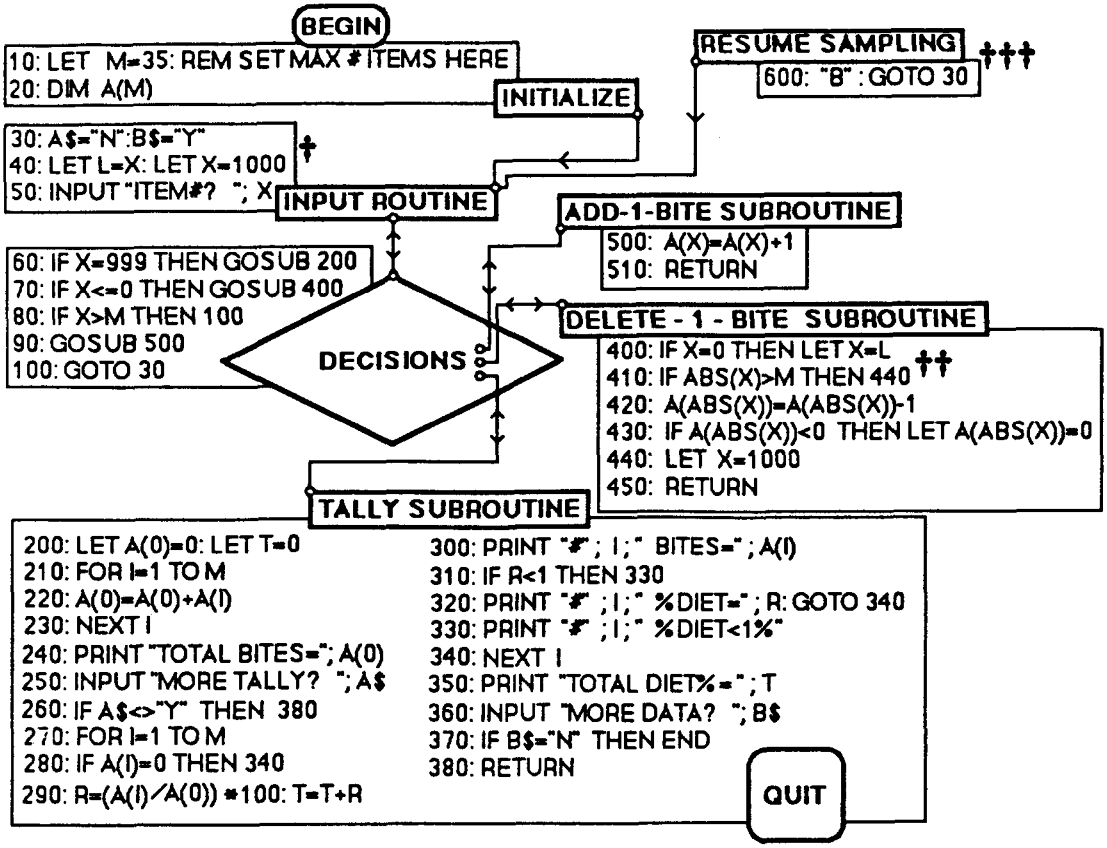
[1]This article is not a product review. The inclusion of trade names does not imply an endorsement by the *Journal of Range Management*.

[2]The algorithm has undergone some minor changes subsequent to field use at the suggestion of two anonymous reviewers.



† Default value prevents double entry of datum.

†† Statement prevents fatal errors.

††† Program execution can be resumed after interruption without losing data by using DEF key to call this statement.

Fig. 1. *BASIC code of a pocket computer program for collecting livestock forage selection data using the bite-count technique. This program runs on the Sharp EL-5400, but with minor changes will run on similar pocket computers.*

pocket. Observed bites are entered at a prompt, *ITEM#?*, which calls for the input of the code number of the dietary item selected. At each input bite, BITECOUNT adds 1 to the item's counter, which is saved as an element of a one-dimensional array variable. A bite mistakenly input can be deleted on the following entry by entering *0*, or at any other input prompt by entering the negative of the incorrectly entered item number.

At any time, the user can invoke a summary (tally) by entering *999* at the input prompt. First, BITECOUNT displays the total number of bites presently recorded, and then prompts with *MORE TALLY?*, giving the user the option to resume sampling. If the tally is continued, the program displays only those diet items that were input during the sample, each with its respective absolute and relative frequencies. As an error check, BITECOUNT displays the sum of relative frequencies (which should be approximately 100%). At the next prompt, MORE DATA?, the user may resume input or terminate the program.

Results

Although Tibetan field technicians with whom I worked had never before used a programmable computer, they found BITECOUNT easy to run after a brief demonstration. The two small lithium type cells required to power the pocket computer lasted for the entire 3 months (and well beyond) of continual programming, editing, and data entry with BITECOUNT, as well as unrelated statistical and arithmetic calculations. Exposure to light rainfall did not affect the performance of the pocket computer.

