JOURNAL OF RANGE MANAGEMENT

NOVEMBER 1977
Volume 30, No. 6

SOCIETY FOR RANGE MANAGEMENT

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Denver, Colorado, U.S.A.
August 14–18, 1978

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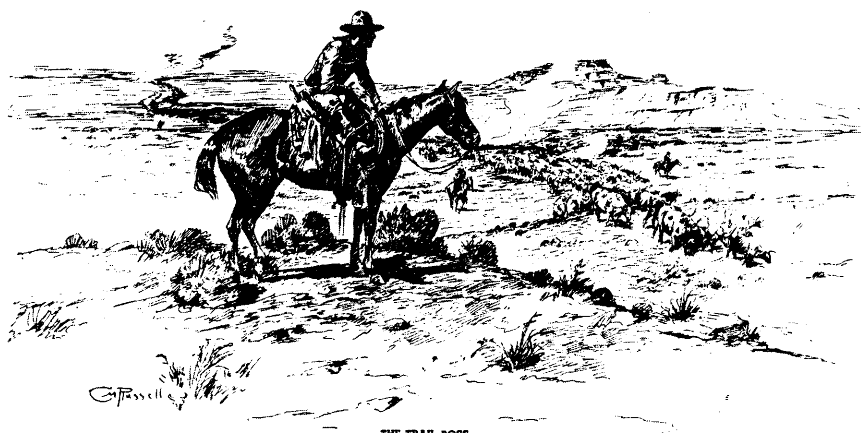

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—to assist all who work with range resources to keep abreast of new findings and techniques in the science and art of range management;

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

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

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JOURNAL OF RANGE MANAGEMENT

Published bimonthly—January, March, May, July, September, November—by the
Society for Range Management
2760 West Fifth Avenue
Denver, Colorado 80204

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INSTRUCTIONS FOR AUTHORS appear each year in the March issue; copies of these instructions are available from the editor.

SECOND CLASS POSTAGE paid at Denver, Colorado.

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COVER: Goats on Santa Catalina Island. (See article by Bruce E. Coblentz on page 415.)

Responses of Game and Nongame Wildlife to Predator Control in South Texas

FRED S. GUTHERY AND SAMUEL L. BEASOM

Highlight: One hundred thirty-two coyotes, 27 opossums, 22 skunks, 18 bobcats, 15 raccoons, 12 badgers, and one gray fox were killed on a 1,550-ha area of mixed brush rangeland in South Texas during January–July 1975 and 1976 to determine the responses of herbivore and quail populations to predator control. When compared to an area without predator control, predator removal at this level had little discernible effect on density trends of bobwhite or scaled quail, rodents, or lagomorphs. However, fawn production per unit area was 70% greater in 1975 on the area with predator control and 43% greater in 1976. These data suggest that intensive short-term predator control on South Texas rangeland results in little or no adverse impact on range forage due to expanding populations of small herbivores. Productivity and populations of white-tailed deer may increase and harvests should be adjusted accordingly, as overuse of range forage could occur.

Several studies have evaluated the efficacy of predator control in increasing the harvestable surplus of game animals (Beasom 1977), but few have concurrently followed the population responses of nongame wildlife. The possibility that predator control could release rodent or lagomorph populations causes concern because of the range management implications. Rodents can maintain less desirable seral states (Norris 1950), remove up to one-third of annual forage production (Fitch and Bentley 1949), and retard weight gain in cattle by forage competition (Howard et al. 1959). The diet of black-tailed jackrabbits (*Lepus californicus*) approximates that of sheep on salt-desert shrub ranges in Utah, and 5.8 jackrabbits consume or waste as much forage as one sheep in the spring (Currie and Goodwin 1966). About 260 black-tailed or 164 antelope jackrabbits (*L. alleni*) consume enough forage to feed one cow in the Southwest (Arnold 1942).

Beasom (1974) found that intensive generalized predator control enhanced reproductive success of white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*) with no apparent effects on rodent or lagomorph numbers in South Texas. Removal of small mammalian predators from experimental areas in South Dakota resulted in large increases in pheasant (*Phasianus colchicus*) populations, with concurrent moderate increases in jackrabbit and cottontail (*Sylvilagus floridanus*) populations and slight increases in rodent populations (Trautman et al. 1974). To our knowledge, these are the only studies published that have quantitatively monitored the responses of both game and nongame prey to predator control.

The present data resulted from a study to determine the efficacy of predator control in reducing predation on Angora goats. This paper discusses the responses of white-tailed deer, bobwhite quail (*Colinus virginianus*), scaled quail (*Callipepla squamata*), lagomorph, and rodent populations to that predator control.

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The study was supported by the Caesar Kleberg Res. Progam in Wildl. Ecol. and the Texas Agricultural Experiment Station. The authors wish to acknowledge J. Williams, R. Fox, and D. Nobles, who aided in field work; M. Ray, who provided deer density and production data; Mr. and Mrs. J. Lee, who granted permission to conduct the study on their ranch; and Drs. C. J. Scifres and W. E. Grant who critically reviewed the manuscript.

The report is published with approval of the Director, Texas Agr. Exp. Sta., as TA 13290.

Manuscript received April 5, 1977.

Study Area

The study was conducted in northern Zavala County, Tex., in the South Texas Plains vegetation region (Gould 1975). Climate of this region is mild. The average annual rainfall (55 cm) is highly erratic yearly and monthly. From August 1974 through June 1975, the study area received about 91.5 cm of rain, and the vegetation responded with lush growth. From August 1975 through June 1976, rainfall totalled 24.8 cm and vegetation growth was retarded, especially during November 1975 through March 1976, when less than 4 cm of rain fell.

Three soil types supported three relatively distinct plant communities on the study area. Fertile clay loams occupied flat lowland sites and supported dense stands of whitebrush (*Aloysia lycioides*). Principal grasses were pink pappus (*Pappophorum bicolor*) and bristlegrasses (*Setaria* spp.) on moister areas and common curly-mesquite (*Hilaria belangeri*) and buffalograss (*Buchloe dactyloides*) on drier areas. Lowlands graded into relatively level red sandy loams where honey mesquite (*Prosopis glandulosa*), spiny hackberry (*Celtis pallida*), and blackbrush acacia (*Acacia rigidula*) occurred in low to moderate densities. Threeawns (*Aristida* spp.) and red grama (*Bouteloua trifida*) were important grasses; forbs were sparse. Gravelly ridges with usually moderate slopes and shallow sandy loams were interspersed with the other soil types. These ridges supported dense stands of guajillo (*Acacia berlandieri*) and blackbrush acacia and a sparse ground cover of threeawns and red grama.

Materials and Methods

The project was designed and executed such that predator removal was the major source of variation influencing results. Sampling was conducted concurrently, when possible, on two experimental areas. Density trends of wildlife were compared between a 225-ha treated (predator control) and a 201-ha untreated (no predator control) pasture (Fig. 1).

Mammalian predators were killed in a 1,550-ha area, which included the treated

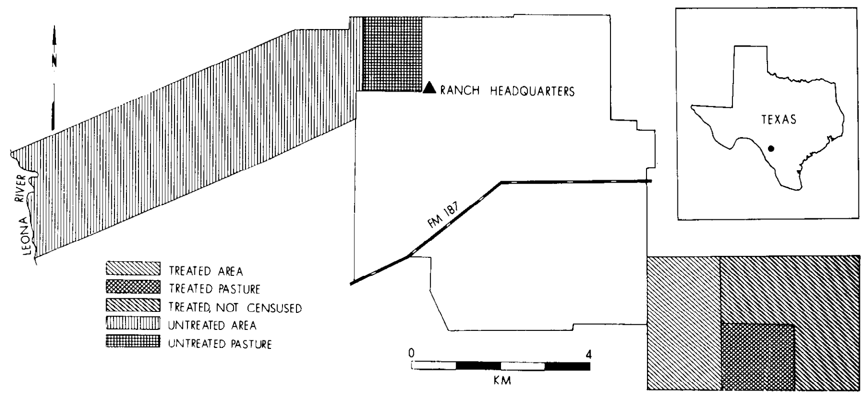

Fig. 1. *The study area in Zavala County, Tex.*

pasture and a 1.6-km buffer zone on three sides of it. Steel traps, snares, and M-44's were deployed at an average intensity of 165 device days/km^2/month, where a device day is one device operative for 24 hours. Also, 1.55 hours of helicopter gunning and 6.2 hours of predator calling were done. Guthery and Beasom (1977) detailed the predator control effort.

Densities of deer, quail, and lagomorphs were estimated with strip census formulas of the King type (Leopold 1933) for comparisons between treatments. Permanent linear transects 0.32 km apart were established in the two pastures and flagged with surveyor's tape. The north-south transects included four 1.8 km long in the untreated pasture and five 1.6 km long in the treated pasture. Counts started at about sunrise and at 2 to 3 hours before sunset. Each transect was walked four times per month. The number, radial flushing distance, and flushing angle were recorded for each individual or group flushed. Distances were paced to the nearest meter, except for long observations of deer where it was estimated visually to the nearest 5 m. Separate analysis (Guthery 1977b) indicated the harmonic mean of radial distances (Hayne 1949) was an acceptable measure of effective transect width for deer and quail, though it likely resulted in underestimates of density. The mode of radial distances was used for cottontails. The harmonic means were stratified by month; this refinement was considered unnecessary for cottontails as there was little seasonal variation in their sighting distance.

Density and fawn:doe ratios of white-tailed deer were determined by helicopter censuses conducted by the Texas Parks and Wildlife Department in October of each year. Systematic flights over about 90% of the study area were designed to give total counts. These data were used to compare deer population response to predator control between a five-pasture block (2,016 ha) that received no treatment and a 698-ha area that received treatment (Fig. 1), because the helicopter censuses were not stratified by individual pastures during both years.

An upland site dominated by blackbrush acacia and guajillo and a lowland site dominated by whitebrush were selected in each pasture to monitor rodent populations. One hundred Sherman live traps, baited with grains, were placed at 15.2-m intervals in a 10 by 10 grid and run for five consecutive days each month of the study period in 1975 and 4 days in 1976. Rodents were marked individually by clipping one or two toes; population size was estimated with the Schumacher-Eschmeyer formula (Overton and Davis 1969). Area trapped was determined by adding the average distance moved between captures to the periphery of the grid (Brant 1962). Because this distance was roughly 30 m for all species (Guthery 1977a), the area trapped was 3.9 ha in each grid.

Jolly (1965:226) derived a method for calculating the "probability that an animal alive at the moment of *release* of the *i*th sample will survive till the time of capture of the $i + 1$st sample (emigration and death being synonymous for this purpose)." To calculate this probability, we considered a monthly trapping period (five days in 1975, four in 1976) as time *i*; data for all species were pooled.

Modified life table analyses were conducted to compare the mortality of cotton rats (*Sigmodon hispidus*) and woodrats (*Neotoma micropus*) between the untreated and treated pastures. Artificial cohorts were created by assigning individuals trapped in February the age of zero. These "cohorts" were comprised, for a given pasture, of animals trapped in both grids during both years to obtain larger samples. Survival was based on trapping records in subsequent months.

Woodrat densities were estimated by spring and summer den counts along the wildlife census transects described earlier. The right-angle distance to dens was paced to the nearest meter, and density was estimated by Leopold et al.'s (1951) formula. Dens were considered active if fresh droppings were nearby, if trails were well defined, if cobwebs were absent from entrances, and/or if there was other evidence of recent use. One adult woodrat per active den (Raun 1966) was assumed.

Results and Discussion

Predator Control

The confirmed kill of coyotes and bobcats (Table 1) apparently reduced the density of these predators to about 0.4 to 0.8/km^2, whereas their density was about 2.0/km^2 on untreated portions of the study area (Guthery 1977a). Guthery speculated that the small kill of badgers (*Taxidea taxus*) and gray foxes (*Urocyon cinereoargenteus*) substantially reduced their numbers because few occurred on the study area. He further noted, based on qualitative appraisal of the abundance of their sign, that raccoon (*Procyon lotor*) and skunk (*Mephitis mephitis*) populations were perhaps reduced by 40 to 60% on the treated area. The fairly large kill of opossums (*Didelphis marsupialis*) did not appear to depress their numbers markedly.

Table 1. Mammalian predators killed on a 1,550-ha area, Zavala County, Tex.

	Number killed	
Species	1975	1976
Coyote	69	63
Bobcat	11	7
Raccoon	10	5
Striped skunk	11	11
Badger	7	5
Opossum	24	3
Gray fox	0	1

White-tailed Deer Responses

Although slightly higher in the untreated pasture, deer numbers were roughly equal in the experimental pastures prior to treatment in August 1974 (Table 2). Fawn:doe ratios were 0.38 (untreated) and 0.48 (treated). The observed number of fawns and does, cross-classed with pastures, indicated homogeneity ($P > 0.05$), however.

Response of the deer population to predator control, which began in Janu-

Table 2. Densities of adult deer on untreated (no predator control) and treated portions of the study area, Zavala County, Tex.

	Number/40 ha	
Time	Untreated	Treated
Aug. 1974	5.8	5.0
Jan. 1975	5.6	5.0
Oct. 1975	4.9	6.5
Oct. 1976	5.5	6.9

ary 1975, was confounded by human disturbance adjacent to the untreated pasture. Density of this pasture apparently declined by about 80% in February (Fig. 2), coinciding with exploratory oil drilling about 2 km from the pasture. Traffic of large trucks on a bordering road was heavy both day and night during this operation. After drilling activities subsided, deer numbers never attained pre-experiment levels in the untreated pasture.

Hood and Inglis (1974) noted the response of white-tailed deer to disturbance associated with intensive cattle roundups in a similar South Texas brushland habitat. They found the main response to be within areas of disturbance rather than between disturbed and relatively undisturbed areas. Rarely did they observe an abandonment of the fidelity for an individual's home range as was indicated in the present study.

An alteration of the flushing behavior of the deer in this study also may have influenced the calculated density in the untreated pasture. The average radial flushing distance of deer in this pasture in February increased by 50% over January levels. In dense brush such as occurred on the study area, increased flightiness of deer probably would result in underestimates of density. This would occur because the probability of sighting a deer decreases dramatically with increasing distance from the observer in brushy habitat, where even under average conditions strip censuses may yield underestimates of density because of failure to detect animals (Guthery 1977b). The average radial flushing distance in the treated pasture, conversely, decreased by 20% from January to February in 1975. Regardless of the response of the deer to disturbance near the untreated pasture, the helicopter censuses indicated the density of the five-pasture block, including the untreated pasture (Fig. 1), remained relatively stable during the study (Table 2).

The October 1975 fawn:doe ratio of 0.72 in the treated area was approximately 29% greater than that on the untreated area, whereas in October 1976 that on the treated area was about 6% lower than the 0.32 value on the untreated area. Although the age-ratio data indicated little difference in fawn production between areas in 1976, the number of fawns produced per unit area

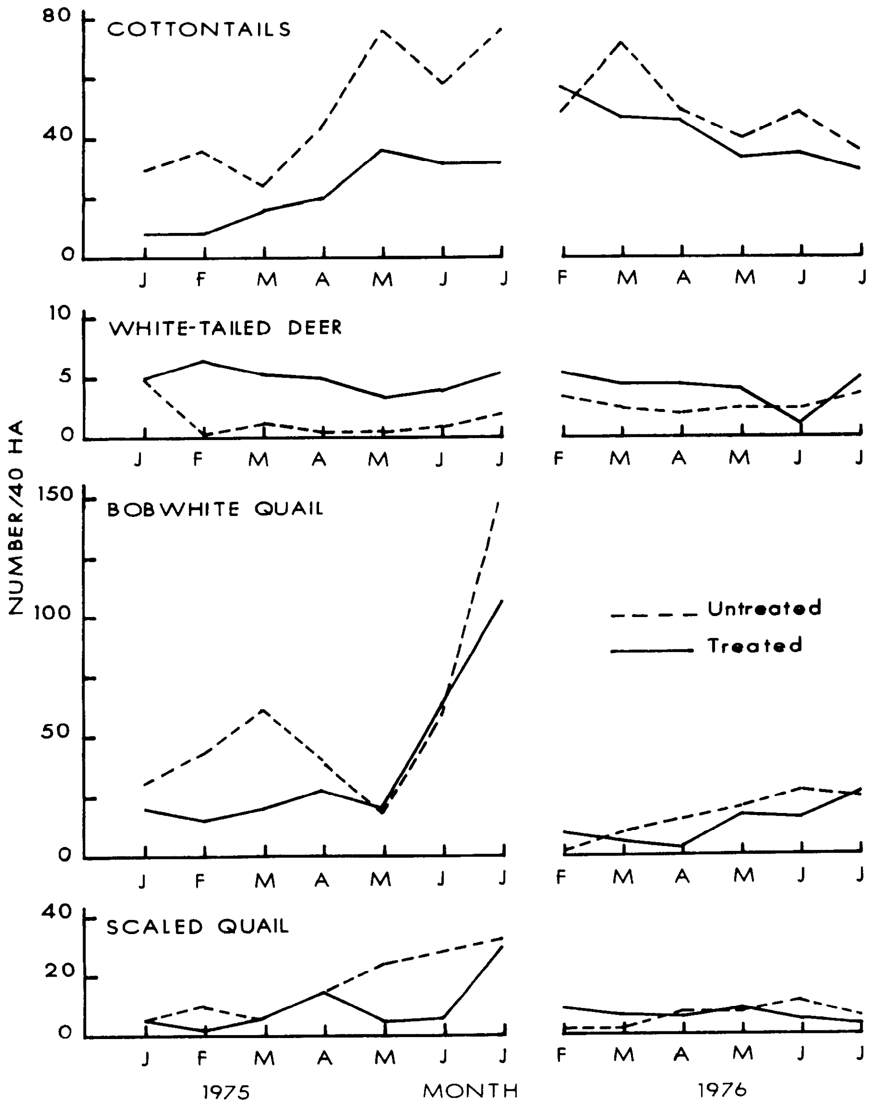

Fig. 2. *Density trends of cottontails, deer, and quails on the untreated (no predator control) and treated pastures, Zavala County, Tex.*

was approximately 70 and 43% greater on the treated area in 1975 and 1976, respectively.

In addition, equal fawn:doe ratios under different deer densities may indicate a positive response to predator control. In central Texas Teer et al. (1965) found that fawn production varied inversely with adult density. If this relationship held in our South Texas area the fawn:doe ratio in the treated area should have been lower because of the roughly 25% greater density. Clearly, age ratios, when interpreted without density estimates, may be an incomplete and sometimes misleading measure of the effects of predator control on game production.

The difference in density of fawns on the experimental areas was a reflection of total numbers of adult does. These females increased on both areas from 1975 to 1976. However, the increase was markedly greater on the treated area (24% above the 5.23 does/40 ha on the treated area compared to 9% above the 3.92 does/40 ha on the untreated area).

Similarly, total numbers of adult deer increased throughout the study period on the treated area and remained relatively stable on the untreated area (Table 2). These data suggest that the approximately 80% reduction in coyote and bobcat activity on the treated area (Guthery and Beasom 1977) resulted in an increased survival of young and/or adult deer and a subsequent increase in the population. That this increase had not become asymptotic was suggested by similar loss rates (1.6/40 ha) in the treated and untreated pastures associated with drought conditions prevailing from November 1975 through March 1976. Most of the carcasses located were too old for unequivocal ascription of cause of death. Two carcasses were assigned to a predator-killed category and several others showed circumstantial evidence of predation, but predation may have represented only proximate mortality, the ultimate agent being nutritional stress. Because deer density was higher, nutrition-induced losses also should have been higher in the treated pasture. The fact that they were not suggests the reduction in predator activity ameliorated, to some extent, total overwinter deer losses on the treated pasture. It is unlikely that this condition could be perpetuated, and the harvest rate of deer in the treated area likely should be increased to prevent the classical habitat destruction associated with unchecked ungulate populations.

Quail Responses

Pre-experiment populations of scaled and bobwhite quail apparently were higher on the untreated pasture (Table 3). This condition held from January through April 1975, with bobwhite densities equalizing in May and scaled quail densities equalizing in January (Fig. 2). Thus the influence of inversity (Errington 1934) on comparative productivity was minimized or cancelled. Reproductive success of bobwhites was excellent in 1975 as density was calculated at over 100/40 ha in July. Scaled quail density trends were similar in the experimental pastures, subject to the inherent variability of counts of flocking species. Both density and productivity of scaled quail were below that of bobwhites.

Table 3. Pre-experiment density indices based on 33.6 and 35.2 km of walking transect in the untreated (no predator control) and treated pastures, respectively, in August 1974, Zavala County, Tex.

Species	Number/km	
	Untreated	Treated
Cottontail	1.04	0.37
Bobwhite quail	6.07	3.32
Scaled quail	0.89	0.51

Whereas little, if any, quail hunting was done on the study area in 1975, it was leased and hunting pressure increased in 1976. It seems unlikely, however, that hunting was solely responsible for a decline in density of about 80% from February of the preceding year (Fig. 2). The droughty period from November 1975 through February 1976 probably played some role in this reduction. Reproductive success of both scaled and bobwhite quail was meager in 1976, as July densities were about 25 and 6/40 ha, respectively. Thus quail populations followed the boom-and-bust cycle typical in South Texas (Lehmann 1953) during the two seasons of study.

The data indicate intensive predator control had but slight influence on quail populations. If there was any effect, it was that the treatment enabled populations on poorer habitat to maintain roughly equivalent numbers with those on better habitat. That the untreated pasture provided better habitat is supported by pre-experiment abundance (Table 3) and by subjective opinion. Similarly, Lehmann (1946) and Beasom (1974) found no significant difference in bobwhite populations or productivity due to predator control in South Texas.

Lagomorph Responses

Pre-experiment cottontail numbers were two to three times higher on the untreated than on the treated pasture (Table 3). This condition held in January 1975 when predator control began. Cottontail densities subsequently increased at rates of 8.43 and 5.04/40 ha/month on the untreated and treated pastures, respectively, during 1975. These significantly different ($P < 0.05$) rates are a reversal of the expected condition if predator control is presumed to release cottontail populations.

Cottontail densities apparently were similar on the two pastures in February 1976 (Fig. 2). Subsequently, densities declined at rates of 3.97 and 4.97/40 ha/month in the untreated and treated pastures, respectively, during 1976. These rates were similar ($P > 0.05$).

Because pre-experiment densities were unequal in the two pastures (Table 3), at a time when predator pressure presumably was equal, ecological factors other than mammalian predation probably played a role in observed density trends. This lack of homogeneity confounds an analysis of predation's effects on cottontail populations. However, an apparent correlation ($P < 0.10$) between monthly densities in the experimental pastures suggests that density, though governed by factors common to the two pastures, fluctuated independent of two levels of predator abundance. Clearly, cottontail populations in the treated pasture showed no irruptive tendencies under the conditions obtaining in this study.

Jackrabbit densities never exceeded 2/40 ha on either experimental pasture, probably because the study area provided unsuitable habitat.

Although predation may account for a substantial proportion of annual lagomorph mortality (Trent 1972; Wagner and Stoddart 1972), it by no means follows that predation controls lagomorph populations, or that decreased predation would release lagomorph populations. Because lagomorph fecundity greatly exceeds that of

Table 4. Life table analysis of cotton rats and woodrats in the untreated (no predator control) and treated pastures, during February–July 1975 and 1976, Zavala County, Tex. Animals trapped in February were given an artificial age of zero and survival was based on monthly trapping records.

Artificial age (months)	Untreated				Treated			
	l_x	d_x	q_x	e_x[1]	l_x	d_x	q_x	e_x
Cotton rat								
0	1,000	478	0.478	1.49	1,000	167	0.167	2.14
1	522	283	0.542	1.41	833	403	0.484	1.47
2	239	130	0.552	1.47	430	236	0.549	1.37
3	109	29	0.266	1.64	194	69	0.356	1.44
4	80	37	0.460	1.05	125	69	0.552	0.95
5+	43	43	1.000	0.50	56	56	1.000	0.50
Woodrat								
0	1,000	636	0.636	1.77	1,000	412	0.412	1.85
1	364	92	0.253	2.99	588	294	0.500	1.80
2	272	45	0.165	2.84	294	59	0.201	2.10
3	227	0	0.000	2.30	235	117	0.497	1.51
4	227	45	0.198	1.30	118	0	0.000	1.50
5+	182	182	1.000	0.50	118	118	1.000	0.50

[1] l_x = number of animals alive at start of age interval; d_x = number dying during age interval; q_x = rate of mortality during age interval; and e_x = mean expectation of life (months) for animals alive at start of age interval.

most mammalian predators, and because limits on predator numbers are imposed, to some extent, by energy available at the secondary consumer trophic level, hare and rabbit numbers apparently may wax and wane irrespective of predation. Such has been the case, with few qualifications, for jackrabbits in Utah (Wagner and Stoddart 1972) and snowshoe hares (*Lepus americanus*) in Alberta (Keith 1974).

Considering the diverse predator fauna in South Texas, which includes reptiles, birds, and mammals, it is apparent that the predator control in this study removed only a segment of potential lagomorph predators. The remaining predators, being freed from a certain amount of competition for food, could increase in numbers and compensate decreased predation rates caused by predator control. Breeding efforts of great-horned owls (*Bubo virginianus*), for example, are enhanced by rising food supplies (Rusch et al. 1972), and populations of other rapacious mammals apparently increase in response to coyote control (Robinson 1961). Such ecological adjustments have been largely overlooked by those concerned about the environmental effects of predator control (e.g. Cain et al. 1972).

Rodent Responses

Infrequent captures of pygmy mice (*Baiomys taylori*), harvest mice (*Reithrodontymys fulvescens*), deer mice (*Peromyscus* spp.), grasshopper mice (*Onychomys leucogaster*), pocket mice (*Perognathus hispidus*), and ground squirrels (*Citellus mexicanus*) made monthly estimates of their populations infeasible. To avoid losing these observations, we based the mark-recapture estimates (Fig. 3) on all species. The observed density trends largely reflect the abundance of cotton rats because they represented, averaging over 2 years, 52 to 85% of the catch in any grid. Woodrats, deer mice, and harvest mice were, in descending order, the next most abundant species. Other species accounted for about 3% of the catch.

In 1975 cotton rats apparently irrupted on the untreated whitebrush grid, achieving a peak density in July of about 1,700/40 ha (Fig. 3). Overall rodent density decreased on the treated whitebrush grid from January through May 1975. This decline was due partially to high trap mortality of harvest mice during January and February, when they comprised 34 and 18%, respectively, of the catch in this grid.

Numbers of all species except woodrats declined in 1976. Deer, harvest, grasshopper, pygmy, and pocket mice virtually disappeared from the catch. Combined numbers of cotton rats and woodrats accounted for 91 to 95% of the monthly catch.

Spring and summer counts in 1975 indicated 252 and 192 woodrat dens/40 ha, respectively, on the untreated pasture. Respective figures for the treated pasture were 212 and 204. In 1976 these counts indicated 368 and 160/40 ha, respectively, on the untreated pasture. Respective figures for the treated pasture were 452 and 288. Because the mean perpendicular distance to dens was stratified by seasons to estimate density, differences in visibility do not fully explain the decline in woodrat numbers from spring to summer in both pastures both years. The relative decline was smaller in the treated pasture both years.

The mean probability of an individual rodent surviving from one month to the next, calculated over the two treatments and years, was 0.57 ± 0.035. Whereas this probability was lower in the drier conditions of 1976 ($P < 0.05$), it apparently was unaffected by predator control ($P > 0.25$).

Monthly mortality rates and expected survival of cotton rats were similar in both pastures (Table 4), based on "cohorts" of 138 (untreated) and 72 (treated). Letting $y = \log(l_x)$, the monthly rates of decline of 0.29 (untreated) and 0.24 (treated) were similar ($P > 0.05$), indicating no discernible effect of predator control on cotton rat survival.

Similar regression analysis for woodrats, based on "cohorts" of 22 (untreated) and 17 (treated), indicated woodrats declined at a lower rate ($P < 0.05$) on the untreated (0.16) than on the treated (0.23) pasture. These rates

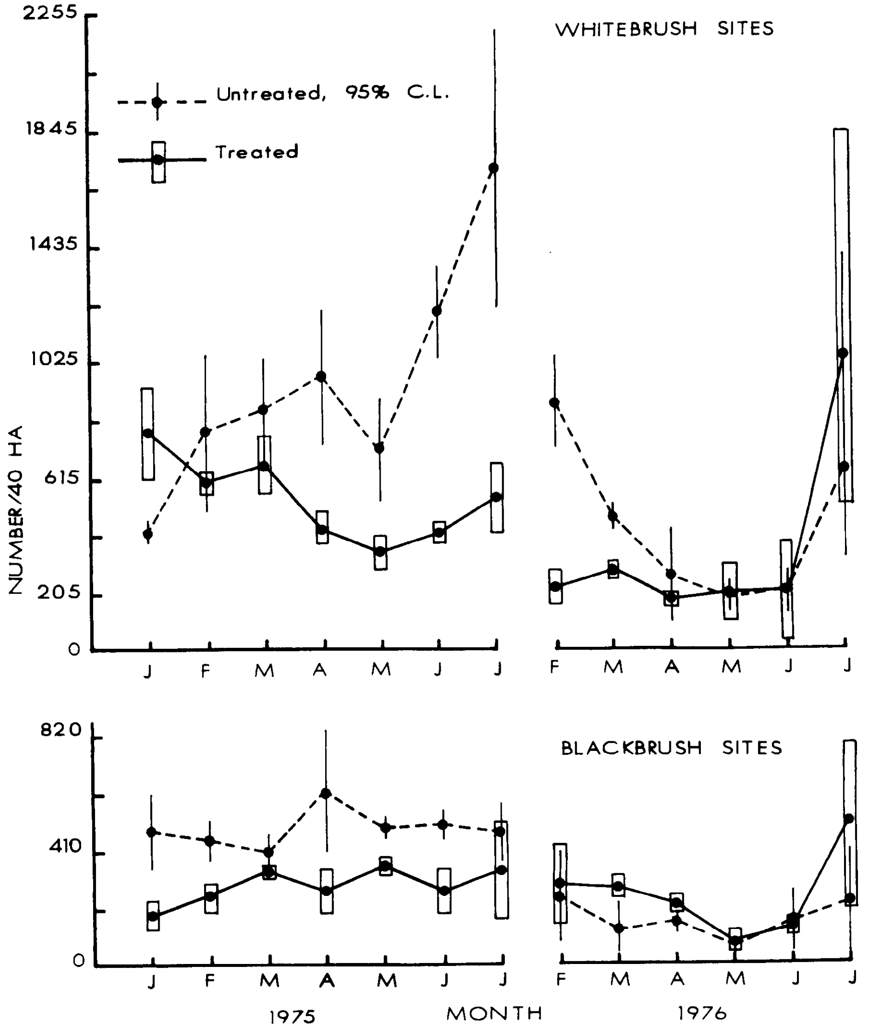

Fig. 3. *Density trends of combined rodent populations on the untreated (no predator control) and treated pastures, Zavala County, Tex.*

are a reversal of the expected condition if predator control is presumed to enhance woodrat survival.

No irruptive tendency of rodent populations in response to mammalian predator control was demonstrated. It therefore follows that intensive short-term predator control in South Texas would not result in adverse impact to range forage due to expanding numbers of rodents.

The present findings support results of Beasom (1974) and Trautman et al. (1974), who also recorded little or no response of rodent populations to predator control. Schnell (1968), however, felt that diverse and highly mobile avian and mammalian predators were more important regulators of cotton rat density than food, weather, or social interactions. He was working with *non-breeding* cotton rats, and while he may have demonstrated that predation is responsible for most mortality, his conclusions about its population regulating effects may well be spurious. Pearson (1964) reported that mammalian predators nearly annihilated a vole (*Microtus* sp.) population in California. However, because house cats were an important component of the predator fauna, suggesting predator density was artificially high, his findings may be valid only under such specialized circumstances.

The present data suggest a possible inversely density-dependent effect (Keith 1974) of predation on rodent populations, assuming that predation on a population is roughly proportional to the number of predators acting on that population. In 1975, a year with plentiful rainfall and good production of grasses and forbs, rodent densities were higher on the untreated grids (Fig. 3). The droughty period from November 1975 to March 1976 probably contributed to decreased rodent densities in 1976 by retarding growth of vegetation. The relative decrease was greater in the untreated grids because the lowest densities were roughly equal in both pastures in 1976. Thus it may be hypothesized that predation caused a greater decline in rodent densities than would be expected under a lower level or absence of predation. Furthermore, predation had possible effect only on declining and relatively low rodent numbers, i.e. it was inversely density-dependent.

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Individual Sustaining Members

We regret our inadvertent omission of the following members from the list of Individual Sustaining Members published in the September 1977 *Journal of Range Management*:

Robert S. Campbell
John D. Freeman

Species Adapted for Planting Arizona Pinyon-Juniper Woodland

FRED LAVIN AND T. N. JOHNSEN, JR.

Highlight: Species adaptation trials were observed over periods varying from 21 to 28 years at ten Arizona pinyon-juniper sites. Fifty-nine species and varieties developing fair to excellent stands and persisting five or more years were considered adapted to one or more of the sites. Fifty-four of these were still present at the last rating. Thirty have reproduced themselves and are spreading naturally. Most widely adapted species are *Agropyron desertorum, A. intermedium, A. smithii, A. trichophorum, Atriplex canescens, Bothriochloa ischaemum, Bouteloua curtipendula, Muhlenbergia wrightii,* and *Tridens elongatus.* Moisture variation caused some cool season grasses to fluctuate more widely in growth and stand than the other adapted species, especially shrubs. Warm-season growers were generally sensitive to low temperatures and cool-season growers to high temperatures. Complete protection from livestock appeared to have detrimental effects on some species. Sites are described and classified to help identify planting potential and facilitate wide application of results. Guidelines are suggested for shortening the time period needed to evaluate species adaption.

Successful improvement of pinyon-juniper rangelands by revegetation depends on the use of adapted species. Species and variety adaptation trials were begun in 1945 at 10 pinyon-juniper sites in Arizona. The plantings varied from 21 to 28 years in age when last evaluated. The long duration of these trials makes them especially useful for selecting species and varieties best suited to different range sites and planting needs. The accompanying site descriptions and classifications will help to identify potential planting sites and facilitate wide application.

Results apply to similar sites within the 13.5 million acres of pinyon-juniper rangeland in Arizona, including many areas invaded by juniper. Additional areas occur within the 37.5 million acres of pinyon-juniper in New Mexico, Colorado, and Utah. Other work on species adaptation in the pinyon-juniper woodland has been reported by Renney (1972), Judd (1966), Judd and Judd (1976) for Arizona; Springfield (1965) for New Mexico; McGinnies, et al. (1963) for Colorado; and Plummer et al. (1968) for Utah.

The study was initiated by the former Southwestern Forest and Range Experiment Station (now Rocky Mountain Forest and Range Experiment Station), Forest Service, U.S. Department of Agriculture, and transferred to the Agricultural Research Service, U.S. Department of Agriculture, in 1954.

Site Descriptions and Classifications

Ten study sites were established at the locations shown in Figure 1. Buckhead Mesa is 5 miles southeast of Pine; Dog Knobs, 36 miles northwest of Flagstaff; Drake, 2 miles north of the town of Drake; Moritz Lake, 6 miles northeast of Spring Valley; Mud Tanks, 25 miles east of Camp Verde; Perkinsville, 1 mile south of the town of

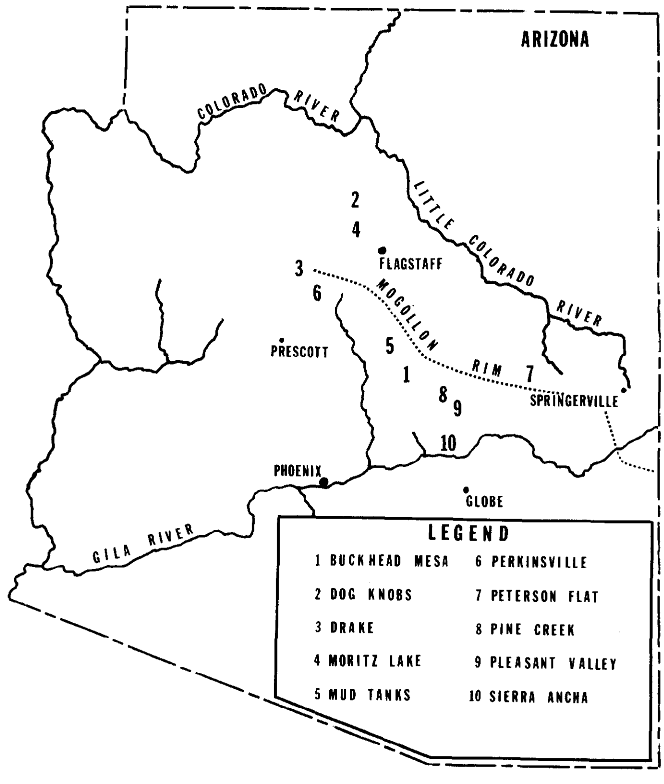

Fig. 1. *Location of the ten pinyon-juniper sites used to study species adaptation.*

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This research involves cooperative investigation by the U.S. Dep. Agr., Agr. Res. Serv.; the U.S. Dep. Agr., Forest Service, Rocky Mountain Forest and Range Exp. Sta., and the University of Arizona Agr. Exp. Sta.

The authors wish to thank those ranchers and personnel in the Forest Service, Soil Conservation Service, and Agricultural Research Service, who cooperated in this study, especially the U.S. Forest Service, Southwestern Region, who provided the land and much of the fencing; the U.S. Soil Conservation Service soil scientists, who provided technical assistance on soils; and the U.S. Soil Conservation Service Plant Materials Center at Tucson, Ariz., who furnished much of the seed.

Manuscript received March 14, 1977.

Editor's Note: Dr. Lavin died on May 5 shortly after revising this manuscript with Dr. Johnsen.

Table 1. Classification and description of Arizona pinyon-juniper study sites.

Subtype and study site	Elevation (ft above sea level)	Precipitation (inches)[1]		Temperature (°F)[1]		Soils		Dominant trees and shrubs[2]
		Annual	Nov.-Apr.	Annual	Jan.	Series	Texture	
Cold-moist								
Moritz Lake	6,600	16	7	49	30	Sponsellor, warm varient	Silt loam	Jumo, Juos, Pied
Peterson Flat	6,500	17	7	49	29	Jacques	Loam	Jude, Jumo, Pied
Cold-dry								
Dog Knobs	6,400	12	4	49	31	Thunderbird	Clay loam	Jumo, Pied
Cool-moist								
Mud Tanks	5,900	18	9	52	32	Thunderbird	Gravelly clay loam, clay loam	Jude
Warm-moist								
Pine Creek	5,200	20	10	53	36	Showlow	Gravelly loam	Jude, Jumo
Pleasant Valley	5,000	19	9	53	36	Lynx	Loam	Jude, Jumo
Buckhead Mesa	4,700	20	10	54	36	Thunderbird	Clay loam	Jude, Jumo
Warm-dry								
Drake	4,600	13	5	54	36	Tajo	Gravelly loam	Juos
Perkinsville	4,000	13	6	57	39	Abra, Partri	Loam, clay loam	Juos
Hot-moist								
Sierra Ancha	4,600	17	9	60	43	White House	Very gravelly loam	Qutu, Jumo, Jude

[1] All precipitation and temperature data are means.
[2] Jude = *Juniperus deppeana*, Jumo = *J. monosperma*, Juos = *J. osteosperma*, Qutu = *Quercus turbinella*, and Pied = *Pinus edulis*.

Perkinsville; Peterson Flat, 1 mile southeast of Pinedale; Pine Creek, 10 miles north of Young; Pleasant Valley, 2 miles east of Young; and Sierra Ancha, 3 miles southeast of the Sierra Ancha Experimental Forest Headquarters.

Elevations, precipitation amounts and seasonal distribution, temperatures, and soils and vegetation of the sites represent a wide range of conditions (Table 1). Detailed site descriptions have been reported by Lavin and Johnsen (1977).

The study sites are placed in six pinyon-juniper subtypes based on precipitation and temperature. Information from nearby weather stations (Sellers and Hill 1974) was adapted for seven sites. A combination of data from the nearest station and more distant stations with similar elevation, physiography, and vegetation was used to extrapolate information for the other three sites, namely Buckhead Mesa, Moritz Lake, and Mud Tanks.

Sites with 15 inches or less mean annual precipitation are classed as dry; those with 16 inches or more, as moist. All sites received 7–10 inches of summer precipitation, mainly in July and August. Cool season precipitation was more variable. The Arizona pinyon-juniper woodland has distinct periods of summer and winter rainfall, with dry springs and falls. Also, there is a gradual reduction of summer rainfall from south to north and of winter rainfall from west to east (Jameson 1969).

Comparisons of available temperature data and survival indicated that mean annual and mean January temperatures apparently were the most significant. Relative temperature groupings, therefore, were delineated on this basis. Sites are classed as: (1) cold, with mean annual temperature 49°F or less and mean January temperature 31°F or less; (2) cool, with 50 to 53°F annual and 32 to 35°F January; (3) warm, with 54 to 58°F annual and 36 to 39°F January; and (4) hot, with 59°F or more annual and 40°F or more January.

Study sites are all relatively level so that slope and aspect effects on temperature and moisture are minimal. Dominant trees and shrubs may have some use as site indicators because they appear to have a relationship to the climate. Alligator juniper grows on the moister sites, while Utah and one-seed juniper dominate the drier sites.

Soils were described from on-site examination by a soil scientist experienced with Arizona pinyon-juniper soils. Nine soil series were found on the study sites (Table 1). Buckhead Mesa, Dog Knobs, Moritz Lake, Mud Tanks, Perkinsville, and Pine Creek all have the same or similar soils classed as Aridic Argiustolls. Peterson Flat and Pleasant Valley have similar Cumulic Haplustolls soils. Drake, with a Petrocalcic Paleustoll, and Sierra Ancha, with a Ustollic Haplargid, have soils different from the other sites. All the soils are loamy, ranging from gravelly to clay loams, with depths varying from moderately deep to deep.

Procedure

Plantings were made from 1945 through 1952 with a total of 240 species and varieties. Several accessions were planted for many of the species. Only results for species and recognized varieties adapted to one or more sites are given here. A listing of all species planted has been made by Lavin and Johnsen (1977).

Plantings were: (1) initial nursery plots of three 12-foot rows, spaced 1-foot apart, and then (2) larger plots up to an acre in size for the more promising species. All plantings were replicated at least twice in separate blocks at each location. Many species and varieties, especially those that did not attain a fair or better stand or were destroyed by some biotic agent, were replanted several times in attempts to establish them.

