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President's Address: Rangeland Is—

C. REX CLEARY



Rangeland is a major land mass. Visualize if you will, that I am holding an apple in my hand which represents our planet earth. Visualize that I cut the apple into four equal pieces. Three of those I set aside because they represent the portion of earth's surface covered by water. The remaining one fourth is land. Now I cut the land fourth in half. One of those halves represents rangeland. This tells us two things. On one hand the earth's rangeland is finite. On the other hand it is a tremendous land mass. More importantly, it is a land mass that does so much more than simply hold the world together.

Rangeland is the watershed of this water-starved planet. Daily, water becomes increasingly scarce and increasingly precious for mankind. However, when properly managed, the rangeland watershed stabilizes, purifies, and stores more water. Any time water doesn't go into the ground where it falls, we're doing something wrong.

Imagine if you will that mankind succeeded in bringing to bear the knowledge that exists, that we reversed desertification and maximized watershed values worldwide. The collective effect on man's water supply alone would be awesome.

Rangeland is home for most wildlife. It is another major value to man. When properly managed, rangeland fosters species diversity. Properly managed, it is the central and essential component of natural ecological balance.

It is also where anti-hunting movements were spawned. Wildlife need to be managed, too, for ecological balance.

Rangeland is the American playground. Recreation is a major American pastime. Recreation takes dozens of forms on rangeland.

Rangeland is the mainstay of rural economics. Throughout the American west, county after county is dominantly dependent on its rangeland for its own economic base. I recently heard a detailed economic analysis of Madison County, Montana. It was demonstrated how rangeland provided 70% of the county's economic base—not the least of which was in the form of livestock grazing.

Rangeland is important to the global environment. Proper managed rangeland stores more carbon and emits less methane. Rangeland accounts for 13% of total terrestrial carbon on earth. Rangeland degradation is a major contributing factor to worsening global environment. Conversely, if properly managed, rangeland would be a major contributing factor to improving global environment. It is, in fact just as important to the global environment as are rain forests.

Rangeland is crucial to mankind.

Rangeland is crucial to saving the "Planet Earth".

Yet Rangeland is generally not thought about or is ignored—viewed as "wasteland".

Rangeland is always slipping into the background of the minds of nations' leaders and nations' budgets. It's always overshadowed by more immediate issues and problems. I'm preaching to the choir here, but the indisputable fact is, we simply haven't reached enough

folks, nor the right folks. We haven't reached them concerning both the importance of rangeland, and the importance of properly managing rangeland.

That leads me to a currently major SRM priority. That is our initiative to package and market the importance of rangelands. All of us in the profession take for granted this importance, but we simply have neither packaged nor marketed our message adequately for those not in the profession.

Therefore, I have asked the I & E Committee to make a concerted effort at packaging. They are going at it comprehensively, including the complex relationships to global environment. The committee has a target to complete the packaging by this coming Summer Meeting.

In the meantime, the Major Enhancement Task Group is working on the marketing end. They are gearing themselves up to receive the package by the Summer Meeting and work it into their overall efforts to market SRM, including the importance of rangeland.

Rangeland is driven by western urbanization. Urban growth, development, and encroachment on rangeland is progressing at an alarming rate. In the greater Reno area, growth is occurring at a rate of 4,000 people per month. In the Las Vegas area it is 7,000 people per month. California is growing at a rate of over 60,000 people per month.

Urbanization has brought new attention and new values to rangeland. Riparian is an example. The green zones along rivers, streams, lakes, and springs are the center of attention and the source of major issues. Upland rangeland is generally in better condition than it has been in this century. However, riparian areas continue to suffer from a high degree of degradation.

Riparian areas play a vital ecological role. The greenstrips are the lifeblood of rangeland. But they do not function alone. They function as one part of the total watershed. Therefore, we need to start at the top of the watershed to properly manage riparian areas.

We have known for many years that exclusion of livestock from poor condition streams resulted in dramatic recovery of riparian areas. This comparison was seen by many as an indicator that grazing and streams were not compatible. In reality, we were comparing no grazing to improper grazing. Research and on-the-ground demonstration projects now show us riparian areas can be restored with proper livestock grazing practices.

Rangeland is a controversial arena for the Endangered Species Act. The desert tortoise is an example. Upwards of 10 million acres of rangeland are impacted. The tortoise populations have been declining and livestock grazing is viewed as a major cause. Critics of livestock grazing have seized this opportunity to justify the removal of livestock from the arid public lands. However, the highest recorded tortoise densities coincided with or immediately followed the greatest levels of livestock use! The decline of desert tortoise populations over the past several decades has roughly paralleled the trend of decreased livestock grazing on public lands. This could suggest that livestock grazing does not play a role in the observed decrease in desert tortoise populations. Recent popula-

Cleary was president of the Society for Range Management in 1990. This address was presented at the Society's annual meeting in Washington, D.C., in January 1991.

tion declines have been caused mainly by an upper respiratory disease syndrome.

Recommendations for livestock grazing in habitat management plans are currently based largely on anecdotal evidence and there is a serious lack of scientific data. A recent extensive literature search failed to produce a single refereed or peer reviewed reference with conclusive evidence of proper livestock grazing having a negative impact on the desert tortoise.

The SRM will henceforth take a more active role in species listing under the Endangered Species Act as well as in the development of recovery plans. In addition, SRM strongly supports long-term interdisciplinary research, demonstration projects, and intensive monitoring of grazing practices within desert tortoise habitat.

Rangeland is where Wild Horses and Burros have their own Endangered Species Act—The WH&B Protection Act of 1971. Tens of millions of acres of rangeland are impacted.

Wild Horses and Burros are to be managed in a manner to achieve and maintain a thriving natural, ecological balance on the public lands. Congress so stated in the 1971 Protection Law.

By far, the greatest obstacle to achieving an ecological balance continues to be the gathering and disposition of excess animals from the populations. On good feed, wild horse populations will about double in four years. Ample studies exist which bear this out.

Thus, if the goal is to sustain a total of 30,000 wild horses on public lands, about 30,000 excess must be removed every fourth year. If the goal is doubled to 60,000, then about 60,000 excess must be removed. The implications are staggering.

Setting the goal obviously carries with it immense responsibility. That responsibility is to gather and dispose of these excesses to assure maintenance of a thriving ecological balance as directed by Congress.

Traditional gathering and disposal strategies have been inadequate for the job. Costs have been enormous and there is currently no viable alternative for disposing of the unadoptable excess. Feed lots, fee waivers, and sanctuaries have all been tried and are no longer available.

I suggest there is a solution that has been applied in both the Susanville, California, and Burns, Oregon, BLM Districts that will provide the answers to both the cost and the unadoptable problems. In short, the solution is to quit gathering and removing unadoptable animals.

Using traditional gathering strategies, about 50% of the animals gathered are unadoptable. It has been demonstrated that with Herd Management, the unadoptable animals gathered can be reduced to near zero, while at the same time enhancing and maintaining herd integrity.

Herd management frees up funds to more adequately manage wild horses and other resource values, provides humane treatment to older wild horses that remain to live out their lives in the wild, and provides excess horses that are more desirable for adoption and domestication.

Herd management consists of five principles:

1. Retain desirable characteristics.
2. Removing undesirable characteristics from the gene pool.
3. Leaving breeding herd on range for natural life.
4. Removing excess from young.
5. Leaving sufficient young to offset death loss and sustain integrity of herd.

I refer to a publication entitled, "A Comparison of Management Methods for Wild Horses" by the Modoc/Washoe Experimental Stewardship Program dated 12/30/90. The publication describes, analyzes, and compares management methods. It explains how Herd Management, from an overall cost standpoint, costs less than half what traditional approaches are costing.

I hope the management agencies will closely scrutinize Herd

Management for the opportunities it presents to "take the bull by the dilemma" and solve the exasperating Wild Horse problem!

Rangeland is where misinformation and misunderstanding prevail. For example, consider range condition ratings and terminology and look at sagebrush prone rangelands in the Intermountain and Great Basin regions. Frequently, we find that a high proportion of sagebrush dictates a poor or fair condition rating under current rating systems. But in the interest of wildlife habitat, the public resists using vegetation manipulation techniques to reduce the sagebrush component. Making that value judgment for wildlife is as it should be. The onerous part is that by definition the range is then held in poor or fair condition. The same public turns around and condemns the managers, the industry, and the range profession for not doing a better job of range management. They make that judgment by looking at the agencies' own range condition data and terminology which can be translated into a large part of rangeland being in unsatisfactory condition. This is happening notwithstanding the fact that tens of millions of acres of sagebrush, for example, are being held in their poor and fair condition class because that's what the American public wants. The range profession is damned if it does—and damned if it doesn't.

There is unquestionably something wrong with the range condition classification system that allows that double standard to exist. Therefore another of SRM's high priorities is our initiative to review and overhaul the system. The Unity in Concepts and Terms Task Groups is charged with this responsibility. They have the complex and challenging responsibility to develop range condition classification concepts and terms which are satisfactory to all agencies and our profession as a whole. The effort will be successful only if all agencies are united behind the outcome—hence, the Task Group name. I believe this is the single most important, and most difficult initiative during my watch.

Rangeland is now a major battleground: "Livestock Free by '93" has become the battle cry of the more extreme environmental groups.

Livestock grazing on public lands has been a traditional and respected use for many decades. In recent years, there has been a growing public awareness and concern for environmental quality and protection of wildlife, watershed, and aesthetic values. Grazing, when poorly managed, can be a destructive agent. When properly managed, it can be beneficial to the rangeland environments.

The more extreme environmental organizations have actively pushed for total removal of grazing on public lands. They argue that unrealistically low grazing fees have encouraged overuse of public ranges and that managing agencies have condoned mismanagement. There have been numerous cases of vandalism to fences and other range improvements and killings of livestock by the most radical.

In the other extreme, certain livestock industry representatives have professed "grazing rights" and advocated formal designation of public rangelands where livestock grazing would have priority over other uses. The most extreme of these advocates represent the "Sagebrush Rebellion" advocating State or private takeover of federal rangelands.

The SRM believes that neither extreme is correct, appropriate, nor in the public interest. SRM believes that grazing of public rangelands in a responsible and well-managed way is both appropriate and beneficial to other multiple use values of these areas.