Observers using the bite-count technique have generally chosen to record samples on a battery powered audio cassette recorder, or by pencil and paper. BITECOUNT eliminated lengthy transcription of audio casettes in the field, and reduced the required amount of data recording on paper.

Discussion

Programming Considerations

The success of BITECOUNT was due to several programming techniques (Fig. 1) that (1) filtered erroneous input; (2) avoided fatal errors; and (3) permitted resumption of program execution without loss of data following unintentional program termination or "power off" status.

Certain intuitive approaches to data collection that succeed in the 64 kbytes of RAM allocated to interpreted BASIC program storage in microcomputers (PC's and compatibles) are unacceptable in pocket computer BASIC. For example, recording plant part and condition for a list of species would be most efficiently stored in a three-dimensional array. However, in pocket computer BASIC only one- and two- dimensional arrays are permissible. Since each array storage location requires a minimum of 15 bytes of RAM (for a numeric variable), it is easy to imagine how quickly the limited available memory can be consumed by a two-dimensional array. Thus, it is advisable to limit array variables to one dimension unless absolutely necessary. Memory constraints will undoubtedly be less of a problem with larger RAM's and expansion kits offered in newer models.

The Future for Pocket Computers

Pocket computers have served as useful tools for physicians in both laboratory (Ledochowski et al. 1985) and clinical settings (Lorentz et al. 1987, Childs and Pang 1988, Castellano et al. 1986). For sequential data collection and field analyses requiring storage of lengthy programs and intermediate files, a different class of machine referred to as "hand-held computers" have proved useful, especially in agricultural field experiments (Law and Reeves 1984, Kidger and McNicol 1986, Jackson and Stone 1987). Hand-held computers are generally equipped with at least 16 kbyte RAM, full keyboard, real-time clock, and have the capability to communicate with microcomputers (various hand-held models appropriate for field data collection are reviewed by Elias 1984). These computers have the disadvantages of a larger size (usually brief case size) and weight (around 2 kg), and higher cost (from $400 to above $2,500).

As one might have expected from observing the dynamism of the computer industry, the advantages of both pocket and hand-held computers have been merged into a new breed of fully transportable and programmable computer. For example, the Psion Organiser II Model XP, which is marketed as a pocket "personal organizer and diary", measures 142 mm × 78 mm × 29 mm and weighs 225 g. This machine features a 16 kbyte RAM (expandable to 128 kbyte), real-time clock, and optional RS232 cable that connects the Organiser II to either a serial port of a MS-DOS microcomputer for uploading and downloading programs and data, or directly to a serial printer. Software is available for PC's and compatibles that emulates the Organiser II's BASIC-like language interpreter, allowing the user to develop and test software in the familiar MS-DOS environment before downloading to the smaller computer.

As pocket computer technology improves, field researchers will have at their disposal the information handling capabilities that are presently thought the domain of much larger machines. It will require a balance of imaginative programming and scientific communication to fully realize the potential that computer-aided field data collection holds for natural resources management and research.

Literature Cited

Baker, D.L., and N.T. Hobbs. 1982. Composition and quality of elk summer diets in Colorado. J. Wildl. Manage. 46:694-703.

Castellano, J., J.E. Toher, M.J. Sindler, and J.D. Dumler. 1986. Pocket computer for real-time ultrasound. South Med. J. 79:1331-1336.

Childs, G.E., and L. Pang. 1988. Analysis of dose response curves for the in vitro susceptibility of *Plasmodium falciparum* to antimalarias using a pocket computer. Amer. J. Trop. Med. Hyg. 38:15-18.

Coppock, D.L., J.E. Ellis, and D.M. Swift. 1986. Livestock feeding ecology and resource utilization in a nomadic pastoral ecosystem. J. Appl. Ecol. 23:585-595.

Elias, M.F. 1984. Handheld computers for recording timed behavior observations. Ethol. Sociobiol. 5:59-60.

Hobbs, N.T., D.L. Baker, J.E. Ellis, and D.M. Swift. 1979. Composition and quality of elk diets during winter and summer: a preliminary analysis. p. 47-53. *In:* M.S. Boyce and L.D. Hayden-Wing (eds.). North American elk: ecology, behavior and management. University of Wyoming, Laramie.

Jackson, H.O., and J.A. Stone. 1987. Improved data collection program for a notebook-sized microcomputer. Agron. J. 79:1087-1089.

Kidger, R., and J.W. McNicol. 1986. A program for data recording on a portable microcomputer. Computers and Electronics in Agriculture 1:213-217.

Law, J.R., and J.C. Reeves. 1984. The use of hand-held data terminals in National Institute of Agricultural Botany [UK] field trial recording. J. Nat. Inst. Agr. Bot. 16:397-414.

Ledochowski, M., M. Herold, and F. Dienstl. 1985. A pocket computer program for differential diagnosis of tumor-induced hypercalcemia and primary hyperarathyruidism. Comput. Method. Program. Biomed. 21:55-56.

Lorentz, A., P. Gasteiger, and P.M. Osswald. 1987. Calculation of the allowable pretransfusion blood loss with a programmable pocket computer. Anaesthesist 36:306-312.