Juniper and pinyon were clear cut and removed from the planting sites as required. Seed beds were plowed, disked, harrowed, and cultipacked, except at Buckhead Mesa and Pine Creek, which were disked and harrowed only, and at Moritz Lake, which was plowed with a Wheatland plow only. Nursery seedbeds replanted because of initial failure were prepared by hand hoeing and raking.

Rows were formed, seeded, and covered by using handtools for the small nursery plantings. On the larger plots, seed was either drilled or broadcast. Broadcast seed was covered by harrowing or cultipacking. Seed rates were 20–40 pure live seed per linear foot for row plantings and 30–50 per square foot for broadcasting.

Seed was planted from ¼–1 inch deep, depending upon seed size and known species requirements. Most of the plantings were made from late June through July. During a few years plantings also were made at Peterson Flat in September, and at Dog Knobs in September and October. Weeds were not controlled except when replanting.

All sites were fenced against livestock except Moritz Lake. Additional fencing with 1-inch mesh wire was used for protection against rabbits at all nursery plantings except Buckhead Mesa and Pine Creek. Cattle grazed the plantings at Dog Knobs, some of them heavily, during August, 1947, when the fence was being replaced. Fencing was removed from some of the larger plantings at Mud Tanks in the fall of 1959 and they have been heavily grazed each year since that time. Moritz Lake had heavy cattle use from June 1 to October 31 starting the year after planting until 1967, and since then has received heavy year-long use.

All plantings were rated at least twice a year from 1945 through 1953, once in 1954, and at irregular intervals thereafter. The last rating was made the fall of 1973. Numerical relative ratings on a scale from one to 10 representing the actual stand in relation to the best possible stand were used to record planting success (Hull 1974). These ratings consider the number, distribution, and vigor of the seeded plants. To simplify presentation, numbers have been converted to adjectives as follows: 0 = failure, 1–2 = very poor, 3–4 = poor, 5–6 = fair, 7–8 = good, and 9–10 = excellent. Other information, such as natural spread, disease, and animal activity, was also recorded.

Table 2. Final and maximum ratings[1] for species and varieties surviving at least 10 years and attaining a rating of fair or better on one or more study sites.

	Cold-moist		Cold-dry	Cool-moist	Warm-moist			Warm-dry		Hot-moist
Species and variety	Peterson Flat	Moritz Lake	Dog Knobs	Mud Tanks	Pine Creek	Pleasant Valley	Buckhead Mesa	Drake	Perkins-ville	Sierra Ancha
Agropyron cristatum	O/E	O/F	O/G	_V/E_[2]	–	O/P	–	O/G	V/E	O/O
A. desertorum	_G/E_	P/G	_F/E_	_G/E_	_F/G_	V/E	_P/G_	V/F	V/E	O/P
A. elongatum	_F/E*_[3]	O/F	_E/E*_	_G/E*_	–	V/E	–	O/E	O/E	–
A. intermedium	_O/E_	O/G	_F/E*_	_G/E*_	_O/E_	_F/G*_	O/E	O/G	O/E	O/O
A. intermedium-Amur	O/E	–	O/G	_V/G_	–	O/G	–	O/F	O/E	–
A. intermedium-Ree	_G/E*_	–	O/G	_F/E*_	–	V/G	–	O/F	–	O/O
A. popovii	O/G	–	P/G	_G/G_	–	_F/E*_	–	_O/G_	_G/E*_	–
A. sibiricum	O/E	O/G	V/E	_F/E**_[3]	–	O/F	–	O/G	–	O/O
A. smithii	_E/E*_	_F/F*_	_E/E*_	_E/E*_	_E/E*_	_E/E*_	_E/E*_	_G/E*_	_E/E*_	O/O
A. trichophorum	_G/G*_	V/G	_O/G_	_E/E*_	_E/E*_	_F/E*_	_O/E_	_F/G*_	P/E	O/O
Andropogon hallii	O/V	–	O/F	O/O	–	_E/E*_	–	O/F	O/G	–
Atriplex canescens	P/G	_F/G_	_E/E_	_G/E_	O/O	_G/E_	O/O	_G/E_	_E/E_	–
Bothriochloa barbinodis	O/O	–	O/G	O/F	–	_V/F_	–	O/F	O/E	O/V
B. caucasica	O/V	–	O/V	_O/G_	–	_O/E_	–	O/O	O/G	_O/E_
B. ischaemum	_F/F**_	–	_O/F_	_E/E**_	O/O	_E/E**_	_E/E**_	_G/G**_	_E/E**_	_G/G**_
Bothriochloa ischaemum-King Ranch	O/F	–	O/G	_G/E**_	–	_G/E**_	–	O/G	O/G	_O/G_
Bouteloua curtipendula	O/V	–	O/E	_V/E_	O/P	_F/E**_	_P/E_	_G/G_	–	_P/G_
B. curtipendula-Tucson	O/E	–	O/F	O/G	–	_O/E_	–	_P/E_	_G/E_	_P/G_
B. curtipendula-Vaughn	_F/G_	–	–	–	–	_O/E_	–	_E/E_	_E/E**_	–
B. eriopoda	_P/G_	–	O/G	O/E	O/F	_O/G_	O/F	P/F	P/G	O/V
B. gracilis	_G/E_	O/F	O/G	P/G	_O/G_	_F/E_	_F/G_	_G/E_	_V/E_	P/G
B. gracilis-Lovington	_O/E_	O/P	O/G	P/G	–	_F/E_	–	_F/E_	_G/E_	–
Bromus erectus	_O/G_	–	O/F	–	–	O/P	–	–	–	O/V
B. inermis	_F/G_	–	O/G	O/O	O/G	O/F	O/G	–	–	–
B. inermis-Achenbach	P/E	–	–	_F/G_	–	O/F	–	–	–	–
Buchloe dactyloides	O/G	–	O/G	_E/E*_	–	_O/G_	–	_E/E*_	_F/E*_	–
Ceratoides lanata	O/O	–	_E/E**_	O/O	–	O/V	–	_F/F**_	_E/E**_	O/O
Digitaria eriantha	–	–	O/O	O/E	–	_V/E_	–	O/O	O/E	O/O
Elymus junceus	_O/E_	_F/E_	P/E	_E/E**_	–	O/F	–	O/F	_F/E**_	O/O
Eragrostis chloromelas	O/G	–	O/F	O/G	–	_O/E_	–	O/G	O/F	_E/E**_
E. curvula	O/E	–	O/E	O/E	_G/E_	_F/E_	_F/E_	O/G	O/F	O/P
E. lehmanniana	–	–	–	O/O	O/P	–	–	O/V	–	_O/E_
E. superba	–	–	–	–	–	O/O	–	O/O	–	_G/E**_
Festuca ovina-duriuscula	V/F	–	–	_E/E**_	–	O/V	–	–	–	–
F. ovina-sulcata	_F/F_	–	–	_E/E**_	–	O/V	–	–	–	–
Hilaria jamesii	O/G	O/V	O/F	O/P	–	_G/E_	–	O/V	–	–
H. mutica	O/V	–	O/V	–	–	_F/F_	–	O/O	–	–
Koeleria cristata	_F/F**_	–	O/P	O/V	–	–	–	–	–	–
Medicago falcata	P/G	–	O/G	_F/E_	–	O/E	–	–	–	–
Melilotus alba	_E/E**_	–	O/E	O/E	_E/E**_	O/E	–	–	–	–
M. officinalis	O/E	–	O/E	O/E	_E/E**_	O/E	–	–	–	–
Menodora scabra	–	–	O/V	–	–	_E/E_	–	O/G	O/E	O/O
Muhlenbergia wrightii	_E/E**_	_F/G**_	_E/E**_	_E/E**_	_G/G**_	_E/E**_	–	P/G	O/F	O/O
Panicum hallii	O/G	–	O/F	–	–	O/E	–	_F/G**_	O/E	O/F
P. obtusum	O/P	–	O/F	O/V	O/P	O/F	_O/E_	_O/E_	O/F	_P/E*_
P. virgatum	O/F	–	O/G	O/F	–	_E/E*_	–	_F/F*_	O/G	–
Poa pratensis	_F/G_	–	–	–	–	–	–	–	–	–
Purshia tridentata	_F/G_	–	O/F	O/O	O/O	O/O	O/O	_V/G_	O/O	O/O
Sanguisorba minor	O/F	–	O/P	O/E	–	_P/E**_	–	O/G	O/E	–
Schizachyrium scoparium	O/V	–	O/F	O/O	–	_F/F_	–	O/O	–	–
Sitanion hystrix	_F/G_	–	O/F	O/E	–	O/P	–	_F/G_	O/F	–
Sorghastrum nutans	_O/F_	–	O/P	–	–	–	–	O/O	–	–
Sorghum halepense	O/P	–	O/F	–	_G/G*_	O/E	–	O/E	–	–
Sporobolus airoides	O/P	–	O/F	O/G	–	_O/G_	–	O/F	_F/F_	O/O
S. cryptandrus	O/G	O/P	O/V	_O/G_	–	O/E	–	O/G	V/G	_V/F_
S. wrightii	O/O	–	O/O	O/F	–	_E/E**_	–	O/O	_O/F_	–
Stipa viridula	O/F	–	O/P	_O/G_	–	V/P	–	O/F	O/F	O/V
Tridens albescens	O/F	–	O/F	O/G	O/P	O/E	_O/G_	O/G	_O/F_	_O/G_
T. elongatus	O/G	–	O/G	_F/F**_	_O/G_	_G/G**_	_O/F_	_O/G_	_F/G_	_V/F_

[1] Final rating/maximum rating: O = failure, V = very poor, P = poor, F = fair, G = good, E = excellent, – = not planted.
[2] Italic indicates sites where species and varieties survived 10 or more years and attained a relative rating of fair or better.
[3] Spreading at time of final observation: * = vegetative spread, ** = spread by natural seeding.

Results and Discussion

Adaption

Fifty-nine of the 240 species and varieties tested were adapted to one or more sites. Fifty-four of these were still present in 1973 (Table 2), 45 with stands rating fair or better. The five species adapted but not present in 1973 had all survived for at least 10 years and some as long as 20 years.

Based on our observation, species adaptation might be considered as persistence for at least 5 years and attainment of relative rating of fair or better. This time period, which is shorter than has generally been accepted in the past, appears to be adequate if it includes at least one prolonged drought. The shorter time interval would be especially important for judging small, test plantings because factors other than site adaptability can affect species survival in them.

Forty percent of the species planted in the cool-moist subtype were adapted. Thirty-four percent were adapted to the warm-moist subtype, and 29% to the warm-dry and to the cold-moist subtypes. Only 13% were adapted to the cold-dry and 9% to the hot-moist subtypes. This indicates that the cool-moist and warm-moist subtypes are most favorable for revegetation with the species tested. All species were not planted on all sites because it was initially known that some were not adapted to certain sites.

The most widely adapted species were crested wheatgrass (*Agropyron desertorum*), intermediate wheatgrass (*A. intermedium*), western wheatgrass (*A. smithii*), pubescent wheatgrass (*A. trichophorum*), fourwing saltbush (*Atriplex canescens*), yellow bluestem (*Bothriochloa ischaemum*), sideoats grama (*Bouteloua curtipendula*), spike muhly (*Muhlenbergia wrightii*), and rough tridens (*Tridens elongatus*) (Table 2). These nine species show the best potential for use on Arizona pinyon-juniper rangelands.

Yellow bluestem, the most widely adapted species, did best in the warmer subtypes where it rated excellent on four sites. It is long-lived and forms a dense ground cover. At Buckhead Mesa it has invaded the native vegetation and dominates the study area. Fourwing saltbush probably is just as widely adapted as yellow bluestem, but was not tested in the hot-moist subtype. Western wheatgrass, rated excellent at seven sites, is outstanding in forming a heavy protective cover. Its main disadvantage is slow establishment. Pubescent wheatgrass rated excellent at Mud Tanks and Pine Creek, but at both sites was stemmy with few basal leaves. Crested wheatgrass at Pine Creek grew in large clumps with wide bare interspaces. This type of growth provides poor protection against both raindrop splash and surface runoff erosion. Spike muhly had a final rating of excellent at four sites. It established slowly but, once established, was vigorous, aggressive, and produced a large volume of foliage. Sideoats grama is widely adapted, apparently doing better on the warmer sites. The difference in responses of the Vaughn and Tucson varieties indicates the need for variety tests on specific sites. Rough tridens was adapted to all but the cold sites. This was a native seed source whose potential is not understood.

Winterfat (*Ceratoides lanata*) became established at only three sites and rated excellent at two. It is probably more widely adapted than our results indicate, but is difficult to establish because the planting techniques used are not reliable. Russian wildrye (*Elymus junceus*) maintained an excellent to fair stand at Moritz Lake despite 22 seasons of extremely heavy cattle use. The sweet clovers (*Melilotus* spp.) maintained excellent stands at Peterson Flat and Pine Creek. Boer lovegrass (*Eragrostis chloromelas*) persisted only at Sierra Ancha. There, however, it dominated the study site, invading bare areas where other species had failed.

Weed competition occurred at all sites but was especially heavy at Pleasant Valley where the study was located on an old cultivated field that had been abandoned for many years. Among the species adaptation characteristics for this site was an ability to overcome weed competition.

Establishment and Survival

Establishment, growth and development of the seedling after initial emergence, was excellent in five of the six subtypes, ranging from 88 to 98%. Poorer establishment, 61%, occurred in the hot-moist subtype. Survival, persistence of living plants from initial emergence to time of the last observation, was 40 to 48% of the planted species in the four most favorable subtypes. Only 27%, however, survived in the hot-moist and 19% in the cold-dry subtypes.

Natural Spread

Thirty species and varieties spread naturally (Table 2). The most vigorous spreaders were western wheatgrass, winterfat, yellow bluestem, and spike muhly. The panicums (*Panicum* spp.), sweetclovers, spike muhly, yellow bluestem, Boer and weeping lovegrass (*Eragrostis curvula*) tended to establish better and spread more rapidly in low-lying areas, such as drainages, swales, and other depressions. Yellow bluestem was the only species observed invading native vegetation. Winterfat was difficult to establish, but, once established, spread widely. It may be practical to transplant winterfat as widely spaced plants and let the interspaces fill in by natural seeding. Fourwing saltbush did not reproduce itself in any of the plantings, although it is widely adapted and long-lived. The sweetclovers, though only biennials, persisted and spread by natural seeding. Buffalograss (*Buchloe dactyloides*) spread vigorously and formed good ground cover where adapted, but produced little foliage. Burnet (*Sanguisorba minor*) established easily and spread aggressively at Pleasant Valley but was short-lived. At nearby Young it is a lawn weed. Some plants originally identified as tall wheatgrass (*Agropyron elongatum*) were spreading by rhizomes. Possibly they had hybridized with pubescent wheatgrass.

Drought

All surviving species and varieties have persisted through severe, extended droughts. For example, a prolonged regional drought occurred from 1950 through 1957. It was especially severe in 1950–53; also 1956 was the driest year on record in Arizona (U.S. Weather Bureau 1956). In 1963 drought was so severe at several sites that fourwing saltbush lost its leaves.

In general, size, vigor, and stand seemed to fluctuate more widely in response to varying moisture conditions for the grasses than for the shrubs. The greatest variation occurred in the cool season grasses. Crested wheatgrass and, to a lesser degree, intermediate, pubescent and western wheatgrass almost disappeared during drought and improved markedly with favorable moisture. For the hot-moist subtype, low effective precipitation during the growing season, because of high temperatures and shallow-soil moisture penetration from high intensity thunderstorms, may have been the reason for poor establishment.

Temperature

Frost damage and winter kill were observed at all sites. Warm season species apparently were more limited by low temperatures than cool season species. Differences in cold resistance among varieties were also observed. For example, yellow bluestem survived lower temperatures better than the King Ranch variety (*Bothriochloa ischaemum*-King Ranch).

Seedlings of some warm-season species were apparently more sensitive to cold than the mature plants at the colder limits of their tolerance. For example, yellow bluestem established at Dog Knobs, Boer lovegrass at Pleasant Valley, and Lehmann lovegrass (*Eragrostis lehmanniana*) at Sierra Ancha during warmer years. All these stands then survived for several years before dying out. Weeping lovegrass seedlings were highly susceptible to frost heaving in the colder subtypes, especially on heavy textured soils.

Low survival in the hot-moist subtype may have been caused by drought and lethal high temperatures. High mortality in the cold-dry subtype may have resulted from slow growth rate, drought and winter kill. Some of the cool-season species, such as Amur (*Agropyron intermedium*-Amur), crested, intermediate, and tall wheatgrass, became established in the warm subtypes but were relatively short-lived there. These results agree with those of Decker (1974), who found that high soil temperatures adversely affected stand persistence for some cool-season species.

Animal Effects

Animal activity was observed at all sites. This is of special concern because animals from neighboring areas concentrating on small plantings often exert disproportionately heavy foraging pressure. This effect is especially detrimental to seedling establishment.

Rabbit-proof fences were beneficial wherever they were used. Rabbit (*Lepus* spp. and *Sylvilagus* spp.) use was heaviest in early spring when other green feed was scarce and in depressions where foliage was most succulent. Shrub seedlings and legume plantings were the most severely damaged. Mice (*Peromyscus* spp.) dug up freshly planted seed at Drake and removed seedheads at Dog Knobs. Gopher (*Thomomys* spp.) damage was extremely heavy at Pleasant Valley, contributing to the decline of weeping lovegrass and the failure of alfalfa (*Medicago sativa*) plantings. Damage from ants, grasshoppers, and beetles was observed at all sites. Large areas of several plantings were denuded by harvester ants at Dog Knobs.

Big game grazed the test plantings at most locations. Heavy spring use of cool-season species was made by elk (*Cervus canadensis*) and deer (*Odocoileus hemionus*) at Mud Tanks and Moritz Lake and by deer at Peterson Flat. Antelope (*Antilocapra americana*) grazed the plantings at Dog Knobs. Although fencing was used to exclude livestock, some cattle grazing, as previously described, did occur.

Fourwing saltbush on heavy soils was especially large and vigorous where gophers were active, indicating plants benefited from the loosened soil that possibly allowed deeper moisture penetration. Greater growth and vigor have also been observed on light textured soils than on heavy ones.

Limited or Nonuse by Livestock

The effects of limited or nonuse by livestock may be important in considering species adaptation. It is generally known that species and varieties differ in grazing tolerance. Also, weed and native plant competition can be modified by the relative palatability and grazing tolerance of the planted species.

Ungrazed bunch grasses often develop large, dense clumps that gradually become senescent and die, apparently because of the dead, ungrazed foliage. This effect is especially common with ungrazed weeping lovegrass. When clumps are kept small by grazing or burning, weeping lovegrass retains a full, vigorous stand. Loss of vigor also was observed on yellow bluestem, sideoats grama, Boer and Wilman lovegrass, spike muhly, and sacaton, all bunch grasses. Some bunch grasses, therefore, may have declined because of nonuse rather than lack of site adaptation.

Fourwing saltbush became unthrifty at all sites where it was protected from livestock grazing. Plants became woody with many dead branches, and most stands had a relatively high mortality. Unprotected fourwing saltbush at Moritz Lake and Mud Tanks heavily grazed for many years is smaller but more vigorous, less woody, and with fewer dead branches than ungrazed plants, and the stands contain few or no dead plants. Winterfat showed similar, but less marked, responses to prolonged protection from livestock grazing. It may be that livestock grazing on forage shrubs prunes back excessive foliage. providing a stimulation which otherwise might not occur for replacement of the old growth. This would indicate a need for moderate grazing beginning about the third year after establishment to encourage optimal production of these plants.

Conclusions

Species and varieties that germinated, established, and survived in satisfactory stands over a 21- to 28-year period under a wide array of adverse conditions are adapted to the different sites as shown in Table 2. Adaptation to Southwestern pinyon-juniper rangeland conditions might be determined sooner than the 10 to 20 years generally accepted if at least one prolonged drought occurs within the shorter period.

Species failure is not, by itself, conclusive proof that plants are not adapted. Some species may require special seed treatment or planting techniques; others, might survive in larger plantings with less severe animal depredation. The reaction to livestock grazing is still undetermined. Moderate livestock grazing may be essential to some bunch grasses and shrubs for long-time persistence with good vigor.

Persisting species and varieties have survived harsh environments and might provide a genetic pool for obtaining new accessions better adapted for seeding ranges of the Southwestern pinyon-juniper type. Further work is needed, especially on the nine most widely adapted species, to refine selection of varieties to specific situations and encourage their use for revegetation.

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Some Range Relationships of Feral Goats on Santa Catalina Island, California

BRUCE E. COBLENTZ

Highlight: Some aspects of forage production, utilization, and percent cover were studied on Santa Catalina Island from July 1971 through April 1973. Food habits of feral goats (*Capra hircus*) were examined in December 1974 and May 1975. During May 1975 herbaceous vegetation comprised 92% of the diet of the goats. It was proposed that goats are not primarily browsers by preference, but are opportunistic generalists and tend to consume the most palatable vegetation available. Significant vegetational differences are found between adjacent goat-inhabited and goat-free areas of the island. It was concluded that precise ecological knowledge is needed to properly manage both domestic and feral goats.

Domestic goats (*Capra hircus*) are the ecological dominant in many areas of the world where they have increased unchecked (Bates 1956). Excessive numbers can severely alter the floral composition of their habitat as well as drastically reduce the total amount of vegetation present. In Lebanon (Talbot 1960) and southern Europe (Darby 1956; Stewart 1956) goats have been blamed for the failure of the forests to regenerate after being cut or burned. The most graphic examples, however, have involved feral goats which were introduced onto oceanic islands. In those areas [Hawaii (Yocum 1967, Baker and Reeser 1972; Spatz and Mueller-Dumbois 1973), New Zealand (Atkinson 1964), Kermadec Islands (Sykes 1969), Guadalupe Island (Greenway 1958; Moran 1967), the Galapagos Archipelago (Hamann 1975), and Santa Catalina Island (Coblentz 1974)] the species has had a readily apparent effect upon the endemic insular vegetation.

Little investigation has been made into the long-term effects that goats have upon an area. Despite the goat's great worldwide importance, especially in the tropics (Devendra and Burns 1970), precise ecological knowledge concerning the species is lacking.

Goats have the ability to utilize coarse, low quality forage efficiently. As a result, when goats are kept in areas having a long history of overutilization, they tend to subsist on the coarse, bitter shrubbery which remains. Because of their high threshold for bitter taste (Bell 1959) and the ability to utilize coarse shrubbery, recent workers have experimented with goats as a tool for brush control in semiarid rangelands (Irvine 1941, cited in Campbell et al. 1962; Hornby and van Remsburg 1948; Davis et al. 1975; Merrill and Taylor 1976). Depending upon the season and the forage species available, goats may selectively suppress or eliminate certain favored plant species, without damaging the overall quality of the range (Campbell et al. 1962; Merrill and Taylor 1976). While there is little question that goats can, at times, prove useful as a tool for selective brush control (Davis et al. 1975), their utility may not be the result of a straightforward preference for browse.

Huss (1971) cited several studies which indicated that goats were primarily browsers by preference, and Yocum (1967) provided similar data from winter-killed Hawaiian goats. Summer food habits of Hawaiian goats were different, however, when as much as 89% of the diet was grasses (Morris 1969 cited in Baker and Reeser 1972). McMahan (1964) presented data which indicated that diets of goats in the Edwards Plateau region of Texas consisted of over 50% browse, but his study was based on the diet of a single animal and may not have been representative. In New Zealand, Riney and Caughley (1959) reported that feral goats fed mainly in areas where there were large amounts of grasses. Malechek (1970) found that forage class preference of goats was seasonal and depended upon availability and stage of growth.

On Santa Catalina Island, differences in cover density and species composition between goat-infested and goat-free areas of the island were obvious, and in some cases extreme. Some areas of the island were actually devoid of vegetation, or had only those plant species which were characteristic of the earliest stages of succession. Catalina Island provided a rare opportunity to assess quantitatively herbaceous layer production and utilization of adjacent areas in terms of presence or absence of goats. A fence, erected in 1956, separated the goat-infested from the goat-free area and prevented movement of goats between the two areas. The goat-free area was utilized considerably by mule deer (*Odocoileus hemionus*), bison (*Bison bison*), and feral pigs (*Sus scrofa*).

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Portions of this paper were presented to the Horace H. Rackham School of Graduate Studies, University of Michigan, in partial fulfillment of the requirements for the PhD degree in wildlife ecology.

Manuscript received November 4, 1976.

The objectives of this study were (1) to determine food habits of the goats both before and after the period of major plant growth, and (2) to test the hypothesis that there were differences between the vegetation of adjacent goat-free and goat-inhabited areas of the island. Both areas sampled had a long history (>150 years) of excessive forage utilization, and the goats had been absent from the goat-free area for nearly 20 years.

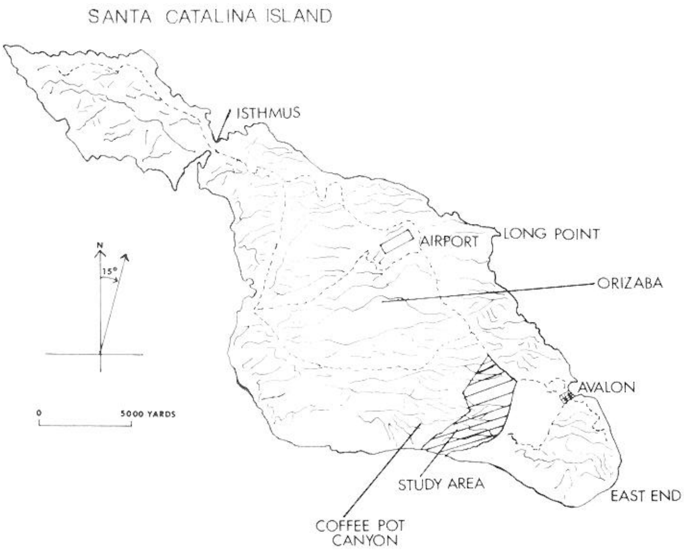

Fig. 1. *Catalina Island.*

The Study Area

Santa Catalina Island is located approximately 35 km off the coast of southern California at the Palos Verdes peninsula. The island is about 35 km long and ranges in width from less than 0.85 km at the isthmus to about 12.9 km at its center (Fig. 1), and is approximately 196 km² in area. The topography of much of the island is rugged and precipitous. The two highest points rise only slightly over 610 m, but the rise is abrupt.

Catalina Island has an oceanic, Mediterranean climate consisting of hot, dry summers and mild, damp winters. Effective rainfall usually falls between October and late April, with most falling from November through February. A 32-year average winter rainfall at Avalon, the island's only town, was 31.37 cm (Dunkle 1950).

It is unknown when the goats were first introduced to he island. They were well established in 1827 when the earliest known record of them was made (Dunkle 1950).

Accurate estimates of goat populations in the past are not available. Curtis (1864) estimated the population at 15,000. Longhurst et al. (1952) gave an estimate of 50,000 goats for 1930, but that figure was not substantiated. By 1949, the estimated population declined to 10,000 animals. During this study there were between 5,000 and 8,000 individuals in a minimum of 20 distinct populations.

The most important vegetation communities in respect to this study were the grassland, coastal sage scrub, chaparral, and woodland. Woodlands were found in canyon bottoms and other protected areas where there was sufficient water. Many woodlands on Catalina consisted of nearly monospecific stands of Catalina cherry (*Prunus ilicifolia lyoni*) or Catalina ironwood (*Lyonothamnus floribundus*). In larger canyons there were permanent springs, and there was a woodland comprised of black cottonwood (*Populus trichocarpa*), willow (*Salix* spp.), elderberry (*Sambucus mexicana*), oak (*Quercus* spp.), and Catalina cherry.

The chaparral community was a complex of chaparral types. The dominant members of the community varied with location. The most frequent dominant was scrub oak (*Quercus dumosa*), followed by chamise (*Adenostema fasciculatum*) and white lilac (*Ceanothus megacarpus insularis*). Other shrubs associated with the chaparral were lemonade berry (*Rhus integrifolia*), laurel sumac (*Rhus laurina*), poison oak (*Rhus diversiloba*), manzanita (*Arctostaphylos catalinae*), toyon (*Heteromeles arbutifolia*), island buckthorn (*Rhamnus pirifolia*), and mountainmahogany (*Cercocarpus betuloides*).

Fig. 2. *Some of the 5,000 to 8,000 goats on Catalina Island.*

Coastal sage scrub was an open community of small shrubs interspersed with annual herbaceous vegetation and occasional small trees (Fig. 2). The major components of this community were white sage (*Salvia apianna*), black sage (*Salvia mellifera*), California sagebrush (*Artemisia californicus*), St. Catherine's lace (*Eriogonum giganteum*), and pricklypear (*Opuntia* sp.).

The grassland community varied both in numbers and kinds of species present and size of individuals. This community was dominated by annual grasses such as wild oat (*Avena fatua*), red brome (*Bromus rubens*), cheatgrass (*B. tectorum*), softchess (*B. mollis*), and ripgut (*B. diandrus*). Perennial bunchgrasses (*Stipa* spp.) were common in areas that had received protection from overgrazing.

Thorne (1967) described the plant communities of Santa Catalina Island in considerable detail.

Food Habits

Methods

Goats were collected by shooting. Rumen samples were taken from goats collected during December 1974 (n=29) and May 1975 (n=28). A full handful was collected from each goat as it was dressed, the rumen liquor squeezed out by hand, and the sample placed in a labeled plastic bag. Samples were frozen until analysis.

For analysis, samples were thawed in warm water, and washed through a sieve (December 1974—1-mm sieve; May 1975—2-mm sieve). The sample was spread in a 17.8-cm × 30.5-cm white enamel pan, and recognizable plant fragments were removed and separated by species for a period of 2 hours. Separated samples were placed in an oven for 24 hours at 100°C and weighed to the nearest 0.01 g.

Results

Annual grasses, primarily *Bromus*, were the most frequently utilized food item in all periods studied. Grasses were least important in winter before the new growth began, but even during this period (December 1974), they had a 100% frequency and comprised more than 20% of the identified fraction in 5 of 29 (17%) goats sampled. As the grasses began maturing toward the end of the growing season, they increased in importance until they were the primary dietary component (>50% of identified fraction) of 27 of 28 (97%) goats. It is clear that browse was the forage class of major importance early in the winter (90% of identified fraction, December 1974) and that herbaceous vegetation increased in importance through the growing season (Table 1). In May 1975 when the samples were taken, grasses comprised 74% of the diet, and forbs another 18%. Woody browse at that time comprised only 8% of the identifed fraction.

Table 1. Percent frequencies and percent by weight of forage classes found in Santa Catalina Island goats. Percent frequencies as the major dietary component (>50% of identified fraction) are in parentheses.

	December 1974 n=29		May 1975 n=28	
Forage class	Frequency	Weight	Frequency	Weight
Grass	100 (0)	6	100 (96)	74
Forb	86 (0)	4	100 (0)	18
Browse	100 (100)	90	100 (0)	8
Other	17 (0)	trace[1]	3.6 (0)	trace

[1] Trace = less than 0.5%.

During May 1975, goats were collected from two specific herds, one occupying what I considered excellent goat habitat, and the other occupying poor goat habitat. Habitat quality was judged subjectively on the basis of my ocular estimate of herbaceous cover and the species composition of the vegetation. The percentages of forage classes by weight, of the identified fraction of the samples, were nearly identical from the two areas (Table 2). However, the species composition of the diets from the two areas was different. Wild oat was identified nearly 5 times as frequently in the goats from the excellent habitat (Orizaba) and comprised 16 times as much of the diet by weight. Annual bromes were found with greater frequency and amount in the goats from the poor area (Coffee Pot Canyon). Fillaree (*Erodium* sp.), an indication of poor or overutilized range, was found twice as often in samples from the poor area and comprised over 8 times as much of the diet by weight. Buckthorn and toyon were found only in goats from the poor area although these species were present in both areas. The reasons for this and other differences in browse utilization were not readily understood, but certainly related to the nutritional content of the plants and relative availability of all forage species.

Table 2. Percent frequencies, percentages of identified fraction by weight, and range of percentages of identified fraction by weight for individuals, of food items identified by herd, in Santa Catalina Island goats collected in May 1975.

	Orizaba n=15			Coffee Pot Canyon n=13		
	% Freq.	% Wt. all	Range % wt. ind.	% Freq.	% Wt. all	Range % wt. ind.
Grass	100	70	49–80	100	69	39–81
Softchess	47	1	0–8	77	1	0–7
Wild oat	100	3	0–16	23	trace[1]	0–1
Cheatgrass	73	1	0–3	77	2	0–5
Red brome	13	trace	0–1	23	1	0–7
Hordeum	7	trace	0–2	—	—	—
Ripgut	20	trace	0–1	—	—	—
Unident. forbs	87	14	0–35	100	15	4–31
Bur clover *Medicago* sp.	60	2	0–15	62	1	0–10
Filaree *Erodium* sp.	47	trace	0–3	92	3	0–14
Blue dicks *Dichelostemna* sp.	7	trace	0-trace	23	trace	0-trace
Unident. browse	47	1	0–4	54	1	0–7
Lemonade berry	73	2	0–7	54	1	0–4
Black sage	20	1	0–19	77	2	0–11
Oak	20	2	0–31	8	trace	0-trace
Monkey flower *Mimulus* sp.	27	trace	0–1	—	—	—
Sugarbush *Rhus* sp.	33	2	0–11	8	1	0–11
Sagebrush	20	trace	0-trace	—	—	—
Buckthorn	—	—	—	31	1	0–8
Toyon	—	—	—	46	1	0–3
Moss	—	—	—	8	trace	0-trace
Opuntia pad	—	—	—	8	trace	0-trace
Mountainmahogany	—	—	—	8	trace	0-trace

[1] Trace = less than 0.5%.

Range Relationships

Methods

Twenty chicken wire cones of 0.0001 acre (0.407 m^2) each were established for two successive growing seasons, 10 each in the goat-inhabited and goat-free areas. The cones were established before the first rains in the fall of 1971, and the plots clipped after growth had ceased after each of the two subsequent growing seasons. In 1972, the plots were clipped 2 months after the growing season had ended; in 1973, it was necessary to clip the plots immediately after growth had ceased, and these data do not reflect total utilization of herbaceous vegetation for the 1972–73 growing season. For each cone an adjacent pair plot was chosen so that an index of utilization could be obtained. Paired plots were deliberately chosen to be nearly equal in vegetation density to the protected plots. The plots were clipped to ground level and the samples were placed into paper sacks, air dried, and weighed to the nearest 0.1 gram.

For the purpose of measuring aerial cover, 20 permanent point transects were established in brushland areas: 10 in goat-inhabited area and 10 in similar habitat in adjacent goat-free area. Each transect was 100 feet (30.5 m) long. A 100-foot (30.5 m) plastic rope was stretched between the stakes. Each foot (30.5 cm) of the rope was marked, and except for ground vegetation, 'hits' (the presence of vegetation) were recorded by species at each foot mark. The type of bare substrate exposed (soil, gravel, rock) was recorded for those points that did not 'hit' vegetation during the November 1972 sampling. Brushland transects were sampled in November of each year of the study and again after growth had essentially ceased for most species.

In June 1972, 30 temporary point transects were established and sampled along ridgetops to determine vegetation density on ridgetops in the presence and absence of grazing by goats. Temporary ridgetop point transects were sampled in two goat-inhabited areas and one goat-free area.

Comparisons of means of all vegetation data were made using the Student's *t*-test.

Table 3. Average herbaceous forage production (g/0.407 m^2) for the 1971–72 and 1972–73 growing seasons on Santa Catalina Island.

	Sample size	1972	1973
Goat area			
Protected	10	33.3*[a]	84.7*
Nonprotected	10	14.6*[b]	62.7*[c]
Goat-free area			
Protected	10	98.6[a]	111.1
Nonprotected	10	50.7*[b]	106.3*[c]

* Means significantly different between years ($P<0.05$).
[a, b, c] Means having common letter superscripts were significantly different within years ($P<0.05$).

Results

Grassland Production and Utilization

In 1972, the means of both protected and nonprotected plots were significantly different ($P<0.05$) between the goat-inhabited and goat-free areas (Table 5). Both production and utilization were much greater in the goat-free areas than in the goat-inhabited area (Table 4); however, percentage utilization in the goat-inhabited area (56.2%) was greater than in the goat-free area (43.4%).

In 1973, winter rainfall was more than three times as great as in the previous year, and production in the two areas not only increased but was more nearly equal between areas. Differences in production between the two areas therefore, was greater when total winter rainfall was low. Production of nonprotected plots was significantly different ($P<0.05$) in 1973, but there were no significant differences between the protected plots.

In 1973, production in the goat-free area was only 25% greater than in the goat-inhabited area, but utilization was about 75% less. Apparently in a winter with high rainfall, production is more nearly

Table 4. Estimates of production and utilization of grasslands in the goat-inhabited and goat-free areas of Santa Catalina Island, based on air-dry weights of forage from protected plots.

	1972		1973	
	Goat area	Goat-free area	Goat area	Goat-free area
Production kg/ha	818	2202	2081	2730
Nonutilization kg/ha	359	1246	1540	2612
Utilization kg/ha	459	954	540	118
Utilization (%)	56	43	26	4

equal across the entire island. In the goat-inhabited area, more forage was utilized in 1973 than in the previous year, but the percentage of the total production that was taken was only about half (Table 4).

Brushland Transect Analysis

Vegetation quality between the goat-inhabited and goat-free areas was visibly different; however, the only statistical differences ($P< 0.05$) of density of forage classes or shrub species among surveys, areas, or years were between California sagebrush and perennial bunchgrasses. In the goat-inhabited area, sagebrush was virtually absent and bunchgrasses were scarce.

By percent cover, white sage was the most prevalent component of the shrubland in goat-inhabited areas (12.35 ± 1.86%) during the study (Table 5) but was only third in the goat-free area, where annual grasses (14.50 ± 3.33%) and sagebrush (9.38 ± 4.75) both exceeded white sage (8.95 ± 2.70%). Forbs did appear to increase greatly in both areas as a result of the increased rainfall. In both the goat-inhabited area and the goat-free area, there was at least five times as much forb cover in April 1973 as there was the previous spring.

Ridgetop Transects

Ridgetops were visibly overgrazed and eroded considerably more than were lower slopes. The amount of bare substrate was much greater in the goat-inhabited area than in the goat-free area ($P<0.05$, Table 6). The reverse relationship applies to the total percent cover of vegetation. It is apparent that there is considerably more gravel and exposed rock on the goat-inhabited area ridgetops. The ridgetop data also indicate a 300 to 400% increase in the vegetative cover in the goat-free area since the goats were eliminated in the late 1950's.

As a further comparison, bare substrate was recorded by frequency and type from the brushland transects in November 1972 (Table 6). Total vegetative cover in the goat-free brushland was about the same as the goat-free ridgetops. In the goat-inhabited area, however, total vegetative cover was at least twice as great in the brushland transects. Bare rock was also much more frequent on the goat-inhabited area ridgetops than in other areas sampled.

Discussion

Food Habits

Intensive observation of the plants within goat-infested portions of the island showed that the goats utilized most, if not all, plant species present. No plant species were observed to be completely free from utilization. Some species which had a sparse distribution, such as toyon, chamise, and island buckthorn, received almost 100% utilization. Some particularly oily and perhaps bitter plants such as vinegar weed (*Trichostema lanceolatum*), locoweed (*Astragalus leucopsis*), and tree tobacco (*Nicotiana glauca*), were utilized only when most other forage was severely depleted, and then only sparingly.

The diet of an individual goat was determined to a considerable extent by what forage classes and/or plant species were present in its particular herd home range. Since the plant species diversity of most goat areas of the island has been severely

Table 5. Mean percent cover of major vegetational components of the brushland point transects in the goat-inhabited and goat-free areas of Santa Catalina Island during four surveys.

Species	Goat presence[1]	Nov. 1971	Mar. 1972	Nov. 1972	Apr. 1973	Average
Annual grass	a	7	6	8	10	8
	b	20	9	14	16	14
Perennial grass	a	trace[2]	trace	trace	1	trace
	b	2	1	1	2	1
White sage	a	11	14	9	16	12
	b	8	11	6	11	9
Pricklypear	a	1	2	2	1	1
	b	2	2	2	1	2
Sagebrush	a	0	0	0	0	0
	b	8	11	6	12	9
Annual forbs	a	2	4	trace	16	6
	b	2	2	3	14	5
Total vegetation	a	24	28	20	47	27
	b	42	37	31	57	42

[1] a = goat-inhabited area; b = goat-free area.
[2] Trace = less than 0.5%.

reduced, relatively few species made up the major share of the diet. Annual grasses, annual forbs, oak, toyon, lemonade berry, pricklypear, and black sage comprised the greater portion of the diet; however, observations of feeding goats indicated that white sage and California sagebrush were also highly utilized browse species in spring and summer. White sage, however, did not appear in the samples examined, and sagebrush, where available, appeared in only moderate amounts (Table 2). Both species were easily chewed into unidentifiable particles, and white sage also lost its distinctive, white, oily coating.

Domestic goats have been characterized as browsers by choice; however, in the current study, goats were observed to regularly concentrate on the few areas of green herbaceous growth during the growing season and remain feeding on this vegetation each day until satiated. This preference for herbaceous vegetation in the spring is clearly expressed in the May 1975 samples (Table 1).

Domestic goats may, in some instances, be almost exclusively browsers out of necessity rather than preference. Goats are frequently kept in range areas that have been severely over-utilized by excessive numbers of other species of livestock and where almost all remaining vegetation is relatively unpalatable shrub species. In these instances, the goat's remarkable ability to subsist on poor quality vegetation enables it to survive, virtually exclusively, on the available browse. Thus, the kind of habitat or pasture in which goats are kept may determine the diet to a greater extent than preference does. Data gathered during this study support the contention that goats are opportunistic

Table 6. Mean percent bare substrate and mean percent total vegetation cover between goat area and goat-free brushlands and between goat area and goat-free ridgetops on Santa Catalina Island.

	Earth	Gravel	Rock	Total base substrate	Total vegetation
Brushland					
Goat area	67±8[1]	12±8	1±2	80±5	20±5
Goat-free area	58±6	10±9	1±3	69±7	31±7
Ridgetops					
Goat area					
Grand Canyon	56±13	29±14	6±4	90±5	10±5
Silver Canyon	48±6	38±7	7±3	93±3	7±3
Goat-free area	52±7	17±8	2±2	70±6	30±6

[1] With 0.95 confidence limits.

generalists and tend to consume the most palatable and nutritious forage that is available.