SRM believes that grazing of range plants by both wild and domestic large herbivores is necessary to maintain long-term plant vigor and species diversity of range ecosystems. Domestic livestock provide a portion of the desired vegetation manipulation.

SRM is actively working with responsible leaders in the envi-

ronmental community as well as the livestock industry to promote coordinated resource management and full consideration of all resource uses and values on public rangelands.

We advocate "Use the range, but use it properly."

Rangeland is where we need to stop educating and start building understanding. People won't be educated by perceived adversaries.

Rangeland is where head banging is not working.

Rangeland is where partnerships are needed above all else. It is the epitome of where "no man is an island".

Rangeland is where people need to work together to *build* partnerships. To that end, Coordinated Resource Management (CRM) advocacy is another major SRM initiative.

In short, CRM simply means all interested folks "working together" at the local level to solve their range management and other problems. Simple enough to say—but sadly enough, it seems to be contrary to basic human behavior.

CRM is a process that can be adapted to any local situation. Successful application relies on the spirit of cooperation as much as anything. However, behavioral and group interaction techniques are also widely applied.

CRM is authorized by virtue of a National Memorandum of Understanding between the Bureau of Land Management, Forest Service, Soil Conservation Service, and Extension Service. It is about twenty years old.

The Memorandum was updated in 1987. At that time, both the Memorandum and the process were strengthened by embracing

the Experimental Stewardship Program. The Stewardship Program was an intensive experiment to improve range condition through enhanced cooperation and coordination. The experiment was eminently successful and the effectiveness of CRM was substantially enhanced by inclusion of what had been learned.

SRM's advocacy role takes many forms. We work to improve techniques. We work to get adversaries to the table to use the techniques. We conduct training seminars to improve people's skills with these techniques.

We believe it is so much more productive and effective for people to work together than to fight. This has been proven time and again. We annually celebrate the successes of working together. We have a video library full of these success stories which highlight how the rangelands have been improved as a result of "people working together." SRM believes that CRM holds the greatest promise for building partnership and creating an endless stream of successes to celebrate.

Finally, **rangeland is**, where failure to work together will result in consequences too gruesome to contemplate. Experts will march in and determine local densities.

On the flip side—when we do work together we all gain so much—individually and collectively. The payoff is powerful. We will determine our destiny and will create that endless stream of success stories.

Remember the adage—"None of us knows as much about something as all of us!"

Thank you very much.

Vegetational responses of a mixed-grass prairie site following exclusion of prairie dogs and bison

M. SILVIA CID, JAMES K. DETLING, APRIL D. WHICKER, AND MIGUEL A. BRIZUELA

Abstract

Combined grazing by black-tailed prairie dogs (*Cynomys ludovicianus*) and bison (*Bison bison*) produces and maintains a series of changes in the vegetation of prairie dog colonies. However, because their grazing patterns differ in frequency and intensity through time, their individual impacts may be different. The objective of this study was to determine the individual and combined influences of these 2 herbivores in maintaining selected vegetation characteristics of a prairie dog colony in a mixed-grass prairie at Wind Cave National Park, S.D. This was assessed by monitoring plant responses during 2 years following exclusion from grazing by 1 or both species. In spite of their different grazing patterns, prairie dogs and bison had similar and independent (i.e., additive) effects in maintaining plant community structure. For example, total above-ground biomass increased 32–36% within 2 years of removal of each species, primarily as a result of increases in accumulation of graminoid biomass. Plant species diversity, equitability, and dominance concentration were similar in all treatments both years, although there were slight decreases in relative abundance of forbs and increases in relative abundance of graminoids in the second year after removal of grazers. Mean graminoid leaf nitrogen concentration (May to September) declined slightly but significantly after removal of prairie dogs (1.49 to 1.38%) in 1985, and after bison exclusion (1.64 to 1.50%) in 1986. We suggest that rate of vegetation change following removal of grazers depends upon weather conditions, plant species composition, and prior intensity and duration of grazing.

Keywords: prairie dogs, bison, grazing patterns, release from grazing, vegetation response, mixed-grass prairie, nitrogen concentration

Where both are present, black-tailed prairie dogs (*Cynomys ludovicianus*) and bison (*Bison bison*) directly and indirectly control numerous structural and functional properties of grasslands (Whicker and Detling 1988a, 1988b). Among the native herbivores, they probably have had some of the greatest impacts on North American grasslands, and there is evidence of positive interactions between them (Krueger 1986). Sedentary, colonial prairie dogs alter the vegetation and produce patches which differ from the surrounding uncolonized grassland. These patches are used preferentially for grazing and resting activities by larger herbivores such as bison, elk (*Cervus elaphus*), and pronghorn (*Antilocapra americana*) (King 1955, Coppock et al. 1983b, Wydeven and Dahlgren 1985, Krueger 1986). Bison herds graze a given prairie

dog colony relatively infrequently, but on these occasions they remove large amounts of forage. On the other hand, the grazing pressure of prairie dogs is relatively constant and intense throughout the growing season. The combined impact of these herbivores alters grassland structure in such a way that prairie dog colonies become patches of intensified biological activity compared with the surrounding, lightly grazed mixed-grass prairie (Whicker and Detling 1988a).

Some studies have directly examined the temporal and spatial effects of combined grazing by prairie dogs and large ungulates (bison or cattle) upon grassland vegetation (Koford 1958; O'Meilia et al. 1982; Coppock et al. 1983a,b; Collins and Barber 1985; Knowles 1986). However, the effects of exclusion or elimination of prairie dogs, large ungulates, or both upon plant or ecosystem characteristics has received less attention (Osborn and Allan 1949, Klatt and Hein 1978, Uresk 1985, Krueger 1986). Because prairie dog control, with the objective of improving forage quantity and quality, is an important management policy on rangelands (Hansen and Gold 1977, O'Meilia et al. 1982), studies of this nature are necessary to better define the rate and amount of change in grasslands following their removal.

Previous studies at Wind Cave National Park, South Dakota indicated that combined grazing by prairie dogs, bison, and other herbivores such as pronghorn decreased the proportional contribution of graminoids to peak biomass, increased plant species diversity and graminoid equitability, and increased shoot nitrogen concentration (Coppock et al. 1983a, Krueger 1986, Archer et al. 1987). We hypothesized that release from grazing by prairie dogs, bison (and other native ungulates), or both would reverse these trends. Furthermore, because prairie dog grazing is relatively continuous throughout the year, and ungulate grazing is intermittent, we hypothesized that prairie dog exclusion would have a greater impact on vegetation than ungulate exclusion. In this paper, we report results of a 2-year field experiment conducted to evaluate these hypotheses.

Study Area

Wind Cave National Park (WCNP) occupies 11,355 ha at the southeastern edge of the Black Hills in western South Dakota. About three-quarters of the Park is northern mixed-grass prairie and the remainder is predominantly ponderosa pine (*Pinus ponderosa*) forest (Dalsted et al. 1981). In 1985 and 1986, there were 9 active black-tailed prairie dog colonies which covered 5–6% of the total area of WCNP. Free-ranging populations of approximately 350 bison, 350 elk, and 75 pronghorn inhabited the park.

This research was conducted in Research Reserve prairie dog colony, a colony that re-established about 1947 on the site of one that had been exterminated in the 1930's. It expanded from 1.2 ha in 1947 to 108.7 ha in 1978 (Dalsted et al. 1981). The experimental site was in an area inhabited by prairie dogs for approximately 27 years (R. Klukas, pers. comm.). Buffalo grass (*Buchloe dactyloides*) was the dominant species, while other major grasses included western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*) and tumblegrass (*Schedonardus paniculatus*). Important forbs included plains milkweed (*Asclepias pumila*), scar-

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We are grateful to the staff of Wind Cave National Park, and particularly to Park Biologist Richard Klukas and Superintendent Ernest Ortega, for their cooperation and logistic support. We are indebted to J.E. Ellis, D.M. Swift, and R.G. Woodmansee for many helpful suggestions and to P.L. Chapman and J. Moore for assistance with statistical analysis. This work was supported by Consejo Nacional de Investigaciones Científicas Técnicas (Argentina) and National Science Foundation (USA) Grant BSR 8406660.

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let globemallow (*Sphaeralcea coccinea*), and various composite species. Fringed sagewort (*Artemisia frigida*) was the principal dwarf shrub (Brizuela 1987).

Data for bison utilization (R. Green, pers. commun.) of the experimental area were not available until July, 1985. In 1985, bison did not use the site in July, but did in August when approximately 40 animals used the area for 3 d. In 1986, bison made frequent use of the study area: the mean herd size was 52 animals using the area an average of 4 d per month from May through August (Cid 1987).

Annual precipitation was 11% lower in 1985 and 27% higher in 1986 than the long-term average (450 mm) for WCNP. Moreover, the area experienced a severe drought until late July of 1985. Not only was 1986 wetter, but also rainfall was more abundant early in the season, with over 40% of the total falling in June.

Methods

In December, 1984, 4 treatments were established: grazing by prairie dogs and bison (+PD+B), bison¹ exclusion (+PD-B), prairie dog exclusion (-PD+B), and exclusion of both (-PD-B). The experimental design was a randomized block with 2 replicates, located approximately 40 m apart. In each block, two 50 m × 50 m fenced (2 m high) exclosures were constructed (+PD-B and -PD-B), and 2 unfenced areas of the same size were delimited (+PD+B and -PD+B). Park personnel removed prairie dogs from 1 of the exclosures (-PD-B) and from 1 of the adjacent unfenced areas (-PD+B) of each replicate at the beginning of the study and, as necessary, throughout the experimental period. Sampling was conducted from May to September of 1985 and 1986.

In treatments with prairie dogs, their density was evaluated monthly as the mean of 3 counts, each of 2 minutes duration (Coppock 1981). Counting was done in the early morning and late afternoon when prairie dog activity was greatest.

Aboveground plant biomass was measured monthly. Plants were clipped in ten 0.25-m² circular frames randomly located in each treatment of each replicate. Plant biomass was separated into current year's biomass by growth form (graminoid, forb, and

dwarf shrub) and previous year's standing dead biomass for all species combined. Samples were oven-dried at 60° C for 48 hr and weighed. Canopy cover by species was estimated monthly in fifteen 0.1-m² (50×20 cm) frames (Daubenmire 1959) located at 10-m intervals along 3 fixed transects 10 m apart from one another in each replicate. Plant species diversity (H' , Shannon and Weaver 1963), equitability, and dominance concentration (C, Simpson 1949) were determined within each replicate from the cover data. Equitability (E) or evenness was expressed as the ratio of the observed diversity index to the maximum value of that index for the same number of species (Pielou 1975). Shoot nitrogen concentration (Kjeldahl method, AOAC 1965) was determined on graminoids and forbs collected monthly from 4 randomly selected plots in each replicate.