Wallmo, O.C., and P.J. Neff. 1970. Direct observation of tamed deer to measure their consumption of natural forage. p. 105-110. *In:* Range and Wildlife Habitat Evaluation: A Research Symposium, USDA Forest Serv. Misc. Pub. 1147.

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

Book Reviews

Planning for Drought Toward a Reduction of Society Vulnerability. 1987. Edited by Donald A. Wilhite and William E. Easterling with Deborah A. Wood. Westview Press, Inc., 5500 Central Ave., Boulder, Colorado 80301. 597p. $42.50.

This book is a presentation of the international symposium and workshop on drought organized to review and assess current knowledge of drought and determine research and information needed to improve national and international capacity to cope with drought. This endeavor was designed to be a forum for discussion of physical and societal implications of drought within the context of the local or farm level as well as international regions such as the Sahel. The desire was to draw up the rudiments for a plan of action for drought preparedness on a global scale. Chapters are presented by leaders in the numerous areas of interest.

The book is presented in a manner to identify principal themes.

1. Background. Drought and desiccation: the twin hazards of a variable climate. Drought phenomenon: definitions.
2. Prediction. Global prospects from a meteorological prospective. Droughts of northeast Brazil and their production. Prediction in Australia and Indonesia. Forecasting probabilities. Drought as a hydrological prospective.
3. Monitoring and early warning. Surface weather monitoring in relation to climate information delivery. Agroclimatic monitoring during the growing season in semiarid regions of Africa. Drought in Australia. Satellite remote sensing of drought conditions. An operational early warning agriculture weather system.
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8. Role of donor organizations in drought and famine. Agricultural development. Media's action in drought. Crises management in Ethiopia.
9. Summary.
10. Workshop summary. Task force reports.

Part of the problem in such a symposium as this is defining drought. The many concepts of drought reflect the respective approach one takes—meteorological, agricultural, hydrological, or socioeconomic. It is possible to recognize the various types of drought do exist.

Causes of drought are not well known at present. Some of the causes are beginning to be known, most commonly short-term in nature. However, causes of the long-term droughts in West Africa and other places are not known. Thus it is not possible to predict long-term droughts may be able to predict short-term droughts fairly accurately within a few years. The many facets of the climatic system—atmosphere, oceans, cryosphere (the ice fields), land surface processes, vegetation, and interactions of these components will make long-term prediction of droughts difficult or impossible for some time.

Governmental and international programs which will help meet the needs of people in countries which experience drought cycles will continue to be important. Obviously there are uncertainties which exist but governments can not hide behind these uncertainties and problems.

In summary, this book appears to bring together current information on a number of facets of drought and the attempts at planning for drought. From a governmental policy approach, this book could have use as a reference for a graduate level class but probably not for a text.—*Lavoy I. Croy,* Stillwater, Okla.

Las Gramineas de Mexico, tomo II. 1987. By Alan A. Beetle, D. Manrique Forceck, V. Jaramillo L., M.P. Guerrero Sanchez, J. Alejandro Miranda Sanchez, Irama Nunez Tancredi, Aurora Chimal Hernandez. Cotecoca, Manzanillo, Mexico, D.F. 344 p.

This is the second volume of a projected set of six volumes that will treat the members of the grass family in Mexico. The first volume was published in 1983 and included keys to subfamilies, tribes, genera and species of genera that begin with the letter *a*.

Volume 2 includes genera beginning with the letters *b*, *ch*, *c*, and *d*. Among important genera included are *Bambusa* Schreber, *Bothriochloa* Kuntze, *Bouteloua* Lag. *Bromus* L., *Chloris* Sw., *Chusquea* Kunth, *Digitaria* Haller.

Authors of volume 2 had access to collections of some 40,000 specimens deposited at regional herbaria and at the Herbarium Central. This broad base of information is evident in the descriptions that typically include ranges in dimensions and much significant information from habit of the plant to the details of the spikelets.

The introduction consists of a brief discussion of some of the key characters, e.g., disarticulation, awns, the caryopsis and inflorescence type. In addition to thorough, well-organized descriptions, many of the approximately 240 species are illustrated including the habit of the plant, the inflorescence, and the details of the spikelet. Habitat sketches are liberally scattered throughout this volume. Some color photographs are included.

The keys are easy to use and appear to be accurate and consistent. Most leads (with the exception of the key to species of *Bromus,* a notably difficult genus) consist of more than a single character, a great aid to field identification.

Each species is accompanied by a distribution map. These inset maps show presence or absence of the taxon within state boundaries.

Other valuable features are the inclusion of the common names, chromosome number of species when known, and native distribution and habitat. The index to taxa is helpful and there is also an index to figures of taxa.

This series of projected six volumes will be a very significant contribution and with the published two volumes already constitutes an important addition to basic knowledge of Mexican grasses. By their comprehensive treatment, the authors of volume 2 have ensured that its utility will span both pure and applied plant science.—*A.J. Gilmartin,* Washington State University, Pullman, Wash.

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