Range Relationships

The difference in feeding methods between goats and other grazers on Catalina has perhaps had greatest significance upon herbaceous production. Goats often ate plants down to the ground level and in fact, ate some by pulling them up. The resultant effect was to reduce the amount of vegetation which remained on the ground until the next growing season began. The major grazing animals found in the goat-free areas, the mule deer and bison, both left considerably more of the plant on the ground after grazing. As a result, a mulch layer formed and associated soil formation occurred in the goat-free area, while the goat-inhabited areas were left largely with bare substrate.

Mulch formation would be expected to contribute to stabilization of the habitat in a semiarid habitat by making more efficient use of rainfall, slowing erosion, and adding to the nutrient pool of the soil. There were significant differences ($P<0.05$) in production of the protected plots (Table 3) between years in the goat-inhabited area, but no corresponding differences in the goat-free area. This indicated that mulch formation was an important factor contributing to herbaceous production on Catalina, and also that the magnitude of its effect was inversely proportional to total rainfall.

Because of the long separation from the mainland, and the equally long time during which they evolved in the absence of grazing or browsing pressure, many endemic species of plants on the island were not able to withstand the degree of utilization imposed upon them when herbivores were introduced. In total, at least 48 indigenous and 18 introduced plant species have apparently disappeared in recent times, and many more may have disappeared before the turn of the century (Thorne 1967). Cactus patches were important in that they provided seedbeds for some favored forage plants. Many annuals in the goat-inhabited areas grew almost exclusively within the cactus patches, or became reproductive only under the protection of the cactus. Without the cactus acting as a refuge for many of these species, some might have been completely eliminated long ago.

Many woody species on Catalina Island were more abundant in the goat-free areas. It was not determined experimentally that these plants had increased only since goats were removed; however, D. Propst (personal communication) states that this is the case for California sagebrush (Table 5). The predominance of white sage in the goat-inhabited area brushland was probably evidence that, although taken in considerable quantity by the goats, it was not highly favored forage, and thus was abundant in some areas where competing plants were eliminated.

Both the climate and the soil of the two adjacent study areas were similar, and this suggests that the observed differences between them were a result of the removal of goats from the goat-free area. Evidence supporting the contention that the removal of goats can allow the increase of certain plant species was presented by Hamann (1975). He reported that on Isla Santa Fe in the Galapagos, goats were completely eliminated, and after 2 years there had been a ''notable regeneration of woody plants . . . undoubtedly due to the cessation of grazing by goats.''

Little is known of the ecology of the goat. Food preferences of the goat may not always coincide with the wishes of the range manager, and thus goats must be used with caution due to their potential for devastating rangeland. More precise ecological knowledge of the goat is needed so that its abilities can be efficiently and safely harnessed.

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Herbicides, Nitrogen, and Control of Tall Larkspur under Aspen Trees

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Highlight: Tall larkspur (*Delphinium barbeyi* Huth.) dominates the herbaceous vegetation under quaking aspen (*Populus tremuloides* Michx.) on large areas of mountain summer ranges in southern Utah. These tall larkspur plants are more susceptible to single applications of 2,4,5-T and silvex than reported for the same species growing in the open subalpine meadows of central Utah. The herbicide treatments evaluated provide a means of manipulating the vegetation to produce various proportions of grasses and forbs that would be safe and desirable for cattle or for dual use by cattle and sheep. Nitrogen fertilization applied in addition to herbicide treatments did not enhance control of tall larkspur or stimulate forage production. High rates of nitrogen applied to otherwise untreated plots did not control tall larkspur, and increased forage production only the first year after application.

In central Utah, at its northern limits of distribution, tall larkspur (*Delphinium barbeyi* Huth.) is typically found at elevations above 9,500 ft. In southern Utah, it grows at elevations as low as 7,900 ft as the dominant understory plant on north-facing slopes in the extensive quaking aspen (*Populus tremuloides* Michx.) woodlands. Particularly in the mountains east of Cedar City, the abundant tall larkspur precludes safe grazing of cattle. Stockmen, except those fortunate few owning summer range free of larkspur, are restricted to grazing sheep. In the recent past this has been a serious economic handicap, forcing many livestockmen to sell their land to developers for summer homes—an irreversible act removing it from our range resource.

Sheep utilize tall larkspur extensively in late summer and fall without toxicity problems; however, some sheepmen in the Cedar City area have reported losses when herding sheep that have ingested large quantities of tall larkspur.

Control of tall larkspur could provide the operator with the option of grazing either sheep or cattle on these summer ranges and could prevent the loss of some sheep each year.

Herbicide treatments for controlling tall larkspur have been studied extensively. Data published by Hervey and Klinger (1961) indicate that tall larkspur growing in aspen ''pockets'' is somewhat less susceptible to herbicides than larkspur growing on aspen slopes. Binns, James, and Johnson (1971) reported good to excellent control after applications of ammonium sulfate, especially in combination with herbicides; however, their paper did not clearly indicate the rate of application. Cronin and Nielsen (1972) and Cronin (1974) found that control of tall larkspur in subalpine meadows required applications of herbicide treatments in two successive seasons.

The objectives of this study were: (1) to evaluate herbicide treatments and nitrogen fertilization alone and in combination for controlling tall larkspur growing under quaking aspen, (2) to

Fig. 1. *Tall larkspur (*Delphinium barbeyi *Huth.) dominates the understory vegetation of quaking aspen (*Populus tremuloides *Michx.) on a summer range on Cedar Mountain east of Cedar City, Utah. On such ranges the density of tall larkspur precludes grazing by cattle.*

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This research represents a cooperative investigation of the Agr. Res. Serv., U.S. Dep. Agr. and the Utah Agr. Exp. Sta. Utah Agr. Exp. Sta. Paper No. 2072.

This is a report on the current status of research involving use of certain chemicals that require registration under the Federal Insecticide, Fungicide, and Rodenticide Act. It does not contain recommendations for the use of such chemicals, nor does it imply that the uses discussed have been registered. All uses of these chemicals must be registered by the appropriate State and Federal agencies before they can be recommended.

Manuscript received November 11, 1976.

evaluate the response of the associated vegetation to the treatments, and (3) to determine the feasibility of manipulating the vegetation for safe grazing by cattle.[1]

Materials and Methods

This study was carried out on Cedar Mountain 11 miles east of Cedar City, Utah, on land owned by the Utah Agricultural Experiment Station, which has been described by Bowns (1971). The site, of which 50% or more was under the quaking aspen canopy, supported an understory of forbs and grasses (Fig. 1). The site at an elevation of 8,200 ft was on an east-facing slope. The dominant forb was tall larkspur, but ballhead waterleaf (*Hydrophyllum capitatum* Dougl. ex Benth.), American vetch (*Vicia americana* Muhl.), mountain bluebell [*Mertensia ciliata* (Torr.) G. Don], sweetnice [*Osmorhiza chilensis* (H. & A.) Torr.), and heartleaf arnica (*Arnica cordifolia* Hook.) were also abundant. Grasses, in order of abundance, were Kentucky bluegrass (*Poa pratensis* L.), slender wheatgrass [*Agropyron trachycaulum* (Link) Malte], and mountain brome (*Bromus carinatus* Hook & Arn.).

Herbicide treatments were applied as an aqueous solution with a knapsack sprayer at 20 gal/acre on June 9, 1971, and for split treatments also on June 6, 1972. Applications were made when the vegetative growth of tall larkspur was 10 inches tall. In 1971, silvex [2- (2,4,5-trichlorophenoxy)propionic acid] was applied at 8 lb/acre and 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] at the rates of 4 and 8 lb/acre. Silvex and 2,4,5-T were also applied as split treatments of 4 lb/acre in 1971 and 4 lb/acre in 1972. Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was applied at 1 lb/acre. Half of each herbicide plot (24 × 100 ft) received an application of 125 lb N/acre as ammonium sulfate applied with a hand-cranked broadcast spreader. For the last treatment in this experiment, ammonium sulfate was applied at 250 lb N/acre over the full plot (24 × 200 ft).

For the 1971 experiment where applications of both herbicides and nitrogen were evaluated, a block of completely randomized paired plots was used. Each of these plots measured 24 × 200 ft. In a second experiment initiated in 1972, applications of nitrogen at rates of 75, 150, 300, 600, and 1,200 lb N/acre constituted the only treatments. Plots were 12 × 50 ft, and treated plots alternated with untreated plots. Nitrogen was applied as ammonium sulfate with a hand-cranked broadcast spreader in the fall of 1972.

In both studies sampling was conducted along the common border between the treated and untreated plots. Estimates of the total herbage production of tall larkspur, of forbs other than tall larkspur, and of the grasses for both experiments were made in August of 1974. An electronic capacitance meter (Neal Electronic Company model 18-1000[2]) was used to estimate herbage production on the plots (Morris et al. 1976 and Neal et al. 1976). Meter readings were obtained and one of every four samples was clipped at a stubble height of ½ inch using a 3-dimensional technique described by Currie et al. (1973). Clipped samples were separated into the three groups of vegetation listed, bagged, oven-dried, and weighed. A coefficient of linear determination (r^2) was calculated between the meter reading and the total oven-dry weight of the herbage and between the estimated percent of the total vegetation of each subgroup and the percent of the oven-dry weight of each subgroup on the clipped samples. Meter readings were converted to oven-dry weight using a linear regression equation. The weight of each subgroup was calculated from the estimated percent in each sample.

For the 1971 experiment 40 paired samples on treated and untreated plots were used to measure the effects of the treatments on the vegetation. These paired samples, between 10 and 20 ft apart were spaced along the common border of the paired plots (Klingman et al. 1943). All samples were at least 4 ft from the border of the plot.

On the smaller fertilization plots of the 1972 experiments, 32 paired samples were used.

Data were subjected to analysis of variance, and differences in treatment means were evaluated with Duncan's multiple range test. Because not all the plots were treated with additional nitrogen, a *t*-test was used to determine significant differences between a herbicide treatment and the same herbicide treatment plus nitrogen.

Results

Coefficient of determination (r^2) between the meter readings and the oven-dry weight of the total herbage was 0.76. The r^2 for estimated percent of total production in samples of tall larkspur, other forbs, and grasses and their percent weight in the oven-dry herbage was 0.83, 0.54, and 0.48, respectively.

All herbicide treatments significantly reduced herbage production of tall larkspur (Table 1). All applications of silvex and 2,4,5-T reduced tall larkspur production to a level that should be safe for grazing cattle; however, the larkspur would have to be reduced to this level all over the grazing area accessible to them (Cronin et al. 1976). Areas treated with 1 lb/acre of paraquat (where production of tall larkspur was reduced by 85%) would be safer for cattle than an untreated area but it is questionable whether production would be reduced enough to prevent all losses. Hyder (1972) reported that applications of ½ lb/acre of paraquat killed 90–95% of Geyer larkspur (*D. geyeri* Greene) but his data indicate timing of applications was critical.

Table 1. Herbage production (lb of air-dry herbage/acre) measured in 1974, where various treatments were applied to one of two paired plots.[1]

Treatment applied: Chemical	Rate (lb/acre)	Year	Pounds of air-dried herbage produced per acre[2]: Tall larkspur	All grasses	Forbs other than tall larkspur	Total herbage
Silvex	8	1971	0.0 f	55.5 a	28.6 ef	84.1 ef
Paired untreated area			28.9 d	20.3 e	47.2 bc	96.4 de
Silvex	4 4	1971 1972	0.6 f	58.3 a	2.5 f	61.4 g
Paired untreated area			45.7 bc	32.2 cd	45.7 bc	123.6 b
2,4,5-T	4	1971	0.0 f	39.1 b	20.1 f	59.2 g
Paired untreated area			28.7 d	38.6 bc	31.6 def	98.9 cde
2,4,5-T	8	1971	1.5 f	40.4 b	33.0 def	74.9 fg
Paired untreated area			29.5 d	31.5 cd	44.2 bcd	105.2 cd
2,4,5-T	4 4	1971 1972	0.0 f	51.8 ab	55.5 a	110.2 bcd
Paired untreated area			52.0 bc	33.6 cd	67.3 a	152.9 a
Paraquat	1	1971	9.3 e	27.7 de	29.1 ef	66.1 fg
Paired untreated area			62.6 a	22.8 de	28.4 ef	113.8 bc
Nitrogen	250	1971	42.6 c	20.8 e	40.5 cde	103.9 cd
Paired untreated area			53.5 b	21.3 e	44.0 bcd	118.8 b

[1] Each value represents the average for 40 samples of vegetation growing ina 12 × 24 × 18 inch cube.

[2] Means followed by the same letter within a column do not differ significantly at the 5% level.

Grass production increased significantly as a result of treatments, except where 250 lb N/acre, 1 lb/acre of paraquat, and the single application of 4 lb/acre of 2,4,5-T were applied (Table 1). Only the silvex treatments reduced the production of forbs other than tall larkspur (Table 1). Total herbage decreased on all treated areas except where 8 lb/acre of silvex was applied, thus the increase in grass production did not replace the production lost by the depletion of larkspur and other forbs.

[1] Cattle should not be permitted to graze treated areas after applications of herbicides until frost has dried the plants. Treated plants can increase in toxicity and palatability immediately after application of the herbicides; this could result in heavier consumption of the poisonous plant.

[2] The use of trade names in this paper is for identification only and does not constitute endorsement of the product.

Differences in production of grasses, tall larkspur, and other forbs were not statistically significant between any herbicide treatment alone and the same herbicide treatment plus 125 lb N/acre (data not shown), and no visible differences were observed in the year of nitrogen application or the season after. Treatment with various rates of nitrogen did not affect the vegetation on plots treated in 1972, but during the following summer, the grasses treated with 300 lb N/acre appeared larger and darker green than those on the untreated plots. The leaf margins of tall larkspur plants became necrotic during the summer after application of 600 and 1,200 lb N/acre, and the latter rate burned the tips of grasses the summer after application. After the 1973 growing season, no visible differences were evident between plants on the treated and untreated plots.

No attempts were made to measure production of the quaking aspen trees on any of the plots. However, trees were observed for signs of herbicide injury and for nitrogen injury. None was observed.

Discussion and Conclusions

Single applications of 8 lb/acre of silvex and 2,4,5-T produced excellent control of tall larkspur growing under quaking aspen trees in this study. Both treatments have consistently failed to produce satisfactory control of tall larkspur growing in the open meadows of the subalpine zone (Cronin and Nielsen 1972; Cronin 1974). Hervey and Klinger (1961) reported similar results from Colorado. Since application costs are a substantial part of the costs of treatments, a single application of 8 lb/acre of silvex or 2,4,5-T would be more advantageous than two treatments of 4 lb/acre in each of two successive years. The success of the single treatment appears to be restricted to sites where the trees provide some protection from the sun and wind. Where these conditions exist, the single treatment might be considered,

Results also suggest that the composition of the plant community can be manipulated by herbicide treatments. Applications of 1 lb/acre of paraquat left less than 15% of the larkspur without statistically significant changes in the amount of grasses or other forbs. It might be the best treatment for a sheep range. Applications of 2,4,5-T or silvex removed most tall larkspur and substantially increased grass production and might be selected for cattle range. Silvex removed both tall larkspur and other forbs, leaving an understory community composed almost exclusively of grasses. Treatments with 2,4,5-T resulted in a mixture of grasses and forbs.

Applications of nitrogen have been reported to have controlled or enhanced the effectiveness of herbicide treatments (Binns et al. 1971), but results from our study do not support these findings. In our study the response of the vegetation to nitrogen, even amounts we considered excessive, was negligible. Perhaps the quaking aspen utilized the nitrogen before it was available to the understory vegetation. This speculation is based on the dominance of the trees on the plots and the observation that growth of the aspen commenced before the snow melted from over the herbaceous plants in the spring. Denitrification could have been a factor; conditions were optimum. During the winter the unfrozen soil was saturated, and during the spring the soil was supersaturated with water from the melting snow. Leaching was also a factor under these conditions.

Results of this study indicate that vegetation such as that found on Cedar Mountain can be manipulated with herbicide treatments so that cattle can graze safely. Production of the understory herbaceous vegetation can probably be increased by harvesting the aspen to open up the canopy and to reduce competition with forage species. Effects of aspen growth and competition were not included in this study but should be investigated on land used primarily for grazing as it is on Cedar Mountain.

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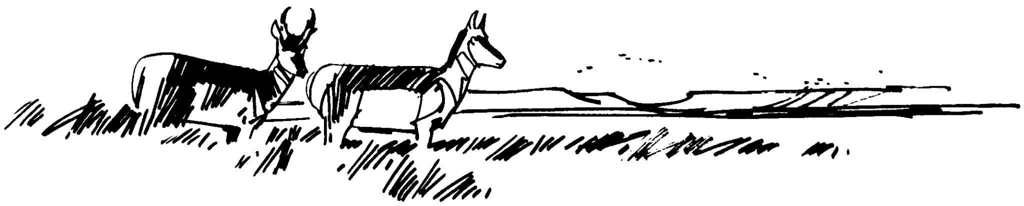

The Effect of Light and Moisture on Columbia Milkvetch Toxicity in Lodgepole Pine Forests

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Highlight: Variations in miserotoxin concentration of Columbia milkvetch located in pure lodgepole pine forests were compared to changes in rainfall patterns during the period 1973 to 1976. The substantial increase in precipitation for 1976 was reflected in soil and plant moisture changes and these conditions appeared to induce the formation of higher miserotoxin levels. In addition, a number of secondary miserotoxin peaks were generated during pod development in 1976. Understory light regimes at 12 lodgepole pine sites were determined by chemical actinometry, which expressed duration in direct sun at each plot as a percentage of "full sun" (FS) control. Sites with <15% FS exhibited lower miserotoxin levels than either the 15-35% or >35% FS groups. Miserotoxin levels above 6% predominated in the latter two categories. A positive relationship between light and toxicity was not apparent in the Douglasfir stands where miserotoxin levels remained low. A gas chromatography method was developed to speed up miserotoxin determinations and to screen Columbia milkvetch samples for the presence of free 3-nitropropanol.

Rangeland livestock poisoning resulting from the ingestion of Columbia milkvetch (*Astragalus miser* var. *serotinus*) could be reduced if danger zones were defined and avoided through a program of cattle movement. Recent surveys in British Columbia have pointed to specific rangeland areas that could be designated as hazardous. Seasonal growth patterns also reflected periodic elevated miserotoxin levels of Columbia milkvetch (Majak et al. 1974; Majak et al. 1976). For example, exceptionally high miserotoxin concentrations were observed with milkvetch plants in the rough fescue (*Festuca scabrella*) grassland zone during pre-bloom growth stages. A resurgence in toxicity during the pod stage on grassland sites was linked to a major rainfall in 1974. Concomitant increases in soil and plant moisture appeared to induce miserotoxin biosynthesis (Majak et al. 1976).

On the other hand, significantly lower miserotoxin levels were observed in Douglasfir (*Pseudotsuga menziesii*) stands, either pure or mixed with aspen (*Populus tremuloides*) and/or lodgepole pine (*Pinus contorta*) situated on Gray Luvisolic soils. A study of the variability of miserotoxin concentration (Majak and McLean 1975) corroborated the results of the earlier composite sampling experiments. The initial survey in 1973 pointed to other potential Columbia milkvetch problem areas including open lodgepole pine stands situated on Brunisolic soils. Pure lodgepole pine forests encompass approximately 50% of the 15 million acres of timbered rangeland in British Columbia.[1] A knowledge of the variation in Columbia milkvetch toxicity in these fire succession communities was required to develop guidelines for predicting hazardous zones.

The earlier study (Majak et al. 1974) suggested a relationship between available light and peak miserotoxin concentration. Miserotoxin maxima were lowest in medium-canopied montane forests, intermediate in semiopen areas such as parklands and savannahs, and highest on rough fescue grasslands devoid of any tree cover (Majak et al. 1974). To further test this relationship, variations in miserotoxin levels were assessed in relation to understory light regimes as determined by chemical actinometry and in relation to changes in rainfall patterns as reflected in soil and plant moisture levels.

Materials and Methods

Composite sampling of Columbia milkvetch was conducted sequentially at 15 experimental plots ranging in elevation from 960 to 1,260 m within a 20-km radius of Kamloops, B.C. (Table 1). These sites represented various successional levels within the Douglasfir zone (Tisdale and McLean 1957), with particular emphasis upon plant communities dominated by lodgepole pine. Plots 103 and 104 (Table 1) were located in pure stands of Douglasfir, plot 102 was in a mixed stand of lodgepole pine and Douglasfir, and the remaining sites were situated in pure lodgepole pine forests. Site indices were determined for lodgepole pine according to the method of Dodd et al. (1972). We confirmed the previous observations (Majak and Bose 1974) that oven-dried milkvetch samples yielded depressed miserotoxin values and, therefore, it was essential to extract fresh-frozen samples and to subsample for dry matter determinations.

That the precipitation patterns for Kamloops Airport (elevation 345 m) were applicable to the Columbia milkvetch experimental plots was substantiated by daily climatological reports at Cherry Creek (elevation 548 m) and Lornex mine (elevation 1,256 m) (Atmospheric Environment Service, AES, 1973–76; 1973a–1976a). The Kamloops Airport and Lornex mine weather stations were situated at the eastern and western ends of the experimental area and the Cherry Creek station was located centrally. Soil moisture was determined gravimetrically as the average of three samples taken from a depth of 10 cm. The system of the Canada Soil Survey Committee (1974) was used for soil classification.

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This report is Research Station Contribution No. 266.

Manuscript received January 18, 1977.

[1] Personal communication, A. McLean, Agriculture Canada, Kamloops.

Table 1. Physical features, site indices, and understory light regimes (% full sun) of Columbia milkvetch experimental plots.

Plot no.	Exposure	Slope (%)	Soil great group	Site[1] index (m)	Full[2] sun (%)
35	—	<1	Eutric Brunisol	—[3]	100^{a}
104	SSW	42	Gray Luvisol	—	60^{b}
100	SSE	6	Gray Luvisol	18	43^{c}
36	—	<1	Eutric Brunisol	14	42^{c}
102	SSW	35	Gray Luvisol	18	35^{d}
71	SSE	15	Gray Luvisol	17	33de
101	S	7	Eutric Brunisol	17	30de
30	—	<1	Eutric Brunisol	18	29^{e}
37	—	<1	Eutric Brunisol	15	28^{e}
29	—	<1	Gray Luvisol	20	22^{f}
103	SW	27	Gray Luvisol	—	18^{fg}
31	WNW	5	Gray Luvisol	23	13^{gh}
72	SSE	15	Eutric Brunisol	23	12^{h}
38	S	4	Gray Luvisol	21	11^{h}
70	SSW	4	Eutric Brunisol	18	10^{h}

[1] Height of lodgepole pine at age 100 years.
[2] Significance based on Duncan's multiple range test at 5% level. values sharing the same letter are not significantly different.
[3] Site index not determined.

Miserotoxin and 3-nitropropanol (3NPOH) Analyses

A rapid quantitative gas chromatography (GC) method was developed to speed up miserotoxin determinations and to screen Columbia milkvetch samples for the presence of 3NPOH, the aglycone of miserotoxin which has been reported as a constituent of other *Astragalus* species (Williams et al. 1975; Harlow et al. 1975).

Standard miserotoxin aqueous solution was obtained from the isolate described previously (Majak and Bose 1974). Synthetic 3NPOH was prepared by Garold Yost, Chemistry Department, Colorado State University, Fort Collins.

One-half of the filtrate from the ethanolic extraction of 15 to 20 g fresh-frozen milkvetch (Majak et al. 1974) was concentrated to dryness, re-suspended in 25 ml hot water, centrifuged at 27,000 × g for 5 min at 1°C, and the supernatant was decanted and stored at 2°C. The supernatant, 0.1 ml, was combined with 0.1 ml β-glucosidase (almond emulsin) solution (0.1% in 0.2*M* phosphate buffer, pH 6.2) and duplicate samples of the supernatant and standard miserotoxin were incubated at room temperature overnight. Beta-glucosidase liberated 3NPOH from miserotoxin in quantitative yield.

Quantitative GC was performed on a Microtek 220 gas chromatograph equipped with a flame ionization detector and 1 m × 4 mm (I.D.) glass columns containing 5% Carbowax 20M on Chromosorb W (HP), 80–100 mesh. The temperatures were adjusted as follows: inlet, 210°; oven, 185°; and detector, 210°C.

One-microliter aliquots of the incubated supernatant, the incubated miserotoxin standard, and the standard 3NPOH were injected with each set of analyses. The retention time for 3NPOH was 1.68 min, and the symmetrical peaks enabled one to use peak height for determinations. For these milkvetch samples it was sufficient to work in the 100–1,000 ppm 3NPOH range. Two microliter aliquots of the unincubated supernatant were injected to estimate the concentration of free 3NPOH, which, in all cases, was extremely low, occurring as <5% of the combined form of 3NPOH.

Chemical Actinometry

Concurrent sunlight readings at the various experimental locations were accomplished with uranyl oxalate chemical light meters (actinometers) according to the method of Heinicke (1963), which was validated spectrophotometrically by Looney (1968). Freyman (1968), however, demonstrated light quality differences in the understory of seral communities of the Douglasfir zone; therefore, direct comparisons between the light regimes of lodgepole pine sites and Douglasfir sites should be qualified.

The actinometric technique was identical to that described by Heinicke (1963), and the exposure time was 24 hours. To facilitate fieldwork, duplicate actinometers (20 cm apart) were placed in racks (Fig. 1) and five racks were placed adjacent to five milkvetch plants selected at random at each plot. The actinometer aperture was 17 cm from the ground. The racks were oriented E-W and the movable support (Fig. 1, S) was aligned so that the actinometer aperture was normal to the direct rays of the sun at noon or the noon solar angle (Fig. 1, a). The noon solar angle for each experiment was computed from the equation $a = 90° - \Theta + \delta$ (List 1951), where Θ = degrees latitude and δ = degrees solar declination. The percent "full sun" value for each site (Table 1) was the mean from 10 actinometer readings. These readings were examined statistically by analysis of variance and Duncan's multiple range test.

Results and Discussion

Rainfall Patterns in Relation to Miserotoxin Concentration

The interval between 1973 and 1976 was characterized by two weather extremes during the summer grazing periods: exceptional drought in 1973 and record-breaking rainfalls in

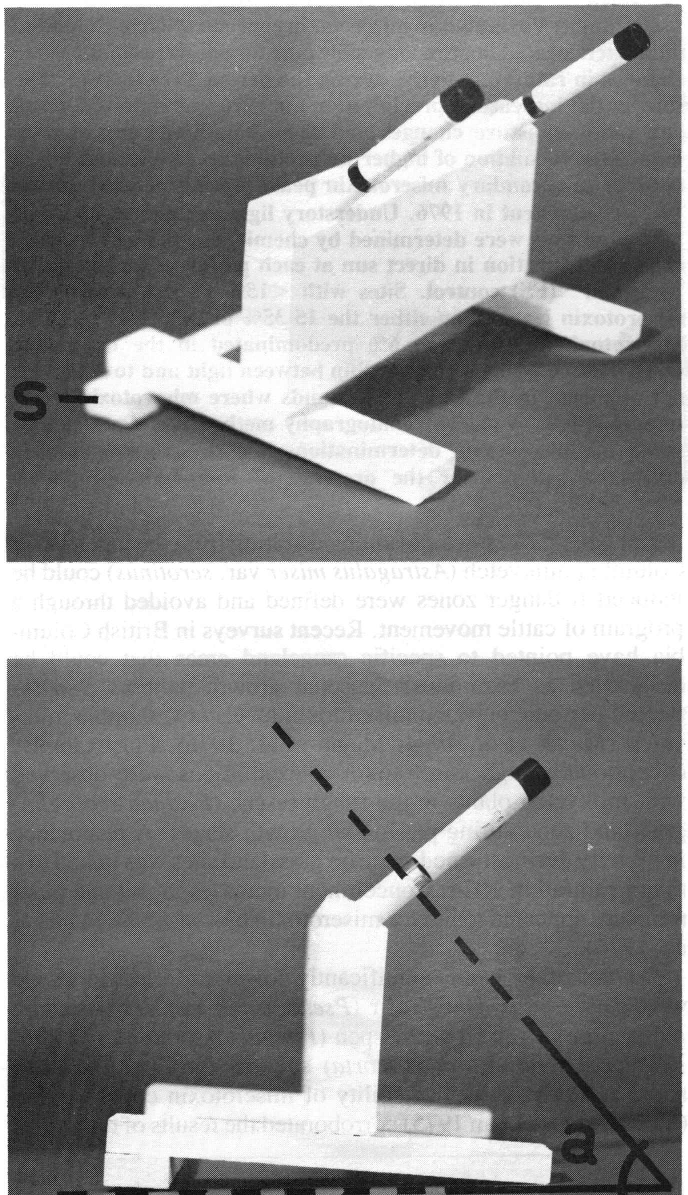

Fig. 1. *Two views of the chemical actinometer rack with the side view showing the movable support (S) set for noon solar angle (a) = 50°.*

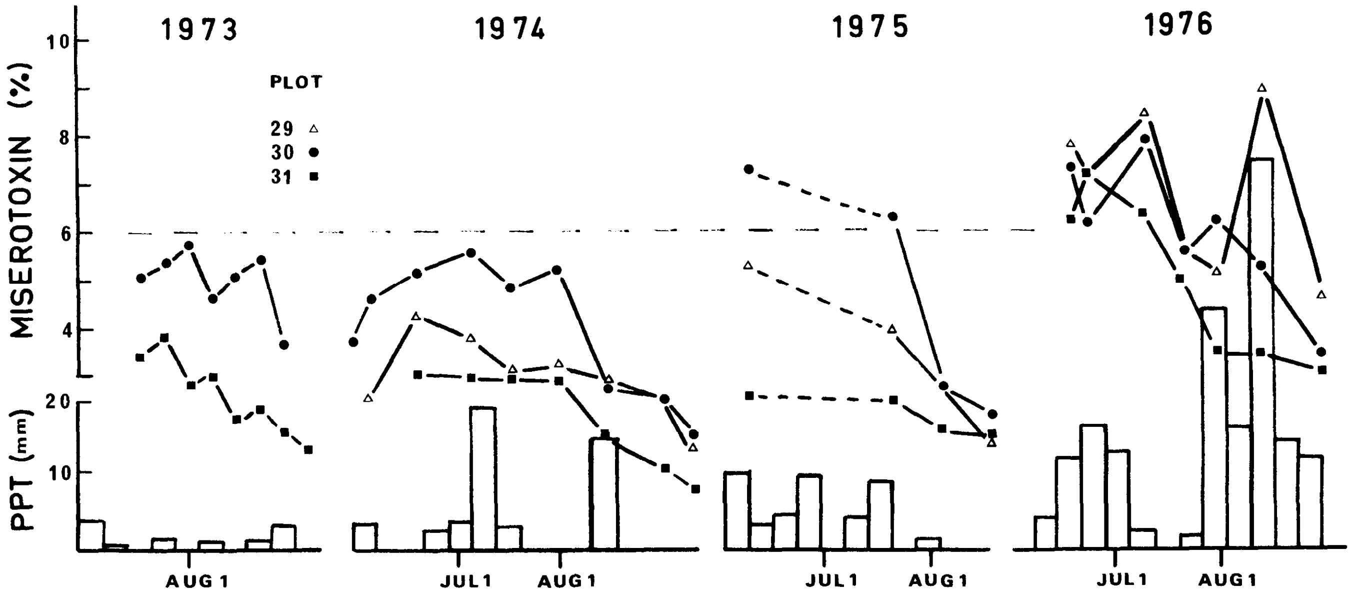

Fig. 2. *Variation in miserotoxin concentration (percent dry weight) of Columbia milkvetch at plots 29, 30, and 31 and weekly precipitation (PPT) for the Kamloops area during the summers 1973 to 1976.*

1976 (AES, 1973a–1976a). These diversified weather patterns afforded a unique opportunity to observe interseasonal variations in Columbia milkvetch toxicity. The precipitation patterns for 1973 to 1976 and the toxicity trends at three milkvetch sites (plots 29, 30, and 31) located in pure lodgepole pine stands are illustrated in Figure 2. Declines in miserotoxin concentrations are evident for the mid-July to late-August interval for the years 1973 to 1975; but 1976 levels were substantially elevated during the same period. A previous comparison between 1973 and 1974 indicated that the additional moisture in 1974 extended and elevated miserotoxin levels on rough fescue grassland plots, but a minimal response to rainfall was observed in milkvetch samples from Douglasfir stands (Majak et al. 1976). The major rainfall (1.27 cm at Kamloops Airport) in July 1974, however, was deposited over a 24-hour period as compared with 19 days of precipitation (12.24 cm) in August 1976. The 1974 situation was a single, convective storm, while the 1976 case can best be described as a large-scale, slow-moving upper trough. These rainfall differences were also reflected in soil moisture differences with little or no change at forest sites in 1974 (Majak et al. 1976). In contrast, sharp increases in soil moisture were maintained at all experimental plots throughout August 1976. This abrupt change in soil moisture, illustrated in Figure 3 for four of the sites, was preceded by a period of water stress producing declines in soil moisture and plant moisture during July (Fig. 3). Recovery from this water deficit coincided with the major rainfalls, which began in late July, resulting in an immediate increase in plant moisture (Fig. 3) similar to that observed in 1974 for Columbia milkvetch on rough fescue grasslands. Three of the sites (plots 70, 71, and 72) in Figure 3 exhibited the most dramatic changes in plant moisture, and plot 29 showed the highest plant moisture levels during the period of August rain. This alleviation of water stress appeared to induce miserotoxin biosynthesis yielding pronounced peaks in mid-August at plots 70, 71, 72, and 29 (Fig. 4). At the remaining sites, the rapid decline in miserotoxin concentrations observed in other years (Fig. 2; Majak et al. 1974; Majak et al. 1976) was arrested. Recently it has been proposed that water stress suspends the aging process of physiologically active leaves (Begg and Turner 1976), and it is conceivable that a resurgence in miserotoxin biosynthesis could be the result of rapid development following recovery from water deficit. The toxicity trends for 1976 confirmed our previous observations that peak miserotoxin concentrations were associated with pre-bloom growth stages, with a decline occurring during bloom, and that the secondary miserotoxin maxima were generated during pod development.

Understory Light Regimes in Relation to Miserotoxin Values

The percentage full sun (FS) for each site (Table 1) indicates the ratio of time in direct sun to time in shade of any part of the foliar canopy (Looney 1968). The sites represented a tenfold change in light regimes, ranging from 100% FS for site 35

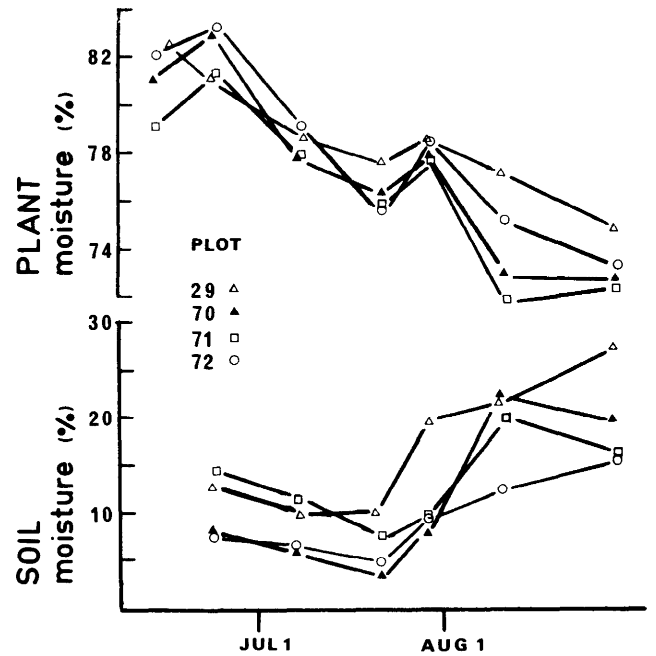

Fig. 3. *Changes in Columbia milkvetch moisture content and soil moisture content at plots 29, 70, 71, and 72 during the summer of 1976.*

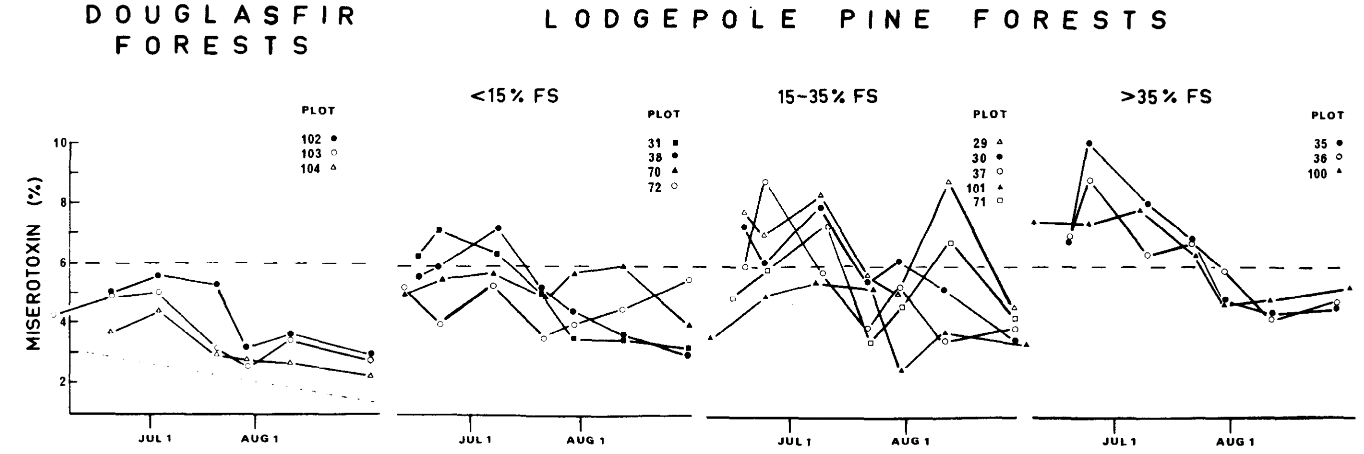

Fig. 4. *Variation in miserotoxin concentration (percent dry weight) of Columbia milkvetch collected in 1976 and located in Douglasfir and lodgepole pine forests. The regression line for Douglasfir sites was developed from data for 1973 and 1974. The lodgepole pine sites are divided into three groups with respect to light regimes as demonstrated by percent full sun (FS) determinations.*

(located on a cleared, hydroelectric right-of-way between sites 30 and 36) to 10% FS for site 70. The miserotoxin levels of Columbia milkvetch growing at three lodgepole pine sites (plots 30, 29, and 31) which had different light regimes (29, 22, and 13% FS, respectively) were determined over the 4-year period 1973–1976 (Fig. 2). The miserotoxin profiles during 1973 to 1975 pointed to a positive relationship between light and toxicity, the higher miserotoxin maxima being associated with site 30 (29% FS) while site 31 (13% FS) showed lower levels and site 29 (22% FS) intermediate values. The pattern for 1976 was somewhat obscured by the additional effects of rainfall (see above), but site 31 continued to maintain a lower position (Fig. 2).

The 12 lodgepole pine sites were divided into three groups with respect to their light regimes (<15%, 15–35%, and >35% FS); and the results of the miserotoxin determinations for 1976 are illustrated in Figure 4. Miserotoxin maxima above 6% predominate in the 15–35% and >35% categories. On the other hand, miserotoxin minima below 4% are found in the <15% and 15–35% FS categories but these two groups yielded secondary miserotoxin peaks as well. In spite of significant differences in light regimes at the Douglasfir plots (60, 35, and 18% FS for plots 104, 102, and 103, respectively) these sites continue to show lower miserotoxin values (Fig. 4). The miserotoxin levels at three Douglasfir sites (plots 13, 20, and 21) which we described previously (Majak et al. 1976) also varied considerably in their percent FS (55, 25, and 30%, respectively); but again, miserotoxin values were depressed during the 1973–74 study, which yielded the regression line indicated in Figure 4. Therefore, a relationship between light and Columbia milkvetch toxicity is not apparent in Douglasfir forests, and the factors which appear to inhibit miserotoxin accumulation at these sites remain to be uncovered. The increased rainfall for June 1976 (91% of normal) and August 1976 (455% of normal), however, could be a contributing factor which resulted in higher miserotoxin levels at Douglasfir sites in 1976 (Fig. 4).

The "% FS" value for each site (Table 1) is really a measure of the relative incoming solar radiation for that site (Heinicke 1963). This energy is used in (a) photosynthesis, (b) heating (air, plant, and soil), and (c) evapotranspiration (Rosenberg 1974). The interaction of these factors in relation to miserotoxin turnover remains to be unravelled. Growth chamber experiments, however, have shown that miserotoxin concentration was greater in *A. miser* plants grown at higher day temperatures and that excluding light from *A. miser* var. *hylophilus* for 2 weeks significantly lowered miserotoxin levels (Parker and Williams 1974).

Previously we reported that low toxin levels in Douglasfir forests were associated with Gray Luvisolic soils. The results for the lodgepole pine sites, however, indicate that high levels of toxin can be produced on both Gray luvisols and Eutric Brunisols (Table 1, Fig. 4). Site indices, which reflect productivity differences between sites, appear to be higher in low toxin areas (Table 1). The corollary suggests, therefore, that the formation of high miserotoxin levels could be a response to moisture stress conditions and this would agree with the miserotoxin observations of Columbia milkvetch situated in the drier conditions of upper grasslands. More detailed soil moisture measurements involving tension as well as amount at various depths within the rooting zone could more clearly define the role of moisture in miserotoxin fluctuations.

The feasibility of predicting Columbia milkvetch toxicity from aerial photographs and forest cover maps remains to be tested but preliminary studies with the present sites indicate that high-toxin areas can be distinguished from low-toxin areas on the basis of tree species and the density of lodgepole pine crown cover.[2]

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Grama (*Bouteloua* Lag.) Communities in a Southeastern Arizona Grassland

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Highlight: Fifty stands, representing six common and three rare species of gramas (genus *Bouteloua*), were sampled for vegetation abundance, species composition, and selected habitat factors. Numerical and statistical procedures were used to aid in obtaining succinct descriptions of the habitat structure of the grama species. Factors such as texture and content of various nutrients of the soils were among those that showed trends.