Data were statistically analyzed with a randomized block design ANOVA, split plot in time, with replicates (blocks), prairie dogs and bison as variables. Prairie dogs and bison were considered at 2 levels, present and absent. For statistical analysis, percentage contribution of graminoids, forbs, and dwarf shrubs to current year's standing crop, percent cover, and nitrogen concentration data were arcsin square-root transformed. However, data are presented with untransformed values. All differences reported are statistically significant at $p \leq 0.05$.

Results

There were no significant ($p > 0.05$) prairie dog × bison interactions for any of the plant characteristics measured in either 1985 or 1986. Consequently, only main effects of prairie dog and bison exclusion are reported in the ANOVA summary shown in Table 1.

Although prairie dog density was not significantly affected by the presence of bison in either year, it increased between 1985 and 1986 (Table 2). Averaged over the growing season, aboveground biomass was about twice as much in 1986 as in 1985 (Fig. 1). Peak aboveground biomass was reached in July–August each year, and graminoids were the dominant growth form in both years. In 1985, none of the variables had a significant effect on any measured biomass characteristic (Table 1, Fig. 2). In 1986, exclusion of prairie dogs and bison each significantly affected plant biomass, and the magnitude of their independent effects was similar. Specifically, averaged over the growing season, exclusion of

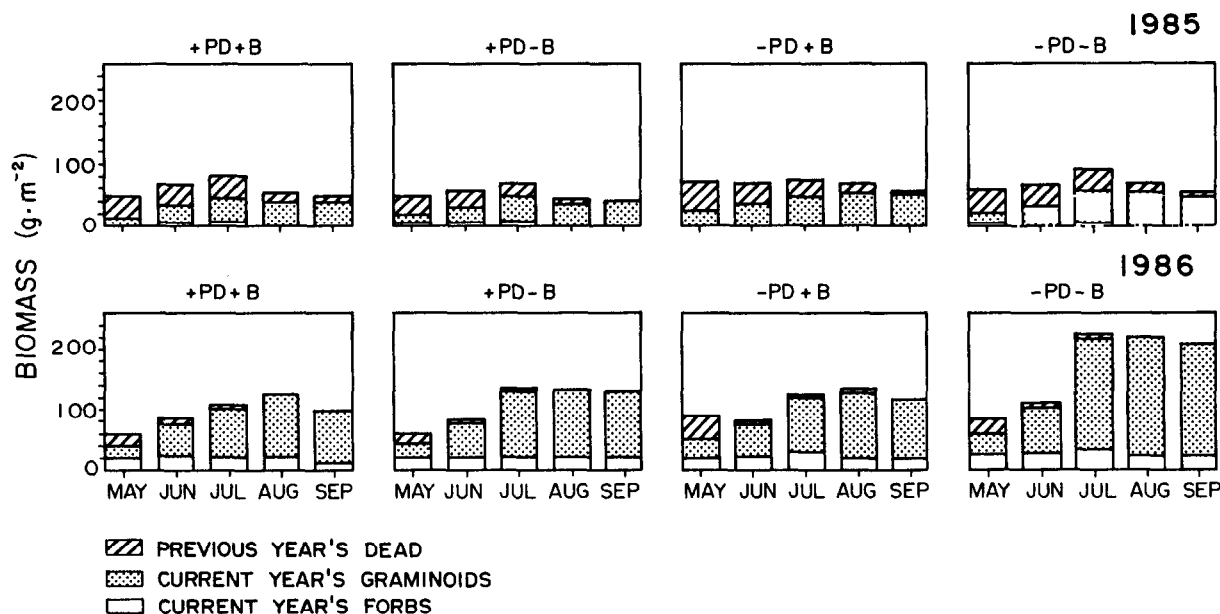


Fig. 1. Monthly composition of aboveground biomass for 4 treatments: grazing by prairie dogs and bison (+PD+B); bison exclusion only (+PD-B); prairie dog exclusion only (-PD+B); and exclusion of both (-PD-B) in Wind Cave National Park during 1985 and 1986. Dwarf shrubs (not shown) accounted for <2% of the total biomass in any treatment.

Table 1. ANOVA results for the main effects of exclusion of prairie dogs (-PD) and bison (-B) on plant characteristics measured during the 1985 and 1986 growing seasons. No prairie dog \times bison interactions were significant ($p > 0.05$) either year. Symbols: * = $p \leq 0.05$; NS = not significant ($p > 0.05$).

Characteristic	1985		1986	
	-PD	-B	-PD	-B
Biomass (g/m²)				
Previous year's dead	NS	NS	NS	NS
Current year's graminoid	NS	NS	*	*
Current year's forb	NS	NS	NS	NS
Current year's shrub	NS	NS	NS	NS
Current year's total	NS	NS	*	*
Total aboveground	NS	NS	*	*
Biomass (% current year's total)				
Graminoids	NS	NS	NS	*
Forbs	NS	NS	*	*
Shrubs	NS	NS	NS	NS
Shoot N Concentration				
Graminoids	*	NS	NS	*
Forbs	NS	NS	NS	NS

prairie dogs resulted in significant (Table 1) increases in above-ground total, current year's, and graminoid biomass of 36%, 36%, and 43%, respectively (Fig. 2). When bison were excluded, these same biomass measures increased 32%, 37%, and 50%, respectively. Moreover, because there were no significant ($p > 0.05$) prairie dog by bison interactions, the effects of excluding each herbivore species were independent and additive. That is, the biomass increase in the treatment from which both prairie dogs and bison were excluded (-PD-B) was not significantly different from the sum of the biomass increases resulting from exclusion of the 2 herbivores individually.

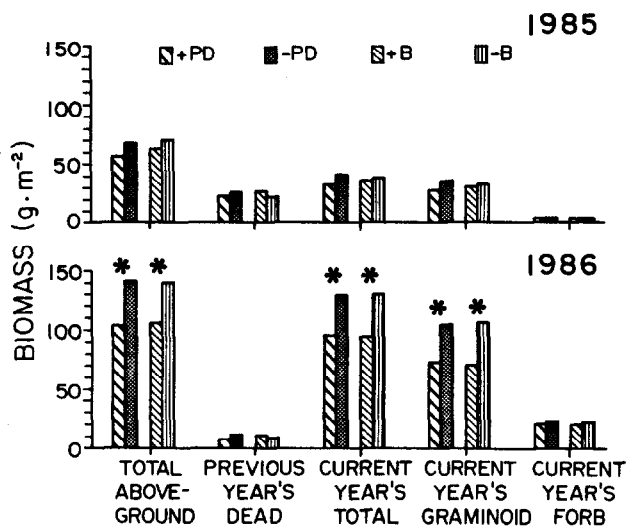


Fig. 2. Mean growing season biomass for treatments with (+) and without (-) prairie dog (PD) and bison (B) grazing in Wind Cave National Park in 1985 and 1986. Main effects of treatments with and without a given herbivore are significantly different ($p < 0.05$) if marked with an asterisk (*). There were no significant PD \times B interaction terms in the ANOVA.

In response to grazer exclusion, the proportional contribution of different growth forms to total current year's biomass changed between years. For all treatments in 1985, 84–88% of the total biomass was graminoids and 10–15% was forbs. In 1986 the proportion of forbs decreased significantly (Table 1) from 28 to 23% in treatments in which either prairie dogs or bison were excluded. Bison exclusion caused a slight, but significant, increase in the

Table 2. Seasonal average prairie dog density (no. ha⁻¹ \pm 1 S.E.) and number of active burrows ha⁻¹ at the beginning and end of the growing season in Research Reserve prairie dog colony, WCNP, with (+PD-B) and without (-PD-B) bison exclusion, during 1985–1986.

	Prairie dog density (no. ha ⁻¹)		Active burrows (no. ha ⁻¹)			
	1985	1986	1985	1986	1985	1986
			May	Sep	May	Sep
+PD+B	15.7 \pm 1.4a	27.1 \pm 1.8b	34	32	30	36
+PD-B	19.5 \pm 1.6a	28.4 \pm 1.8b	28	26	30	37

For each year or treatment, prairie dog densities with different letters differ significantly ($p < 0.01$).

proportion of graminoids (from 71 to 77%); however, prairie dog exclusion had no significant effect. Dwarf shrubs were a minor component of the vegetation (less than 2% of the total biomass), and their proportion was not affected by treatment in either year.

In both years, species diversity, equitability, and dominance concentration were similar for all treatments (Table 3). However, species diversity and equitability were greater in 1986 than in 1985.

Over the growing season, mean shoot nitrogen concentration of graminoids decreased significantly from 1.49 to 1.38% in 1985 where prairie dogs were absent and from 1.64 to 1.50% in 1986 where bison were absent (Fig. 3, Table 1). Because there was no prairie dog by bison interaction on graminoid nitrogen concentration in either year, the decrease in seasonal nitrogen concentration was primarily a result of prairie dog exclusion in 1985 and bison exclusion in 1986 (Fig. 3). Effects of grazer exclusion were greatest in late summer 1985 and in late spring 1986 (Fig. 3). Shoot nitrogen concentration of forbs did not change significantly (Table 1) in response to grazing treatment in either year and, across treatments, averaged 2.1% in 1985 and 1.8% in 1986. The variability in forb nitrogen concentration among treatments and between years was high because of the patchy distributions of many uncommon species and their different phenologies.

Discussion

Only modest vegetational changes were observed in the 2 years following exclusion of bison and prairie dogs. The slow rate and small magnitude of the observed changes, particularly in 1985, might have been related to the amount and seasonal distribution of precipitation during the study. During the dry portion of the 1985 growing season, bison grazed principally in wetter areas of WCNP (R. Green, pers. commun.); therefore, treatments with and without bison were essentially the same until August when bison began utilizing the area. In 1986, when annual precipitation was above average, standing crop increased and bison used the study area intensively. Consequently, the difference between treatments with and without bison was greater in 1986, and the magnitude of plant response to these treatments also was greater.