Black grama (*B. eriopoda*) was found to be associated with soils higher in nitrate, potassium, organic matter, pH, and lime. Most similar to stands of black grama were stands of eludens grama (*B. eludens*) and sideoats grama (*B. curtipendula*), which tended to also be associated with sandy clay textured soils and steep, rocky slopes. All stands of eludens grama were found on southerly exposures. Hairy grama (*B. hirsuta*) and spruce-top (*B. chondrosiodes*) were most widely distributed and tended to occur together on relatively level sites with clayey, acidic soils. Curly mesquite (*Hilaria belangeri*) was nearly always associated with these two gramas. Blue grama (*B. gracilis*) tended to be most abundant on acidic, relatively infertile, sandy clay loam soils.

The grama grasses (*Bouteloua* species) are the single most important group of perennial grasses in southern Arizona, not only in terms of abundance but economics. According to Humphrey (1958), the gramas constitute the major portion of the range forage in this region and consequently they are managed for maximum production in preference to many other grass species.

The objective of this study was to generate hypotheses about the habitat structure of the six important species of grama within the boundary of a southeastern Arizona study area. Structural characterization included the description of habitat characteristics where the species occurred. Physical and chemical soil attributes were the primary abiotic factors considered in the structural descriptions. Other plant species that consistently occurred within the grama communities were the most useful and easily measured biotic component.

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Description of Area

All samples were taken within the boundaries of The Research Ranch, Inc., located 9.6 km south of Elgin, Santa Cruz County, Arizona. The total area of the ranch is approximately 30 km^2. Elevation ranges from 1,618 m at the northeastern corner to 1.774 m at the southern boundary. The northern half of the study area is characterized by narrow ridges and steeply sloping canyons. The relief in this portion may be as much as 35 m, with slopes as steep as 35 degrees. The southern half of the study area consists of small plateaus that are deeply dissected into narrow, steep-walled canyons. Relief in this area ranges up to 70 m, with slopes as steep as 35 degrees.

The vegetation is predominantly perennial grasses; gramas and threeawns (*Aristida* species) along with wolftail (*Lycurus phleoides*) are the most important. Dense stands of alkali sacaton (*Sporobolus airoides*) are found on most flood plains. In the northern part of the study area, oaks (*Quercus* species) are found only on north-facing slopes, while in the southern portion at higher elevations oaks are important on all exposures. Oaks also form some savannah-like areas.

Methods and Procedures

Fifty vegetation stands were sampled in August and September, 1971. Stand boundaries were established to delineate homogenous grama types with respect to the most abundant grama species occurring within the stand. Nine species are endemic to the study area, while only six are commonly encountered. Consequently, out of the 50 stands, 45 were of the common species type.

Initially, a species list was made as an index of species richness. Frequency (quadrats of occurrence/total quadrats × 100) was determined for each species in each stand. Eighty 40 × 40-cm quadrats were located at regular intervals throughout each vegetation stand. The first quadrat location was selected at random and the remainder of the quadrats were spaced at equal intervals to insure that all portions of the stand were represented in the 80 samples. Basal cover was estimated by classes for all graminoid species by locating an additional 24 40 × 40-cm quadrats in each stand. Six cover classes were utilized:

(i) 0–5%; (ii) 6–25%; (iii) 26–50%; (iv) 51–75%; (v) 76–95%; (vi) 96–100%. Mid-points of the class interval were used to compute means for each species in each stand.

The degree of the slope and angle of exposure for each stand was measured. Elevation was estimated from 50-foot contour intervals on a U.S. Geological Survey Map.

A composite soil sample from the surface 6 inches was obtained from five subsamples taken at regular locations in each stand. The soil samples were first sieved to determine percentage rock (by mass) of five particle size classes: all rocks greater than 2 mm; this was further subdivided into 2–4 mm, 5–14 mm, 15–30 mm, and greater than 30 mm. The remainder of the sample (less than 2 mm) was mechanically analyzed for texture using the hydrometer method. Percent soil water (by mass) at zero bars water potential was determined by a modification of the Hilgard (1906) method.

Standard procedures were used to determine pH, percent lime, soluble salts (electrical conductivity), percent organic matter, available phosphorus, potassium, nitrate-nitrogen, zinc, and iron, and percent water at ⅓ and 15 bars soil water potential.

Assuming we encountered about 35 species per stand, the above procedures resulted in 1,750 individual frequency and 1,750 cover observations for the 50 stands. The 24 habitat factors measured resulted in 1,200 individual observations. Such large data matrices cannot be synthesized by casual inspection. Therefore, we chose to utilize three numerical methods, which would reduce the original data matrices into relevant and succinct descriptions: correlation, regression, and phytosociological ordination.

Product-moment correlation coefficients were computed between all habitat factors and the 18 most frequent species themselves (Nicholson 1972). However, only the grama species vs habitat factor correlations will be presented herein. Coefficients greater than 0.36 were significantly different than zero at $P = 0.05$ level (Rohlf and Sokal 1969). All correlations that are mentioned hereafter were significant at least at the $P = 0.05$ level.

A stepwise multiple regression was also used as an aid in determining cognate habitat variables. The general multiple regression formula was:

$$Y = a + b_1x_1 + b_2x_2 + \ldots + b_ix_i \qquad (1)$$

where a is a constant, $b_1, b_2, \ldots b_i$ are the regression coefficients on the independent variables $x_1, x_2, \ldots x_i$ selected. The frequencies of the six most common grama species were the dependent variables. Regressions with independent variables consisting of habitat factors were calculated separately from those using the frequencies of 12 associated species. To choose the number of independent variables, the multiple coefficient of correlation, the standard error of the estimate, and the partial F ratios were used. The assumption was made that the resultant independent variables chosen were those that would be most likely associated with the gramas.

Ordination procedures of Swan et al. (1969) were used in this study. Interstand distances were computed for each stand-pair combination according to the Euclidean formula:

$$d = [\Sigma\,(x_{ni} - x_{nj})^2]^{\,1/2} \qquad (1)$$

where x_n are values of the variables 1 through n; and i and j are the two stands involved in the pair-combination. Values used to order all stands on all possible stand-pair defined x axes are computed according to the formula:

$$alpha = \frac{d^2_{AB} + d^2_{AP} - d^2_{BP}}{2d_{AB}} \qquad (2)$$

where d= interstand distance, A and B are the two stands defining the axis, and P is the stand being located. The best possible axis is then selected by using the stand-pair with the greatest mSS_a where:

$$mSS_a = m\Sigma(a-\bar{a})^2 = m\Sigma a^2 - (\Sigma a)^2 \qquad (3)$$

with $m = 50$ (number of stands) and SS_a = the sum of squares of the interstand distances along the x-axis. Subsequent axes were selected from the residuums of the nonperfect fit of the stands on the best preceding axis.

Greig-Smith (1964) recommended that variables having greatly differing magnitudes of absolute value (such as elevation and organic matter percentage) should be relativized for this type of ordination so that no one variable has an undue amount of influence upon ordinal stand locations. Each variable was first summed over the entire 50 stands, then each value for that variable, resulting in a relative value for each of the variables in each stand. Frequency values did not need to be transformed since they are inherently relative and within the same range of variability as the transformed habitat values.

The computer program SDW∅RD (Hoag 1971) was used to compute coordinates on three axes for the 50 vegetation stands. Different sets of variables were used resulting in four partial ordinations and one ordination in which all variables were utilized: (A)

Table 1. Mean values for all quantitative habitat factors in 45 stands. Stands included in each grama group were those with the highest percent basal cover.

	Grama groups						
Factors	Spruce-top	Sideoats	Eludens	Black	Blue	Hairy	Mean
Sand (%)	37.3	51.7	50.8	41.2	54.1	41.6	45.6
Silt (%)	18.0	12.4	12.8	19.7	17.5	15.2	16.0
Clay (%)	44.6	35.8	36.2	39.0	28.2	43.1	38.2
>2 mm rock (%)	34.4	56.7	61.8	50.2	21.4	41.0	43.7
2–4 mm rock (%)	5.7	9.2	11.5	7.1	9.4	6.6	8.1
5–14 mm rock (%)	11.2	18.4	20.4	12.4	6.8	11.1	13.2
15–30 mm rock (%)	10.1	15.4	14.8	10.7	2.7	11.5	10.8
>30 mm rock (%)	7.3	13.4	15.0	20.0	2.4	11.6	11.4
0 bar (% soil H_2O)	54.7	49.9	49.2	56.6	40.6	54.3	51.1
⅓ bar (% soil H_2O)	21.0	16.1	16.8	22.1	13.2	19.3	18.2
15 bar (% soil H_2O)	14.5	11.1	12.0	14.5	8.0	13.2	12.3
Slope (degrees)	4.2	15.4	19.7	3.4	2.2	4.7	8.0
Elevation (feet)	4900.0	4835.0	4810.0	4807.0	4832.0	4878.0	4847.0
Mean no. species	30.5	39.0	27.1	32.1	43.1	37.5	34.7
Total no. stands	9	7	7	7	7	8	7
pH	6.0	7.0	7.7	7.8	6.2	5.8	6.7
Salts (mmohs)	0.3	0.4	0.3	0.4	0.3	0.2	0.3
Organic matter (%)	1.8	1.7	1.8	2.1	1.1	1.9	1.7
Available P (ppm)	4.1	3.4	5.4	6.6	9.2	3.4	5.2
Available K (ppm)	231.8	236.4	139.8	128.2	192.4	261.2	201.2
Available NO_3 (ppm)	1.4	5.2	1.1	4.9	3.4	1.5	2.8
Available Zn (ppm)	1.2	1.0	0.4	0.4	0.9	1.0	0.8
Available Fe (ppm)	12.8	12.1	4.5	3.3	18.6	14.9	11.2

frequency values of all species averaging greater than 10%, (B) all measured physical habitat factors, (C) all measured chemical (soil) habitat factors, (D) B and C combined, (E) A, B, and C combined. Only the first two axes of the five ordinations were used due to the difficulty of portraying graphs in three dimensions and the fact that the first two axes account for most interstand distances.

Results and Discussion

Of the 50 stands, 45 were assigned to one of six categories, using the grama species with the largest percent basal cover as the criterion for selection (Table 1). The remaining five stands had one of the three other species as the most abundant grama.

Mean percentage frequency for all species having an overall mean frequency greater than 10% and the grand mean for all stands were computed (Table 2). These were considered the most important species and were then utilized in subsequent detailed analysis to determine which associated species were most important in the habitats of the gramas.

Table 2. Mean frequencies of the six grama species. Each grama group was composed of the set of stands having the greatest percent basal cover for the said grama species. *P* = <0.5 percent mean frequency.

	Grama groups						
Grama species	Spruce-top	Side-oats	Eludens	Black	Blue	Hairy	Mean
Spruce-top grama	91	12	16	9	11	62	37
Sideoats grama	1	91	55	25	4	9	29
Eludens grama	0	0	89	14	P	0	16
Black gama	P	5	46	83	20	P	24
Blue grama	5	15	P	3	78	3	16
Hairy grama	37	16	9	16	5	83	29
No. of stands	9	7	7	7	7	8	

Correlation Analysis

Caution should be exercised in interpreting correlation coefficient significance levels in plant-environment relationship studies, since the procedures used herein could, for example, be used to characterize the habitats of utility poles. However, where habitat factors cannot be subjected to control by the experimenter it is a convenient method of first approximation (Sokal and Rohlf 1969).

Grama-Physical Habitat Correlations

Spruce-top grama (*Bouteloua chondrosioides*) and hairy grama (*Bouteloua hirsuta*) were negatively associated with slope (Table 3), indicating that these two species were less important on steeper slopes and more important on flatter sites. However, in the Great Plains, Hulett et al. (1968) reported that hairy grama expressed its greatest importance on steep slopes. Spruce-top grama was more important at the higher elevations on the present study site, which was most likely a function of the general broad topographic effects of Bald Hill, not elevation alone. Nearly the entire northern one-half of the study area is dominated by this important topographic feature.

Of all species, eludens grama (*Bouteloua eludens*) had the highest mean value for slope, (19.7 degrees) for the sites upon which it occurred (Table 1). The fact that it occurred on so few of the 50 stands probably accounts for the low correlation between this species and slope (Table 3). Exposure for eludens grama was limited to a range of 85 through 240 degrees (Nicholson 1972).

In contrast, sideoats grama (*Bouteloua curtipendula*) showed a positive slope association with a mean slope of 15.4 degrees. Dix (1968) also found sideoats grama to be associated with steep slopes in the North Dakota badlands, as did Hulett et al. (1968) in the central Great Plains. This phenomenon was easily observed in the field, where sideoats grama reached its prominence on the steeper slopes of the study area. A positive and probably real correlation was also found between sideoats grama and the 2 to 4-mm rock fraction (Table 3). Results of a study in the central Great Plains were in accord with the correlation between this species and surface rock (Nicholson and Hulett 1969).

Table 4. Correlation coefficients (*r* × 100) computed between chemical habitat factors and the six grama species. Each grama group was composed of the set of stands having the greatest percent basal cover for the said grama species.

Grama species	pH	Salts	O.M.*	P	K	NO_3	Zn	Fe
Spruce-top grama	−35**	−06	−03	−09	−23	+24	+05	+25
Sideoats grama	+33	−03	−13	+13	−12	−24	−22	−22
Eludens grama	+12	+15	+19	−01	+02	+21	+12	−09
Black grama	+14	+04	−03	+11	−10	+33**	−14	−16
Blue grama	+18	−04	−07	−12	−08	−41***	−09	−20
Hairy grama	−16	−13	−17	−02	00	+05	+10	+16

* Organic matter.
** Coefficients significantly different than zero (p = 0.05).
*** Coefficients significantly different than zero (p = 0.01).

Grama-Chemical Habitat Correlations

As soil pH increased so did the abundance of sideoats grama (Table 4). Spruce-top grama, on the other hand, reacted negatively with pH. Linnell (1961), in an investigation in western Kansas, demonstrated that sideoats grama was the most important species on the more alkaline soils of that region.

Black grama (*Bouteloua eriopoda*) was more important on sites where nitrates were more available, which implies that this species distribution could be dependent upon higher nitrate levels. Blue grama showed an opposite relationship in that it was more abundant on sites where nitrates were less available.

Coefficients of correlation between habitat factors and the remaining 12 of the 18 most important species were also computed (Nicholson 1972). It was noted from the correlation

Table 3. Correlation coefficients (*r* × 100) computed between physical habitat factors and the six grama species. Each grama group was composed of the set of stands having the greatest percent basal cover for the said grama species.

	Soil particles			Percentage rock					Soil water					
Grama species	Sand	Silt	Clay	>2 mm	2–4 mm	5–14 mm	15–30 mm	>30 mm	0 bar	1/3 bar	15 bar	Slope	Elev.	# spp.
Spruce-top grama	+12	+12	−18	−08	−03	−07	−13	+01	−08	−04	−10	−34*	+56**	+05
Sideoats grama	−11	+10	+05	+13	+29*	+20	+06	−04	−06	+09	00	+32*	−06	−13
Eludens grama	+11	+08	−14	+10	−07	+10	−08	+19	+04	−04	00	+04	−01	+16
Black grama	+01	−09	+02	−03	+04	+11	+09	−21	−01	00	+01	+02	−02	−25
Blue grama	−04	+11	−01	−26	+09	−21	−20	−18	−01	+05	00	−06	−24	−18
Hairy grama	+13	+06	+16	−27	+01	−30*	−11	−19	00	+10	+03	−33*	−07	−12

* Coefficients significantly different than zero (p = 0.05).
** Coefficients significantly different than zero (p = 0.01).

matrices that the 12 associated species appeared to be more closely associated with the habitat factors measured than were the six grama species. Associated species were significantly correlated with 30% of all the habitat factors. Two-thirds of those significant correlations were significant at a probability of at least $P = 0.01$, while the remaining ⅓ were significant at a probability of at least $P = 0.05$. The grama species were significantly correlated with only 7% of all habitat factors (as compared to 30% above). Six of the 7% were significant at least at the $P = 0.05$ level, and the remaining 1% of the significant correlations were significant at least at the $P = 0.01$ level. This was probably because the site samples were selected upon the basis of having an abundance of one or two grama species regardless of the other species in the stand. Fewer stands were selected that had several grama species with low and intermediate abundances. This meant that stands often had zero values for a given grama species and therefore did not correlate well.

Regression Analysis and Habitat Factors Selections

Draper and Smith (1966) caution that step-wise multiple regression is sensitive and that independent variable selection must be carefully subjected to sensible judgement. Only the regression equations considered important for the stated purpose of studying variation are discussed. The variables are presented (Table 5) in order of selection and the number of variables is equivalent to the number of steps necessary to obtain those multiple correlation coefficients given. The factors selected do not necessarily agree with the product-moment correlation analysis, since the multiple regression analysis describes the relationship between a species and more than one variable.

Few habitat factors were found to be in common among the grama groups. Spruce-top, blue, and eludens grama were apparently more adapted to sandy soils, while spruce-top and hairy grama were more abundant on acidic soils. Steep slopes appeared to be a likely habitat for both eludens and sideoats grama; however, other factors varying between the species can be seen to be the ones really important in distinguishing the most favorable habitats of these two species.

The soils occupied by eludens and black grama were similar in that both were more abundant where potassium was less available and organic matter was high. Additional factors were noted that could be effective in distinguishing between the sites most often occupied by these two species (Table 5).

Partial Ordinations

Many of the relationships discovered by the correlation and regression analysis were also revealed by the ordinations; however, several new factors were indicated by the ordination methods. No attempt was made to compare the methods since the original intent was to only discover grama-environment and intergrama relationships. Ordinations using different combinations of factors resulted in defining the grama species interrelationships.

Species Ordination

Isolines based upon the maximum percent basal cover in the stand of one of the six most common grama species were drawn around stand locations (Fig. 1). The resulting groupings will be referred to as grama species groups. In this ordination, lines defining groups were least tortuous. We expected this since frequency and cover are vegetation indices that are usually correlated. While some of the other ordinations were better at defining some grama groups, this one was judged best for eliciting ecological relationships of all gramas and was chosen for more detailed analysis.

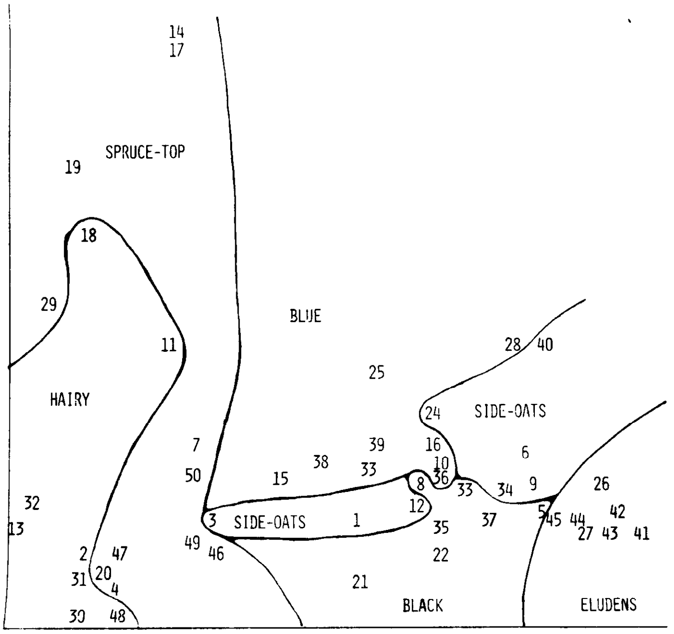

Fig. 1. *Location of stands on the two-axis partial ordination using plant frequency data only. Numerals are identification numbers.*

From left to right on the *x*-axis (Fig. 1) hairy grama (*Bouteloua hirsuta*) and spruce-top grama (*Bouteloua chondrosiodes*) show close association by virtue of their relatively close location. To the right, blue grama (*Bouteloua gracilis*) and black grama (*Bouteloua eriopoda*) are separated from sideoats grama (*Bouteloua curtipendula*) on axes representing continuity from one species to another in several directions but generally changing from left to right. Aggregated in the lower right corner are the eludens grama (*Bouteloua eludens*) stands.

The lines defining all groups represent in two dimensions the relative relationships of the grama species to one another with

Table 5. Results of stepwise multiple regression analysis. Variables chosen are those that were assumed to be most cognate in the habitats of the six gramas given. Each grama group was composed of the set of stands having the greatest percent basal cover for the said grama species.

	Grama species				
Spruce-top	Sideoats	Eludens	Black	Blue	Hairy
Elevation (+)	5–14 mm rock (+)	slope (+)	potassium (−)	15–30 mm rock (+)	pH (−)
% sand (+)	slope (+)	potassium (−)	organic matter (+)	% sand (+)	total species (−)
pH (−)	nitate (+)	organic matter (+)	nitrate (+)	>2 mm rock (−)	
Iron (−)	total species (+)	% sand (+)	zinc (−)	nitrate (−)	
R^*=0.80	R=0.84	R=0.70	R=0.90	R=0.71	R=0.63

* Multiple coefficient of correlation.

respect to total species composition and abundance in stands. Since there was little clumping of stands, we did not use ordination for reclassifying stand groups.

A simplified form of defining such intergrama relationship was used and judged more efficacious than plots of the stand numbers (Fig. 2). Lines connecting two species indicate proximity of stands on the ordination. Length of lines is proportional to the degree of overlap of stand locations.

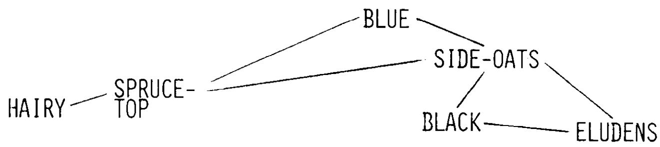

Fig. 2. *Diagram showing the general relationship of grama stands to one another based on the partial ordination in which plant species frequency data were used.*

Physical Factors Ordination

In the second ordination (Fig. 3) three groups exhibited considerable peripheral convolution; hairy grama divided both black and spruce-top grama stand locations. The behavior exhibited by the hairy grama stands, being very interspersed with these species stands, indicated that the levels of the measured physical habitat variables were similar. Conversely, within the eludens grama group, a tight homogenous pattern was exhibited, implying that physical habitat factor levels exhibited homogeneity. Eludens and blue grama were most different. The most likely physical factors associated with such patterns were those in which grama group means were most different (Table 1). The disparity of sideoats grama stands indicated probably adaptation to a wide variety of habitats. Its wide geographic distribution has been well documented by F. W. Gould and associates at Texas A&M University (Nicholson 1972).

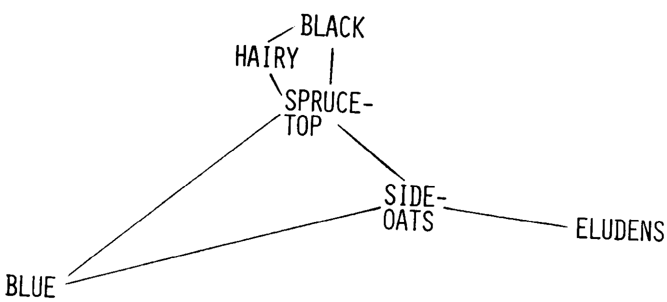

Fig. 3. *Diagram showing the general relationship of grama stands to one another based on the partial ordination in which physical factors of the soils were used.*

Chemical Factors Ordination

This ordination (Fig. 4) was effective in separating stands of eludens and black grama, indicating some degree of soil chemical uniqueness on the *x*-axis. Correlation analysis did not reveal this; however in the multiple regression, potassium and organic matter were two variables that each species had in common. Eludens grama stands were located quite close to spruce-top grama, whereas in other ordinations these two species are widely separated. The environments of these two species were more similar with regard to soil chemical factors than physical site factors and/or their related species.

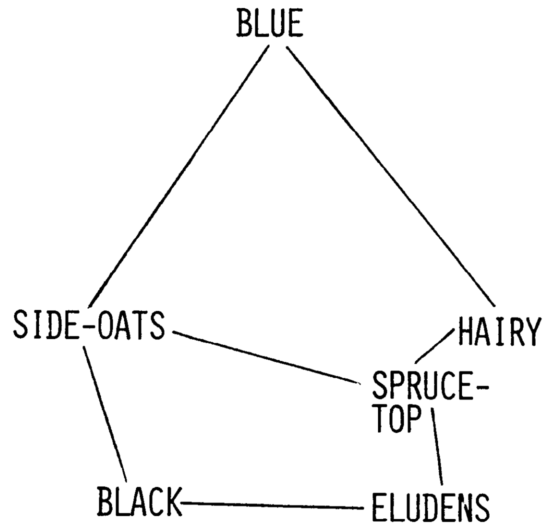

Fig. 4. *Diagram showing the general relationship of grama stands to one another based on the partial ordination in which chemical factors of the soils were used.*

Physical + Chemical Ordination

Combining physical and chemical factors in an ordination (Fig. 5) was an attempt to assess the total soil environment and its relationship with the gramas. Little additional insight was gained. Eludens grama stands retained their consistent relative homogeneity as in previous and subsequent ordinations, and hairy and sideoats grama stands remained mixed.

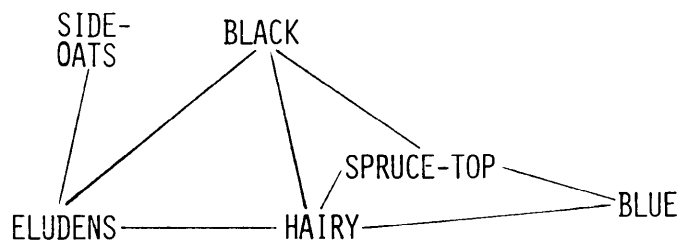

Fig. 5. *Diagram showing the general relationship of grama stands to one another based on the partial ordination in which both physical and chemical factors were used.*

Species + Physical + Chemical Ordination

The ordination in which all three types of data were combined (Fig. 6) exhibited more discernible stand groups than the previous combinations. This apparently was due to the inclusion of frequency data, since the resulting locations of the stand groups were similar to the frequency ordination. This is probably the best overall depiction of the ecological intergrama relationships. Hairy and spruce-top were intimately related and unique with some spruce-top stands being similar to blue and sideoats but not to black grama. However, black grama stands were more similar to sideoats grama than blue or spruce-top grama. Sideoats grama stands were in turn most similar to eludens grama.

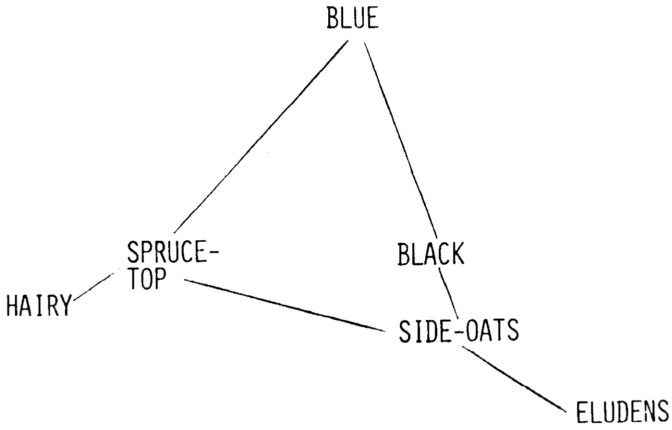

Fig. 6. *Diagram showing the general relationship of grama stands to one another based on the partial ordination in which all factors and plant frequency were used.*

Variables Plotted on Species Ordination

Values of habitat variables (physical, chemical, and species) were plotted directly on the stand positions of the two dimensional *species* ordination graph (Fig. 1) as described earlier. A total of 43 of such graphs were prepared. Isolines were drawn on each graph to separate stands in which variables have similar or equivalent value. By inspecting these 43 graphs, we discerned the variables that showed trends with respect to the ordination axes. Most in-group variation was best indexed by noting the relative degree of tortuosity of the isolines. One of the 16 physical factor graphs is presented to demonstrate the procedure (Fig. 7).

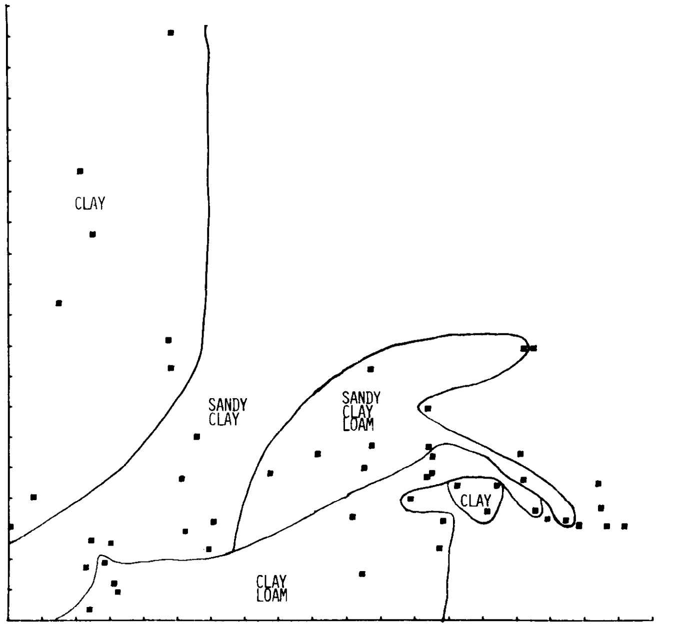

Fig. 7. *Textural classes plotted on stand locations of the frequency data ordination.*

Physical Factor Plots

The effects of soil texture is best summarized by noting the gradation from the clay class (upper left) to clay loam class (lower center), between which are the sandier classes of soils. It was informative to relate positions of maximum percent basal cover of the grama species (Fig. 1) to the positions of the textural classes on the same ordination (Fig. 7). Eludens grama stands were all in the same position as the sandy clay class, and blue grama stands were all classed as sandy clay loams. Sideoats grama did not occur abundantly on clay soils, and the other gramas showed no clear-cut association with any textural class. A similar procedure was followed thenceforth to discover additional associations between grama species and habitat and between grama species and associated species.

Rock content of the upper soil surface is probably best overall indexed as the total rock fraction (all rocks greater than 2 mm). Stands with low rock content in all classes seemed to be somewhat centered on the ordination surface, while stands of higher rock content were distributed in the periphery. By comparing the plotted values of the >2-mm rock on the frequency ordination with the grama stand groups, we found that the blue grama stands appeared to be associated with the low rock content. Few discernible trends were observed in the other stand groups and most showed variable responses. However, eludens grama stands consistently were located in the region of the ordination of higher surface rock in all size classes.

Responses of species were somewhat variable with respect to the percent soil water at the three levels of soil water stress. It appeared that black, hairy, and spruce-top grama were associated with moderate to high values, eludens and sideoats grama with moderate values, and blue grama with low values.

Slope was another variable in which the highest values were centered. Eludens grama stands were consistently found on steeper slopes in addition to the fact that none of these stands had any northern exposure. Also notable was the fact that all but one of the spruce-top grama stands were located at higher elevations and this was the only habitat factor that showed any consequential association with this species. Blue grama stands were mostly northern exposures.

Chemical Factor Plots

Eludens, hairy, and sideoats stand group soils generally tended to be alkaline and higher in lime, while the soils under the remaining three species were lower in lime and acidic. Soils of blue grama stands were mostly low in organic matter while soils of spruce-top, hairy, black, and eludens grama stands had generally higher values. Potassium was probably more available in black and eludens grama soils, while in the soils under blue and hairy grama potassium was less available. The exact reverse situation was found to be the case with iron and zinc availability. In addition, zinc tended to be more available under high cover of spruce-top and sideoats grama.

Nitrate-nitrogen levels were lower in stands predominantly covered by blue grama and eludens grama. The reciprocal of this was true with respect to stands with highest cover values of black grama.

Species Plots

Some of the gramas tended to occur consistently with certain species. These kinds of interspecies associations were determined utilizing the ordination isoline comparison method previously described regarding grama-habitat relationships.

Inferences made from these comparisons were made only on the order of which species one might expect to occur *abundantly* with the *abundant* occurrence of a species of grama, or which species one would *not* expect to occur abundantly with abundant occurrences of a grama. The advantage of this method was that zero frequency values could be interpreted as ecologically meaningful, while in the interspecific correlation analysis zeros do not convey any information.

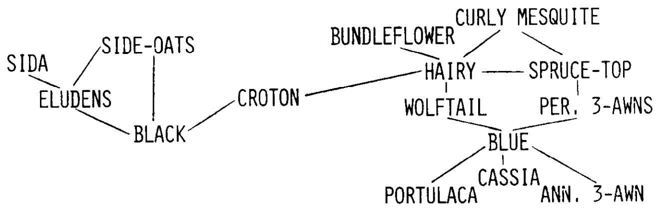

Fig. 8. *Diagram representing interspecies relationships derived from multiple stepwise regression.*

The interspecific associations so determined were summarized in a matrix. A two-space picture appeared to be the best method of presentation of these results (Fig. 8). The general pattern of intergrama relationships is similar to that determined from the different types of ordinations, especially the all-factors ordination (Fig. 6). The most important species in the stands in addition to the gramas are shown with respective associations. The length of lines connecting species is only roughly proportional to the intensity of the interspecies association.

Conclusions

The initial intent of this research was to describe the habitats of six grama species in an area of southern Arizona. Gramas were chosen because of the large number of species and the importance of these species as range plants.

The following descriptions of grama community structure were found. Environmental factors that were not mentioned exhibited continuous variation within and among the groups to the extent that categorical generalizations were not feasible.

1. Black grama: Relatively larger amounts of available nitrate, available potassium, and/or organic matter distinguished the habitat associated with this species. Soil water percentages at the various water potentials were high. Most of these soils were also high in pH and/or lime. Coryumbed croton (*Croton corymbulosis*) was found consistently on these sites. Black grama stands were most similar to eludens and sideoats grama stands.

2. Blue grama: Soils associated with this species were found to be low in pH, available nitrate, potassium, and/or rock. They were sandy, consequently low soil water percentages were found at all levels of induced stress. Portulaca (*Portulaca parvula*), partridge pea (*Cassia leptadenia*), wolftail (*Lycurus phleoides*), perennial threeawns (*Aristida* species), and annual threeawn (*Aristida adscensionis*) were commonly associated species. Blue grama habitats were considered relatively unique and not well associated with other grama species.

3. Eludens gama: Light textured soils, steep, and/or rocky slopes were commonly associated. Sites were much drier than the sideoats grama stands, mostly because eludens grama stands were all southern exposures. Soils occupied were more alkaline than those of sideoats grama, high in organic matter, relatively lower in available nitrate, and/or higher in available potassium. Available soil water was low. Stands in this group were most uniform of any, not only with regard to the physical-chemical habitat but also associated species. Coryumbed croton, sida (*Sida procumbens*), black and sideoats grama were consistently found in the eludens grama stands.

4. Hairy grama: Sites associated were relatively flat with soils that were low in potassium and/or acidic. These stands were most similar to spruce-top grama. Percent soil water at 0, ⅓, and 15 bars induced stress was generally high. Stands were species poor, yet had a large number of species which were characteristically associated: perennial threeawns, wolftail, bundle flower (*Desmanthus cooleyi*), and curly mesquite (*Hilaria belangeri*).

5. Sideoats grama: Steep and rocky slopes were characteristic of the environment of the species. Associated soils were generally alkaline, relatively high in available nitrate, and low in available water percentages. Species richness characterized most of these stands, yet no individual species was found to be associated with sideoats grama.

6. Spruce-top grama: An abundance of this species was found on shallow slopes and/or the higher elevations, nearly always mixed with hairy grama. Soils associated with this species were low in pH (acidic), clay in texture, and therefore able to maintain fairly high percentages through the ranges of soil water potential. Species commonly associated were the threeawns and curly mesquite.

Structural descriptions are a necessary first stage in ecosystem analysis. Structural hypotheses formulated, tested, and found to be statistically significant can lead to the formulation of functional hypotheses, which in turn can be tested. Such procedures lead to the knowledge requisite for learning how range ecosystems are organized and function. In turn, fundamental knowledge of range ecosystems is a prerequisite to wise and fruitful management.

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Economics of Tall Larkspur Control

DARWIN B. NIELSEN AND E. H. CRONIN

Highlight: Tall larkspur (*Delphinium barbeyi* Huth.) was chemically controlled in the subalpine areas of the Manti Canyon Cattle Grazing Allotment in Central Utah, and the reduction in cattle losses on controlled areas was observed. Without control, an average of 36 mature cattle were lost per year over a 15-year period, and an average of 11 calves were lost per year over an 8-year period. Cost of control ranged from $15–$22 per acre of larkspur for the first application, and from $13–$17 per acre for the second application. Cattle losses were reduced over 90% in the sprayed pastures. Thus, the estimated annual value for adult cattle saved was $8,250 and for saved calves it was $1,200. Internal rates of return ranged from 72.25% to 60%, with the rate dependent upon whether calves saved were included. A return of 10% can be expected from larkspur control if eight to nine cows are saved each year for 10 years.

Larkspur (*Delphinium*) species cause greater economic loss to the range cattle industry than any other group of poisonous plants in the 17 western states (Cronin 1971). Tall larkspur (*Delphinium barbeyi* Huth.), the most poisonous species (Kingsbury 1964), is particularly important on the Wasatch Plateau in central Utah.

In the mid 1950's, a group of ranchers who grazed cattle on the Manti Canyon Allotment, Manti-La Sal National Forest, Utah, requested research on the problem of tall larkspur poisoning. They wanted to know: if the plant could be controlled with herbicides; if cattle deaths could be prevented; and and if tall larkspur control was economical. The Agricultural Economics Department, Utah State University, and the Agricultural Research Service, U.S. Dep. Agr., responded with a joint research effort.

The Manti Canyon Allotment ranges in elevation from 5,800 ft to 10,400 ft. It is divided into three main grazing units according to vegetation type determined by elevation. Most problems involve poisonous plants on the 8,000 acres of the subalpine grazing zone. This pasture unit produces about 2,000 animal unit months (AUM's) of forage, which makes it of major importance to the overall management of the allotment. These 8,000 acres are grazed from about the middle of July until about the first of October. This range is infested with 344 acres of dense, moderate, and sparse patches of tall larkspur. Larkspur occurs throughout the area in low densities along the edges of permanent streams, springs, and seeps (Ellison 1954).

Records have been kept since 1956 on the number of adult cattle presumed killed from tall larkspur poisoning (Table 1); however, not all of these losses were verified as larkspur poisoning by autopsies (Cronin et al. 1976). In the early years of this study (1956–1971), it was assumed that calf losses on the upper allotment were not caused by tall larkspur poisoning. During the 1972 grazing season, however, direct observations showed that calves weighing from 350–500 lb can and occasionally do ingest enough tall larkspur to get a lethal dose (Cronin et al. 1976). Since complete records have not been kept on calf losses on this high elevation pasture, it is impossible to determine the exact magnitude of this larkspur-induced loss.

After several years of research, it was concluded that control sufficient to reduce livestock losses substantially could be accomplished with 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] or silvex [2-(2,4,5-trichlorophenoxy)propionic acid] (Cronin and Nielsen 1972; Cronin 1974; Cronin et al. 1976). Control was most effective when the chemicals were applied at the rate of 4 lb acid equivalent per acre each year for two consecutive years. No attempt was made to eradicate the plant on the allotment.

Table 1. A record of the yearly losses of cattle from tall larkspur poisoning on the Manti Canyon Allotment, Utah, 1956–75.

Year	Calves	Mature cattle
1956	12	53
1957	14	58
1958	30	103
1959	15	45
1960	NA[3]	19
1961	NA	17
1962	NA	37
1963	NA	13
1964	NA	13
1965	NA	19
1966	NA	18
1967	NA	22
1968	NA	57
1969	NA	32
1970[2]	NA	34
1971[1]	NA	14
1972	5	14
1973	3	3
1974	2	7
1975	9	32
Total	90	610

[1] First large-scale spray project took place in 1971 on the North Fork unit.
[2] Total cattle losses for the period 1956–1970 were 540 head, with an average loss of 36 head per year.
[3] Not available.

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The authors wish to express their appreciation to the U.S. Forest Service and its personnel at the Ephraim District Office, Manti-La Sal National Forest, for their cooperation throughout this study.

This is a report on the current status of research involving use of certain chemicals that require registration under the Federal Insecticide, Fungicide, and Rodenticide Act. It does not contain recommendations for the use of such chemicals, nor does it imply that the uses discussed have been registered. All uses of these chemicals must be registered by the appropriate State and Federal agencies before they can be recommended.

Table 2. Actual costs for transportation, application, and herbicides for tall larkspur control on Manti Cattle Allotment, Utah, 1975.

	Cost
Herbicide:	
2,4,5-T (4 lb acid equivalent per gallon) [(2,4,5-trichlorophenoxy)acetic acid]	
Ranch cost bulk rate	$15.00/gallon
Forest Service cost (August, 1974)	$ 7.75/gallon
Labor cost:	
Hired labor	$ 2.50/hour
Permittee labor	$25.00/day
Mileage:	
Pickup truck—to and from allotment, also water carrying	$ 0.12/mile
Pickup—4-wheel drive	$ 5.00/hour

Control efforts were concentrated on the dense patches of larkspur found on snowdrift areas. Treatment of these patches the year after the initial spraying was essential. Larkspur plants that are missed or not completely killed with the first treatment can be treated individually. The 2 years of treatment reduced the probability of new larkspur plant establishment and effectively stopped livestock losses. Natural establishment of a plant community dominated by grasses resulted after the larkspur and other forbs were removed (Cronin and Nielsen 1972). Late-season grazing in the initial treatment year and rest the next year appear to encourage establishment of a grass cover on the treated areas.

Several types of spray equipment were tested. Aircraft spraying was ruled out because of the danger of flying over the terrain. Various types of boomless sprayers proved ineffective. Cost estimates cited later in this paper are based on the use of a spray-rig specifically developed for the project. Two light-weight hoses were mounted on retractable reels. Upright, spring-mounted hose supports helped get the hoses over brush and rocks. The finished sprayer requires 3 persons for efficient operation. A 225–240-ft swath can be sprayed, with the chemicals applied directly to the target plants.

Cost of Tall Larkspur Control

Specific costs cited in this report are based on the Manti Canyon Larkspur Control Project for the summer of 1975. Labor costs are based on rates paid by the Manti Cattleman's Grazing Association in 1975. Mileage and rental on trucks are based on actual costs to the Association. These costs are summarized in Table 2. Cost of the spray-rig is based on data provided in Table 3. Most of the salvage value is in the retractable reels and the pump unit, exclusive of the engine. Chemicals used were provided by the ranchers and the Forest Service. The rancher cost, based on the best bulk rate they could obtain, was $15 per gallon for 4 lb acid equivalent, 2,4,5-T. The Forest Service cost was $7.75 per gallon, based on a purchase from GSA in August of 1974.[1] Two cost estimates per acre of larkspur controlled are, therefore, indicated in Tables 4 and 5.

Based on data from 4 years, 3 acres per hour is the average rate for the first application with this specially designed spray-rig. About 6 hours per day is the average spraying time one can expect. The remainder of the day is spent filling the sprayer, moving from one pasture to another, making repairs, cleaning filters, etc. Thus, 18 acres per day could be sprayed on sites similar to the upper allotment of Manti Canyon.

At the ranchers' cost for the herbicide, spraying cost about $23 per acre of larkspur treated (Table 4). When the Forest Service provided the herbicide and the ranchers provided the labor and equipment, the cost was about $15.50 per acre of larkspur controlled (Table 4).

The second application of herbicide to a given patch of tall larkspur should be made the year following the initial spraying. This application is intended to control the larkspur plants not killed in the first treatment. The same area must be covered and

[1] The 1977 GSA price for 2,4,5-T in 55-gallon drums is $10.30/gallon of 4 lb acid equivalent.

Table 3. Cost of power pump and retractable hoses for larkspur spraying, 1975.

Item	Cost
30-gallon capacity power sprayer	$ 392.00
2 @ retractable reels × 125 ft of hose per reel	782.00
2 @ spray heads, nozzles, and fittings	36.00
Platform and upright hose holders with guides	336.00
	$1,500.00
Estimated salvage value	−500.00
Net cost	$1,000.00
Estimated minimum useful life of spray-rig 750 hrs spray time	
Cost per hr $= \frac{\$1,000}{750 \text{ hrs}}$	$1.33
Repairs and fuel cost per hr	0.20
Interest on investment at 10% annually for 4 years = $600	
Hours required to treat 344 acres of larkspur (twice)—253 hrs*	
Cost per hr $= \frac{\$600}{253 \text{ hrs}}$	2.37
Total cost per hour	$3.90

* This assumes the sprayer could be sold for its remaining value after 4 years.

Table 4. Cost per acre of spraying tall larkspur (first application)—Manti, Utah, 1975.

	Cost
Data Base:	
Average spraying time—3 acres/hour or 20 minutes/acre	
Actual spraying time per day—6 hours/day	
(Other time used to fill sprayer, repairs, etc.)	
3 acres/hour × 6 hours spray time/day = 18 acres/day.	
Labor costs:	
1 permittee	$25.00
2 laborers at $2.50/hour	
2 × $2.50 × 8 hours/day =	40.00
	$65.00
Equipment costs:	
4-wheel drive pickup $5/hour × 8 hours =	$40.00
Sprayer $3.90/hour × 6 hours =	23.40
Water truck and cost of getting crew on job	
45 miles/day on spray truck × $0.12/mile =	5.40
35 miles/day on water truck × $0.12/mile =	4.20
	$73.00
Chemical costs:	
4 lb acid eq/acre = 1 gallon/acre at $15/gallon (Rancher cost) $15× 18 acres	$270.00
4 lb acid eq/acre = 1 gallon/acre at $7.75 (FS cost) $7.75 × 18 acres	139.50
Rancher cost per acre:	
$65 + $73 + $270 = $408 ÷ 18 acres =	$22.67/acre
FS cost per acre:	
$65 + $73 + $139.50 = $277.50 ÷ 18 acres =	$15.42/acre

Table 5. Cost per acre of spraying tall larkspur (second application—1 year after first application)—Manti, Utah, 1975.

	Cost
Basis for calculations:	
Second application required 50%[1] as much herbicide per acre but increased time required per acre by 25%.[2]	
20 minutes/acre × 1.25 = 25 minutes/acre	
360 minutes (6 hours) ÷ 25 minutes/acre = 14.4 acres/day	
Labor costs:	
1 permittee ($25/day)	$25.00
2 laborers at $2.50/hour	40.00
	$65.00
Equipment costs:	
4-wheel drive pickup—$5/hour × 8 hours =	$40.00
Sprayer $3.90/hour × 6 hours =	23.40
Mileage water truck 45 miles × $0.12/mile =	5.40
Mileage spray truck 35 miles × $0.12/mile =	4.20
	$73.00
Chemical costs:	
4 lb acid eq/acre of larkspur—½ gallon/acre at $15/gallon (Rancher cost) $7.50 × 14.4 acres	$108.00
4 lb acid eq/acre of larkspur—½ gallon/acre at $7.75/gallon (FS cost) $3.875 × 14.4 acres	55.80
Rancher cost per acre:	
$65 + $73 + $108 = $246 ÷ 14.4 acres =	$ 17.08/acre
FS cost per acre:	
$65 + $73 + $55.80 = $193.80 ÷ 14.4 acres =	$ 13.46/acre

[1] Density of larkspur reduced, although application is still made at a rate of 4 lb acid per acre to each surviving plant.
[2] Time increased because sprayers must search out small and scattered plants that survived the first spray application.

more time spent finding the small, scattered plants that still survive. On the Manti Allotment, about half the herbicide and 25% more time was required for the second application than for the first. About 14.4 acres per day were sprayed the second year, with an application rate equal to 4 lb acid equivalent. The costs per acre of making the second application are ranchers $17, Forest Service $13 (Table 5).

An estimated 344 acres are infested with tall larkspur on the upper elevations of the Manti Canyon Allotment. Research has indicated that cattle losses can be reduced by about 90% if the dense patches of larkspur are controlled (Table 6, Cronin et al. 1976). Losses without control would have been 52 head on the North Fork Grazing Unit. Actual losses were 3 head; thus, losses were reduced by about 94%.

The total cost of controlling tall larkspur on the high elevation Manti Allotment is estimated below:

1st application: 344 acres × $22 per acre = $7,912
2nd application: 344 acres × $17 per acre = 5,848
Total = $13,760

Benefits from Tall Larkspur Control

The benefits from control of tall larkspur on cattle ranges include not only the value of animals saved from poisoning but also increased management flexibility and increased forage production. Ranchers on the Manti Allotment were reluctant to move cattle onto larkspur ranges when the plants were most palatable and toxic (Williams and Cronin 1963). Thus, they tended to use the lower elevation pastures longer than range readiness on the upper pastures dictated. Control of larkspur on the high-elevation pastures could permit their use earlier in the season and reduce pressure on the lower-elevation pastures. Larkspur control also permitted heavier utilization of the high-elevation pastures during September, which is desirable in a rest-rotation system. It is reasonable to expect that the increased flexibility in range use brought about by control of larkspur could result in increased AUM's for the entire allotment. An increase in efficiency in the use of resources would result through the cattle saved. Cows and calves are fed and cared for almost completely through the production cycle; then a portion of them are lost to these poisonous plants. Thus, all of the inputs expended on these animals are wasted. Also, as larkspur plants were sprayed, they were replaced with high quality forage species. The net effect is an increase in forage produced.

Table 6. Cattle losses from 1971 through 1975 in North Fork Grazing Unit as compared with predicted losses expected without control of larkspur.

Year	Total losses recorded in Manti Canyon Allotment (numbers)	North Fork Grazing Unit[1]: Cattle losses with Unit: Actual losses (numbers)	Predicted[2] losses (numbers)	Grazing period in Unit
1971	14	0	7	Sept. (late)
1972	14	3	25	July 15–Aug. 10 (early)
1973	2[3]	0	1	Aug. 10–Sept. 1 (mid-season)
1974	6[4]	0	3	Sept. 1–Oct. 1 (late)
1975	32	0	16	Sept. 1–Oct. 1
Total	68	3	52	

[1] The tall larkspur control program was initiated in the North Fork Grazing Unit in 1969, with small areas of the unit treated each year.
[2] The predicted losses are based on losses that occurred on the remaining, nontreated subalpine grazing units in each of the 5 years.
[3] After these two cattle were poisoned, the herd was moved into the North Fork-Jolly's Hole Grazing Unit to prevent further losses.
[4] Some patches of tall larkspur in the South Fork-Hougard Fork Grazing Unit were treated in 1973, which probably reduced losses for 1974.

Although the benefits of larkspur control are important, only the value of animals saved will be used in this analysis. The other benefits are difficult to measure and land managers and/or ranchers may not agree on their magnitude.

Cattle losses from larkspur poisoning have been reduced by over 90% on the treated areas of the Manti Canyon Allotment. Since the grazing unit that historically had the highest loss was the one treated and used to estimate the effectiveness of control, one might expect an even higher reduction in losses as the other subalpine grazing units are sprayed. Adult cattle losses on this allotment averaged 36 head annually from 1956 through 1970 (Table 1). If the loss reduction on the North Fork-Jolly's Hole Grazing Unit (94%) is applied to the entire larkspur loss area, an expected 33 cows could be saved annually. In addition, calf losses could be reduced. The recorded calf losses for 8 of the 20 years listed in Table 1) averaged 11.25 head per year. A 90% saving would average about 10 calves per year.

The following assumptions are made on the value of cattle lost. First, cows of all ages are equally likely to be poisoned and the long-term (20-year) average value of production breeding cows is $250 per head. Second, steer and heifer calves are equally susceptible to poisoning; they will aveage 400 lb at weaning and have an average value of $30 per cwt. When a rancher loses a calf, regardless of its weight at the time of death, he is losing the opportunity of selling the calf at weaning time.

The expected value of cattle saved each year would, therefore, be:

33 cows × $250 per head = $8,250
10 calves × $120 per head = 1,200
Total = $9,450

Ranchers who run cattle on this allotment must spend $13,760 for larkspur control, and the expected value of animals saved equals $9,450 per year for the effective life of the spraying. What then is the effective life of spraying or, for how may years after spraying can one expect this reduction in losses to persist?

Based on observation, the expected larkspur control should last at least 10 years. Even with an almost immediate reinvasion of larkspur plants, it would take several years before they would be large enough and dense enough to become a significant factor in the grazing by cattle (Holman 1973). Also, research has shown that grasses quickly fill the spaces where larkspur and other forbs have been removed and retard the rate at which larkspur plants reestablish themselves (Cronin 1976).

Cattle occasionally consume tall larkspur after it has been sprayed, even if it looks dry and unpalatable. Because the sprayed plants still retain their poisonous properties (Williams and Cronin 1963), grazing should be deferred on a sprayed area until after a heavy frost. Such late-season grazing, after the first application of herbicide, is critical for the establishment of grasses on the spray site. The grazing action of the cattle scatters the grass seeds and covers some of them with soil. After the second year's spraying, grazing should again be deferred to protect new grass seedlings. If livestock must be completely removed from a grazing unit, nonuse costs[2] should be included in the cost of larkspur control. However, nonuse costs can often be higher than the value of lost animals, so ranchers would probably prefer to manage grazing on the sprayed areas, even if losses are sustained.

The Manti Grazing Allotment has a rotation grazing system that allows the grazing units being rested to be sprayed without a loss of grazing. Such an approach, however, increases the number of years required to control the larkspur. For example, it would take at least 4 years or more to complete the control work if the pastures are sprayed initially the year before they are rested.

Can one afford to spend $13,760 in order to obtain an annual income stream of $9,450 for 10 years? The return of a dollar each year for 10 years is not worth $10 today. Therefore, the income stream expected over these 10 years has to be put in terms of the present. The process by which the flow of future returns are brought to the present is called discounting.

The concept of discounting may be understood easier by working through a simple example. Suppose a project is expected to return $10 per year for 5 years; this amounts to $50. If our discount rate is 5%, this $10 per year for 5 years is only worth $43.29 today. Let's look at this problem in more detail. The present value of $10 for each of the 5 years is given below:

	Present value of $10
1st year	$ 9.52
2nd year	9.07
3rd year	8.64
4th year	8.22
5th year	7.84
	$43.29

If a rancher borrows $10 at 5% interest for 1 year, at the end of the year he will have to pay the $10 plus $.50 interest or $10.50. Most ranchers have experienced this situation where they pay for the use of money. Suppose the rancher has an obligation to pay $10 at the end of 1 year. He wants to know how much money he will have to put in a savings account at 5% interest today in order to have $10 one year from now. He would have to put $9.52 in the bank today. At the end of 1 year he would have $9.52 + .48 interest = $10. Therefore, the present value of $10 1 year from now is $9.52 if the interest rate is 5%.

The above method has the disadvantage of forcing one to select an interest rate or discount rate. In this paper a method will be used that gets around this problem. The discount rate which makes the discounted returns equal to the cost of obtaining the income stream will be computed. The discount rate which makes these two sums equal is known as the "internal rate of return." The decision to invest or not to invest is based on the magnitude of the internal rate of return.

With two simplifying assumptions, the internal rate of return on spraying tall larkspur can be approximated. The first assumption is that all costs occur the same year. The second is that the benefits begin the year after treatment and continue for 10 years. The equation used to compute this return is:

$$I = R\left[\frac{1-(1+i)^{-n}}{i}\right]$$

where,

I = initial cost of spraying

R = expected annual benefit of spraying (value of cattle saved)

n = number of years that benefits will last

i = internal rate of return.

The unknown in this equation, as applied to spraying larkspur on the Manti Grazing Allotment, is i.

$$\$13,760 = \$9,450\left[\frac{1-(1+i)^{-10}}{i}\right]$$

The internal rate of return, i, is equal to 68.68%. This rate is above the cost of capital and should rank high as a use of capital.

If the value of calves saved is not included in the benefits, because the evidence for calves saved is not as conclusive as it is for adult cattle, the internal rate of return then becomes:

$$\$13,760 = \$8,250\left[\frac{1-(1+i)^{-10}}{i}\right]$$

i = 59.95%.

A more realistic analysis can be made if we assume that the actual larkspur spraying takes place over a 4-year time period. Under this plan, half the larkspur acreages are sprayed while the other half are grazed. Two years are required to complete the control on each half. However, some grazing is allowed late in the grazing season following the initial application of herbicide. The unsprayed half of the larkspur will receive the initial treatment in year 2 (the third year of the project, Table 7), and the cattle will graze the area that was treated the previous 2 years. Since grazing takes place on an area where the larkspur has been controlled, one would expect losses to be reduced by about 90%; thus, the benefits from spraying start in year 2 (the third year of the project).

The benefits and costs of spraying tall larkspur over a 4-year period with an expected life of 10 years are presented in Table 7. Expected net benefits each year of the project life are discounted separately. Finding a discount rate that makes the sum of the discounted returns equal to the initial investment made in year "0" is the problem. The discount rate that does this is the internal rate of return. In the case used in Table 7, where both cattle and

[2] Nonuse costs are the costs of providing an alternative source of forage while cattle are off the grazing land.

Table 7. Internal rate of return for tall larkspur spraying done over 4 years; cows and calves saved included in benefits.

Year	Cost	Net benefits	Discounted benefits at 72.25% Annual	Accumulated
0[1]	$3,956[2]			
1	2,924[3]	−$2,924	−$1,698	−$1,698
2	3,956	5,494[4]	1,852	154
3	2,924	6,526	1,277	1,431
4	0.0	9,450	1,073	2,504
5	0.0	9,450	623	3,127
6	0.0	9,450	362	3,489
7	0.0	9,450	210	3,699
8	0.0	9,450	122	3,821
9	0.0	9,450	71	3,892
10	0.0	9,450	41	3,933
11[5]	0.0	9,450	24	3,957

Internal rate = 74.5%

[1] Year "0" is the year the decision is made to spray.
[2] Spray half the area (344 acres ÷ 2 = 172 acres) 172 × $23 = $3,956.
[3] Second application on 172 acres. 172 × $17 = $2,924.
[4] First application on remaining 172 acres, cost $3,956. It is assumed that animals will graze the sprayed areas and the benefits will be $9,450. Net benefits $9,450 − $3,784 = $5,494.
[5] Year "11" used because no benefits assumed in year "1."

Table 8. Internal rate of return for tall larkspur spraying done over 4 years with calf losses excluded in benefits.

Year	Cost	Net benefits	Discounted benefits at 63.5% Annual	Accumulated
0[1]	$3,956[2]			
1	2,924[3]	−$2,924	−$1,788	−$1,788
2	3,956	4,294[4]	1,606	−182
3	2,924	5,326	1,219	1,037
4	0.0	8,250	1,154	2,191
5	0.0	8,250	706	2,897
6	0.0	8,250	432	3,329
7	0.0	8,250	264	3,593
8	0.0	8,250	162	3,755
9	0.0	8,250	99	3,854
10	0.0	8,250	60	3,914
11[5]	0.0	8,250	37	3,951

Internal rate = 65.5%

[1] Year "0" is the year the decision is made to spray.
[2] Spray half the area (344 acres ÷ 2 = 172 acres) 172 × $23 = $3,956.
[3] Second application on 172 acres. 172 × $17 = $2,924.
[4] First application on remaining 172 acres, cost $3,956. It is assumed that animals will graze the sprayed areas and the benefits will be $8,250. Net benefits $8,250 − $3,956 = $4,294.
[5] Year "11" used because no benefits assumed in year "1."

calves saved are used as benefits, this rate of return is about 72.25%. When calves are not included, the internal rate of return is about 63.5% (Table 8).

All of the internal rates of return computed in this analysis of the economics of tall larkspur control are quite high. If the success of spraying tall larkspur is measured by numbers of animals saved from poisoning as compared to the costs of spraying, one can look at the problem in a different way. Suppose that 10% is acceptable as a reasonable rate of return on an investment in larkspur spraying. If this is the case, only eight to nine cows would have to be saved per year over 10 years to yield the return of 10%. However, results of this research indicate that about 33 cows and 10 calves could be saved annually if 344 acres of larkspur are controlled. This problem can also be analyzed in another way. If the 33-cow estimate is accepted, one could afford to pay $147 per acre to treat the 344 acres of larkspur and still get a 10% return on investment.

Summary

The average loss of mature cattle on the Manti Canyon Cattle Grazing Allotment over a 15-year period was 36 head per year. In addition, average calf losses, based on 8 years of data, were about 11 head per year.

Tall larkspur can be successfully controlled if it is sprayed for two consecutive years with 4 lb acid equivalent of 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid]. Cost of control ranges from about $15–$22 per acre of larkspur for the first application and from $13–$17 per acre for the second application. The difference in cost for each application is dependent on the cost of the herbicide.

Assuming the higher herbicide costs, it would cost $13,416 to control the 344 acres of tall larkspur on this grazing allotment.

The value of 33 head of adult cattle saved each year was estimated at $8,250. The value of 10 calves was estimated at $1,200 per year. Internal rates of return for this control project ranged from 72.25% to about 60%, depending on the time sequence of control and whether calves saved were included in the analysis. If a 10% return on investment is considered adequate, the project would have been economically feasible if only eight or nine cows were saved each year for 10 years.

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Seed Germination of True Prairie Forbs

JOHN W. VOIGT

Highlight: A study was conducted on 20 species of prairie forbs collected from Illinois tallgrass prairie to determine their levels of germination without treatment of the seed and to determine their expected higher levels of germination with various seed treatments. The present assay of forb seed germination was made to aid those engaged in prairie restoration. Seed fill was visually and physically determined. Seed viability was determined by use of triphenyl tetrazolium chloride, which turns living embryos red. Germination was done on moist filter paper inside petri plates in darkness at constant temperature. From tests on 20 species only three germinated without treatment; 12 germinated under 2 months of moist-cold treatment; and four germinated with scarification. When treated with rootone, five species germinated. Three species germinated with single application of .005% potassium gibberellate spray. These results suggest most of the 20 species could be planted with success with the proper preparation or treatment of the seed.

The former extent of Prairie in North America or its disappearance through settlement, agriculture, and grazing, are well recorded (Weaver 1954; Transeau 1935). That this magnificent resource has all but disappeared was dramatically told in the Disney movie "The Vanishing Prairie."

Like the word *ecology* (until recently), *prairie* was not a household word. Hardly anyone but the professional understood that prairie was a kind of vegetational resource. As in the case of many other resources, concern was not shown until it was nearly gone. Today, for the most part, only remnants exist in most midwestern states; they are found along highways and railroad rights-of-way. These remnants are often not valid prairies but can be managed and restored to good replicas. Prairie species sometimes exist in these locations because of practices aimed at keeping down brush and tree growth. There are some managed prairies, mostly in the hands of educational institutions or owned by state governments as a part of their preservation programs. There are some smaller prairies in Illinois overlooking the Mississippi River, where they are inaccessible to cultivation (Evers 1950; Kilburn 1970).

In the past 10 years there has been a revival of interest in prairie preservation through restoration and in the use of prairie grasses and forbs in natural landscaping. In the fall of 1968 the first Symposium on Prairie Restoration was held at Knox College, Galesburg, Ill. The second symposium was held at the University of Wisconsin Arboretum in 1970 with about 300 attending. This was about a threefold increase from the first meeting. At least a third of those in attendance were lay people who had acquired sufficient knowledge to attend a basically scientific meeting (Anderson 1972). The Prairie Restoration Symposium has grown to an annual event, with meetings held in different geographic parts of the True Prairie Association.

Evidence of wide and increasing interest in restored prairies is shown in the number of commercial sources for prairie grass seed. Limited commercial seed has been available for reseeding grazing lands for several years. Recently, prairie grass seed has been proposed for natural landscaping purposes (Wilson 1976). Doctoral theses on prairie restoration are also noted (Christiansen 1967). Recently, native grass seed, forb seed, and pot-grown herbs are noted in a few nursery plant price lists. The pot-grown herbs are used for transplants into prairie restoration plots where grasses are established first.

Highway departments, the Corps of Engineers, and other Federal and State agencies are increasingly employing ecologists or using them as consultants in connection with prairie restoration projects. Right-of-way management has assumed new importance to all aspects of conservation. Corporate bodies such as utilities companies have shown an interest in prairie restoration on their lands. An 800-acre prairie restoration project is now being carried out on lands owned by the National Accelerator Laboratory near Batavia, Ill. (Brukoff 1974). Establishment of prairie by corporate bodies has public relations value, educational use, and low maintenance cost.

These growing interests in prairie restoration bring a demand for forb seed which presently does not exist in quantity or quality (Sorenson and Holden 1974). The early research of Blake (1935) reveals some difficulties in the germination of the seeds of prairie species. Recent work by Sorenson and Holden (1974) revealed that 65% of 23 species of forbs investigated gave germination without treatment of moist-cold periods or scarification.

The regularly appearing forbs of a square mile of Nebraska prairie numbered 181 (Steiger 1930). Seeds of goodly number of forb species have not been studied and tested for germination performance. Prairie restoration management will be aided by further information on conditions needed for germination of other prairie forbs.

Methods

Seed for this study was collected from prairie remnant situations in Illinois mainly from two localities, one in Carroll County approximately 4 miles south of Savanna on Highway 80 and the other about 8 miles north of Carbondale, Ill., on Route 51. The following were collected from the northern Illinois station: clustered poppy mallow (*Callirhoe triangulata*), tickseed (*Coreopsis palmata*), and shaggy false gromwell (*Onosmodium hispidissimum*). The remaining 17

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Manuscript received February 28, 1977.

species were from the southern site. Seeds were collected during the last week of September, 1974. Additional collections of seeds from the southern location were made about 3 weeks later the following year.

In the production of seeds, not all become filled. Germination tests were made only on those seeds which were visually judged to be filled or containing embryos. Those seeds thus selected visually were confirmed by pressing them lightly with a pair of forceps. Subsequently, the filled seeds were tested for viability by soaking overnight in 0.1% triphenyl tetrazolium chloride (TTC) (Machlis and Torrey 1956; Hartman and Kester 1968; Sorenson and Holden 1974). Seeds having a hard seed coat were cut in half with a razor blade prior to treatment with TTC.

The first germination test was a normal laboratory test. Arasan, a fungicide, was placed in a paper bag with the seeds to be tested and shaken to coat the seeds thoroughly with fungicide. The seeds were then removed to sterile petri plates containing moistened filter paper (Nichols 1934; Sorenson and Holden 1974). The petri plates were maintained in an open laboratory on tables in an air conditioned building which provided a temperature of about 75°F. The petri plates were covered with two layers of brown wrapping paper and blotters from a plant press to provide a darkened environment. The seeds were exposed to light only for counting seeds which had germinated. Daily recordings were made of seeds germinating over a 30-day period. Each time a seed germinated, it was removed from the petri dish. Germination was considered as the emergence of the radicle from the seed coat. Germination tests on each species involved 100 seeds. A maximum of 25 seeds was placed in each petri dish. From these initial germination tests, those species failing to germinate or to germinate well were subjected to other methods of treatment to improve germination or to break dormancy. Percentages of germination are expressed as the nearest whole number.

All 20 species were subjected to moist-cold treatment. Seeds were placed on moistened filter paper in petri plates and stored in the bottom of a refrigerator for a period of 2 months. After this interval the seeds of each species were removed and tried for germination as described for normal germination. The refrigerator temperature was 40°F on the lower shelf where the seeds were stored.

Results and Discussion

Poor seed performance is often due to the time the seed is collected. Seed collected too early may have immature embryos. Seed collected too late may be ravaged by insects or fungus organisms, or the best seed with the best-developed embryos may have already been dispersed. Good timing in the collection of seed is based upon detailed knowledge of the life history of the plant. The collection of seed for this study was made in late September, which appears to have been generally a favorable time. Seed development in the 20 species studied ranged from 40 to 100% (Table 1).

When the seeds of 20 selected species were tested for

Table 1. Seeds developing mature embryos (%), and seeds showing viability (%) when tested with 0.1% triphenyl tetrazolium chloride (TTC); germination (%) and days to germinate under 2 months of moist-cold treatment and untreated; germination (%) after treatment with rootone and treatment with .005% potassium gibberellate (aerosol spray), and days to germinate.

Species	Developing embryos	Viability (TTC)	Moist-cold germination	Days	Untreated germination	Days	Rootone treated	Days	Gibberellate treated	Days
Biennial gaura (*Gaura biennis*)	60	98	—	—	—	—	77	14–28	—	—
Bush lespedeza (*Lespedeza capitata*)	100	100	85	7–20	81	14–20	80	14–21	87	14–21
Clustered poppy mallow (*Callirhoe triangulata*)	90	100	71	7	30	14–30	—	—	50	14–21
Compass plant (*Silphium laciniatum*)	100	100	41	10–14	—	—	—	—	—	—
Cup plant (*Silphium perfoliatum*)	100	100	—	—	—	—	—	—	—	—
Entire-leaved rosinweed (*Silphium integrifolium*)	54	100	—	—	—	—	—	—	—	—
Flat-topped spurge (*Euphorbia corallata*)	100	100	69	5–20	—	—	—	—	—	—
Feverfew (*Parthenium integrifolium*)	50	52	—	—	—	—	—	—	—	—
Green milkweed (*Acerates viridiflora*)	100	100	59	7–20	—	—	—	—	—	—
Hairy sunflower (*Helianthus mollis*)	40	100	63	6–10	—	—	—	—		
Long-fruited anemone (*Anemone cylindrica*)	100	74	—	—	—	—	—	—	—	—
Prairie dock (*Silphium terebinthinacium*)	70	100	73	8–10	—	—	—	—	—	—
Rattlebox (*Crotalaria saggitalis*)	90	100	—	—	—	—	20	3–20	—	—
Rattlesnake master (*Eryngium vuccifolium*)	63	90	—	—	—	—	—	—	—	—
Shaggy false gromwell (*Onosmodium hispidissimum*)	100	100	—	—	—	—	—	—	—	—
Squarrose blazing star (*Liatris squarrosa*)	80	60	42	14–21	—	—	—	—	—	—
Tall baptisia (*Baptisia leucantha*)	100	100	2	7	—	—	—	—	—	—
Tall blazing star (*Liatris pycnostachya*)	70	50	40	14–21	—	—	—	—	—	—
Tickseed (*Coreopsis palmata*)	50	96	98	6–12	40	4–30	40	14–21	—	—
Virginia lespedeza (*Lespedeza virginica*)	73	87	39	14–20	—	—	30	14–21	70	14–21

germination without any kind of treatment after gathering, only three showed germination (Table 1). Twelve species showed germination after receiving a moist-cold treatment for 2 months. The percentages of germination of these twelve species ranged from 2 to 98% (Table 1).

Moist-cold treatment improved germination of the three species which had germinated without any kind of treatment. No species were found in which the moist-cold treatment reduced the germination percentage over that achieved without treatment. The moist-cold treatment results in after-ripening and produces embryonic growth or metabolic change within the embryo (Hartman and Kester 1968; Mayer and Poljakoff-Mayber 1968).

Some species remain dormant because of a seed coat which is a many-layered membrane of impervious nature or whose outer layer is covered with waxy substances impervious to water or gasses. Many Composites such as rosinweeds, tickseed, some sunflowers, and the blazing stars have such waxy coverings on the seed coat. Such species, after being given the moist-cold treatment also had their seed scarified by nicking them or slicing a thin section from the edge of the seed. This combined treatment gave germination of seven species, usually within 2 weeks. Seven other species showed no germination response to this treatment.

There are other species which have hard and mechanically resistant seed coats. There were four species which responded to scarification of the seed coat as a single treatment. The legume family is notable for this feature, and two of the four species belonged to this family (Table 2).

Table 2. Seed germination (%) of four prairie forbs after scarification treatment, and days to germinate.

Species	Percent germination	Days
Clustered poppy mallow (*Callirhoe triangulata*)	90	14–17
Battlebox (*Crotalaria saggitalis*)	100	3–5
Shaggy false gromwell (*Onosmodium hispidissimum*)	80	8–20
Tall baptisia (*Baptisia leucantha*)	100	7

Scarification was done with an emory board such as used in filing fingernails. Small seeds were held with forceps and ten strokes of the fine side of the emory board usually broke the seed coat. Because of the tedious nature of this technique the number of seeds per petri plate, for this part of the experiment, was reduced to ten. With four replications the total number of seeds thus tested was 40 for each species. The germination percentage ranged from 80 to 100% and generally occurred promptly (Table 2).

Dormancy may sometimes be broken with chemical growth-producing substances or hormones. Seeds of all 20 species were treated with both the commercial rootone powder and the .005% potassium gibberellate from an aerosol can. Five species responded to rootone, but only one of these showed improved germination over that of the other treatments. A species whose seeds showed no germination under other treatments was the biennial gaura. It showed a germination of 77% when treated with rootone. Only three species had seeds which germinated when treated with one application of the gibberellate spray. The bush lespedeza and Virginia lespedeza gave improved germination percentages with 87 and 70% respectively (Table 1).

Conclusions

The germination of prairie forb seed is high enough with the proper treatment for each kind of seed that good success in planting can be expected. This should be true either in field seeding or growing in the greenhouse in pots or flats. Because of certain advantages such as control of competition the latter method is often favored. The germination response after proper seed treatment ranges from 6 days to 30 days. Germination for most species is around 2 weeks.

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Factors Limiting Liveweight Gain of Beef Cattle on Rangeland in Botswana

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Highlight: Six range parameters measured monthly over an 11-month period on nine ranches distributed throughout the main ecological zones of Botswana were related to the monthly liveweight changes of growing cattle. Clipped and esophageal fistula samples provided estimates of crude protein content (CP) and dry matter digestibility (DM), while available DM and grazing index provided estimates of available herbage. Linear, quadratic, and multiple regressions all indicated that liveweight change was influenced primarily by the CP content of the herbage selected. The CP content of fistula samples accounted for 54% of the variation in liveweight gain, while digestibility of the same samples accounted for 32%. Quadratic regressions failed to account for any more variance than linear regressions. The inclusion of digestibility with CP content in a multiple linear regression failed to have any effect. The addition of grazing index to CP content increased the variance accounted for in both the fistula and clipped samples from 54% to 56% and 48% to 53%, respectively. It appears that under the natural range conditions of Botswana, crude protein is presently the major limiting factor, and initial research efforts must be directed towards increasing the CP content of the diet available to beef cattle.

Botswana is an elevated plateau situated between 17° and 27° south and 20° and 30° east, covering 572,000 km^2 at a mean altitude of 1,000 m. Natural grasslands cover approximately 450,000 km^2 and support a population of 3 million cattle, and 1.5 million goats and sheep. The population of game animals is unknown but is probably several million head.

The composition of the natural grasslands varies considerably throughout the country largely due to highly variable rainfall. The extreme northeast receives a mean rainfall of 700 mm, which drops to 500 mm in the east and decreases progressively towards the west, while less than 300 mm is received in the southwest. Annual rainfall can fluctuate from less than half to twice the annual mean, while in the west some years are completely without rain. The rains occur normally between October and April.

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Manuscript received February 24, 1977.

Under these adverse climate conditions, efficient pasture management and utilization is difficult. Results of completed work have been comprehensively reviewed by McKay (1968). Much of this earlier work was conducted on two sites only and, therefore, is not representative of all the ecosystems in Botswana.

The importance of cattle production in Botswana cannot be over emphasized. It is the country's main foreign currency earner and will remain so for many years. In 1975 cattle exports realized S.A. R40 million (BMC Annual Report 1975).

The objectives of the work described in this paper were to evaluate the usefulness of different range parameters for establishing limiting factors in animal production, and to indicate future lines of research in a more rational manner. An initial survey was conducted to determine the questions that needed to be answered rather than to provide any answers.

Materials and Methods

The investigations were conducted on nine beef cattle stations, situated in differing ecological zones, from October 1972 to August 1973. Several measurements were made at monthly intervals at each station. Rainfall (mm) was determined with standard rain gauges. Monthly estimates of available herbage dry matter (ADM) were made from fifteen 1-m^2 quadrats randomly distributed throughout the grazed paddocks and harvested to ground level. ADM is a simple estimate of dry matter available per unit area. Grazing index (GI) was calculated to account for station variations in ADM per unit area, paddock size, number of animals, and mean weight of the animals. GI was felt to be an improved alternative to stocking rate as an estimate of grazing

Table 1. The total rainfall (mm) for each station from October 1972 to August 1973 and the 5-year mean.

Station	5-Year mean 1970–75	Year of trial Oct. 1, 1972–Aug. 1973
Masama	536	240
Impala	504	213
Good Hope	592	291
Boswelatlou	619	444
Musi	580	313
Masiatilodi	511	360
Matlolakgang	432	250
Tsetseku	444	109
Sunnyside	612	319
Mean	537	282

Table 2. **Means and standard deviations (S.D.) for the variables included in the study.**

	Whole year (Oct.–Aug.)		Wet season (Oct.–Apr.)		Dry season (May–Aug.)	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.
Liveweight gain (kg/month)	10.0	10.86	14.5	9.48	2.1	7.75
Crude protein (%)						
a) of clipped	4.7	1.77	5.2	1.93	3.7	.65
b) of fistula	8.5	2.79	9.6	2.68	6.5	4.37
Dig. of dry matter						
a) of clipped	34.7	5.37	36.0	5.88	32.5	2.78
b) of fistula	41.3	5.61	42.9	5.87	38.4	3.62
Quantity						
a) Grazing index (kg DM/kg liveweight)	19.1	7.64	22.0	6.05	13.9	3.40
b) Available dry matter (kg/ha)	1150	107.30	1168	289.35	1118	252.26

Table 3. The linear regression coefficients of the independent variables on monthly liveweight change and the coefficients of determination for the whole year, the wet season, and the dry season.

Variable y=LVG (kg/month)	Whole year b	Whole year r^2	Wet season b	Wet season r^2	Dry season b	Dry season r^2
x_1=CP % clipped	4.27**	0.48**	3.04**	0.38**	6.91**	0.34**
x_2=CP % fistula	2.87**	0.54**	2.25**	0.41**	2.63**	0.25**
x_3=Dig. clipped	1.04**	0.26**	0.76**	0.22**	0.83	0.09
x_4=Dig. fistula	1.09**	0.32**	0.83**	0.26**	0.55	0.07
x_5=Grazing index (kg DM/kg liveweight)	0.33**	0.05*	0.39	0.06	0.84*	0.14*
x_6=Available DM (kg/month)	0.0005	0.0003	0.0003	0.0001	0.008	0.07

* Significant at P 0.05.
** Significant at P 0.01.

pressure. This was constructed as kilograms of dry matter available per kilogram of animal liveweight from the following formula:

$$\text{Grazing Index} = \frac{(\text{Kg ADM/ha}) \times \text{No. of ha}}{(\text{No. of animals}) \times \text{Mean wt. of animals}}$$

Crude protein (CP) content of the same clipped samples was determined using the Kjeldahl method. In vitro digestibility of DM of the same clipped and fistula samples were determined using the method of Tilley and Terry (1963) as modified by Minson and McLeod (1972). CP content of esophageal fistula samples was also determined. These were collected on two consecutive days from three fistulated steers grazing with the animals whose performance was being recorded. Monthly liveweight gains of cattle born between October 1971 and January 1972 and weaned by July 1972 were also determined. The average group size was 80 animals with a mean age of 10 months and mean weight of 187 kg at the start of the trial. All cattle were allowed access to a bonemeal and salt mixture throughout the study, as previous work had shown the benefits of such a practice (APRU 1971). The cattle were also allowed 24-hour access to grazing and water.

Results

The period was much drier than usual with many stations receiving less than half the normal rainfall (Table 1). Note that rainfall amounts in the second column are only for 11 months as the rains came early in September. Since the important fact is the rainfall occurring in one growing season, it would be wrong to include the September rainfall here, because it begins a second season.

There was a positive relationship between CP content, digestibility, and liveweight gain but no apparent relationship between liveweight gain and available dry matter or grazing index (Fig. 1).

There was considerable variation in each parameter throughout the year and from ranch to ranch (Table 2). The greatest amount of variation in liveweight change (54%) was accounted for by CP content of the fistula sample, followed by CP content of the clipped sample (48%) (Table 3). The two digestibility measurements accounted for only 32% and 26%, respectively, of the variation in liveweight change. Relative to digestibility, crude protein was more important in both the wet and the dry season. However, the effect of digestibility was much greater in the wet season than in the dry. While digestibility of the fistula and clipped samples accounted for 26% and 22%, respectively, of the total variance in the wet season, they accounted for only 9% and 7% in the dry season.

Quadratic regressions failed to account for any more of the variation in liveweight gain than did linear regressions and are consequently not reported here.

Multiple linear regression analyses using two and then three independent variables were calculated (Table 4). In every case one variable was used from each of the groups representing alternative methods of describing the herbage.

Table 4. Multiple linear regression analyses on two and three independent variables on monthly liveweight change and the coefficients of determination for the whole year, the wet season and the dry season.

	Whole year				Wet season				Dry season			
Independent variables	b_1[7]	b_2	b_3	r^2[7]	b_1	b_2	b_3	r^2	b_1	b_2	b_3	r^2
CPC[1] + DC[2]	4.39	−.05	—	.48	3.06	−.008	—	.38	6.48	.28	—	.35
CPC + GI[3]	4.23	.31**	—	.53	3.05	.005	—	.38	6.17	.34	—	.36
CPC + ADM[4]	4.31	.002	—	.49	3.07	−.002	—	.39	6.56	.004	—	.35
CPF[5] + DF[6]	2.83	.02	—	.54	1.99	.15	—	.41	3.11	−.29	—	.26
CPF + GI	2.79	.17	—	.56	2.34	.09	—	.41	2.20	.40	—	.27
CPF + ADM	2.87	.001	—	.54	2.29	.003	—	.41	2.45	.003	—	.25
CPC + DC + GI	4.40	−.07	.31*	.53	3.07	−.009	.005	.38	5.92	.21	.30	.36
CPC + DC + ADM	4.48	−.08	.002	.49	3.15	−.03	−.002	.39	6.22	.24	.003	.36
CPF + DF + GI	2.75	.03	.17	.56	2.07	.18	.11	.41	2.72	−.33	.42	.28
CPF + DF + ADM	2.83	.02	.001	.54	2.06	.14	.003	.42	3.03	−.39	.004	.27
CPC + GI + ADM	4.24	.30*	.001	.53	3.20	.09	−.003	.39	6.16	.26	.002	.36
CPF + GI + ADM	2.79	.18	.0	.56	2.31	.02	.002	.41	2.24	.48	−002	.27

[1] CPC = Crude protein, clipped sample.
[2] DC = Digestibility, clipped sample.
[3] GI = Grazing index.
[4] ADM = Available dry matter
[5] CPF = Crude protein, fistula sample.
[6] DF = Digestibility, fistula sample.
[7] In Table 4, all b_1 values and all r^2 values are significant at $P<0.01$.
** Significant at $P<0.01$.
* Significant at $P<0.05$.

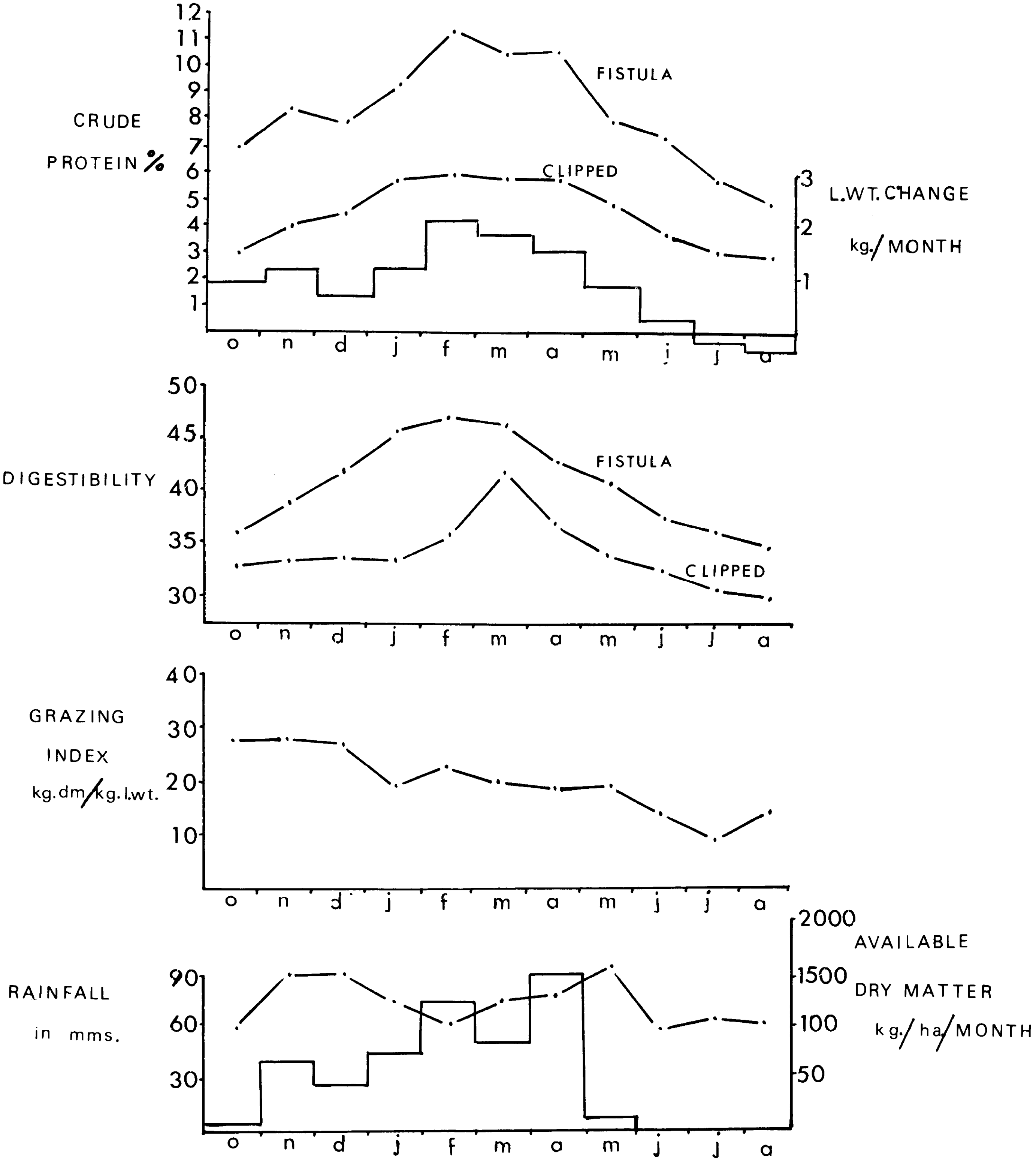

Fig. 3. *Summary of results from nine stations illustrating the relationship of each parameter measured to liveweight change.*

The inclusion of digestibility to CP content as a second independent variable did not account for any more variance compared with CP content used aone in a linear regression. However, the addition of GI to CP content of the clipped sample accounted for 53% of the variance for the whole year compared to 48% when CP content of the clipped sample was used alone. The addition of GI to CP percentage from the fistula sample increased the variance accounted for frm 54% to 56%.