In 1986, the increased graminoid biomass but unchanged forb and shrub biomass in the grazing exclusion treatments was probably caused by selective herbivory. Because prairie dogs and bison prefer graminoids over other types of forage (Peden et al. 1974, Hansen and Gold 1977, Fagerstone et al. 1981, Popp 1981), it is not surprising that graminoid biomass accumulation increased when released from grazing pressure. Although aboveground net primary productivity (ANPP) can vary tremendously among years and sites at WCNP, it is relatively similar across a wide range of grazing intensities (Whicker and Detling 1988a). Similarly, Williamson et al. (1989) found that, depending upon weather patterns, ANPP of blue grama (an important grass at WCNP) remained constant or increased slightly with increasing grazing intensity on a shortgrass

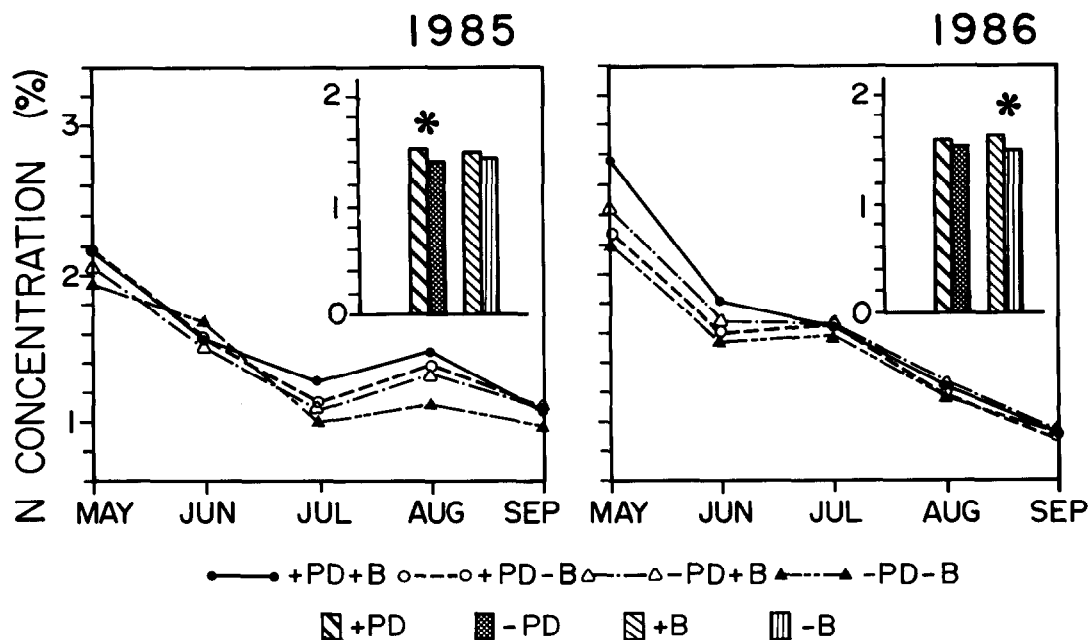


Fig. 3. Seasonal changes in graminoid shoot nitrogen concentration and mean seasonal values (inset figures) for sites grazed by prairie dogs and bison, or with one or both herbivore species excluded. Symbols and statistics are as in Figures 1 and 2.

Table 3. Seasonal means within treatment for species diversity (H'), species number (N), equitability (E), and Simpson Index (C) for 4 treatments: grazing by prairie dogs and bison (+PD+B); bison exclusion only (+PD-B); prairie dog exclusion only (-PD+B); and exclusion of both (-PD-B) in Wind Cave National Park during 1985 and 1986.

	1985				1986			
	H'	N (*)	E	C	H'	N (*)	E	C
+PD+B	1.35	11 (6-4-0-1)	0.57	0.15	2.01	20 (6-7-6-1)	0.67	0.13
+PD-B	1.18	11 (6-4-0-1)	0.50	0.21	1.96	20 (6-7-6-1)	0.60	0.20
-PD+B	1.33	12 (6-5-0-1)	0.53	0.14	2.07	20 (6-7-6-1)	0.69	0.15
-PD-B	1.31	11 (6-4-0-1)	0.55	0.21	1.77	17 (6-6-5-0)	0.64	0.24

(*,*,*,*) Indicates number of species of graminoids, perennial forbs, annual forbs, and dwarf shrubs, respectively.

steppe. Thus, the greater biomass accumulation in areas from which grazers had been excluded may have resulted more from reduced removal of the graminoid biomass than from an increase in its rate of production.

The temporal pattern of biomass accumulation in response to herbivore exclusion is somewhat comparable to other prairie dog-bison/cattle exclusion experiments in mixed-grass prairies. In the growing season following individual and simultaneous elimination of ungulate and prairie dog grazing, Krueger (1986) found no differences in plant biomass between treatments. Even 4 years after prairie dog removal from a prairie dog-cattle grazed rangeland, Uresk (1985) did not find increased production of grasses or forbs. In all of these studies, the intensity and duration of grazing by each species before removal no doubt affected the magnitude and timing of plant response.

As a consequence of the biomass responses, the relative proportion of graminoids increased and that of forbs decreased after exclusion of prairie dogs and bison. The reverse situation, increased forb:graminoid ratios following prairie dog colonization, has been observed in various grasslands (Koford 1958, Bonham and Lerwick 1976), including WCNP (Dalsted et al. 1981, Coppock et al. 1983a, Archer et al. 1987). Our study suggests that this effect of colonization may be reversed within 2 years of exclusion of prairie dogs or bison. In tall-grass prairie, abandonment of a prairie dog colony over a 10-year period resulted in fairly rapid secondary succession (Osborn and Allan 1949). The dominant

species changed from forbs and annual grasses, to short grasses, and, finally, to midgrasses at the edge of the former colony. In shortgrass prairie, the number and cover of forbs actually increased and the grass cover decreased following several years of prairie dog abandonment (Klatt and Hein 1978). Grazing, in that case, had favored the maintenance of matforming grasses, blue grama and buffalo grass.

Plant species diversity may either increase or decrease in response to grazing, depending on initial conditions, intensity and duration of grazing impact, and how selective the grazers are for specific food items (Harper 1969). On short- and mixed-grass prairies, diversity is usually greater in prairie dog colonies than in nearby uncolonized sites (Bonham and Lerwick 1976, Archer et al. 1987, Coppock et al. 1983a, Collins and Barber 1985); however, Agnew et al. (1986) observed higher plant species richness in uncolonized mixed-grass prairie than in prairie dog colonies. In our study, 2 years of grazing exclusion did not produce large changes in plant species diversity. Mean seasonal diversity averaged over treatments increased in 1986, principally because of higher number of species, especially annual forbs (Table 2). This increase in species numbers was similar in all treatments and probably was related to the greater precipitation in 1986.

Many studies have demonstrated that grazing or defoliation increases shoot nitrogen concentration (Jameson 1964, Everson 1966, Chapin 1980, Detling and Painter (1983). Coppock et al. (1983a) found that plants in prairie dog colonies had higher shoot

nitrogen concentrations than those of the same species in uncolonized sites. In another study, shoot nitrogen concentration of western wheatgrass plants was highest in areas grazed by prairie dogs and native ungulates, intermediate in areas excluded from grazing by prairie dogs or ungulates, and lowest in areas excluded from grazing by both (Krueger 1986). Our finding that graminoid shoot nitrogen concentration decreased when herbivores were removed is consistent with these observations. The seasonal pattern of graminoid shoot nitrogen concentration suggests a strong relationship between this variable, grazing patterns, and precipitation. In particular, differences in shoot nitrogen concentration between treatments were greatest during that part of the growing season (Fig. 3) when the greatest amount of precipitation had occurred.

Lower shoot nitrogen concentrations following grazer exclusion may result from a combination of causes. Grazing reduces average leaf age in the canopy, and younger leaves have lower C:N ratios (Jameson 1964, Kamstra et al. 1968). In addition, defoliation may increase nitrogen uptake (Whicker and Detling 1988a) and allocation of nitrogen to leaves (Reuss et al. 1983, Jaramillo and Detling 1988, Polley and Detling 1988). Grazing may also reduce carbon translocation belowground (Detling 1988) and indirectly affect soil temperature (Archer and Detling 1986). Together or individually, these changes may increase net nitrogen mineralization rates (Stanford et al. 1973, Holland and Detling 1990). Moreover, fecal and urinary inputs to soil at frequently grazed sites may also increase nitrogen availability to plants (Davidson 1964, Floate 1981). Therefore, lower shoot nitrogen concentration in areas where prairie dogs or bison had been excluded also may reflect a lack of nitrogen inputs from their excretion products as well as decreased net nitrogen mineralization rates.

Our results indicated that continuous grazing by prairie dogs and intense, periodic grazing by bison and other native ungulates were of approximately equal importance in maintaining the vegetative characteristics of this prairie dog colony. While this and other studies have suggested that these changes are reversible, the rate of recovery probably depends to a large extent upon grassland type, initial plant species composition, grazing intensity, and weather conditions following the removal of herbivore pressure.

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Mineral salt supplementation of cattle grazing tall larkspur-infested rangeland during drought

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Abstract

Mineral salt supplements are used in attempts to reduce cattle losses to tall larkspur (*Delphinium* spp.). We determined the effects of a mineral salt mix on larkspur consumption, ruminal fluid kinetics, and water intake during 4 periods in June, July, and August, 1988 (Trial 1), and during an 18-day grazing period in August, 1989 (Trial 2). In 1988, 12 ruminally cannulated heifers were divided into 3 treatment groups: control with no access to mineral (CONT), 0.5 g mineral (LOW), and 1.0 g mineral • kg body weight⁻¹ • day⁻¹ (HIGH) dosed intraruminally. In 1989, 10 cows were allocated to either a control group or 0.75 g mineral • kg body weight⁻¹ • day⁻¹. During Trials 1 and 2, consumption of larkspur peaked at 5 and 7% of cattle diets, respectively; these low levels were attributed to drought. There were no differences ($P>0.1$) in consumption of total larkspur or larkspur plant parts. Mineral supplement increased water consumption ($P<0.05$) during Trial 1, but not during Trial 2. The HIGH group averaged 0.1 liters • kg body weight⁻¹ • day⁻¹ compared to 0.07 liters for the CONT and LOW groups. Ruminal fluid passage rate, turnover time, volume and fluid outflow rate (FOR) did not differ ($P>0.05$) among treatments during Trial 1, but FOR was increased by mineral treatment in Trial 2. Alkaloid concentration in larkspur declined with maturity, and was apparently elevated by drought in Trial 2. This study found little indication that mineral salt supplement altered the amount of larkspur consumed by grazing cattle. Increased water intake one summer did not alter ruminal fluid kinetics. If dietary minerals alter toxicity of larkspur to cattle, other mechanisms than those tested are responsible.