The two quantity measurements, ADM and GI, were then both included in a regression analysis with CP content. This was done as GI and ADM need not be related. However, no additional variance was accounted for with this combination.

Discussion

The levels of CP content under which this trial was conducted were low compared with those of temperate conditions. The mean for the year from esophageal fistula samples was 8.5%, rising from a mean of 5.7% in the dry season to a mean of 9.4% in the wet part of the year. Under these conditions it would appear that CP content is more important in limiting weight gain of cattle in this region than is digestibility.

As digestibility accounted for more variation in weight gain during the wet season than in the dry season, it would indicate that as CP content becomes less of a limiting factor, digestibility has more influence on cattle weight change.

As quadratic regressions failed to account for any more variance than linear regressions, further substantial increases in live weight gain could be expected if CP and digestibility of the herbage could be increased.

The inferences of the CP content and digestibility data are in disagreement with workers in temperate climates (Hodgson 1968; Rodriquez and Hodgson 1974), who found that energy is the major limiting factor, but are in agreement with many workers in the tropics and subtropics (Topps 1962; Van Niekerk 1974). Van Niekerk, in a recent review of work under similar conditions in South Africa, states that the feeding of energy-rich but protein deficient foods gives poor responses in animal production and depresses forage intake. He concludes that energy is not the first limiting factor in these dry grasslands.

The increased amount of variance accounted for by the fistula samples compared with the clipped forages was rather small. In many areas of Botswana, the use of fistulated steers is not possible, but the results indicate that combining data from clipped samples and grazing index represents an index of opportunity for selection and gives a reasonable measure of quality, which accounts for as much variance as fistula samples.

As CP content has been shown to be a major limiting factor to growth of beef cattle, the feeding of nonprotein nitrogen licks is indicated as a possible method of overcoming this problem. Results of these trials are reported by Capper et al. (1976).

Another approach is to encourage grasses having above-average levels of CP. Since April 1974, 30 different species of grass have been collected monthly and screened for CP content and digestibility. The results to date (APRU 1976) indicate that certain species are superior in CP content and digestibility. Large scale grazing trials have now been initiated in an attempt to encourage the better species and to determine if improved cattle performance results. A further approach has been to remove the bush cover and monitor the improvement or otherwise in the species composition.

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Optimum Size and Shape of Quadrat for Sampling Herbage Weight in Grasslands of Northern Greece

VASILIOS P. PAPANASTASIS

Highlight: Five quadrat sizes, 0.0625, 0.125, 0.250, 0.500, and 1 square meter and three shapes, square, rectangular, and circular were tested in an ungrazed foothill bunchgrass range of northern Greece to determine the optimum quadrat for sampling herbage yield. Data on total herbage weight and clipping time were collected, which showed a high degree of variability. Shapes did not produce significantly different results. Larger quadrats were more efficient statistically but less efficient timewise than smaller quadrats. By maximizing the product of statistical and time efficiency, it was found that a quadrat of 0.0625 m^2 of any shape was the optimum quadrat for herbage weight estimates.

The subject of size and shape of quadrat for herbage weight estimates has been studied by several investigators working both on range and nonrange vegetation and several reviews are available (Brown 1954; Joint Committee 1962; Greig-Smith 1964; Morris 1967; Kershaw 1973). No uniform size was found to be applicable to all vegetation types; on the contrary, the most suitable size of quadrat depends on the distribution of vegetation and a special size was suggested almost for every particular type (Milner and Hughes 1968).

More conclusive is the information about the right shape of quadrat. Although square plots have been used commonly almost by tradition, considerable recent evidence has revealed that rectangular quadrats are most appropriate for maximum accuracy and they are suggested for range vegetation (Joint Committee 1962). However, Van Dyne et al. (1963) have found that circular plots were more suitable on a bunchgrass range than square or rectangular quadrats.

Optimum quadrat size and shape takes into account not only the accuracy of the estimate but also the time required for sampling, which is the cost of sampling. Despite the importance of the cost in field studies, relatively few investigators have considered this factor in their studies (Pechanec and Stewart 1940; Wiegert 1962; Van Dyne et al. 1963).

This research was designed to determine the optimum quadrat size and shape for sampling herbage weight in a foothill bunch-grass range of northern Greece. Such a quadrat will be of considerable value for any detailed study of herbage production undertaken in those grasslands.

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Manuscript received March 11, 1977.

Study Site

The experiment was carried out in an area located 25 km east of the city of Thessaloniki, fenced against grazing for almost 20 years. The vegetation was typical of the foothill grasslands of northern Greece, which is dominated by the two bunchgrasses *Andropogon ischaemum* and *Chrysopogon gryllus*. Among the rather distinct bunches of these grasses, several other species, mainly annuals, were grown (Fig. 1). A list of the species encountered in the plots is given in Table 1.

Soils were shallow clayloams with small quantity of organic matter, typical of the brown Mediterranean soil type.

Procedures

Five quadrat sizes, 0.0625, 0.125, 0.250, 0.500, and 1 m^2, and three quadrat shapes, square, rectangular, and circular were tested. For each size and shape combination five samples were taken from each of three blocks, 10 × 10 m^2, which were selected and located about 50 m apart. Table 2 shows the characteristics of quadrats used in the experiment. From here on, the five quadrat sizes are referred to as 1, 2, 3, 4, and 5 from the smallest to the largest size, respectively.

Fig. 1. *Study site of the foothill grassland. Bunchgrass in the foreground is* Andropogon ischaemum; *tall grass in the background is* Chrysopogon gryllus.

Table 1. Species encountered in the plots with their frequencies (%).

Species[1]	Frequency[2]
Grasses	
Perennials	
Andropogon ischaemum	67
Chrysopogon gryllus	33
Cynodon dactylon	22
Annuals	
Elymus caput-medusae	100
Triticum villosum	100
Avena sterilis	89
Bromus commutatus	56
Bromus arvensis	22
Aegilops triuncialis	11
Forbs	
Short lived perennials	
Carlina graeca	78
Centaurea caerulescens	56
Pastinaca sativa	56
Eryngium creticum	44
Lithospermum officinale	33
Annuals	
Trifolium angustifolium	89
Asperula hirta	78
Hymaenocarpus circinatus	56
Nicella damascina	44
Trifolium campestre	44
Linum gallicum	33
Onobrychis aequidentata	33
Cerastium pilosum	22
Gnaphalium germanicum	22
Lamium amplexicaule	22
Medicago tribuloides	22
Valerianella coronata	22
Other (12 species)	11 or below

[1] Nomenclature from Kavvadas, D. S. 1956. Econografimenon Botaniconphytologikon Lexikon. Vol. I-IX, Athinae.
[2] Frequencies based upon nine quadrats of 1 m² size.

Quadrats were made of iron rods of 8 mm diameter and they were placed randomly in each block.

Sampling was done in June 1974, by a group of five persons. Of those, three were assigned randomly to the various quadrats for clipping the vegetation with hand-operated shears, one recorded the clipping time, and the fifth person supervised the random placing of the quadrats in each block. The three-man clipping crew was dictated mainly by time considerations, since clipping herbage by hand is a slow process. This may have caused some variability in the data due to personal differences. However, these differences were kept to a minimum by selecting men with adequate experience in clipping and by frequent check of their work by the fifth person of the group. In addition, the different sizes and shapes of quadrats were interchanged among the three laborers in order to spread any possible variation uniformly over the treatments.

Total vegetation contained in each plot was clipped to ground level and put into paper bags. In the laboratory, the herbage yield was dried to 65°C in an oven prior to weighing. No attempt was made to separate green material from dead (litter).

Table 2. Area (m²) and dimensions (length × width × diameter) (m) of the quadrats used in the experiment.

Size No.	Size Area	Shape Square	Shape Rectangular	Shape Circular
1	0.0625	0.250×0.250	0.500×0.125	0.282
2	0.1250	0.354×0.354	0.500×0.250	0.399
3	0.2500	0.500×0.500	0.250×1.000	0.554
4	0.5000	0.707×0.707	0.500×1.000	0.798
5	1.0000	1.000×1.000	0.500×2.000	1.128

Table 3. Herbage weight means with their standard errors (g/plot) for the various quadrat sizes and shapes.

Size	Shape: Square	Rectangular	Circular
1	20.3± 4.72	25.0± 3.15	15.4± 1.83
2	42.4±10.50	50.6± 8.48	43.1± 7.27
3	89.0± 9.44	94.6±14.29	91.4± 9.66
4	172.5±19.53	145.7±13.96	207.6±30.43
5	317.9±26.85	292.2±22.34	325.4±28.35

Recorded time included the time required to find and put each quadrat in a random place as well as to compile the data.

Results and Discussion

Weight Means

Herbage weight means are shown in Table 3. As expected, there was an almost linear increase in yields per quadrat from the smaller to the larger sizes. Also, rectangular quadrats gave higher yields than square or circular quadrats except for the two largest sizes, where yields of circular quadrats exceeded those of the other shapes.

Distribution of the weight data was pronouncedly skewed. Moreover, the weight variances of vegetation harvested from various quadrat sizes and shapes are not homogeneous because these quadrats sample different populations (Van Dyne et al. 1963).

To make the analysis of variance valid, herbage weight data were subjected to logarithmic transformation, which takes care of both the skewed distribution and the unequal variances (Greig-Smith 1964; Milner and Hughes 1968). Then, they were analyzed as a 5 × 3 factorial in a randomized complete block design with three blocks and five samples per block at a 0.05 level of significance (Hicks 1964).

Quadrat sizes were the only treatment which produced significantly different results. Further application of Duncan's test (Hicks 1964) showed that no two of the five quadrat sizes gave the same means.

The failure of the shapes to produce significant differences in herbage yields by this analysis may be attributed to the high variation of vegetation. Data not included in this paper show that *Andropogon ischaemum*, a leafy bunchgrass, contributed about 48% of the herbage yield although its frequency was relatively low (see Table 1). *Chrysopogon gryllus*, a bunchgrass also, contributed to about 15% of the herbage yield; while the remaining 37% was contributed by over 30 slender, mostly annual, species (Table 1). The sparseness of bunchgrass may be the main cause of yielding insignificant differences among shapes. Similar results were found by Hanson (1934) and Van Dyne et al. (1963).

Weight Variation

Comparison of the herbage yields was restricted to sizes, because shapes and size and shape interaction produced no significantly different results. The weight data were converted to a common basis, i.e. to quadrats of size 5 (g/m²), and they were averaged over the shapes within each size class. Their means with their standard errors and variances are given in Table 4.

Since the number of quadrats (sample size) was the same for every quadrat size, it would have been expected that the variance decreased as the size of quadrat increased (Milner and Hughes 1968). This did happen to some extent because the largest size gave the lowest variance. However, the decrease

Table 4. Herbage weight means with their standard errors (g/m²), their variances, and the efficiencies, compared to the least variance, of the five quadrat sizes.

Size of quadrat	Means	Variance	Statistical efficiency
1	323.34±32.47	47,452.78	0.21
2	363.20±40.16	72,574.44	0.14
3	366.74±23.98	25,905.92	0.38
4	350.44±26.37	31,313.17	0.32
5	311.85±14.80	9,851.85	1.00

was not quite clear in the other sizes (Table 4). This indicates the high variability of the range vegetation sampled.

Minimum variance indicates low variability. Therefore, the quadrat with the least variance can be considered to have provided an efficient estimate of the herbage weight compared to the estimates of the same population parameter by the other quadrat sizes. This concept of efficiency has been used by Pechanec and Stewart (1940) and Van Dyne et al. (1963) for statistical evaluation of quadrat size in herbage weight estimates.

The ratio of the least variance to the variance of each of the quadrat sizes can be considered as a measure of statistical efficiency (Table 4). The quadrat of the largest size (5) was statistically the most efficient quadrat; the size 2 quadrat was the least efficient.

Edge effect is an important source of error in quadrat work (Greig-Smith 1964; Kershaw 1973). Van Dyne et al. (1963) detected a positive bias in small plots which was attributed to their higher perimeter-to-area ratios compared to the larger plots. In this work, the ratios of weight per meter of perimeter per square meter of area were 76.9, 87.7, 89.3, 87.2, and 76.6 grams, respectively, for the sizes 1 to 5. These ratios show that edge effect due to size possibly did not cause an error in herbage estimates.

Clipping Time

Clipping time varied from one minute for the smallest size to 23 minutes for the largest size. Analysis of variance of the time data, as a design similar to the one used for the weight data also gave significant results among sizes at the 0.05 level of significance. Shapes did not produce significant differences in clipping time as well as blocks and the interaction between size and shape. Use of Duncan's test gave significant differences among all size means.

Regression of herbage weight (X) to clipping time (Y) produced the following linear equation with $r = 0.945$:

$$\hat{Y} = 1.94 + 0.046\,X$$

Correlation coefficient was found significantly higher than zero with a t-test at the 0.05 level of significance (Snedecor and Cochran 1971). This means tht 89% of the variance in clipping time is accounted for by variation in herbage yield. The result agrees with what was found by Pechanec and Stewart (1940), who in addition indicated that clipping time accounted for 81% of the total time spent in collection and compilation of field data. Wiegert (1962) and Van Dyne et al. (1963) also found that clipping time increases with the size of quadrat. These results show the importance of selecting the optimum quadrat in clipping studies.

The average clipping time per quadrat size, all shapes combined, is shown in Table 5 along with the standard error of the means. Clipping time was increased by 50–55% from the smaller size to the next larger. Exception was found for size 4, the clipping time of which was increased by 87% over the size 3.

Table 5. Clipping time means with their standard errors (minutes) and the efficiencies, compared to the least time, of the five quadrat sizes.

Size of quadrat	Means	Time efficiency
1	2.44±0.11	1.00
2	3.69±0.16	0.66
3	5.78±0.20	0.42
4	10.80±0.43	0.22
5	16.62±0.48	0.15

This suggests that the size 4 was large enough to cause increased fatigue over the smaller sizes.

The ratio of the minimum time to the time required by each quadrat size and shape can be considered as a measure of time efficiency. This ratio decreases as the quadrat size increases (Table 5).

Optimum Quadrat

An optimum quadrat size and shape is the one that provides an efficient estimate of herbage yield with the least cost, which is the sampling time. Assuming constant time (cost) for the sampling work, which is independent of the size of quadrat (walking between stations, weighing, etc.), Wiegert (1962) determined the optimum quadrat size by minimizing the product of variance and cost of each size relative to the variance and cost of the smallest size.

Based on Wiegert's notion and assuming that clipping time is the main cost factor in clipping work, the optimum quadrat in this study was determined by maximizing the product of statistical and time efficiency. Both efficiencies are the reciprocals of the relative measures used by Wiegert and they are shown in Tables 4 and 5. The data are graphed on Figure 2.

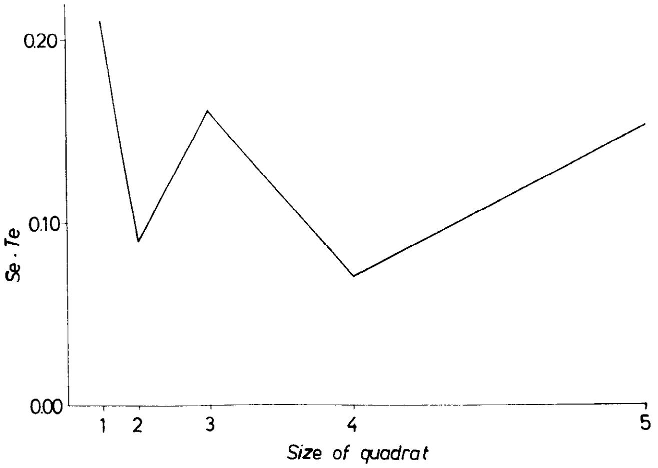

Fig. 2. *Graph of statistical efficiency (Se) times time efficiency (Te) against the size of quadrat (1 = 0.0625 m², 2 = 0.125 m², 3 = 0.250 m², 4 = 0.500 m², and 5 = 1 m²).*

It turns out that, regardless of shape, a quadrat of size 1 (0.0625 m²) appears to be the optimum plot for sampling herbage weight in ungrazed foothill bunchgrass ranges of northern Greece.

Under grazing conditions, however, the optimum quadrat is expected to be larger. This is because grazing usually increases the variability in bunchgrass ranges (Van Dyne et al. 1963) which in turn would decrease the statistical efficiency of the small quadrats. Under these conditions, Figure 2 shows that a quadrat of size 3 (0.250 m²) would be possibly the optimum quadrat. A plot of about the same size, but of circular shape, is suggested for bunchgrass ranges, also, of the western U.S. by Van Dyne et al. (1963).

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Canopy Reflectance and Film Image Relations among Three South Texas Rangeland Plants

H. W. GAUSMAN, J. H. EVERITT, A. H. GERBERMANN, AND R. L. BOWEN

Highlight: Field spectroradiometric measurements for canopy reflectances of three dominant south Texas woody plants (cenizo, honey mesquite, live oak) were used successfully to predict their color infrared film images and distinguishability: cenizo, whitish; honey mesquite, relatively light magenta; and live oak, darker magenta.

Three plant communities are prominent in south Texas (Kuchler 1964; Davis and Spicer 1965): (i) live oak (*Quercus virginiana* Mill.) on deep sands that grows in formations ranging from dense, uniform stands to frequent thickets or motts in underbrush; (ii) honey mesquite (*Prosopis glandulosa* Torr.) that grows as motts or dense stands on a variety of soil types (deep sands, sandy loams, clay loams, heavy clays); and (iii) cenizo [*Leucophyllum frutescens* Berl.) I. M. Johnst.] that grows as either dense or sparse stands among a wide variety of woody shrubs on shallow soils. The distribution and condition of these plant communities should be inventoried regularly to provide optimum livestock and wildlife management on south Texas rangelands.

The visible (0.40 to 0.74 μm) and near-infrared (0.75 to 1.35 μm) laboratory measured leaf reflectance was much greater for cenizo than for honey mesquite (Gausman et al. 1976). We speculated that this difference could be used to distinguish remotely between cenizo and honey mesquite plants on rangelands. Unfortunately, we did not determine the reflectance of live oak leaves in the laboratory.

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This study was supported in part by the National Aeronautics and Space Administration under Contract No. S-53876-AG. The authors thank J. Noriega and R. R. Rodriguez for assisting with spectroradiometric measurements and J. A. Cuellar for obtaining microdensitometric readings.

Manuscript received March 14, 1977.

Field spectroradiometric measurements have been used to determine canopy reflectance differences between stressed and nonstressed crop plants (Gausman et al. 1974, 1975). Unlike laboratory measurements, field measurements take into account plant, soil, and shadow reflectance (Richardson et al. 1975). However, there is a paucity of canopy reflectance data for rangeland plants.

Our objective was to measure the canopy reflectances of cenizo, live oak, and honey mesquite plants in the field and to relate these data to the plants' images on Eastman Kodak Aerochrome[1] infrared color film.

Materials and Methods

Canopy reflectances over the 0.5- to 2.5-μm waveband of cenizo, honey mesquite, and live oak plants were field measured in June 1976 with an Exotech Model 20 spectroradiometer (Leamer et al. 1973). The sensor had a 15-degree field-of-view (0.5 m^2) and was placed 3 to 3.4 m above each of five randomly selected canopies for each plant species.

Reflectance data at selected wavelengths were analyzed using analysis of variance techniques, and Duncan's multiple range test was used to test the statistical significance among species' means (Steel and Torrie 1960). Wavelengths selected were 0.55, 0.65, 0.85, 1.65, and 2.2 μm, representing, respectively, the green reflectance peak, chlorophyll absorption band, a wavelength on the near-infrared plateau, the 1.65-μm peak following the 1.45-μm water-absorption band, and the 2.2-μm peak following the 1.95 μm water-absorption band. Field measurements were made on clear sunny days in June 1976 at three different locations in south Texas. Measurements of cenizo were made on a shallow ridge range site in Jim Wells County, 15 miles north of Alice; honey mesquite measurements were made on a red sandy loam range site in Hidalgo County, 20 miles north of Edinburg; and live oak measurements were made on a sandy mound range site in Kenedy County, 15 miles south of Sarita.

[1] Mention of company name or trademark is for the readers' benefit and does not constitute endorsement of a particular product by the U.S. Dep. Agr., over others that may be commercially available.

Photographic equipment used included: (i) Hasselblad camera (80 mm lens, 5.7 × 5.7 cm format); (ii) filter packet of Hasselblad 4 × 0-2 (orange) and 3,5 × CB12-1.5 (blue filters; and (iii) Eastman Kodak Aerochrome color infrared (CIR) type-2443 film. The camera exposure used was f8 at 1/250 sec. Aerial photographs were taken between 1250 and 1530 hours under clear sunny conditions on September 23, 1976, at 3,050 m altitude above the ground. Photographs were taken about 3 months later than the field reflectance measurements because of inclement weather and cloudy conditions. Shortly after field measurements were made, inclement weather and cloudy conditions set in and postponed the aerial photography for 3 months. Due to the subtropical climate in south Texas, these woody plant species initiate annual growth in March and attain relative stable growth conditions by mid-June. Therefore, phenological changes among these species from June through September were probably minimal.

Optical count readings were made on CIR film with a Joyce, Loebl automatic recording microdensitometer using a red (Wratten 92; 0.615 to 0.700 μm) bandpass filter in the light beam. Red-filtered light is more responsive to CIR's red color tones than green- and blue-filtered light (Gausman et al. 1977). The microdensitometer output is an optical count (reciprocal of transmission) that is related to optical density (O. D.) by the relation:

O. D. = [(optical count − base reading) (wedge factor)] + (step wedge density).

One scan line was run for each of three plant canopies of each species. There were 65 readings (data bits) for each scan line on the film. The area of a data bit was about 1.0 mm^2 and represented 14.5 m^2 of ground.

Results and Discussion

A knowledge of vegetation geometry is needed to understand canopy reflectance differences among plants. Overhead views of the three species showed that their leaf densities within the canopies were: live oak > cenizo > honey mesquite. Live oak had a planophile (horizontal-leaf) canopy with a regular leaf distribution with minimized gaps (Allen et al. 1975); cenizo's canopy was shaped irregularly with drooped branches and clumped leaves with a few gaps; and honey mesquite's canopy had many crooked and drooped branches with small leaflets with many gaps.

Reflectances of the three species are shown in Figure 1. Whitish cenizo plants had significantly greater (p=0.01) visible (0.45 to 0.70 μm) reflectance than did the greener live oak and honey mesquite plants. Near-infrared (0.75 to 1.30 μm) reflectance was significantly greater for the dense live oak canopy than for the less dense cenizo and honey mesquite canopies as vegetation density and near-infrared reflectance are positively correlated until a stable reflectance is reached (Wiegand et al. 1974). The leaves of live oak canopies had a high water content (74.4%) that caused significantly lower (p=0.01) 1.65- and 2.2 μm wavelength reflectances than did leaves of lower water content for cenizo (72.8%) and honey mesquite (55.7%) canopies with their lower water content. However, honey mesquite canopies had lower reflectance and lower leaf-water content than did cenizo. Apparently, undetermined soil background reflectance and plant shadow effects interacted with cenizo's and honey mesquite's vegetation reflectance (Richardson et al. 1975).

The aerial CIR film images were predicted for the three species from the reflectance data within the 0.45- to 0.90-μm waveband (Fig. 1): (i) cenizo's very high visible light reflectance gave a whitish image, (ii) honey mesquite's low visible and intermediate near-infrared reflectance gave a relatively light magenta image, and (iii) live oak's very high near-infrared light reflectance gave a darker magenta image. These results were

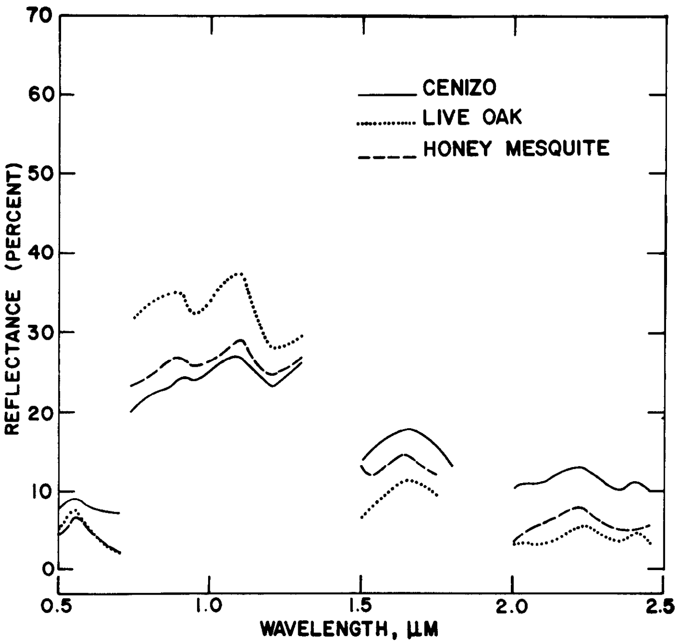

Fig. 1. *Field spectroradiometric measurements over the 0.5- to 2.5-μm waveband for canopy reflectances of three important woody plant species on south Texas rangelands.*

substantiated by microdensitometric measurements made with red-filtered light. Optical counts were significantly lower (p=0.01) for live oak (32) than for cenizo (57) and honey mesquite (74); honey mesquite's optical counts, in turn, were significantly higher than cenizo's.

In conclusion, field spectroradiometric measurements of canopy reflectances for three important south Texas plants (cenizo, honey mesquite, live oak) were used successfully to predict their CIR film images and distinguishability. The ability to remotely distinguish among these three plants should enhance future rangeland inventories in south Texas.

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Possible Effects of Weather Modification (Increased Snowpack) on *Festuca Idahoensis* Meadows

T. WEAVER AND D. COLLINS

When compared with undrifted sites, meadow sites with artificially induced drifts have shorter growing seasons, higher average growing season temperatures due to the absence of a cool spring, similar growing season soil water availabilities, and slightly less available nutrients due to leaching. Community composition, plant production, and plant phenology were affected slightly by doubling snow pack to 12-dm and were affected considerably by quadrupling snow pack to 24-dm. Though larger increases in snowfall might, it seems unlikely that 20–30% increases in winter precipitation would significantly affect the vegetation of *Festuca idahoensis* meadows.

Operational seeding of winter orographic clouds might increase snowfall in the Rocky Mountains by 20 to 30% (National Research Council 1973; Weaver and Super 1973). Weisbecker (1972) argues that the benefits of an operational program to downstream service areas (additional summer water and perhaps flooding) would outweigh the small adverse effects felt in the target areas (lengthened skiing season, shortened grazing-logging-mining-tourist season, increased avalanches, and interference with transportation). Several reports summarize the effects of added snow on tundra (Teller et al. 1975), subalpine forests (Teller et al. 1973; Knight et al. 1975), and mountain grasslands (Frank 1973 ; Weaver 1974; Knight et al. 1975). The possible effects of seeding agents have been considered by Cooper and Jolly (1970), Klein and Sokal (1973), Teller and Cameron (1973), Weaver and Klarich (1973), White (1973), and Knight et al. (1975).

Additional snow deposited by cloud seeding programs might lie as a uniform sheet (20% increase = approximately 90 mm of water), be redeposited in deep drifts (most likely), or be blown out of the mountain range (Costin et al. 1961). In the first case, snow packs would be uniformly 20–30% deeper. In the second case they would be doubled or quadrupled, but localized; and in the third case there would be no effect.

Weaver (1974) contrasted the "climax" vegetation of naturally occurring early melting, middle melting, and late melting sites in a series of *Festuca idahoensis* meadows; snow packs at the middle and late melting sites were approximately twice and four times those at the early melting sites. This report describes the responses of the vegetation in one of these meadows to an experimental doubling and quadrupling of snowpack.

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This work was supported by National Science Foundation grants GB-7302 and GB-20960 for studies of the ecological effects of weather modification and to a lesser extent by National Science Foundation grants GB-31862X and BMS-73-02027 AO2 to the Grassland Biome, U.S. International Biological Program.

Authors give special mention to L. Taylor, I. Bordeau, and S. Arthun for immediate supervision of field and laboratory work and are grateful for soils analyses performed by the Montana State University Soil Testing Laboratory.

Manuscript received April 28, 1977.

Methods

The study area lay in a *Festuca idahoensis-Agropyron caninum* (Mueggler and Handl 1974) meadow in the Bridger Range, 19 km northeast of Bozeman, Mont., and at an altitude of 2,380 m. Soils of the site are loamy typic cryoboralls; average annual precipitation is about 960 mm, with 125 mm (13%) falling as rain in the June to August growing season; average July maximum and minimum temperatures are 22°C and 8°C; average January maximum and minimum temperatures are −5°C and −10°C; and the frost-free season is about 70 days. The vegetation and climate of the study area are described in more detail by Weaver (1974), and the vegetation and climate of similar meadows in the Gravelly Range are described by Mueggler (1971, 1972). The vegetation of the study area has received little grazing since the 1930's when it was fenced to provide forage for the horses of rangers staying at the nearby Bangtail U.S. Forest Service Ranger Station.

Sites with normal snowpacks (3 to 6 dm) were compared with sites with 12 dm and 24 dm of snow; the latter were created with snowfences, which were removed each summer to avoid shelter effects (Marshall 1967). The 12-dm treatment, approximately 30 × 30 m in size, was created by installing five 1.2 × 30 m snowfences at 6-m intervals across the path of prevailing winds. The 24-dm treatment, approximately 30 × 50 m in size, was created by installing 2.7 × 30 m snowfences at 10-m intervals across the path of prevailing winds. The 6-dm treatment was not snowfenced. The fences were first installed late in the summer of 1968.

The physical effects of the treatments were contrasted by the following methods: (1) Snow water contents were determined by standard methods with a Federal snow sampler (Chow 1964). (2) Dates by which the snow drift melt had occurred were determined by periodic visits. (3) Rates of soil warming after snow melt were determined by distance thermographs with sensors buried at 25 cm and parallel to the earth's surface. (4) Soil water stresses were determined with plaster blocks (Taylor et al. 1961) calibrated in a pressure membrane apparatus. The blocks were buried in sets of three (at 10, 25, and 75 cm) at five regularly spaced points in each treatment and read at weekly intervals during the field season. (5) Available elements were compared in soils collected on October 16, 1974. Four samples were taken from the top 15 cm of the soil in each treatment with an Oakfield sampler; each sample consisted of ten subsamples equally spaced in the treatment area. The soils were analyzed by the Montana State University Soil Testing Laboratory as follows: potassium, calcium, magnesium, and sodium were extracted with 1-m ammonium acetate and determined by atomic absorption; phosphorus was determined by a modified Bray method; nitrate was determined by the phenoldisulfonic acid method; organic matter was measured colorimetrically after dichromate oxidation; and the pH was determined on a 1:2 soil water paste.

The vegetational composition of the 6-dm, 12-dm, and 24-dm plots was compared after 6 years of treatment by the canopy coverage method of Daubenmire (1959). On August 29, 1974 twenty-five 2 × 5-dm plots were placed at regular intervals over each area treated. The cover of each plant species present was recorded as 0–5%, 5–25%, 25–50%, 50–75%, 75–95%, and 95–100%. Means and standard errors were calculated by using midpoints of the classes observed, i.e., 0–5% = 2.5%. Plant names follow Hitchcock and Cronquist (1973).

Aboveground standing crops on the 6-, 12-, and 24-dm drift sites were measured seven times in 1969; six times in 1970, 1971, and 1972; three times in 1973; and once in 1974. Plots were clipped fortnightly beginning on June 5, 1969, June 8, 1970, June 15, 1971, and June 12, 1972. The 1973 clips were made on June 21, July 16, and August 21. The 1974 clip was made on August 29. Material was clipped at ground level, separated by species (or species group), dried at 60°C and weighed. Ten quadrats were clipped in each treatment at each sampling period. In 1970–74, 0.5 × 1 m-plots were chosen at random from preestablished blocks. In 1969, 2 × 5dm quadrats were "thrown at random" and clipped materials were pooled by species, which prohibited calculation of standard errors for 1969 data. Litter was collected by hand.

Belowground biomasses were compared on the 6, 12, and 24-dm drift plots on August 29, 1974. A 2.05-cm diameter soil core 30 cm long was taken from each plot clipped for determination of aboveground biomass and divided into three 10 cm sections. The core sections were then soaked in Calgon solution and sieved wet. Roots retained by a 0.5 mm screen were pooled with decantable organic matter, dried at 60°C, weighed, ashed (600°C), and reweighed. Belowground biomass is expressed on an ash-free basis.

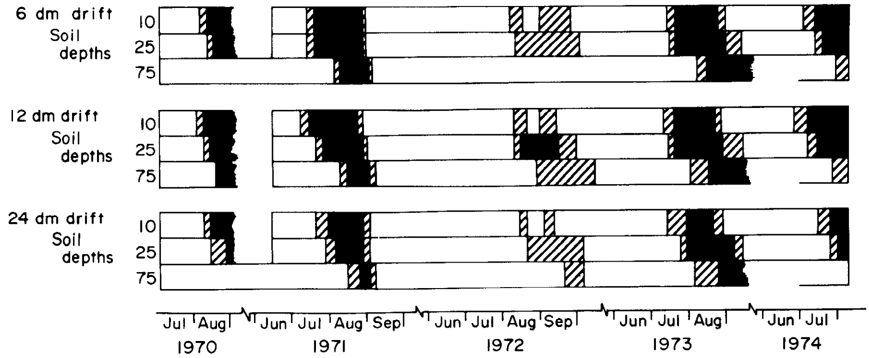

Fig. 1. *Soil water stresses at 10, 25, and 75 cm in a* Festuca idahoensis *grassland treated with 6-dm (normal), 12-dm, and 24-dm snowdrifts for six winters. Clear areas indicate soil water stresses of 0–2 bars, hatched areas indicate 2–10 bar stresses, and blackened areas indicate stresses greater than 10 bars.*

Phenologic responses of major plant species to the 6, 12, and 24-dm drift treatments were recorded in five permanent 1 × 10-m plots in each treatment area. Phases recorded included green leaf (before and after flowering), buds, flower, fruit, fruit ripe (being shed), and leaves dry. Flowering data are emphasized here because their determination is least likely to have varied between observers. Flowering is recorded in Figure 3 only if flowers were present in three of the five plots observed. Grasses entered the flowering stage when the flower was in the boot, entered the fruiting stage when the seed was hard, and entered the ripe stage when the seed was shed.

Results and Discussion

Physical Effects

The physical effects of installing snowfences in a mountain meadow were (1) accumulation of snow in proportion to snowfence height and (2) effects related to the presence of that snow. Snow accumulated in unfenced areas to depths of about 6 dm, in the lower snowfence areas to depths of about 12 dm, and in the higher snowfence area to depths of about 24 dm. The shallow snow areas melted free earlier than drift sites did; approximate melt dates from the 6-dm, 12-dm, and 24-dm areas were May 1, May 16, June 2, 1969; May 24, June 2, and June 15, 1970; and May 15, June 5, and June 19, 1971, respectively. After snowmelt the soils of drifted areas warm rapidly to temperatures similar to those of surrounding areas due to the "clothesline effect" (Tanner 1957): in June of 1971, for example, soil temperatures at 25 cm rose in 4 days from 0°C to the 10°C of soils in adjacent drift-free areas. With the melting of the snow on the three sites, vastly different amounts of water must have entered the profiles since no overland flow was noticed; on April 11, 1970, water equivalents on the 6-dm, 12-dm, and 24-dm sites were 114 ± 15 mm, 478 ± 8 mm, and 937 ± 28 mm, respectively. Melting snow and May-June rains provide the 25 to 30 cm of water needed to bring the soil profile to field capacity on all treatments, so all sites have similar initial water contents (Buchanan 1972 and Fig. 1). Excess water percolates through the profile and must leach soluble materials from it: (1) Soils at large natural-drift sites generally contain significantly less available magnesium, potassium, sodium, and nitrate and have lower conductivities than do those under nearby driftless sites (Weaver 1974); and (2) after 5 years of treatment soils of the 12-

Table 1. Selected characteristics of soils subjected to snowpacks of 6-dm (normal), 12-dm, and 24-dm for six winters. Means are given with their standard errors.

	Maximum snow depth		
	6 dm	12 dm	24 dm
Organic matter (%)	6.02 ± 0.23	6.02 ± 0.17	5.66 ± 0.11
pH	6.23 ± 0.10	6.10 ± 0.00	6.00 ± 0.00
Conducivity (mmhos)	0.44 ± 0.08	0.33 ± 0.00	0.23 ± 0.00
Nitrogen NO_3 (ppm)	1.71 ± 0.20	2.37 ± 0.26	2.10 ± 0.13
Nitrogen NH_4 (ppm)	29.44 ± 25.60	29.01 ± 10.00	26.05 ± 6.91
Phosphorus (ppm)	16.38 ± 1.17	17.00 ± 3.14	20.50 ± 2.47
Potassium (ppm)	553.00 ± 20.00	453.00 ± 7.00	435.00 ± 9.00
Calcium (ppm)	2780.00 ± 92.00	2810.00 ± 60.00	2692.00 ± 38.00
Magnesium (ppm)	460.80 ± 20.40	460.80 ± 8.40	434.40 ± 8.40
Sodium (ppm)	75.90 ± 4.60	75.90 ± 6.90	64.40 ± 4.60

and/or 24-dm sites are generally poorer in most elements than are those of the 6-dm site (Table 1). Despite leaching, more phosphorus is available on drift than driftless sites, perhaps because the soils there are more acid.

Relative to driftless (6 dm) sites, drift sites have (1) slight nutrient deficiencies, (2) similar initial soil water availabilities, (3) higher average growing season temperatures, and (4) a shorter growing season due to a relatively late start and a similar closing date. As demonstrated by melt dates given above, the growing season begins as much as a month later on drift sites than on driftless sites. If the growing season is closed by hard frosts or snow, it affects all sites simultaneously. More often the growing season is closed by drought: soil water was usually exhausted from the upper 25 cm of the driftless area by late July or early August; soil water was usually exhausted from the upper 25 cm of the 12-cm drift area almost simultaneously, and soil water was usually exhausted less than 10 days later on the 24-dm drift site (Fig. 1). The relatively rapid exhaustion of water from the filled soil profile of the 24-dm drift site is almost certainly due to the strong evaporative power of air movement from large relatively dry areas across much smaller relatively moist areas (Tanner 1957). Advection is also responsible for the high average growing season temperatures; after snowmelt plants are plunged, without experiencing a cool spring, into summer.

Table 2. Aerial cover of species after 6 years of 6-dm, 12-dm, and 24-dm drift treatments. Means and standard errors are given for all species occupying over 2% of any area.

Cover	Drift treatment 6 dm	12 dm	24 dm
Snow decreaser species			
Festuca idahoensis	25.1 ± 2.4	7.6 ± 1.3	1.0 ± 0.3
Litter	16.6 ± 2.9	8.6 ± 4.3	4.2 ± 3.4
Danthonia intermedia	6.3 ± 1.2	3.9 ± 1.1	0.4 ± 0.2
Erigeron speciosus	6.2 ± 2.5	1.3 ± 0.6	2.0 ± 1.0
Arenaria congesta	2.4 ± 0.4	1.8 ± 0.3	0.7 ± 0.3
Snow neutral species			
Lupinus argenteus	10.9 ± 2.4	5.9 ± 1.3	8.0 ± 2.2
Achillea millefolium	3.1 ± 0.5	4.8 ± 1.1	1.9 ± 0.6
Agoseris species	2.6 ± 0.8	2.8 ± 0.7	2.8 ± 0.8
Stipa richardsonii	3.9 ± 1.1	0.2 ± 0.2	2.6 ± 1.5
Snow increaser species			
Bare ground	5.2 ± 1.8	28.9 ± 4.4	35.9 ± 3.6
Galium boreale	5.0 ± 1.3	9.0 ± 1.3	11.2 ± 3.2
Agropyron caninum	4.7 ± 1.8	4.0 ± 1.2	7.7 ± 1.3
Bromus marginatus	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 2.0
Collomia linearis	0.0 ± 0.0	2.0 ± 1.0	9.3 ± 1.7

Vegetation Response

Vegetation composition, production of various plants, and phenologies of important plants were recorded as indicators of effects of the physical differences associated with different snow pack treatments on the vegetation originally occupying the site.