Key Words: poisonous plants, *Delphinium* spp., cattle diets, alkaloids, toxicity

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Tall larkspur (*Delphinium* spp.) is a major cause of cattle losses on mountain ranges in the U.S. (Ralphs et al. 1988). Preventative measures to reduce cattle losses have been sought for many years. One commonly touted measure is mineral salt supplementation (Hughes 1941, Logan 1973, Knowles 1974). Claims that mineral salt supplement reduced cattle deaths (e.g., Hughes 1941) have not been verified under controlled research situations. Studies by Logan (1973) and Knowles (1974) attempted to determine if mineral salt supplements were effective, using death losses and/or plant-based measurements of larkspur utilization in different pastures. Both studies were inconclusive, in part due to confounding of treatments and pastures.

The objective of this study was to determine if various levels of a mineral salt supplement would influence tall larkspur consumption by cattle. Presumably, mineral-satiated cattle may be less inclined to experience 'specific hungers' (Denton and Sabine 1963) that may exacerbate larkspur ingestion. Further, we wished to determine if mineral supplementation would alter water intake and ruminal fluid passage rate (FPR). Increased mineral salt intake by cattle has increased water intake and FPR (Rogers and Davis 1982, Schneider et al. 1988). Such changes may alter absorption and excretion kinetics of larkspur alkaloids, thus reducing the susceptibility of supplemented animals.

Materials and Methods

Trial 1

Twelve yearling Hereford heifers (mean liveweight 267 kg) were used in 1988. All animals had grazed the previous summer on larkspur-infested ranges near the study pasture. The heifers were randomly assigned to 3 treatment groups (4 animals/treatment): control with no access to mineral (CONT), 0.5 g mineral • kg body weight⁻¹ • day⁻¹ (LOW), and 1.0 g mineral • kg body weight⁻¹ • day⁻¹ (HIGH). These doses were chosen because larkspur toxicity tests (J.D. Olsen, personal communication) indicated some

Table 1. Mineral composition (mg/kg unless otherwise noted) and ingredients^a of "Binns #1 Alleviator" mineral salt mixture^b.

Element	Amount
Al	3,439
B	10.7
%Ca	4.36
Cd	10.0
Co	90.9
Cr	76
Cu	569.0
Fe	2,304
%K	0.81
%Mg	4.33
Mn	76.5
Mo	3.9
Na	197,900
Ni	3
%P	3.83
%S	1.59
Sr	58.1
Zn	1,494.0

^aIngredients in this mineral salt mixture as reported on the label: monocalcium phosphate, sodium chloride, monoammonium phosphate, dicalcium phosphate, cane molasses, beet molasses, corn oil, potassium sulfate, magnesium oxide, beet pulp, wheat bran, sodium bicarbonate, calcium carbonate, barley, yeast culture, Vitamin A, D-activated animal sterol, ferrous carbonate, manganous oxide, zinc oxide, copper sulfate, ethylene diamine dihydride, cobalt carbonate.

^bManufactured and distributed by Walton Feed West, Inc., Cache Junction, Utah 84304.

benefit from this level of supplemental mineral salt. The trace mineral mix was a granulated commercial preparation "Binns No. 1 Alleviator¹." Micro- and macro-mineral nutrients in the mixture (Table 1) were determined using inductively coupled argon plasma spectrometry². The label states that the mix is formulated "to help reduce losses in areas of larkspur infestation". The mineral was intraruminally dosed each day at about 1200 hours to heifers on the various treatments. Preliminary trials indicated no adverse effects (i.e., inappetence or diarrhea) in ruminally cannulated animals dosed for several weeks with the HIGH level.

Cattle grazed on pastures infested with duncecap larkspur (*Delphinium occidentale* [Wats.] Wats.) in the Sawtooth National Forest in southern Idaho near Oakley at 2,500 m elevation. Besides *D. occidentale*, other dominant plants included mountain big sagebrush (*Artemisia tridentata vaseyana* [Rydb.] J. Boivin), snowberry (*Symphoricarpos oreophilus* Gray), Great Basin wild-rye (*Elymus cinereus* Scribn. & Merr.), Idaho fescue (*Festuca idahoensis* Elmer), oniongrass (*Melica bulbosa* Geyer), yarrow (*Achillea millefolium* L.), mountain dandelion (*Agoseris glauca* [Pursh] Raf.), and goldenrod (*Solidago canadensis* L.). Phenological stages of *D. occidentale* were used to define 4 grazing periods: bud stage (15 to 24 June), early flower (29 June to 8 July), full flower (12 to 21 July), and pod stage (26 July to 2 August). Most *D. occidentale* plants were in each phenological stage during the respective periods. During the bud stage, plants had not yet elongated reproductive racemes; during early flower most racemes had elongated but flowers had not opened fully. Initially a 2.8-ha pasture was established with an electric fence for the first period; this pasture was expanded to 3.6, 4.4, and 5.3 ha for subsequent grazing periods so that forage availability was not restricted. Heifers were given several days adaptation to pastures and dosing regime when the study began, and were maintained on their treatments in a pen and fed alfalfa hay between grazing periods.

Cattle diets were quantified using daily bite counts (Pfister et al.

1988a,b). Order of observation was predetermined at the start of the study. Beginning at daybreak, each heifer was focally observed for a 5-min period before observing the next heifer. Heifers were continuously observed in sequential order during all active grazing periods until dark. Generally, we obtained about 20 min of daily observation time on each animal. Bites were categorized as shrubs, grasses, other forbs, and larkspur bud, flower, pod, leaf or leaf and stem.

Research on animals' diets using bite counts is limited by the number of animals that can be observed. Only 1 mineral salt mix was tested because of limitations in animal numbers. Two other common measures of diet composition, fecal analysis and use of esophageally fistulated animals, were considered and rejected. Fecal analysis is not an option because larkspur lacks distinguishing epidermal characteristics, and fecal analysis also would obscure the episodic nature of larkspur consumption. Esophageally fistulated animals are also not a viable alternative because of the episodic nature of larkspur consumption by grazing cattle.

Ruminal fluid passage rate (FPR; %/hour) was quantified during the last 24 hours of each period for the CONT, LOW, and HIGH groups by dosing intraruminally at 0700 with 500 ml of cobalt ethylenediaminetetraacetate (Co-EDTA; Uden et al. 1980). The Co-EDTA doses contained 2600, 2530, 2510, and 2361 mg Co/liter for the 4 periods, respectively. Rumen samples were taken at 0, 4, 8, 12, and 24 hours post-dosing, and frozen at -20° C. After centrifugation at 10,000 × g for 20 min, the supernatant fluid was filtered with a 0.2 μm membrane filter. Co concentrations were determined using atomic absorption spectrophotometry with an air-acetylene flame, and FPR calculated by regression of the natural logarithm of Co concentration on time. Rumen volume (VOL; liters) was calculated by dividing Co dose by ruminal Co concentration extrapolated to time 0. The reciprocal of the slope gave turnover time (TOT; hours). Fluid outflow rate (FOR; liters/hour) was calculated as VOL × FPR. The mineral salt mixture contained cobalt (Table 1), but rumen fluid taken before addition of the Co-EDTA solution contained only 0-0.5 mg Co/liter.

Water intake was measured over 2 days near the end of each period, but not during the times when FPR was measured. Water was available only in a large corral, and the heifers were habituated to entering the corral to drink each day around 1200. On the day before initial water intake measurements, animals were herded to water at 1230, and allowed to drink ad libitum until 1300, when they were shut off from water. During the subsequent 2 days, all animals were gathered at 1230, and given two 5-min opportunities in the next 2 hours to drink individually while consumption was measured. Total water consumption (liters/heifer) over the 2 days was divided by 2 to obtain daily average water consumption. We verified that animals would drink their fill during the allotted times by allowing the entire group access to water after all animals were tested twice. Only twice did an animal approach the water and drink, and only a few sips were taken.

Blood samples were drawn by jugular venipuncture into tubes with no additives on 22 July and 5 Aug. 1988. After allowing blood to clot, serum was separated by centrifugation and frozen at -20° C. Although blood mineral levels do not mirror dietary mineral intake, blood values have been useful as indicators of normal mineral metabolism (Samokhin 1982). Blood calcium (Ca) levels were determined on duplicate serum samples using an automated blood analyzer³, using established procedures and reagents.

Standing crop of vegetation was measured at the beginning and end of each grazing period by clipping thirty .25-m² plots to ground level. Plots were randomly placed along transects, and clipped material was separated into *D. occidentale*, other forbs, and grasses.

¹Walton Feed West, Inc., Cache Junction, Utah 84304. Mention of a trade name, proprietary product or specific equipments does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable.

²Jarrell-Ash ICA-P 9000 Plasma Spectrometer

³Abbott Biochromatic Analyzer 200

Table 2. Water consumption (liters • kg body weight⁻¹ • head⁻¹ day⁻¹) and ruminal fluid passage rate (%/hour), volume (liters/kg body weight), turnover time (hours) and outflow rate (liters/hour) for cattle on various mineral salt supplement levels during 1988 and 1989.

Item	Mineral dose (g • kg body weight ⁻¹ • day ⁻¹)				Period				Response ^a
	0.0	0.5	1.0	Response ^a	1	2	3	4	
Trial 1									
Water intake	.07	.07	0.1	L*	.06	.07	0.1	0.1	1 vs 3** 1 vs 4** 1&2 vs 3&4**
Fluid passage rate	12.1	11.6	12.7	NS	12.5	12.8	11.3	11.9	1 vs 3 P=0.06 1 vs 4 NS 1&2 vs 3&4*
Turnover time	8.6	8.9	7.9	NS	8.2	7.8	9.2	8.7	1 vs 3 P=0.08 1 vs 4 NS 1&2 vs 3&4*
Volume	0.23	0.22	0.22	NS	0.20	0.21	0.27	0.22	1 vs 3** 1 vs 4 NS 1&2 vs 3&4**
Fluid flow rate	7.1	6.7	7.3	NS	6.4	7.1	8.0	6.7	1 vs 3** 1 vs 4 NS 1&2 vs 3&4*
	0.0	0.75			Begin	End			
Trial 2									
Water intake	.05	.07		NS	.04	.07			**
Fluid dilution intake	10.3	11.4		NS	10.7	11.1			NS
Turnover time	10.3	8.9		NS	9.6	9.6			NS
Volume	0.22	0.25		NS	0.31	0.16			**
Fluid flow rate	7.7	10.3		*	11.8	6.2			**

^aL = Linear; *P<0.05; **P<0.01; NS = Nonsignificant at P>0.05

D. occidentale plant parts were harvested periodically for total alkaloid analysis. Plant material was oven-dried at 40° C for 48 hours, then ground through a 1-mm screen in a Wiley mill, and total alkaloid determinations done using the procedures of Manners and Ralphs (1989). Briefly, this entails sequential extraction with ethanol, chloroform, and ether, and determining alkaloid weight after concentrating to dryness.

Daily cattle diets were averaged for each individual for each period and analyzed by analysis of variance procedures (SAS 1987) using a split-plot design with repeated measurements (Gill 1978). Treatments were level of mineral, individual animals were nested within treatment, and the study was repeated during the 4 periods. This analysis was also used for water intake, ruminal fluid variables, and blood Ca, except that serum samples were only taken on 2 dates. Diet composition, water intake, Ca levels, FPR, VOL, TOT, and FOR were tested for linear and quadratic responses using orthogonal polynomials. Specified contrasts were used to test for differences in period 1 vs. 4, periods 1 and 2 vs. 3 and 4, and period 1 vs. 3. When period by treatment interactions were found, simple effect means were separated using the LSD procedure (Steel and Torrie 1980).

Trial 2

Ten ruminally cannulated cows (mean liveweight 365 kg) used during the previous year were randomly allocated to either a control group with no access to mineral, or given 0.75 g mineral • kg body weight⁻¹ • day⁻¹ intraruminally. The mineral mix was the same as given in 1988, and treatment animals were given free-choice access to the mineral for 30 days before the field study began. The 1989 study was conducted near Manti, Utah on range-

land dominated by *D. barbeyi* L. Huth. The study site was the same as reported by Pfister et al. (1988a,b). Briefly, this tall forb community was composed primarily of tall larkspur patches on snow-drift areas, and an open *Ribes-Agropyron* dominated site. The pasture was about 6 ha in size and was enclosed with an electric fence.

The study was conducted during an 18-day grazing period (9 to 27 August) when larkspur was in the flower and pod stages, and is generally most palatable to cattle (Pfister et al. 1988a,b). Procedures used in 1989 for dosing mineral, bite counts, water intake, alkaloid analysis, and ruminal fluid variables (i.e., dosing with Co-EDTA) were identical to those used during 1988. Bite counts were taken each day during all daylight hours when cattle were actively grazing. Water intake measurements and blood serum samples were taken near the beginning (14 August) and end (27 August) of the grazing period. Analysis of sera for sodium (Na), potassium (K), chloride (Cl), Ca, and magnesium (Mg) was done using standard procedures⁴ at a regional medical center. Forage samples were from thirty 0.25-m² plots using 3 transect lines that bisected the pasture with 10 plots per line. The Co-EDTA solution contained 2520 and 2122 mg Co/liter when dosed at the beginning and end of the grazing period, respectively. In addition, pH of rumen samples was determined concurrently when samples were taken for Co analysis using an Orion portable pH meter with combination electrode.

Bite count data were analyzed using a repeated measures analysis of variance; model components were treatments, animals nested within treatments, and repeated measurements over the 18-day

⁴Monarch 2000 Analyzer

trial. Water intake, fluid passage variables and blood mineral components were also analyzed with the above model, except that the repeated measurements were taken at the beginning and end of the grazing period. Ruminant pH values were tested using the above repeated measures analysis, with an additional factor for hour post-dosing included in the model. All differences are reported at the $P < 0.05$ level unless otherwise noted.

Results

Trial 1

Total larkspur consumption was low during the summer, with mean values from 1 to 2% for the various treatments. No differences due to mineral treatment were found for consumption of larkspur plant parts, total larkspur, or for forbs or grass (Fig. 1).

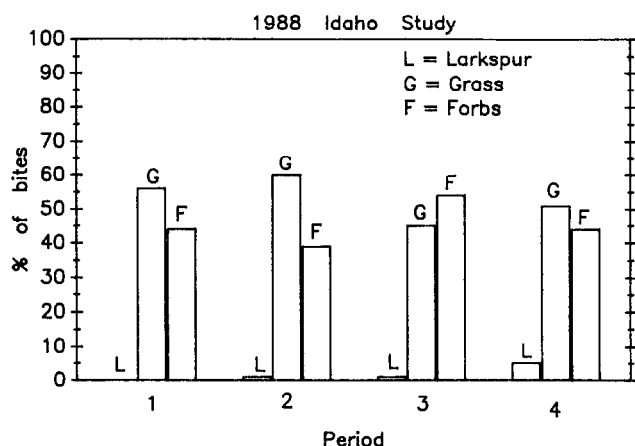


Fig. 1. Diet composition (% of bites) of cattle during summer, 1988 in southern Idaho. During 1988 larkspur consumption was examined during 4 phenological stages: bud, early flower, flower and pod, corresponding to periods 1 to 4, respectively.

Periods were different for every variable. Cattle ate about 5% total larkspur bites during the last period (pod stage) compared to less than 1% during the other 3 periods. The only treatment by period interaction was for bites of larkspur leaf, but these were always $< 5\%$ of diets. Cattle diets were generally about 45% other forbs and over 50% grasses during the summer (Fig. 1).

Water intake differed among treatments (Table 2). The HIGH treatment increased water consumption compared to the CONT and LOW groups. Mineral supplementation at the HIGH level increased mean daily water intake by 30% over the CONT and

LOW groups. Periods were different as water consumption increased during the last 2 periods. No period by treatment interaction was noted.

There was no period by treatment interaction for FPR, VOL, TOT or FOR (Table 2). No significant treatment effects were found for each variable. Period effects were noted, with periods 1 and 2 different from periods 3 and 4 for each variable (Table 2).

Calcium levels were not affected by treatment, but were higher on the last sampling date (Table 3). No treatment by period interaction was found for blood Ca.

The standing crop estimate for the beginning and end of each period is given in Table 4. Cattle generally had ample amounts of forage during each period. The amount of larkspur available for grazing declined over the summer, but was always a major component of the available forage.

There was a marked effect of maturity on total alkaloid concentration (TAC) of larkspur plant parts (Table 5). Immature larkspur stem, bud, and leaf material was highest in TAC, and levels declined as the season progressed. Flowers and pods maintained relatively high levels until the flowers matured into pods, and the pods shattered.

Trial 2

Total larkspur consumption did not differ between treatments, averaging 3% of bites over the grazing period (Fig. 2). No differences were found in consumption of larkspur plant parts. There was a

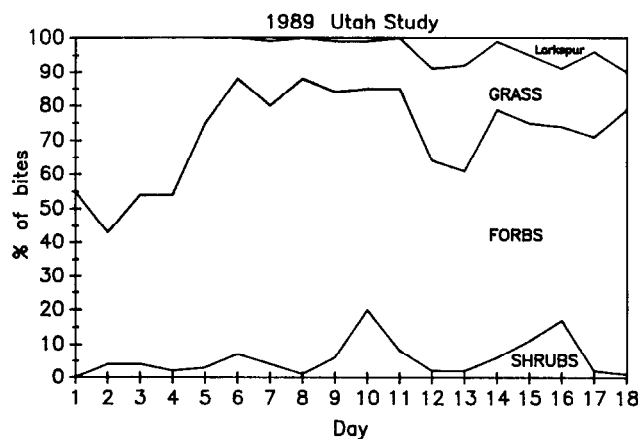


Fig. 2. Mean daily diet composition (% of bites) of cattle during 1989 in central Utah. During 1989 larkspur consumption was examined during an 18-day grazing trial when larkspur was in the flower and pod stages of growth.

Table 3. Blood serum levels (mg/dl: Ca, Mg; meq/liter: Cl, K, Na) in cattle receiving various mineral salt supplements in Idaho and Utah, 1988 and 1989.

Item	Mineral dose ^a			Response ^b	Date		Response
	0.0	0.5	1.0		7/22	8/5 ^c	
<u>Year 1</u>							
Calcium	9.3	9.5	9.3	NS	9.3	9.6	P = 0.09
		0.0	0.75		8/8	8/25 ^c	
<u>Year 2</u>							
Calcium		9.9	9.4	NS	9.2	10.1	**
Magnesium		2.4	2.3	NS	2.2	2.5	**
Chloride		104.2	104.6	NS	101.7	107.1	**
Potassium		4.8	4.8	NS	4.7	4.9	NS
Sodium		138.8	141.7	*	136.9	143.6	**

^ag • kg body weight⁻¹ • day⁻¹

^bNS=Non-significant at $P > 0.05$, ** $P < 0.01$, * $P < 0.05$.

^cIn 1988, the study began on 15 June, but no beginning blood sample was drawn; In 1989 blood was drawn when the study began and ended.

Table 4. Standing crop [kg/ha (S.E.)] of vegetation on the study pasture during 1988 and 1989 in Idaho and Utah.

Item	Period							
	6/15 begin	– 6/24 end	6/29 begin	– 7/8 end	7/12 begin	– 7/21 end	7/26 begin	– 8/2 end
Year 1								
Grasses	246 (30)	270 (52)	334 (42)	276 (41)	280 (49)	287 (60)	525 (112)	313 (50)
Other forbs	446 (31)	438 (44)	416 (85)	533 (81)	418 (75)	245 (54)	338 (74)	277 (48)
Subtotal	692	708	750	809	698	523	863	590
Larkspur	731 (130)	624 (141)	676 (289)	523 (145)	537 (141)	559 (142)	479 (132)	436 (122)
Total	1423	1332	1426	1332	1235	1091	1342	1026
Year 2								
		8/8 – 8/25						
		begin	end					
Grasses		246 (62)	119 (26)					
Other forbs		1340 (301)	737 (97)					
Subtotal		1586	856					
Larkspur		957 (335)	729 (324)					
Total		2543	1585					

day effect, as animals consumed essentially no larkspur (<1%) during the first 11 days, then individual animals consumed from 0 to 33% total larkspur (mean of 7%) during the last 7 days of the study (Fig. 2). Consumption of grasses or forbs was not affected by treatment, with grass and forb consumption averaging 25 and 66% of bites, respectively.