The vegetational composition of the driftless plot (6-dm) differs significantly from the vegetational composition of initially similar plots treated with increased snow-packs (12- and 24-dm) for 6 years. (1) *Festuca idahoensis, Danthonia intermedia, Erigeron speciosus,* and *Arenaria congesta* disappear from drift sites; *Bromus marginatus, Galium boreale,* and *Collomia linearis* increase on drift sites; and *Stipa richardsonii, Lupinus argenteus, Agoseris* sp., and *Achillea millefolium* are little affected (Table 2). Under longer treatment *Achillea millefolium* and *Lupinus argenteus* will likely become decreasers, while *Agoseris* sp., *Galium boreale,* and *Stipa richardsonii* will be snow neutral as they are in natural drift sites in adjacent meadows (Weaver 1974). Weaver (1974) lists other snow increaser and decreaser species and discusses their biological characteristics; note that his labeling of dates and soil depths in Table 2 of the 1974 paper is reversed. Given equal production, the forage quality of the increasers would apparently be similar to the quality of the decreasers. (2) The amount of bare ground exposed is greater on drift than driftless sites, both after 6 years (Table 2) and at naturally occurring sites near equilibrium (Weaver 1974). (3) Litter on the 6-dm, 12-dm, and 24-dm drift sites covered 17%, 9%, and 4% of the ground, respectively; its decline may be due to decreased production of lignaceous grasses, increased gopher use (Bleak 1970; Haglund 1972; Steinhoff 1973; vs Weaver 1974), or high decomposition rates on snow-covered sites

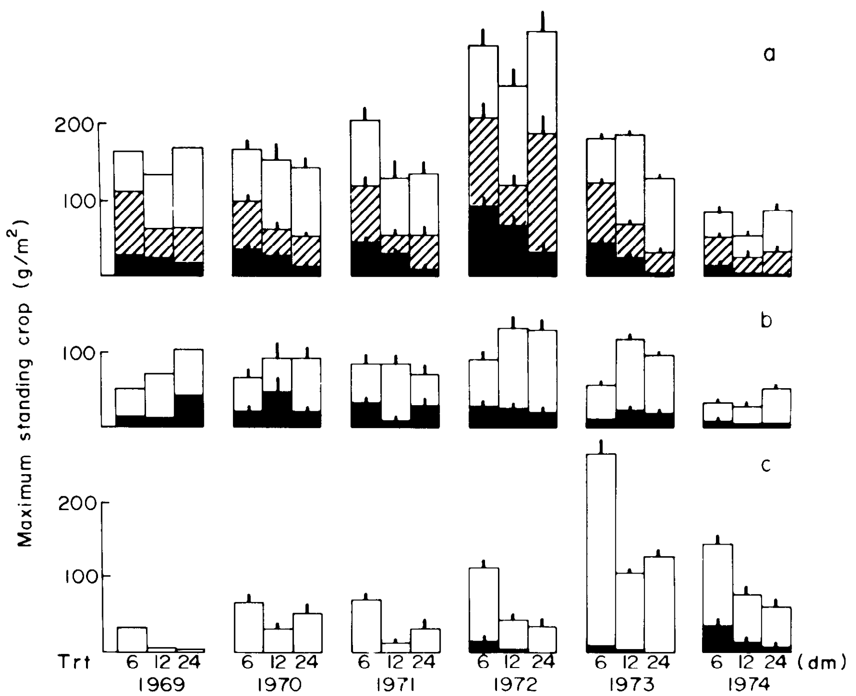

Fig. 2. *Maximum standing crops in a* Festuca idahoensis *grassland treated with 6-dm, 12-dm, and 24-dm snowdrifts for 6 years. (a) Total standing crop is indicated; the contributions of other grasses (stippled) and* Festuca idahoensis *(blackened) are also shown. (b) Forb standing crops and the contribution of* Lupinus argenteus *(blackened) are indicated. (c) Standing crops of litter and standing dead are shown; weights contributed by standing dead are stippled. Vertical lines indicate standard errors.*

(Bleak 1970; Emerick 1973). A dynamic view of the high rates of "decomposition" under deep snow is presented in Figure 2: production was both high and similar on the 6-dm, 12-dm, and 24-dm treatments in 1972, but in the following summer litter was much less on the 12- and 24-dm drift sites than on the 6-dm drift site.

Annual production was estimated (1) as the maximum standing crop and (2) as the sum of the maximum standing crops of each species (or group of species) separated (Kelly et al. 1974; Singh et al. 1975). Maximum standing crop data are presented (Fig. 2) to make 1969–1972 data comparable with 1973–1974 data, which were based on fewer clips. For 1969–1972 the sum of species peaks estimate was 1.27 times as great as the maximum standing crop; this value is near the "general" 1.26 proposed by Singh et al. (1975). Total 1969–1972 production on the 6-dm driftless site consisted of 25% *Festuca idahoensis,* 18% *Agropyron caninum,* 3% *Carex* spp., 4% *Danthonia intermedia,* 4% *Koeleria cristata,* 7% miscellaneous grasses, 11% *Lupinus argenteus,* 4% *Arenaria congesta,* 2% *Achillea millefolia,* 3% *Agoseris* spp., 4% *Erigeron speciosus,* 3% *Cerastium arvensis,* 3% *Galium boreale,* and 9% miscellaneous forbs.

After 6 years, standing crops and annual production are apparently lower on drift than on driftless sites, and the differences may be expected to increase as succession proceeds. (1) Total production on the 12-dm site is less than (or equal in 1973) that of the 6-dm site; the difference is statistically significant (5% level) in 1971 and 1972; and the difference may be due in part to a tendency for soils there to dry before those of the 6-dm site (Fig. 1) as they are slightly shallower. Total production on the 24-dm site was less in 1970, significantly less in 1971 and 1973, and was never significantly greater than that of the 6-dm site. Billings and Bliss (1959), Emerick (1973), Knight et al. (1973), and Weaver (1974) report production declines with shortened growing seasons. Weaver's report (1974) suggests that equilibrium production on the 12- and 24-dm sites might be approximately 90% and 25% of the production on the 6-dm site. (2) Total graminoid production was lower on drift than on driftless sites in all cases except on the 24-dm site in 1972; grass production in this case was due to the unusually great growth of *Agropyron caninum* in mid-August. At equilibrium, early melting sites are expected to have higher graminoid frequencies than do middle melting sites (slightly) or late melting sites (considerably) (Weaver 1974). The production of *Festuca idahoensis*, the dominant grass in the meadows studied, declines with increasing snow pack in every year (Fig. 2). The contribution of *Festuca idahoensis* to total production in the 24-dm treatment also declined over the 1969–1974 period (17%, 10%, 8%, 9%, 4%, and 1%), but this trend was not seen in the 12-dm treatment. The production of other grasses also showed trends consistent with those suggested by the 1974 cover data (Fig. 2). (3) Forb production tended to be higher on the drift than on the driftless sites in every year except 1971. The differences are statistically significant in 1973 only. The production of the dominant forb of the study area, *Lupinus argenteus,* has not been affected by 6 years of added snow; its production does not vary consistently between treatments within years; and its contribution to the total production of the 24-dm site, 1969–1974, shows no clear trend (21%, 17%, 19%, 7%, 14%, and 10%). On large natural drift sites of the area, forb frequencies, including that of *Lupinus argenteus,* are lower than on driftless sites (Weaver 1974). (4) Belowground biomass in the top decimeter of the soil is significantly greater on the driftless site than on the drift sites, but no statistically significant differences were observed at 10–20 cm or 20–30 cm (Table 3).

Phenologic Response

Both the beginning and ending of the blooming period were later for plants occupying the 24-dm drift site than for plants on the 6-dm driftless site (Fig. 3). For early blooming plants (e.g., *Dodecatheon conjugens* through *Festuca idahoensis* in Fig. 3), blooming was simultaneous on the 6-dm and 12-dm sites even though the 12-dm site usually melted at least 10 days later than the 6-dm site. For many later-blooming plants (e.g., *Cerastium arvense, Arenaria congesta, Achillea millefolium,* and *Companula rotundifolia*), blooming was later on the 12-dm drift site than on the 6-dm driftless site. Blooming time in plants of the second group may be controlled by accumulated heat units, while in the first group blooming may be more strongly influenced by day length, i.e., given a minimum development time, often not satisfied on the 24-dm drift site, all plants bloom simultaneously. Among the "photoperiodic plants" note the strong tendency of *Agropyron caninum* to begin flowering near June 25.

If one assumes that the first fruits shed are products of the first flowers produced, he finds relatively constant maturation times, which tend to be shortest for later-blooming species and which are apparently shortened in the face of drought stress. Maturation times observed in the 6- and 24-dm drift areas were *Senecio integerrimus* 31 ± 1 day, *Agropyron caninum* 60 ± 2 days, *Festuca idahoensis* 58 ± 2 days, *Cerastium arvense* 54 ± 4 days, *Arenaria congesta* 40 ± 3 days, *Lupinus argenteus* 35 ± 3 days, *Achillea millefolium* 41 ± 1 day, *Danthonia intermedia* 32 ± 1 day, *Erigeron speciosus* 41 ± 4 days, and *Galium boreale* 33 ± 3 days. Maturation times may possibly be shortened in the face of drought stress for some species. When water stress was not experienced by *Festuca idahoensis* (1972) on the 24-dm site, maturation time was 63 days (cf. the 58-day "normal"); but when water stresses were experienced early (August 1, 1970 and 1971) maturation times dropped to 37 and 38 days, respectively. Similarly, maturation times in moist 1972 and dry 1971 were 73 and 30 days, 41 and 36 days, 36 and 22 days for *Agropyron caninum, Achillea millefolium,* and *Danthonia intermedia,* respectively.

Table 3. Root biomass (g/m²) after 6 years of 6-dm, 12-dm, and/or 24-dm treatments. Means and standard errors are given.

	Drift treatment		
Root depth	6 dm	12 dm	24 dm
0-10 cm	1849 ± 172	1425 ± 61	1394 ± 153
10-20 cm	576 ± 48	849 ± 230	697 ± 77
20-30 cm	303 ± 38	455 ± 54	394 ± 67

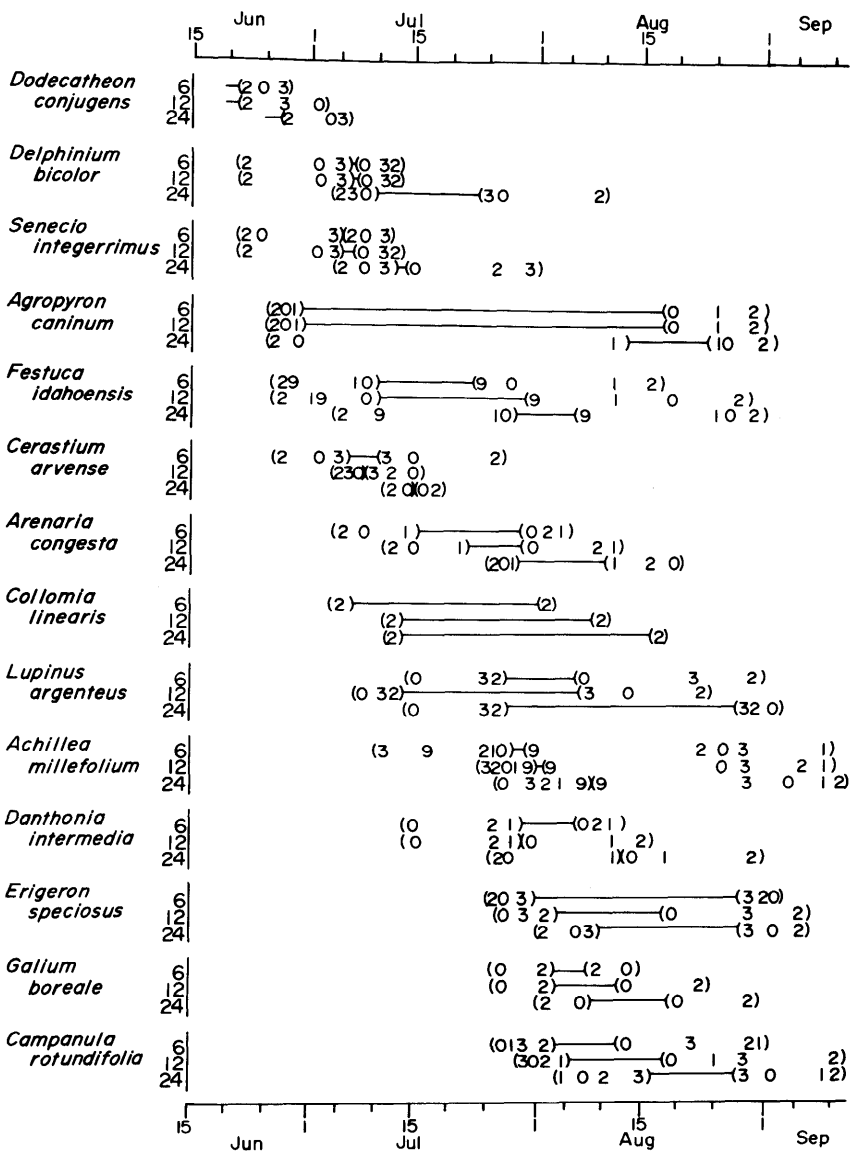

Fig. 3. *Time lines show the flowering periods of 14 species on sites with maximum snowpacks of 6-dm, 12-dm, and 24-dm. Bracketed areas indicate the beginning and ending of the flowering period; numbers indicate the first and last blooming observed in 1969 (9); 1970 (0); 1971 (1); 1972 (2); and 1973 (3).*

Conclusions

It appears that the impact of seeding winter orographic clouds for 10 to 30% increases in snowfall on the vegetation of *Festuca idahoensis* meadows would be slight. (1) Imposition of snow packs greater than 24-dm large drifts will probably result in decreased vegetation cover, decreased litter, decreased production, and a change in species composition (Weaver 1974). Experimental treatment has already produced the expected trends in vegetational cover, vegetational composition, and litter cover; but production did not decline strikingly in 6 years of treatment. Since changes in summer temperatures, soil water stresses, and nutrient availabilities (due to leaching) were slight and the growing season was almost a month shorter, one may conclude that the latter factor was responsible. This conclusion is reinforced by the observation that plant development (e.g., flowering) was postponed significantly by snow packs deeper than 24-dm. Gopher plowing, if it is greater on drift sites, probably reinforces these trends to an unknown degree. (2) With respect to vegetational composition and production, plant phenology, and soil water stresses, the vegetation of 12-dm sites (= approximately "middle melt") shows similar trends but is more similar to that of the 6-dm treatment than to that of the 24-dm treatment. (3) If snowfall were increased by 10 to 30% (significantly less than the 12-dm, "middle melt" treatment) and if the snow lay flat, resultant changes in the vegetation should be small, cumulative, and perhaps undetectable. If, on the other hand, most of the snowfall increases were deposited in drifts, drift size would be increased slightly and the vegetation now at their edges would be converted rather quickly to that now found under natural drifts.

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A study of heath aster (*Aster ericoides* L.) was conducted in Brazos County, Tex., between October 1972 and May 1973. Only about 17% of heath aster achenes from field collections made in late fall were germinable. In no case was a seedling of heath aster established under greenhouse conditions. Similarly, no heath aster seedlings were observed under field conditions.

Heath aster regenerated readily from detached rhizomes with intact or decapitated apices and from two-node sections. The apical meristem of intact rhizomes dominated sprout development from all lateral buds preceding it. There was no significant bud inhibition in rhizomes with decapitated apices. Serially excised rhizome segments closer to the rhizome apex developed more rapidly. In all trials, lateral buds released from apical dominance developed new rhizomes which regenerated plants.

Heath aster was in full bloom by November with profuse rhizomatous growth. Rhizomes developed into winter rosettes which bolted by late February or early March. Rosettes and young elongating plants had lanceolate leaves. There was a progressive decrease in leaf size and increase in axillary branching with increasing degree of maturity. Average leaf length and width reduced from 4.5 cm and 5.4 mm to 2.1 cm, and 1.6 mm, respectively, between March 3 and May 20. Axillary bud growth began when average plant height was 12.8 cm. Axillary shoots elongated more slowly (0.5 to 5.8 mm per day) than did the primary stem (2.2 to 24.1 mm per day). Growth rate of primary stems was greater in April than in March or May. Plant height and length of the third elongating axillary branch were significantly correlated ($r = 0.97$).

Significantly less total nonstructural carbohydrates (TNC) were extracted when the procedure was terminated at the takadiastase level than when followed by acid hydrolysis. Thus, the predominant nonstructural polysaccharides stored in heath aster were probably fructosans. Percentages of TNC varied with growth stage between 20.0 to 28.6 in rhizomes; 11.2 to 25.3 in roots; 4.5 to 15.5 in stems; and 3.6 to 17.2 in leaves. High TNC levels were recovered from rosettes and fully elongated plants, while TNC levels were lower at bolting and anthesis.

Nitrogen content declined from 1.1% in herbaceous stems to 0.1% in caudices. Nitrogen increased steadily in leaves to 2.3% in March but declined to 1.8% and then appeared to remain relatively constant for the remainder of the study. The in vitro coefficients of digestion (COD) varied fom 81% to 73% in leaves, and 60% to 25% in stems. Percentages of ash ranged from 8.7% to 13.5% in leaves and 2.4% to 11.1% in stems. Variations in COD and ash content of dry matter related to stages of development were greater in stems than in leaves.

Heath aster, when compared with Texas wintergrass, tall dropseed, silver bluestem, and dallisgrass, was utilized in similar amounts. Percent utilization of each species by cattle was limited by forage availability rather than by grazing preference. Utilization of heath aster ranged from less than 1% to 6% during the period March 3 to May 20. There were no significant differences between percent utilization of the species at the particular period.

Grazing affected heath aster growth by enhancing the release of axillary buds on caudices. Grazing reduced TNC content of stems and roots, although it had no significant effect on TNC content of leaves or nutrient content or heath aster.

Measuring Soil Compaction on Rangeland

GERALD F. GIFFORD, ROBERT H. FAUST, AND GEORGE B. COLTHARP

Highlight: Several instruments used for measuring soil compaction have been evaluated on a homogeneously-textured, nongravelly silt-loam soil. The instruments used in the study were the air permeameter, proving ring penetrometer, volumeasure, pocket penetrometer, and gamma ray scattering device. Correlation coefficients and regression equations were developed between each instrument and bulk density as determined by the soil core method. Readings from all instruments were significantly correlated with soil core bulk density.

The two instruments which had the highest correlation with bulk densities during initial testing, the air permeameter and the proving ring penetrometer, were further evaluated on a rangeland soil. In this instance, predicted bulk densities (using the above regression equations) from air permeameter readings correlated better with soil core bulk densities than did predicted bulk densities from proving ring penetrometer readings.

Measurement of soil compaction is often a problem on both agricultural lands and wildlands. Compaction of the mineral soil fraction in surface soils has important hydrologic implications in terms of reduced infiltration rates and subsequent impacts on plant growth. For example, trampling by livestock and big game animals may cause compaction of both forest and rangeland soils. Compaction is most severe in the spring when the soil is moist, or after heavy rainfalls. With increased soil compaction, surface runoff potentials are increased, erosion potentials may be increased, and given sufficient time, plant composition and cover may change.

Compaction is usually measured in terms of the severity of soil compression. However, before compression can be measured, reliable instruments are needed to measure the degree of soil compaction. The two objectives of this study were: (1) To determine the correlation between several soil compaction-measuring instruments and (2) to evaluate and compare the performance of various instruments under controlled and actual grazing conditions.

Methods and Procedure

North Logan Study Area

For initial compaction tests, a nongravelly, homogeneous silt loam soil was selected. The study area was 27 m × 14 m and was fenced to exclude animals. In the spring of 1968, the site was rototilled twice to a depth of 2.4 to 3.2 cm, vegetation in the form of grass clumps and sizeable roots was raked out of the plots, and each plot was rolled with a lawn roller. The completely randomized design called for 32 plots, each 1.7 m × 1.7 m. Four treatments (a control [unpacked, except for lawn roller], a light, a medium, and a heavy compaction treatment) were used with each treatment replicated eight times. Within each plot were four subplots (0.8 m × 0.8 m) and four samples were taken within each subplot. In all, 16 samples were taken with each instrument on each of the 32 plots for a total of 512 samples per instrument.

A gasoline-driven soil tamper was used to compact the soil. The control plots were unaltered, the light treatment plots received two passes with the soil tamper, the medium treatment plots received four passes, and the heavy treatment plots received six passes. After the tamping treatment, the plots were again rolled. The plots were then watered with gentle spray from a fire hose. When the top 0.6 cm of soil was wet, the plots were allowed to drain overnight. The next day they were sampled.

Eureka Study Site

To evaluate soil-compaction measuring instruments on rangeland, a site 9 miles south of Eureka, Utah, was selected. Twenty-six seeded experimental pastures were available and were being grazed by sheep, cattle, or a combination of both at various stocking rates. Each pasture (28–32 ha) contained an ungrazed exclosure (0.4 ha), and, in addition, a native range pasture (240 ha) had been fenced.

Pastures 6, 7, 14, and 17 were selected for sampling because of similarity in grass species and sheep grazing intensities. Pastures 6 and 7 were seeded with intermediate wheatgrass (*Agropyron intermedium*). Pastures 14 and 17 were seeded to crested wheatgrass (*Agropyron cristatum*). Pastures 6 and 14 had been grazed heavily by sheep while pastures 7 and 17 had been grazed lightly by sheep.

The four grazing units were sampled twice, first in the spring of 1968 (March 30 and April 13) before the livestock went on the grazing units, the second in the summer of 1968 (July 24 and August 8) after the livestock had been removed.

The proving ring penetrometer, the air permeameter, and the Uhland soil core sampler were utilized at the Eureka site. Each pasture was divided into four quadrants for sampling. Within each quadrant, 25 samples were taken with the proving ring penetrometer, 25 samples with the air permeameter, and 5 samples with the Uhland soil core sampler. Two transect lines were established in each quadrant, and the sampling sites were taken at random along these lines. To reduce the effects of soil variability at each sampling point, air permeameter, proving ring penetrometer, and soil core readings were all taken within 20 cm of each other. Sampling procedures in the untreated native pasture were similar. Within the exclosure in each pasture the 25 sampling sites were chosen at random.

Soil moisture during the first sampling period was high because of spring precipitation in the form of rain and some snow. During the summer sampling periods, the soil was again kept moist by frequent thunderstorms. For this reason, the soil moisture content during each sampling period was comparable.

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This research was in cooperation with the Utah Agricultural Experiment Station, Project 749. Journal paper 2187, Utah Agr. Exp. Sta., Logan 84322.

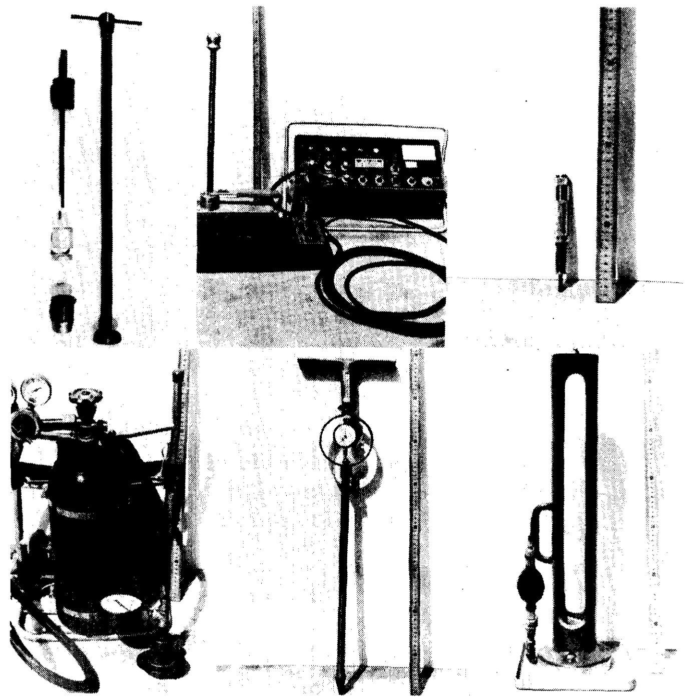

Fig. 1. *(Top row, left to right) Uhland soil sampler, gamma ray scattering device, pocket penetrometer. (Bottom row, left to right) Air permeameter, proving ring penetrometer, and volumeasure.*

Description of the Instruments

Description and operation of the six instruments evaluated are as follows.

Soil Core Sampler

The Uhland sampler (Fig. 1) extracts cores 7.5 cm in diameter × 7.5 cm deep (Hoover et al. 1954). Use of soil core samplers is well covered in the literature (Coile 1936; Jamison et al. 1950; Smith 1951; Andrews and Broadfoot 1957; Smith and Larson 1959; Fox and Page-Hanify 1959; Van Groenewoud 1960; Zwolinski and Rowe 1966).

Pocket Penetrometer

The pocket penetrometer is an instrument designed for use by road engineers and soil scientists (Soiltest, Model CL-700). The penetrometer is 2.4 cm long and weighs about 230 g (Fig. 1). The instrument registers (in kg/cm^2) the weight required to push the tip of the instrument into the soil to a depth of 0.3 cm. Use of various penetrometers have been discussed by Richards (1941), Shaw et al. (1942), Watson (1951), Terry and Wilson (1953), Vomocil (1957), Carter (1967), and Thompson (1968).

Proving Ring Penetrometer

The proving ring penetrometer (Soiltest Model CN-970) consisted of a cone, shaft, and proving ring with a dial indicator (Fig. 1). The resistance of a soil to the cone penetration causes the proving ring to distort, which, in turn, causes the indicator on the dial to move. The force required to push the cone into the ground 3.2 cm is then read from the dial. A calibration curve is used to convert the dial reading into load (expressed in pounds).

Volumeasure

The Volumeasure (Soiltest, Model CN-980) is composed of a density plate, graduated glass cylinder and guard, and pressure-vacuum bulb with control valve (Fig. 1).

In calculating soil density, volume of a hole is determined essentially by the quantity of water (contained within a flexible rubber container) needed to completely fill the hole. The weight of the soil removed from the hole is then determined. Bulk density is calculated by dividing weight by volume. Variations of the method are discussed by Israelson (1918), Beckett (1928), Curry (1931), Lutz (1944), and McClintock (1959).

Air Permeameter

The air permeameter consists of an air cylinder, regulator, toggle air valve, pressure gauge, and soil cup (Fig. 1). The soil cup has an outside diameter of 4.3 cm and penetrates the soil to a 2.5 cm depth. The cup is pushed into the ground until the flange around the cup is in contact with the soil surface. The resistance of the soil to the air causes a back pressure, which is then read off the pressure gauge, and recorded. Air permeameters have been discussed by Torstensson and Erickson (1936), Russell and Balcerck (1944), Evans and Kirkham (1949), Wilde and Steinbrenner (1950), Tanner and Wengel (1957), Steinbrenner (1959), and Tueller (1962).

Gamma Ray Scattering Device

The gamma ray scattering device (Troxler Model SC-120H) is a soil density gauge with a radioactive source consisting of 3 millicuries of radium-beryllium (Fig. 1). For operation, the probe is lowered into a hole about the size of the rod. Gamma rays are emitted into the soil. The density of the soil weakens and transforms the emitted gamma photons into slowed gamma photons. These photons are detected in the gauge and recorded by the scaler. The reading is then adjusted for soil moisture and the density of the soil is read from a calibration curve. This technique has been discussed by Vomocil (1954a, 1954b), Van Bavel et al. (1957), Phillips et al. (1959), Phillips (1960), Phillips and Brown (1966), and Taylor and Kansara (1967).

Results and Discussion

North Logan Study Area

Bulk density values from the soil cores (Table 1) show that there was a difference in the four sampling treatments applied. The greatest difference was between the control and heavy treatment, though differences were small among the light, medium, and heavy treatments. To produce greater differences, more passes with the soil tamper would have been desirable on the medium and heavy treatments.

Proving Ring Penetrometer Samples

Because the proving ring penetrometer measures soil com-

Table 1. Means and standard deviations of the various compaction measures on the North Logan study plots.[1]

	Compaction treatment									
	Control		Light		Medium		Heavy		Combined	
Variables	mean	sd[2]	mean	sd	mean	sd	mean	sd	mean	sd
Soil core bulk density (gms/cc)	1.06[a]	0.04	1.22[b]	0.04	1.27[c]	0.03	1.29[c]	0.03	1.21	0.01
Gamma ray scattering device (gms/cc)	1.73[a]	0.11	1.57[b]	0.09	1.54[b]	0.09	1.56[b]	0.13	1.60	0.13
Volumeasure (gms/cc)	1.08[a]	0.08	1.20[b]	0.09	1.23[b]	0.09	1.24[b]	0.12	1.19	0.12
Proving ring penetrometer (load in pounds)	22.16[a]	0.76	66.46[b]	1.49	97.58[c]	1.73	115.77[d]	2.14	75.49	3.90
Air permeameter (pounds back pressure)	2.30[a]	0.82	6.52[b]	1.72	8.72[c]	1.60	10.12[d]	1.40	6.91	3.28
Pocket penetrometer (kg/cm^2)	0.83[a]	0.19	1.87[b]	0.49	2.59[c]	0.73	3.11[d]	0.84	2.10	1.05

[1] Any means within a given row with the same letter are not significantly different at the .05 level of probability.
[2] sd = standard deviation.

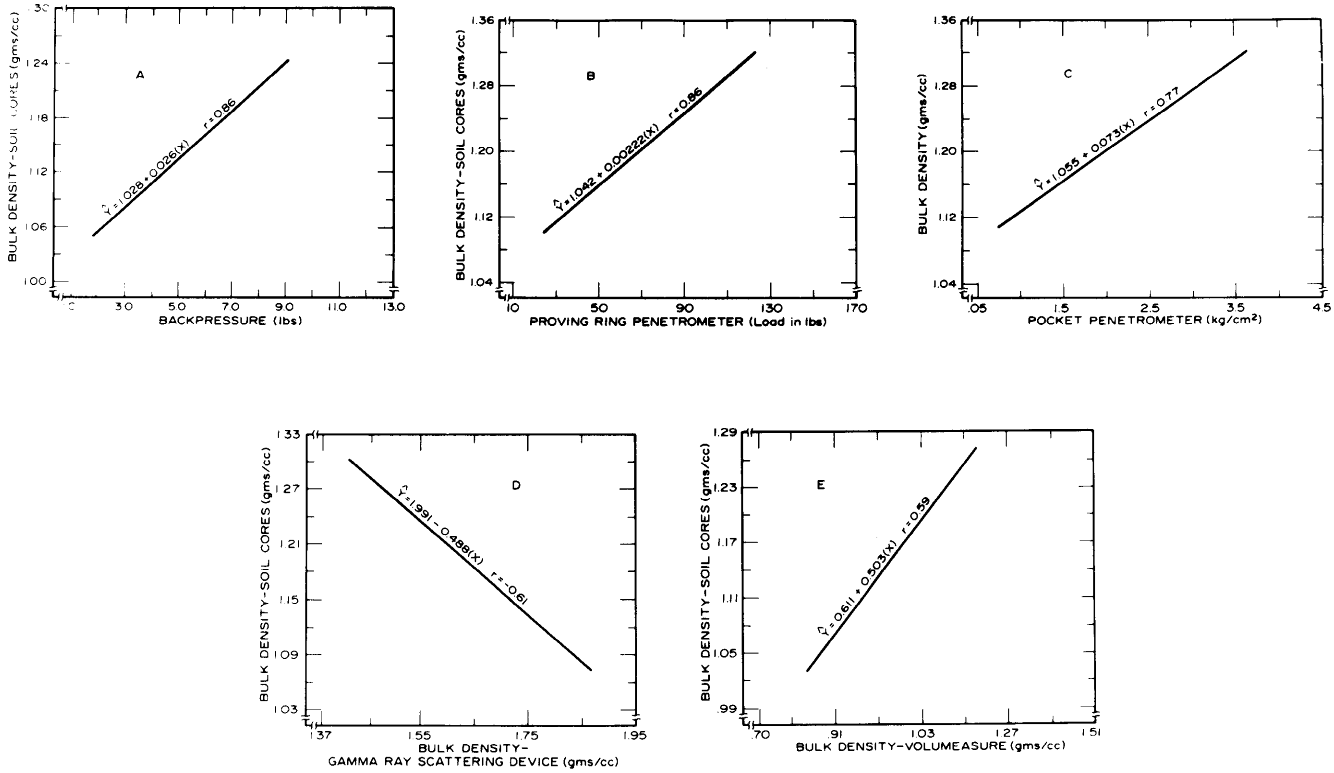

Fig. 2. *Linear regressions for predicting bulk density using the various instruments shown in Figure 1.*

paction in terms of pounds and not gms/cc, a linear regression equation was developed to predict bulk density. Pooling data for all treatments yielded a regression equation $\hat{Y} = 1.042 + .002X$ (Fig. 2B). Despite the fact that soil moisture, bulk density, presence of small gravel, and root and worm channels all influence penetrometer readings, the correlation ($r = 0.86$) is significant at the .01 level of probability.

Pocket Penetrometer

The linear regression equation for predicting bulk density from soil compaction readings in kg/cm² is shown in Figure 2C. Though the correlation coefficient was 0.77 (significant at .01 level of probability), the pocket penetrometer was deemed a difficult instrument to use under field conditions. Examples include difficulty in accurately reading the scale, the small sampling area of th 0.3-cm-diameter tip, problems with crusting of the soil surface and accurately determining when the tip has penetrated the soil the required 0.3 cm.

Volumeasure

Of all the instruments tested, the volumeasure values showed the poorest correlation ($r = 0.59$; significant at .01 level of probability) with soil core bulk density. However, the volumeasure and soil cores gave similar mean bulk density values (Table 1). Difficulties in using the instrument include possible loss of soil when digging the hole, reading the meniscus on the glass cylinder, and determining when the water has reached the lowest level in the cylinder as water enters the hole.

Air Permeameter

The linear regression equation for predicting bulk density from pounds of back pressure is shown in Figure 2A. The correlation coefficient (r) between back pressure and bulk density (from soil cores) was 0.86 (significant at .01 level of probability). Problems in using the instrument can result when soil moisture is high (back pressure becomes higher than normal) or if the soil cup is not correctly pushed into the ground.

Gamma Ray Scattering Device

The gamma ray scattering device measures the inverse of the soil core bulk density (Fig. 2D; $r = -0.61$; significant at .01 level of probability). Taylor and Kansara (1967) attribute this inverse relationship to greater scattering and absorption of the gamma photons as the soil density increases. Since soil moisture increases the occurrence of photon slowing, each reading was corrected for soil moisture. A major problem in the practical use of the instrument was that readings could not be taken at a soil depth of less than 10 cm. All the other instruments measured soil compaction in the surface 5 cm.

Eureka Study Area Composition Measures

Bulk density estimated (using the regression equations shown in Fig. 2) from the air permeameter and proving ring penetrometer closely matched the bulk density obtained from the soil cores at the Eureka study site. In fact, most of the instrument deviations from the actual bulk density were small. Both the air penetrometer and the proving ring penetrometer had average deviations of 0.049 gms/cc (extreme deviations were 0.11 and 0.14 gms/cc for the two instruments, respectively). Table 2 shows the correlations between bulk density (gms/cc), the air permeameter (lb back pressure), and the proving ring penetrometer (lb). These correlations were made using combined data from both sampling periods. Bulk densities predicted from air permeameter readings had higher correlations with actual bulk densities than did bulk densities predicted from the proving ring penetrometer. The capability of these instruments to estimate bulk density within 0.04 to 0.05 gms/cc is notable.

It may be concluded that the air permeameter and proving ring penetrometer can be used to obtain estimates of soil

Table 2. Correlation coefficients (*r* values) between predicted bulk densities using the air permeameter and the proving ring penetrometer and actual bulk densities (as determined from soil cores) as obtained from combining the observations from the pastures, exclosures, and native rangeland units at the Eureka study site. All correlation coefficients are significant at the .01 level of probability.

	Pasture (n = 200)	Exclosure (n = 40)	Native rangeland (n = 64)	Combined Combined (n = 304)
Bulk density vs air permeameter	0.65	0.63	0.52	0.66
Bulk density vs proving ring penetrometer	0.37	0.47	0.46	0.47

compaction on rangelands, particularly if the soil density (without gravel) is between 1.06 to 1.29 gms/cc.

Summary and Conclusions

The present study evaluated several instruments for measuring compaction on a homogeneous nongravelly soil. The instruments were the air permeameter, proving ring penetrometer, volumeasure, pocket penetrometer, and gamma ray scattering device. Correlation coefficients and regression equations were developed between each instrument and bulk density values as determined with soil cores. The volumeasure had the lowest correlation with soil core bulk density while the air permeameter and proving ring penetrometer had the highest correlation. The gamma ray scattering device was inversely correlated with soil core bulk density.

All readings of the instruments were affected by soil moisture and plant roots. Each instrument has certain advantages and disadvantages. The proving ring penetrometer has the advantage of being moderately correlated (r = 0.86) with soil core bulk density plus speed and ease of taking readings. A disadvantage of this instrument is the small area sampled by the cone. Advantages of the pocket penetrometer are that readings can be taken quickly and that the instrument is simple to use. This instrument, however, has limitations on a crusted soil surface; the scale has a limited range of values; a shallow depth and extremely small area of soil is sampled; and spring fatigue is possible. The air permeameter is moderately correlated (r = 0.86) with soil core bulk density, and readings can be taken quickly and with ease. Inaccuracies in readings with the air permeameter result from improper contact of flange on the soil surface and disturbing of soil in the soil cup. The volumeasure has practical use on very thin or rocky soils. The operation of this instrument, however, is time consuming and there is always the possibility of puncturing the balloon. An advantage of using the gamma ray scattering device is the capability of the instrument for taking soil compaction measurements at various depths without greatly disturbing the sampling site. Possible errors in the readings with this instrument are (1) need for correction for soil moisture, (2) difficulty of field calibration, (3) incapability of instrument to make measurements at the 5-cm depth, and (4) presence of minute air pockets under the detector plate.

The air permeameter and proving ring penetrometer are the most promising instruments for measuring soil compaction on rangeland soils because they have the highest correlations with soil core bulk density; readings can be made in a few seconds; and they are lightweight and mobile, easy to operate, and inexpensive. These two instruments were tested on a loamy rangeland soil that was subjected to grazing by livestock near Eureka, Utah. Readings from the two instruments were converted to predicted bulk densities using the regression equations. When the predicted values were compared to soil core bulk density, the average deviation of both instruments was 0.049 gms/cc.

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Forage Yields of Five Perennial Grasses with and without White Clover at Four Nitrogen Rates

JAMES W. DOBSON AND E. R. BEATY

Highlight: One of the current interests in cattle production research is the inclusion of a legume which might be expected to increase forage yields and reduce the need of N fertilization. The clover should lengthen the growing season over that of straight grass. An investigation measured the influence of white clover on grass forage yields where perennial grass species were grown at four N rates with and without white clover (*Trifolium repens* L.). White clover/perennial grass mixtures were superior to grass/N, and including clover significantly increased forage yields at N rates up to 112 kg/ha. Only when 336 kg N/ha was applied were average yields of clover/grass and grass/N comparable. The average increase in forage yields when clover was added to the perennial grasses at the 0, 37, 112, and 336 kg/ha N rates was 218.9%, 93.0%, 34.1%, and 0.2%, respectively. Clover production was concentrated in the first 7 months of the season and dropped sharply in August and September. Average clover/grass yields were consistently higher over the 4 years than were grass/N yields. White clover should be included in grass mixtures grown in Southern pastures to reduce the need for N fertilization.

There are an estimated 197 million acres, 80 million ha, of Southern range, most of it grazed by either wildlife or cattle sometime during the year (Williams et al. 1955). Practically all Southern ranges are seasonal and their successful use is usually dependent upon being combined with cultivated pastures where cattle can be cared for during the 6 to 7 months when they should be off the range.

Nitrogen fertilization of grass pastures and hay baling have been used widely to increase forage production and preservation. However, both are expensive, and using clover to replace N in forage production and field stockpiling reduces both production and harvesting costs. Farmer interest in reducing production cost is high.

Coastal Bermudagrass has been extensively researched for forage production in the South, and limited research has been completed on common Bermudagrass and tall fescue. Forage research on Dallisgrass and orchardgrass is not current, and research on the contributions of white clovers when grown with the major grasses is almost not existent.

All of these forage plants are grown somewhere in the Southeast. A knowledge of the different growth patterns would be extremely helpful to ranchers who must grow tame forages to provide fall forage for grazing during drouths and for wintering when cattle are not allowed to graze the ranges.

White clover (*Trifolium repens* L.) is one of the most versatile and in many instances the most durable of the clovers. It is adapted over much of the world and the southeastern United States but has received little research attention during the last two decades. Some of the last research on white clover in forage mixtures was that reported by Blaser et al. (1956), where the difficulty of maintaining white clover in pastures was reported.

In the 1940's, white clover stands were difficult to maintain due primarily to varied disease, fertility, and physiological limitations (Gibson 1957; Jones and Tisdale 1921; Kreitlow et al. 1957). Various viruses have been shown to reduce clover stands (Smith and Gibson 1960), and high soil and air temperatures tend to interfere with nodulation, flowering, and persistence. Generally, nonflowering clover plants out-yield and persist longer than flowering types. However, flowering types which produce seed are able to reestablish after stand loss, while nonseed producers are not. In the early white clover research, ladino was popular, but by 1955, it was recognized that ladino white clover was not persistent and was being replaced by seed-producing types.

Johnson, Donnelly, and Gibson (1970) developed 'Regal' white clover, which is more disease resistant and physiologically less susceptible to high temperatures; and it is now grown in place of ladino. Carter and School (1962) have obtained increases in forage yields by including white clover in planting mixtures, while others have reported no significant increases in forage yields (Templeton and Taylor 1966).

Early research with white clover tended to concentrate on the fertility, disease, and physiological problems associated with stand maintenance. Little emphasis was placed on white clover's contribution to a grass sod in terms of increased yield, seasonal distribution of yield, and quality of the forage.

Forage yields of Coastal Bermudagrass and tall fescue when grown alone have been reported (Beaty et al. 1973; Taylor and Templeton 1976), but data on yields when white clover is included are not widely available. Present indications suggest the grasses are likely to be grown with clover in the future.

Cowling and Lockyer (1965) con-

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Manuscript received April 15, 1977.

cluded that the grass and white clover components of a mixture were inversely related to N application or soil N. Growing white clover with grasses was found to be equal in increased yield to that obtainable from the application of 120 to 205 pounds of N/acre (134–230 kg/ha) to the grass without clover.

This investigation was completed to determine the yields of several perennial grasses in the lower South, using grass without clover and white clover/grass mixtures each grown at various N rates. A second objective was to establish yield modifications produced by including white clover and duration of the influence.