Table 5. Total alkaloid concentration (% dry weight) of *Delphinium occidentale* and *D. barbeyi* plant parts during 1988 in southern Idaho, and 1989 in central Utah.

Date	Plant Part					
	Stem	Bud	Leaf	Flower	Flower & Pod*	Pod
<i>D. occidentale</i>						
6/16	1.38	3.10	2.45			
6/24	1.50	2.93	2.43			
6/30	0.75	2.42	2.11			
6/30			1.39	1.94		
7/15	0.38		1.59	1.83	1.49	
7/22	0.46		1.21	1.56	1.59	
8/02	0.40		1.02			1.51
<i>D. barbeyi</i>						
8/09	0.50		1.18	0.84		
8/18	0.43		0.92			1.01
8/26	0.27		0.39			0.98

*Reproductive raceme with some residual flower blossoms and some seed pods.

Water consumption was not different (Table 2). There was a date effect but no date by treatment interaction. Water intake increased over 50% from the first measurement made on 14 August compared to 27 August.

Fluid passage rate, TOT and VOL were not affected by mineral treatment (Table 2). FOR was increased due to mineral supplement (Table 2). No treatment × period interaction was found for any variable. FOR and VOL decreased at the end of the trial; there was no period effect on FPR and TOT. No treatment effect on ruminal pH was found (data not shown). As expected, hour after dosing with Co-EDTA did affect pH. As animals grazed throughout the day, pH declined (6.4 to 5.8) as carbohydrate-rich substrate was ingested.

No date × treatment interactions were found for any blood variable. Na levels were increased by mineral supplementation (Table 3). There was a date effect for all variables except K.

Forage availability at the beginning and end of the study is given in Table 4. Grasses, forbs and total forage declined during the study period, while total larkspur did not decline substantially.

Alkaloid concentration of *D. barbeyi* plant parts is given in Table 5. Leaves declined substantially in TAC during the trial, while flower and pod TAC remained relatively constant.

Discussion

The 1988 Idaho study was conducted during a severe drought, and the pasture only received 27 mm of precipitation from 15 June to 5 August. During 1989 the drought was less severe in central Utah, but only 28 mm of rain were received during the study period, compared to 8 cm at this site during the same 3 weeks in 1987. The larkspur was apparently of low palatability during both summers, and we speculate that palatability may have been influenced by precipitation patterns. In previous studies (Pfister et al. 1988a,b) cattle have eaten from 10–20% of their diets as larkspur. Water stress increases alkaloid concentration in many species (Gershenzon 1984), and the bitter taste of alkaloids is presumed to deter grazing by herbivores (Bate-Smith 1972). The total alkaloid concentration we found in *D. occidentale* during 1988 was lower than noted by Ralphs et al. (1988) and Olsen (1983), but was similar to values reported by Laycock (1975) and Williams and Cronin (1966) for plants collected at a similar elevation. The alkaloid concentration of *D. barbeyi* leaves was 25 to 50% higher than noted in August for flowering plants at this site in earlier studies (Pfister et al. 1988a,b).

Following the only major storm during June, 1988, one heifer (HIGH group) consumed a large amount of larkspur during the night, and at daybreak and throughout the morning, she alternated between periods of sternal recumbency and muscular tremors while standing, classic signs of larkspur intoxication (Olsen 1978). Previous summers experience with *D. barbeyi* in Utah has shown that cool, wet weather apparently triggers increased larkspur consumption (Pfister et al. 1988a,b), perhaps due to changes in levels of individual alkaloids (Pfister, unpublished data).

Previous research on the question of mineral salt supplementation to reduce larkspur consumption or cattle deaths has not been conclusive (Knowles 1974, Logan 1973). Results from our study must also be viewed with caution with respect to ingestion of larkspur, due to the low levels of consumption. The low level of larkspur consumed was unexpected in light of previous experience, but when cattle did consume greater quantities during the pod

stage, mineral salt supplement had no influence on the amount of larkspur selected. Based on toxicity tests of larkspur collected during August, 1989, at the Utah site, we estimate that animals could have consumed 25–30% of their diets (dry weight) as larkspur with little danger of acute intoxication. The previously reported LD₅₀ (median lethal dose) is near 2.5 g/kg body weight (Olsen 1978), and material collected during 1989 and dosed at >5 g/kg body weight produced only slight muscular tremors in cattle (Pfister, unpublished data).

The levels of mineral salt given to cattle in this study greatly exceed the requirements for Na (NRC 1984). Further, free choice ingestion of mineral would rarely approach the treatment levels we used (Cohen 1987). When evaluating mineral supplements when consumption is unknown, Ellis et al. (1988) recommend using an intake figure of about 50 g • head⁻¹ • day⁻¹, which would correspond to 0.18 g/kg body weight for our 1988 study. Other cattle grazing with the experimental animals in 1988 and allowed to consume mineral for 30 min each day consumed 0.2 g mineral/kg body weight (Pfister, unpublished data). Knowles (1974) reported an average daily trace mineral salt consumption of about 0.25 g/kg body weight for free-ranging cows on a larkspur-infested range in Idaho.

Profiles of blood minerals have been used extensively to identify dietary causes of poor production (Maas 1983). Blood values for Ca, Mg, Cl, K, and Na were within normal ranges, indicating that animals were within homeostatic limits.

Water intake was increased by 30% during 1988 by the addition of the HIGH mineral level. No differences were noted in 1989, but the mean daily maximum temperature was 13° C lower than during 1988, and water consumption was low. Others have noted increases in water intake in cattle in response to high mineral salt feeding (Croom et al. 1982, Rogers and Davis 1982, Schneider et al. 1988). Schneider et al. (1988) and Rogers and Davis (1982) reported increases in FPR in cattle receiving high mineral salt diets. However, most studies on the use of mineral salts have been conducted to study effects of buffers on high concentrate diets, and results have been less consistent with forage diets. Addition of large amounts of mineral salt can result in hypertonic rumen fluid and decreased ruminal fermentation (Durand and Komisaraczk 1988).

We saw no indications of increased FPR, VOL or TOT with increased mineral salt supplementation in grazing cattle. The increase in FOR during 1989 resulted from slight, but insignificant increases in both FPR and VOL. It is unclear whether this increase has pharmacological significance for animals consuming larkspur alkaloids. The increase in water intake we observed during 1988 was apparently not sufficient to alter ruminal fluid kinetics. Funk et al. (1987) speculated that increased water consumption resulting from elevated ambient temperatures may influence FPR in grazing cattle, but Harrison et al. (1975) found that infusions of water into the rumen did not alter FPR.

This study is limited because only 1 mineral salt supplement was tested. Obviously there are a large number of potential mineral supplements (type × dose) that could be examined, and we have no indication of the generality of this study to other combinations of minerals. We tested this mineral salt mix because of widespread use of this formulation throughout Utah, Idaho, and Colorado.

This specific mineral salt supplement may have little impact on ingestion of tall larkspur by grazing cattle. Other factors such as drought stress likely have a much greater impact on acceptability of larkspur to cattle. Moreover, we found little evidence to support the idea that mineral salt supplement will lower animal susceptibility through changes in ruminal fluid kinetics. We conclude that livestock producers should consider mineral salt supplementation in relation to animal requirements and forage deficiencies, and use caution when supplementing mineral for the sole purpose of reduc-

ing losses to poisonous plants.

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Influence of Spanish goats on vegetation and soils in Arizona chaparral

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Abstract

The key to managing Arizona chaparral depends on creating and maintaining brush-free or savanna-like habitats. Brush control using fire, chemicals, and mechanical methods has been tested previously; but limited information is available on goats. This study evaluated the effect of 4 goat-stocking levels in a short duration grazing system and mechanical brush crushing on chaparral shrubs, herbaceous vegetation, litter, and soils. After 4-1/2 years, percent total shrub cover was lower ($P < 0.05$) on paddocks stocked at 1.4, 2.4, and 4.2 Spanish goats/ha (35, 39, and 38%, respectively) compared to unstocked controls (51%). Crushing brush increased the effectiveness of goats; mean total shrub cover was lower ($P < 0.05$) on paddocks where brush was crushed vs not crushed (33 and 50%, respectively). Shrubs least preferred by goats were not affected, while preferred browse was impacted at all stocking levels. Goat stocking and brush treatments did not affect perennial herbs, while annuals were generally increased by soil disturbance. Less litter ($P < 0.05$) accumulated under shrubs subjected to heavy stocking levels compared to unbrowsed paddocks. Concentrations of N and P in the soil were also affected ($P < 0.05$) under desert ceanothus (*Ceanothus greggii* Gray) where the soil bulk density was also increased ($P < 0.05$). While goats can reduce total shrub cover, problems may result. Perennial herbaceous vegetation did not respond. Shrubs preferred by goats were also preferred by native deer. Reduced forage diversity and nutritional stress could result if these species were eliminated from the stand. Also, trampling disturbance by goats affected nitrogen accumulation in the litter and soil, but more importantly heavy browsing may eliminate nitrogen-fixing shrubs.

Key Words: *Quercus turbinella*, litter, soil nitrogen, soil phosphorus, organic carbon, wildlife habitat

Chaparral covers about 1.2 million ha in Arizona. Research has shown that conversion of chaparral to herbaceous vegetation improves water yield, increases forage production, improves wildlife habitat, and provides more aesthetically pleasing landscapes

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that have a reduced fire hazard (Hibbert et al. 1974).

Although considerable research has been conducted on using fire, mechanical methods, and chemicals for controlling brush, only limited research has evaluated biological agents such as goats. Vallentine (1980) quoted a 1970 FAO report that stated goats can be a potent factor in controlling woody plants and in preventing their return in areas of low and erratic precipitation. Davis et al. (1975), using Angora and "milk-type" goats, and Riggs and Urness (1989), using Spanish goats, both reported success in controlling Gambel oak (*Quercus gambelii* Nutt.). Green et al. (1978) used goats to maintain fuelbreaks in California chaparral. Two short-term studies in Arizona chaparral are available. Knipe (1983) reported some success in converting chaparral by using Angora goats after prescribed burning and seeding with grasses but indicated success would require intensive management. Boles (1987) stated that shrub live oak (*Quercus turbinella* Greene), the dominant shrub in his study area, was not being killed by browsing at Angora goat-stocking levels of 6 goats/ha yearlong (average browsing times 7 days with 35 days rest).