Materials and Methods

Tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.). Dallisgrass (*Paspalum dilatatum* Poir.), 'Coastal' and common Bermudagrass (*Cynodon dactylon* L. Pers.) were grown as whole plots on Fannin clay loam, a fine loamy mixed mesic family of the Cumulic Haplumbrepts, with and without ladino clover (*Trifolium repens* L.) as split-plots. Plots were further split for nitrogen (N) variables of 0, 37, 112, and 336 kg/ha as ammonium nitrate in three applications annually. Treatments were replicated five times, and forage harvests were made on approximately May 1, June 15, August 1, and September 20. Only tall fescue and orchardgrass plots were clipped at the first harvest, but all plots were harvested at clippings 2, 3, and 4. Yields of dry forage were determined by clipping a 75-cm swath to a stubble height of 6.3 cm through 6.3-m long plots. Forage was dried with forced heat.

Phosphorus (P) and potassium (K) were applied annually as 560 kg/ha of 0-4.4-16. Forage yields were collected for 4 years and botanical composition was determined on the grass/clover treatments of all grasses for 1952 and 1953.

Results and Discussion

Grass forage averaged 1,029 kg/ha without clover or N, but clover increased forage production to 3,284 kg/ha or 219%. Grass yields were doubled to 2,046 kg/ha by applying 37 kg of N; adding the white clover increased the total yield an additional 93% to 3,946 kg/ha. When 112 kg of N was applied, four times as much grass forage was produced as with 0 N but the clover added an additional 1,378 kg or 34%. Only at the 336 kg N rate were grass yields equal to grass and clover yields (Fig. 1).

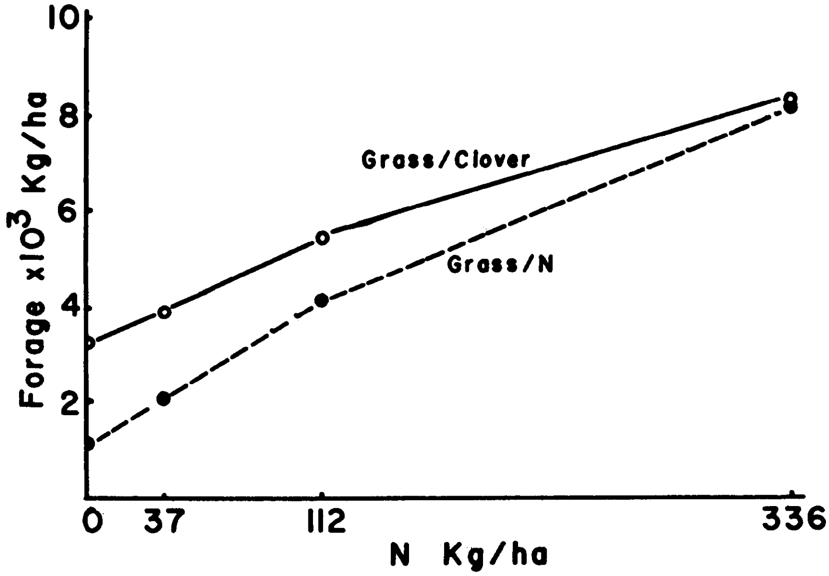

Fig. 1. *Average dry forage yield of tall fescue, orchardgrass, Dallisgrass, Coastal and common Bermudagrass with and without white clover at four N rates. Four-year average. Blairsville, Georgia 1952-1955.*

White clover was an advantage in grass sods, with the greatest benefit at low N levels. In terms of increased forage production, forage produced by grass/clover at zero N was equal to approximately 96 kg of N applied to grass alone and compares favorably with that reported by Cowling and Lockyer (1965). Except for hay production, N fertilization of pastures is usually below 100 kg/ha, indicating justification for renewed interest in legumes in general and in white clover specifically. Yield data for Coastal Bermudagrass with/without clover are shown in Figure 2. Bermudagrass, being more efficient photosynthetically, would be expected to produce more forage than the orchardgrass. (Chen et al. 1969). White clover grew equally well with either cool- or warm-season grasses (Table 1). Yield data for all forage grasses, with/without clover, included in the investigation are shown in Table 1. Forage yields of Dallisgrass, common Bermudagrass, and tall fescue at the different N rates with/without white clover followed a yield trend similar to that of Coastal Bermudagrass and orchardgrass and yield data are shown in Figure 2.

Yield data were from a uniform clipping height and do not insure harvesting a uniform percent of all species present. Different plant growth types as well as amount of forage present will appreciably influence the amount harvested (Beaty et al. 1973). Ethredge et al. (1973) showed that reducing clipping height from 14 to 0 cm increased the yield of Coastal Bermudagrass 161% when no N was applied but 68% with 448 kg N per ha. It is probable that forage yields of the

Table 1. Yield of five forage grasses under influence of N fertilization.[1]

	kg N/ha			
Grass	0	37	112	336
Orchardgrass	1290*	2000	3780	6840
Orchardgrass with white clover	3250	3590	5270	7260
Tall fescue	360	1240	2720	6050
Tall fescue with white clover	2540	2690	4000	6650
Coastal Bermudagrass	1230	2310	5120	10300
Coastal Bermudagrass with white clover	4170	5020	6370	10240
Common Bermudagrass	1070	2410	3830	8510
Common Bermudagrass with white clover	3600	4300	5760	7990
Dallisgrass	1190	2260	4770	9180
Dallisgrass with white clover	2860	4130	5710	8820

[1] Over a 4-year average.
**LSD:* 0.05 366 kg/ha.

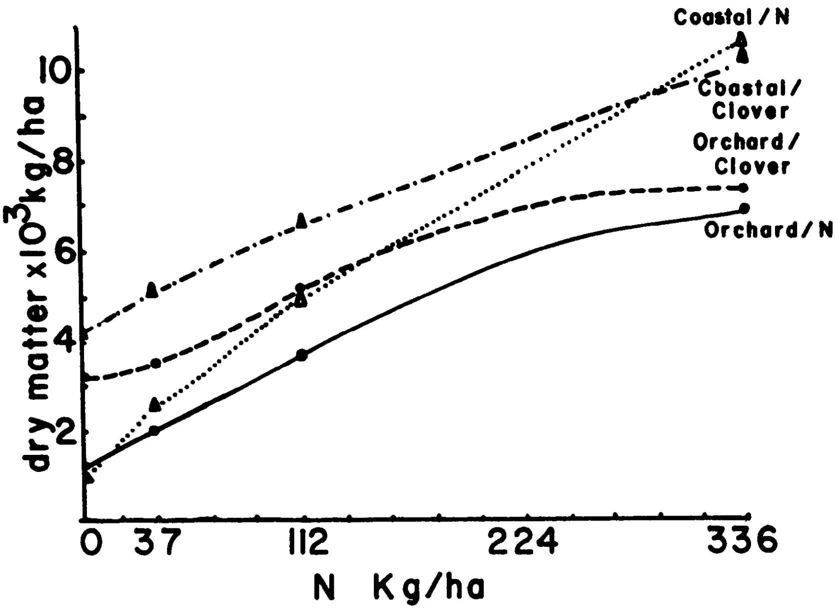

Fig. 2. *Average dry forage yield of orchardgrass and Coastal Bermudagrass with and without clover at four N rates. Four-year average. Blairsville, Georgia 1952-1955.*

low growing tall fescue, Dallisgrass, and common Bermudagrass represent a smaller percentage of the forage present than do the yields of the upright growing orchardgrass and Coastal Bermudagrass. Care should be exercised when comparing yields of grasses with different growth types as forage yields reflect height of harvesting and low growing ones may have yields underestimated.

Only tall fescue and orchardgrass plots were harvested at the first clipping but all plots were harvested at clippings 2, 3, and 4. When total annual yields are fractionated to percent of total, 25% of tall fescue alone was harvested at the first clipping and 50% at the second. Clippings 3 and 4 accounted for 12.4% each. Inclusion of clover had no influence on percent of yield harvested at the first clipping, reduced the second by 7%, and increased the third 5% as compared to the grass alone. The fourth clipping, with 12.4% of the annual yield for tall fescue alone, was not significantly influenced by the inclusion of clover, which had 13% of the year's total production.

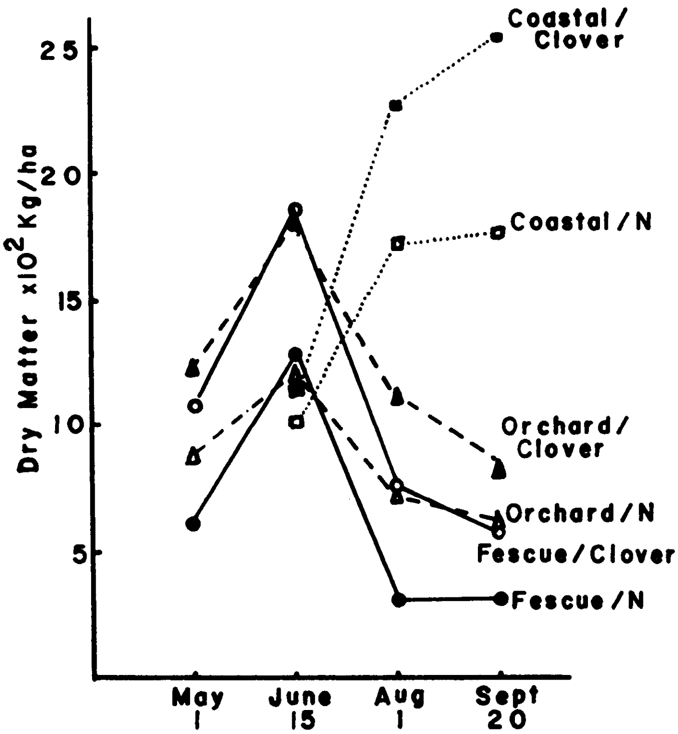

Fig. 3. *Average dry forage yield of tall fescue, orchardgrass, and Coastal Bermudagrass with and without clover by harvest dates. Average over 4 years at four N rates. Blairsville, Georgia 1952-1955.*

Orchardgrass and orchardgrass with clover were much more evenly distributed through the season than were tall fescue or tall fescue and clover. Orchardgrass alone was split 26.0, 35.5, 20.4, and 18.2% among harvests 1 through 4, respectively. When clover was added, the distribution of forage production was split 24.4, 36.7, 33.4, and 16.4% among the same harvests. Orchardgrass has been recognized for some time for having greater regrowth than tall fescue has during the summer and fall (Washko et al. 1967). The three summer-growing grasses followed a seasonal production trend which was significantly different from that of the cool season grasses. The second harvest (first for the summer-growing grasses) was small and highest average forage were obtained at the third harvest, with a small decline for the Dallisgrass and common Bermudagrass with white clover occurring at the fourth harvest.

In general, presence of white clover in the mixture increased forage present at all clips as compared to grass alone but had little influence on total seasonal distribution. Early growth of tall fescue and orchardgrass is shown in Figure 3, as is the significant reduction of growth in summer and fall. Growth of Dallisgrass and Bermudagrasses was low at the June 15 harvest and high at the August 1 and September 20 harvests. Seasonal forage distribution of monospecific summer-growing perennial grasses with N compared poorly to that produced by a cool-season grass growing with one of the warm-season grasses.

The lowest annual cultivar yield when averaged over four N rates was tall fescue without white clover at 2,593 kg/ha; this was followed by orchardgrass with 3,478 kg. Common Bermudagrass had an average yield of 3,955 kg/ha. Dallisgrass producing 4,350 and Coastal Bermudagrass producing 4,740 kg/ha were highest yielders. Average yield of all grasses over all N rates was 3,818 kg/ha, which was 1,393 kg/ha lower than the 5,211 kg/ha when white clover was included.

Average forage yield in 1952 was 3,678 kg/ha, followed by 3,789 kg in

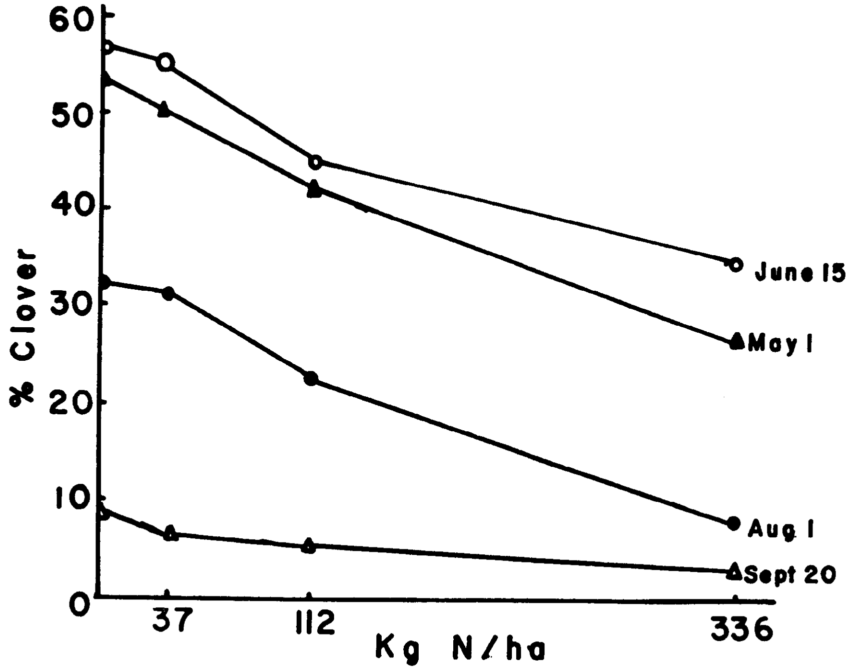

Fig. 4. *Average percent white clover content of tall fescue, orchardgrass, Dallisgrass, Coastal and common Bermudagrass by four N rates and four harvest dates. Clipping one included tall fescue and orchardgrass only. Other clippings include all grasses. Blairsville, Georgia 1952-1953.*

1953. In 1954, dry weather reduced the average forage yield by 300 to 400 kg/ha or approximately 10%. Increased rainfall in 1955 caused yields to increase 15% above the average (Fig. 5).

Average yields of grasses with clover were highest in 1955 when 6,087 kg/ha were produced, as compared to 4,613 kg/ha for the monocultures. Forage production during the other 3 years was similar, with average grass forage production being 3,686, 3,730, and 3,258 kg/ha for 1952, 1953, and 1954, respectively. When clover was added, average forage production was 4,768, 5,119, and 5,024 for the same 3 years.

In 1954 grass production was reduced somewhat by dry weather, but grass/clover yield was similar to that obtained in 1952 and 1953. The data would suggest that during years when grass growth is reduced, clover may grow more in the reduced competition. During favorable years when grass growth is vigorous, clover growth may be reduced. Clover growth in years unfavorable for grass growth should compensate for the reduced grass growth; and during years favorable for grass growth, clover growth may be reduced. The higher clover production in 1954 is attributed to dry weather reducing competition of the grasses.

The relatively poor forage production of fescue as compared to orchardgrass is possibly due to growth habit. Tall fescue, particularly at low fertility levels, tends to produce tillers that grow at sharp angles from the vertical (Bahrani 1973) while orchardgrass produces tillers that grow more vertically. When harvesting at a given height, more of the orchardgrass will be harvested than the tall fescue. As a consequence of removing a greater percent of the orchardgrass present, yields should be higher than tall fescue yields and clover would be expected to grow better with upright growing grass tillers or where more forage is removed at harvest. The data in Figure 3 show that the orchardgrass/clover combination did yield more than fescue/clover by some 853 kg. A similar effect is also shown where the upright growing Coastal Bermudagrass with its open sod yielded more than the low growing common Bermudagrass with a closed sod.

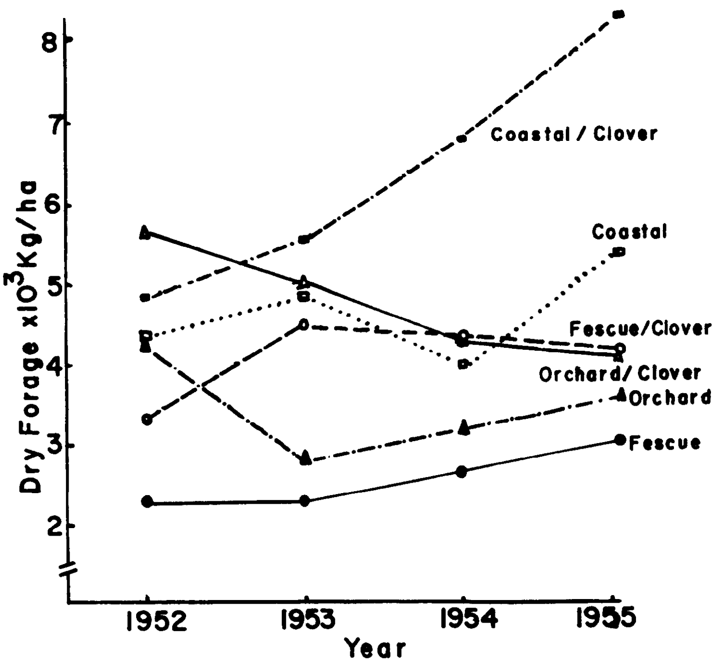

Fig. 5. *Average dry forage production of tall fescue, orchardgrass, and Coastal Bermudagrass by years. Averaged over four N rates. Blairsville, Georgia 1952-1955.*

Harvest management and fertilizers required to maintain a given white clover content in these perennial grasses were not evaluated specifically. However, increasing N application reduced percent clover in the mixture (Fig. 4). As sod density of perennial grasses tends to increase with heavier N applications, heavier grazing or closer clipping of spreading type forage grasses would appear to be favorable for clover establishment and production. This concept appears to support the report of Cowling and Lockyer (1965).

Difficulties of keeping white clover in rotationally grazed pastures have been noted (Blaser et al. 1956), but no data were provided as to the amount of forage present. Removing the forage by mowing as in this investigation probably reduced competition between grass and clover. Height of clipping or grazing probably will have a significant effect on clover retention. Young tillers tend to grow horizontally until sod is formed, and as the sod thickens, the tillers grow more upright. Thus, a lax clipping or grazing regime that allows an accumulation of forage shades the soil and interferes in the germination, establishment, and growth of annual seedlings and probably low growing clovers as well. It is probable that a multi-species pasture can be attained in the southeastern United States by limiting the N fertilization, utilizing the dense, sod-forming grasses to a height of less than 4 cm, and using persistent clover cultivars such as 'Regal' or 'Tillman.'

Using white clover to replace N and field stockpiling of forage for wintering should significantly reduce the cost of cattle production. One of the grasses tested is adapted throughout the range areas of the South. Combining range with cultivated pastures was considered to be a good practice by Williams et al. in 1955 and is probably a necessary one now.

Integrating cultivated pastures and ranges will probably include provisions for both grazing and hay, which can be made during the summer while cattle are grazing the range. The range plants are summer-growing species and in general require a rather specific time-related management.

The tall fescue and orchardgrass are cool-season perennials well adapted to either fall and winter grazing or field stockpiling. Tall fescue is sometimes seeded in clean-cut areas to prevent soil erosion. It could well be integrated into range grazing schemes to complement the time of grazing the native plants.

Dallisgrass growth is usually associated with heavy or wet soils. Such areas may not be adapted to growing specific trees, and an alternative use could well be forage for grazing during drouths. Including the white clover would essentially eliminate the need for N fertilization.

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The Botanical Composition of Cattle Diets on a 7-Pasture High-Intensity, Low-Frequency Grazing System, by Charles Andrew Taylor, Jr., MS, Range Science, 1973.

The botanical and nutritive composition of cattle diets were determined on a 7-pasture high-intensity, low-frequency grazing system in the Edwards Plateau region of Texas. Five esophageally cannulated heifers were used for 22 collection periods from September 24, 1971, to May 11, 1972. Diets were collected in each pasture during the first 3 days and last 3 days of each grazing period. Forage available for consumption was measured prior to the movement of animals into the pasture.

Though cattle selected grass as the major component of the diet, forbs, pricklypear, and browse were highly significant components at different periods during the study. Higher percentages of forbs, lower percentages of pricklypear and browse, and about equal amounts of grasses were consumed in the first 3-day collection periods compared to the last 3-day collection periods. Grass consumption tended to be greater during the fall and spring season than during the winter, while forbs were highly selected throughout the study. Pricklypear was utilized fall and spring. Browse was important in the diet in the spring.

Forbs were the most preferred class of forage. Grasses were consumed in proportion to their availability during the fall, but during the winter they had negative preference values. Pricklypear has negative preference values for the fall period but was highly preferred in two pastures during the winter period.

The nutritive composition of diets varied considerably between collection periods A and B and reflected changes in the botanical composition. Crude protein levels were usually higher for the first 3 days than for the last 3 days of the grazing periods. Larger amounts of ash in the diets were associated with greater consumption of pricklypear. Neither cell walls nor in vitro organic matter digestibility differed significantly between the two collection periods. Higher levels of cell walls in the diet were normally associated with a greater consumption of grasses. In vitro digestibility of diets from pastures grazed in the spring was higher than for other periods of the year and paralleled the initiation of growth from the warm-season perennial grasses and browse.

TECHNICAL NOTES

Selecting Letter Sizes for Technical Data Slides

B. J. WALKOWIAK AND R. E. RIES

Highlight: Careful selection of letter size and amount of information to be included before photographing slides is essential for legible slides. This article presents information that can be used to select the correct size of lettering for a specific drawing size before drafting and photographing them so as to insure that the 2 × 2 inch slides produced will be legible even to those sitting in the back of the audience.

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Most photographs or drawings that are prepared for manuscripts do not make good slide copying material (Smith 1957; Woolfolk 1963). Manuscript copy reduced to slide size is too small to be legible and will cause viewers to lose interest. To increase audience appeal and interest, a good slide must stress a single point clearly and quickly. Therefore, slide copying material must be planned carefully before photographing.

In general, if you can readily and easily read the lettering on a slide held at normal reading distance, it will be legible under most conditions to all members of an audience. Even though there is some variability between individuals in how this rule of thumb is interpreted and perceived, it has proven to be very useful (Beeler 1974). The information contained in Figure 1 provides the opportunity to apply this traditional rule and to determine letter sizes objectively before drafting and photographing the material to insure proper letter sizes on the finished slide.

Methods and Discussion

Ten different sizes of progressively larger letter sizes were used in Figure 1 with eight different sized margins. By moving the camera farther away from each successive sized drawing, we duplicated what happens to each slide as the drawing is amplified from 4 × 6 inches (10.2 × 15.2 cm) to 16 × 24 inches (40.6 × 61.0 cm). The first frame of Figure 1 shows a 3 × 4.5 inches (7.6 × 11.4 cm) photograph of a typed card reduced to slide size. The

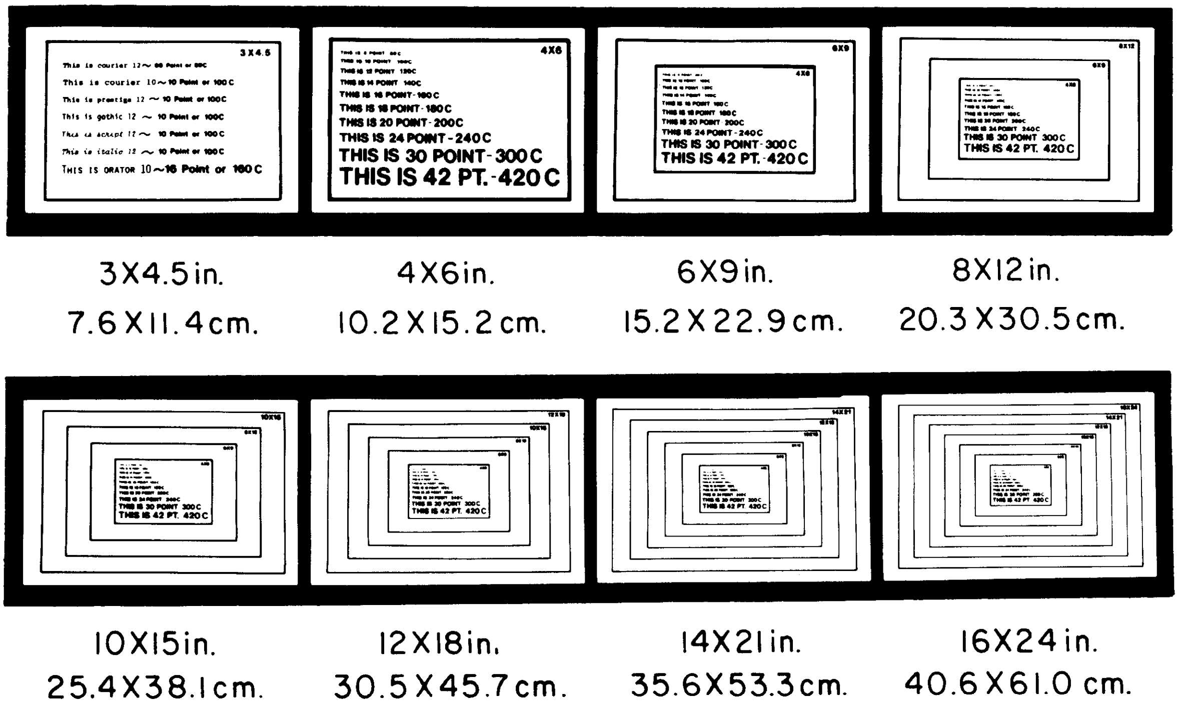

Fig. 1. *Actual slide size. The lettering style is helvetica medium for both the transfer lettering and letter template.*

MINIMUM LETTER SIZE

DRAWING SIZE (INCHES)	PRINT SIZE	TEMPLATE
4X6	18 POINT	180C
6X9	20 POINT	200C
8X12	24 POINT	240C
10X15	30 POINT	300C
12X18	30 POINT	300C
14X21	42 POINT	420C
16X24	42 POINT	420C

Fig. 2. *Recommended minimum letter sizes for each drawing size.*

maximum number of typing spaces for each line is 54 for elite and 45 for pica (Eastman Kodak 1975). The maximum information space is 3 × 4.5 inches (7.6 × 11.4 cm) for a 35-mm camera, which has a height to width ratio of 2:3 respectively. In Figure 1 for example, it is possible to read all the lines in the 4 × 6 inches (10.2 × 15.2 cm) frame. However, by allowing your eyes to scan the whole slide, 18 point lettering (Leroy size 180C) is the first size you can comfortably see. Therefore, for slide preparation from a 4 × 6 inch (10.2 × 15.2 cm) drawing, 18 point lettering should be the smallest sized lettering used. As the drawing size is increased to 6 × 9 inches (15.2 × 22.9 cm), the 18 point lettering is no longer easily read and 20 point lettering becomes the new minimum letter size. As the drawing size is increased, so must the letter size (Eastman Kodak 1975). When using Figure 1, measure the actual picture to be photographed and not the paper size. Proper selection of lettering shown in Figure 1 will assist a draftsman in selecting an optimum letter size.

The most favorable and versatile letter sizes, as viewed by the authors, are summarized in Figure 2. Under some conditions, you may wish to deviate from the lettering shown in Figure 2 and reduce or enlarge the letter sizes. However, a change in letter sizes can adversely affect the versatility or the legibility of the slides. Examples of where reduced letter sizes may be desirable would be when (a) projection facilities are outstanding, like room size, projector location, and area of projections; (b) when deemphasizing particular data; and (c) when large quantities of information must be included. Some examples of where enlarging letter sizes might be desirable would be for (a) titling; (b) emphasizing; and (c) very poor projection facilities.

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Impact of Herbivores on Arid and Semiarid Rangeland Ecosystems—

Proceedings of the Second Workshop of the US/AUSTRALIA RANGELANDS PANEL—Adelaide, 1972.

We have received a small number of copies of the above **Proceedings** on consignment from the Australian Rangeland Society, publishers of the Second Workshop. These copies are available from the *Society for Range Management, 2760 West Fifth Avenue, Denver, Colo. 80204,* for approximately $7.50 (US dollars). The publication contains the contributions of the 10 United States and 23 Australian scientists participating in the Second Workshop.

Also available from the SRM Denver headquarters is a limited supply of ***Arid Shrublands—Proceedings of the Third Workshop of the US/ AUSTRALIA RANGELANDS PANEL, Tucson, Ariz. 1973. ($3.00 postpaid)***

BOOK REVIEWS

Reclamation and Use of Disturbed Land in the Southwest. Edited by John L. Thames. The University of Arizona Press, Tucson, Arizona. 85722. 1977. 362 p. $8.50 paper, $14.50 cloth.

This book evolved from the symposium, "Disturbed Land Use and Reclamation in the Southwest," given at the University of Arizona in 1975. The book is divided into six parts that contain a total of 33 chapters. The 41 authors include land managers, research scientists, professors, consultants, a metallurgist, an agronomist, an archaeologist, an attorney, etc. Although some material is repetitious, the book does meet its overall objective. It describes constraints, alternatives, and techniques of land reclamation.

Part I discusses mining reclamation and land use planning. The first chapter illustrates how environmental and economic forces created an effective land use planning system through trial and error. Chapter 2 warns us that government legislation should not replace natural economic constraints in land use planning systems. Chapter 3 explains why flexible reclamation legislation is needed, and how legislation influences decision-making processes in the Forest Service. The last chapter has low utility in the Southwest because it reviews reclamation methods in Illinois.

Part II deals with several constraints in disturbed land reclamation. Chapters 6 and 9 both present strong arguments, with examples, for allowing economics to govern environmental programs. Chapters 7 and 8 warn us that stringent zoning and regulatory standards are potentially harmful when they precede mineral exploration and technical advancements. Social and political constraints are discussed in the last chapter.

Part III is concerned about the relationship between mining and the environment. One chapter reviews NEPA; and another chapter suggests that the mining industry can benefit and learn from the environmental impact statements. The authors of Chapter 13 explain why a new field of ecology, mining ecology, should be created. Chapters 14 and 15 present approaches for evaluating the environmental implications of coal-fired electricity production and oil shale technology. The final two chapters describe how mining activities place additional water demands on the hydrologic environment.

Part IV discusses mining and the amenities. The first chapter defines recreational opportunity costs and explains why "public intervention" is needed in land use planning. Two chapters emphasize the importance of amenity resources. Another reviews a method of quantitatively assessing and predicting public perception of landscape disturbances. The last chapter states that there are other alternatives rather than striving for a previous man-made state.

Part V is titled "Revegetation Techniques." Reclamation efforts and associated soil fertility problems and the problems associated with irrigation, hydroseeding, and mechanical soil surface treatments are discussed. Five of the six chapters present general information. The most useful information for Southwesterners is in Chapter 25. It presents research data from the reclamation of two mine spoils in New Mexico.

Part VI is titled "Plant Species for Disturbed Lands." Chapter 29 convinces us that mining and range management can be compatible. Its worthwhile message is editorially misplaced and logically belongs in Part III, Mining and the Environment. Chapter 31 is an informative discussion of revegetating disturbed sites, and also contains a useful list of adaptable species. Its information negates the usefulness of Chapters 30, 32, and 33.

Each of the six parts contributes to the book's usefulness. It is not possible, however, to predict reader response to the first four parts. This is because many of the topics are subjective and will be judged by the reader's personal experience, values, and purposes. Those readers who are actually reclaiming disturbed sites will find Parts V and VI most useful but may be disappointed in the general coverage of the information. I found the following chapters to be the most interesting: "Land Use and the Mining Industry" by Jerry L. Haggard; "Operating Considerations" by Thomas J. O'Neill; "Economic Constraints" by George F. Leaming; "Ecology and Mining or Mining Ecology?" by Mohan K. Wali and Alden L. Kollman; "Reclaiming Coal Mine Spoils in the Four Corners" by Earl F. Aldon and H. W. Springfield; "Range Management and Surface Mining" by Phil R. Ogden; and "Revegetation of Disturbed Intermountain Area Sites" by A. Perry Plummer.

The text should be enlightening for the reader with a general interest in disturbed land reclamation. It is applicable as a college text for an introductory course in reclamation and use of disturbed lands. Although the text could be used in planning reclamation efforts on disturbed sites, additional "site-specific" data is needed before its general concepts can be applied in the field.—*John R. Lacey,* Socorro, New Mexico.

NEW PUBLICATIONS

SOILS: An introduction to soils and plant growth, Fourth Edition, by Roy L. Donahue, Raymond W. Miller, and John C. Shickluna. Prentice-Hall Inc., Englewood Cliffs, N.J. 07632. 1977. 626 p. $15.95. This edition has been rewritten to engender a greater awareness of the soil as a largely nonrenewable world resource. It is intended as an introduction to soil science for the student at all levels, emphasizing an easy understandable text including details for further study. New chapters include "Saline and Sodic Soils and Their Reclamation," "Soils Requiring Unusual Management," and "Soils, Food Production, and World Population." An increasing need for wise water management is recognized by extensive and enlarged coverage of the chapters on "Soil Water" and "Water Quality and Irrigation." "Soils and Plant Nutrition" and "Fertilizers and Their Use" have been rewritten to make them more descriptive and current. Overall, there is a new emphasis on soil ecology, environmental quality, and soil surveys as a basis for wise land use. Metric units are given in parenthesis following all U.S. units of weights and measures.

ARID LANDS RESEARCH INSTITUTIONS: A World Directory, Second Edition, by Patricia Paylore. The University of Arizona Press, Box 3398, Tucson, Arizona 85722. 1977. 317 p. $7.50. This edition contains revised and updated listing of institutions throughout the world. Entries are alphabetical by continent, country, and institution. Entries include (1) Name, (2) Address, (3) Scope of Interest, (4) Research Programs, (5) Finances (Optional), (6) Staff and Organization, (7) Facilities, (8) Publications, and (9) History—establishment, major accomplishments, changes in name, etc.

THESIS: UNIVERSITY OF IDAHO

Prescribed Burning Effects on Nutrition, Production, and Big Game Use of Key Northern Idaho Browse Species, by Duane A. Asherin, PhD, Wildlife, 1973.

Prescribed burning effects on the production and nutritional quality of four northern Idaho key browse species were investigated in three spring burns (1967, 1968, and 1969) in each of two main study areas—the Lochsa and St. Joe River drainages—and in 1968 and 1969 prescribed burns on the University of Idaho's experimental forest. Big game use of burned and nonburned sites was also compared. Only dormant plant tissue was sampled for nutritional effects corresponding to the critical big game winter stress period.

Nutrient analyses of current annual growth (CAG) not longer than 4 inches from four key browse species—mountain maple (*Acer glabrum*), serviceberry (*Amelanchier alnifolia*), redstem ceanothus (*Ceanothus sanguineus*), and willow (*Salix* spp.)—indicate species specific responses to spring prescribed burning. Crude protein was significantly higher the first year after burning in 83.3% of the burned vs nonburned comparisons for all species. This effect was absent by the end of the second year, suggesting spring burns are of low intensity. With one exception, redstem ceanothus protein content was lower on burned compared to nonburned sites. Strictly maintenance forages are indicated by the protein content noted. Fat content generally was lower the first year but higher in the second and third years after burning. Willow was considerably higher in fat than any other species and redstem the lowest. Crude fiber was significantly lowered in 72.7% of the comparisons for all 3 years of burns, indicating increased overall digestibility. Crude fiber content increased, however, in mountain maple on burned sites. Ash showed no apparent trends for any browse species but was highest on controls and burns in willow. Calcium was lower in 66.6% of the significant comparisons through the 3 years of burns. Phosphorus increased in all first year comparisons but no difference was detectable after 2 years. The combined effect was a significant reduction in the C:P ratio over all species for the first two years. This may benefit effective reproduction of forest ungulates present. All first year moisture comparisons were significantly higher. However, 87.5% of the significant comparisons were lower in the second and third years following burning. Preference by big game for burned sites compared to nonburned sites and for the most recent burn may be associated with the higher succulence of plant tissue on burned sites.

Available production of redstem ceanothus on Lochsa burned sites exceeded control plant production after 2 years, while redstem plants on Avery burned sites produced less available browse than control plants after 3 years, due primarily to heavy summer use. Willow plants produced significantly larger amounts of available browse on all 3 years of burns in both study areas compared to control plants. Increased available production of such tall-growing shrubs as willow more than offset the loss of available redstem production for the first few growing seasons following spring prescribed burning.

Pellet group and utilization counts substantiate higher summer and winter use of burned compared to nonburned sites by big game. Utilization data also show a higher preference for redstem ceanothus over the other three browse species examined. Increased use of burned sites as well as forage species preferences are questioned as being solely attributable to associated nutritive values. Nutrient data do not support the contention that big game select or prefer certain browse species over others on the basis of higher protein content. The higher carbohydrate fraction found in redstem ceanothus nutrient analyses compared to the other three browse species analyzed may be responsible for the higher preference for redstem by big game.

Winter CAG availability, seedling survival, and possibly the future vigor of the shrub community were found greatly affected by the degree of summer utilization of preferred browse species by big game, snowshoe hares (*Lepus americanus*), and possibly other rodents during the first few growing seasons following burning. Burning scattered areas on a given tract of winter range appears more beneficial than one area of the same acreage. This way, the CAG available in adjacent nonburned sites may be utilized more fully. Nonburned sites may thus receive a regrowth stimulus, maintain better growth form, and animal distribution and plant utilization may be more uniform over the entire winter range.

Three potential problems associated with spring prescribed burning as opposed to fall prescribed burning are discussed. Re-examination of the effects of and the potential for more fall burning is posed. The past and present practice of intensive fire suppression on our forest ecosystems is also discussed and the probability of producing unnatural ecosystems is predicted if this practice continues.

THESIS: TEXAS A&M UNIVERSITY

Remote Detection of Deer Habitat Factors, by Kenneth Ray Moore, MS, Range Science, 1973.

Color-IR aerial photography and ground observations were acquired at two sampling dates from three grazing pastures and two soil types at the Sonora Range Station. Vegetation characteristics influencing deer habitat components (food and cover) were measured from ground and air photo surveys. Aerial photography provided information necessary for evaluating deer habitat by delineating and classifying food-cover types on three study pastures. Reliability of the habitat classification scheme was determined by comparing the location and extent of favorable types to available deer density counts.

Ground observations provided fundamental data for assessing the accuracy of air photo measurements. The point-centered quarter (PCQ), plotless technique was employed to measure composition, density, and canopy cover of woody vegetation from ground and air photo surveys. Air photo quadrat methods were used to estimate density and canopy cover. An air photo dot grid method was also employed to determine canopy cover.

Woody plant composition measured by ground and air photo survey compared well for major species. Density estimated from ground and air photo PCQ data were consistently higher than air photo quadrat counts. Canopy cover was poorly estimated from ground observations but was accurately measured by air photo methods. The air photo quadrat and dot grid techniques produced very similar canopy cover percentages. Air photo measurements were obtained with relative ease and in a small fraction of the time required for ground measurements. Qualitative estimates of herbage yield and standing green biomass compared well with quantitative ground measurements.

Important vegetation characteristics of deer habitat were used to classify food-cover types. Food-cover type mapping and characterization were possible from medium to large-scale color-IR aerial photography. Suitable classes of food-cover types developed for this investigation agreed well with available deer density data for the test pastures.

Range Management Theses 1968–1975

Compiled and Edited by
REX D. PIEPER
New Mexico State University, Las Cruces

A considerable amount of information concerning our range resources is contained in theses and dissertations, many of which are never published. Currently, there is a great demand for information on rangelands, but it is often difficult to obtain thesis and dissertation titles.

In the past, the Range Science Education Council has compiled titles of range theses and dissertations (Box 1966; Kinsinger and Eckert 1961, 1962; Schmutz 1967; and Tueller 1968). However, these have not been compiled for some time. Consequently, the current list is broken into sections for publication in several issues of the Journal. Asterisks identify PhD dissertations.

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Official bimonthly publication of

Society for Range Management

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. . . (founded in 1948) is a private, non-profit, professional association dedicated to advancing a comprehensive understanding of range ecosystems and the intelligent use of all range resources. The Society assists all who work with rangelands to keep abreast of new findings and applications in range management and strives to create a public appreciation of the benefits to be derived from proper range use.

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. . . include two bimonthly periodicals—*Journal of Range Management* and *Rangeman's Journal*—as well as special publications that are issued from time to time. Through these publications (which feature timely articles of general interest, research reports, management notes, viewpoints, book reviews, and news about Society members and activities) members are kept current on information pertinent to rangeland management and use.

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2760 W. 5th Ave., Denver, CO 80204

FOR OFFICE USE ONLY No.								C/M	SEC	
RR	K	ID	SS	AP	D	JRM RJ		C	ZL	L

Please Print

Date ______________ 19 ___

NAME ______________________________

ADDRESS ______________________________

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MEMBERSHIP CLASS: **Regular** ☐ **Student** ☐ **Individual Sustaining** ☐ **Life** ☐

Dues paid herewith $ __________ are for calendar year 19 ____

I wish to be affiliated with the ______________________ Section

Membership solicited by ______________________

Make check, draft, or money order payable to SOCIETY FOR RANGE MANAGEMENT. Mail to the Society at 2760 West 5th Avenue, Denver, Colorado 80204.

Your cooperation is requested in completing the following information for our files. Please print.

Date of birth ______________________

Occupation (or Position Title) ______________________

Employer ______________________

Education (This information is for statistical purposes, not used on an individual basis.)

High School ☐ College(s)–Degree(s)–Major(s) ______________________

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Applicants for Student membership please complete the following:

Name of school ______________________

Freshman ☐ Sophomore ☐ Junior ☐ Senior ☐ Graduate ☐

1978 DUES SCHEDULE

	Regular	Student	Individual Sustaining	Emeritus
ARIZONA Section	$23.00	$12.00	$34.00	$16.50
CALIFORNIA Section	23.00	11.00	33.00	16.50
COLORADO Section	21.00	11.00	31.00	14.50
IDAHO Section	22.00	12.00	32.00	15.50
KANSAS-OKLAHOMA Section	22.00	12.00	32.00	15.50
NEBRASKA Section	23.00	11.00	33.00	16.50
NEVADA Section	22.00	12.00	32.00	15.50
NEW MEXICO Section	22.00	11.00	32.00	15.50
NORTHERN GREAT PLAINS Section	23.00	13.00	33.00	16.50
INTERNATIONAL MOUNTAIN Section	22.00	12.00	32.00	15.50
PACIFIC NORTHWEST Section	22.00	12.00	32.00	15.50
SOUTH DAKOTA Section	22.00	12.00	32.00	15.50
SOUTHERN Section	25.00	15.00	35.00	18.50
TEXAS Section	23.00	12.00	33.00	16.50
UTAH Section	23.00	13.00	33.00	16.50
WYOMING Section	23.00	12.00	33.00	16.50
NATIONAL CAPITAL Section	21.00	11.00	31.00	15.50
MEXICO Section	24.00	14.00	34.00	17.50
NORTHCENTRAL Section	22.00	12.00	32.00	15.50
Unsectioned*	22.00	12.00	32.00	15.50

Effective October 1977