We conducted a study designed to determine whether goats in a short duration grazing system can be used to reduce chaparral in Arizona and to evaluate the impact of goat browsing on the vegetation and soil resource. Specific objectives were to determine effects of goat-stocking rates, with and without mechanical brush crushing, on (1) the regrowth and survival of chaparral shrub species, (2) herbaceous vegetation, and (3) litter and soils.

Study Area

The 435-ha study site was located on the Conway Ranch in Greenback Valley, Ariz., 26 km SE of Tonto Basin. Elevation ranged from 1,280 to 1,460 m. Soils were derived from diabase and topography was rolling to hilly. Precipitation averaged 508 mm per year, 60% falling between October and May and 40% from June through September.

The site was a shrub live oak-mixed shrub community (Carmichael et al. 1978), the most widespread within the chaparral type. Shrub live oak was the dominant species. Desert ceanothus (*Ceanothus greggii* Gray) and Pringle manzanita (*Arctostaphylos pringlei* Parry) occurred in about equal amounts and were the second most abundant. Skunkbush sumac (*Rhus trilobata* Nutt.) and wait-a-bit (*Mimosa biuncifera* Benth.) were plentiful. Netleaf hackberry (*Celtis reticulata* Torr.), Wright silktassel (*Garreya wrightii* Torr.), and hollyleaf buckthorn (*Rhamnus crocea* Nutt.)

occurred with regularity. There were occasional one-seeded juniper (*Juniperus monosperma* [Engelm.] Sarg.) and pinyon (*Pinus edulis* Engelm.) trees. Herbaceous perennials were occasionally found in openings and under the shrub canopy. These consisted mainly of squirreltail (*Sitanion hystrix* [Nutt.] J.G. Sm.), blue grama (*Bouteloua gracilis* [H.B.K.] Steud.), and Palmer penstemon (*Penstemon palmeri* Gray). Sideoats grama (*B. curtipendula* [Michx.] Torr.) and curly mesquite (*Hilaria belangeri* [Steud.] Nash) were common on open, rocky hillsides. Red brome (*Bromus rubens* L.) and Fremont goosefoot (*Chenopodium fremontii* Wats.) were common annuals.

Methods

Experimental Design

Treatments were imposed on a 17-paddock allotment constructed in a "wagon wheel" design. Five of these paddocks were not included in the experimental design but an additional 4 units were fenced separately to serve as unbrowsed control areas, for 16 experimental paddocks on 228 ha. Treatments were 4 stocking levels (0, 1.4, 2.4, and 4.2 goats/ha based on actual days of use in a 1-year period) and 2 land treatments (brush crushed and not crushed), with each combination replicated 2 times. Stocking levels for moderate (2.4 goats/ha) were based on a previous study in Arizona chaparral (Knipe 1983). Light and heavy levels were fixed at approximately one-half and 2 times the moderate rate. Brush was treated with a Marden brush crusher in March–April, 1984. The area was stocked with 600 Spanish goats which were managed as 1 herd, and stocking rate was regulated by paddock size; that is,

all paddocks were browsed by the same number of goats. Goats were placed in paddocks on 28 February 1984. Paddocks were browsed in time-controlled moves. Duration of use of each paddock was based on growth state of the plants in the most heavily used paddocks (4.2 goat/ha). In order to keep stocking rates constant and consistent, paddocks stocked at the other levels were used for the same length of time through a full rotation. The general program was to graze each paddock 3 days when plants were growing and 5 days during dormant seasons.

Sampling Methods

Vegetation

Tree, shrub, and half-shrub cover was determined, by species, using the line intercept method (Canfield 1942). The line started at the hub and ran the length of the paddock. Density of herbaceous plants, grasses, and forbs was estimated from 30 × 61 cm quadrats placed at regular intervals along the line. The interval was determined by paddock length and a required minimum sample of 100 quadrats per paddock. The number of individuals of each species were counted and converted to density per square meter.

Shrub data were collected in November 1983 (pretreatment), May and October beginning in 1985 through 1987, and in May 1988. Herbaceous data were collected in May and October, 1986 and 1987, and May 1988.

In October 1987, every individual shrub intercepted by the line described above was classified as dead or alive and all live plants were examined for use by goats and assigned to 1 of 4 utilization

Table 1. Percent cover of shrubs over a 4-1/2 year period on paddocks subjected to 4 goat stocking rates and 2 brush treatments, central Arizona. Data expressed as mean ± standard error.

Categories/Time		Stocking rates (goats/ha)							
		Brush not crushed				Brush crushed			
		0	1.4	2.4	4.2	0	1.4	2.4	4.2
Total shrub cover	11/83	51 ± 1a*	56 ± 3a	64 ± 3a	61 ± 1a	61 ± 4a	54 ± 3a	61 ± 6a	55 ± 2a
	5/85	56 ± 2	49 ± 5	53 ± 1	42 ± 5	32 ± 1	28 ± 1	24 ± 4	28 ± 4
	10/85	54 ± 2	43 ± 4	46 ± 2	37 ± 6	40 ± 5	27 ± 3	24 ± 2	20 ± 5
	5/86	58 ± 1	54 ± 5	55 ± 1	42 ± 3	44 ± 1	31 ± 4	32 ± 1	27 ± 6
	10/86	63 ± 2	51 ± 2	51 ± 1	48 ± 7	51 ± 5	36 ± 3	33 ± 3	31 ± 5
	5/87	62 ± 5	49 ± 6	52 ± 1	45 ± 5	46 ± 5	36 ± 2	33 ± 3	29 ± 4
	10/87	63 ± 6	43 ± 4	46 ± 2	42 ± 3	47 ± 4	31 ± 1	30 ± 7	27 ± 6
	5/88	56 ± 7a	48 ± 1ab	47 ± 1ab	41 ± 4bc	50 ± 1ab	30 ± 3cd	28 ± 1d	28 ± 11d
Shrub live oak cover	11/83	32 ± 1a	27 ± 8a	34 ± 1a	28 ± 4a	29 ± 4a	28 ± 1a	33 ± 6a	30 ± 2a
	5/85	34 ± 1	29 ± 4	27 ± 2	21 ± 3	18 ± 2	17 ± 2	11 ± 2	13 ± 1
	10/85	34 ± 1	24 ± 6	23 ± 1	18 ± 1	24 ± 6	13 ± 1	14 ± 1	12 ± 2
	5/86	36 ± 2	27 ± 4	28 ± 2	22 ± 1	24 ± 1	17 ± 2	18 ± 1	17 ± 4
	10/86	34 ± 1	27 ± 2	23 ± 2	18 ± 2	33 ± 3	17 ± 1	16 ± 1	17 ± 3
	5/87	36 ± 1	26 ± 5	25 ± 3	20 ± 1	31 ± 2	18 ± 3	17 ± 2	17 ± 3
	10/87	36 ± 1	28 ± 7	22 ± 1	17 ± 2	31 ± 3	19 ± 3	17 ± 3	15 ± 4
	5/88	28 ± 4abc	32 ± 8abc	21 ± 3bcd	17 ± 6cd	34 ± 5a	18 ± 2cd	15 ± 3d	15 ± 5d
Most preferred shrubs	11/83	12 ± 4a	13 ± 2a	8 ± 1ab	8 ± 1ab	6 ± 2ab	11 ± 4a	5 ± 2b	13 ± 3a
	5/85	12 ± 3	6 ± 0	4 ± 1	4 ± 0	3 ± 1	2 ± 0	1 ± 1	1 ± 0
	10/85	12 ± 3	8 ± 2	3 ± 0	2 ± 0	3 ± 1	2 ± 1	1 ± 0	1 ± 1
	5/86	12 ± 2	7 ± 2	3 ± 0	2 ± 0	3 ± 1	2 ± 1	0 ± 0	1 ± 1
	10/86	16 ± 3	6 ± 1	3 ± 0	2 ± 0	5 ± 1	2 ± 1	1 ± 0	1 ± 1
	5/87	14 ± 1	6 ± 1	3 ± 0	3 ± 0	5 ± 0	2 ± 2	0 ± 0	0 ± 0
	10/87	16 ± 3	5 ± 1	2 ± 0	2 ± 1	4 ± 0	2 ± 2	0 ± 0	0 ± 0
	5/88	13 ± 2	4 ± 0	2 ± 0	1 ± 0	3 ± 1	2 ± 2	0 ± 0	0 ± 0
Least preferred shrubs	11/83	9 ± 1a	6 ± 1a	16 ± 3b	10 ± 1a	9 ± 9a	9 ± 1a	16 ± 4b	9 ± 0a
	5/85	9 ± 1	5 ± 1	16 ± 2	7 ± 1	3 ± 3	5 ± 3	4 ± 1	3 ± 2
	10/85	8 ± 0	5 ± 1	14 ± 1	6 ± 1	3 ± 3	7 ± 3	5 ± 1	3 ± 2
	5/86	8 ± 0	5 ± 1	16 ± 3	7 ± 2	5 ± 2	7 ± 3	6 ± 2	5 ± 3
	10/86	8 ± 0	6 ± 0	16 ± 0	7 ± 2	4 ± 2	7 ± 3	6 ± 2	7 ± 3
	5/87	8 ± 1	6 ± 0	18 ± 1	9 ± 1	3 ± 3	7 ± 2	7 ± 3	7 ± 3
	10/87	7 ± 1	7 ± 2	16 ± 3	7 ± 1	4 ± 3	7 ± 2	6 ± 3	7 ± 4
	5/88	9 ± 0	6 ± 2	16 ± 1	4 ± 0	4 ± 3	6 ± 3	6 ± 2	5 ± 5

*Values within a row followed by the same letter are not significantly different at the 0.05 probability level.

classes: 0 = no use, 1 = light use, 2 = intermediate use, and 3 = heavy use. Classes were summed for each species within each treatment and divided by the total number of shrubs involved for an average utilization index.

Soils and Litter

The effect of goat browsing on soils was evaluated on paddocks receiving 1 of 3 stocking levels (0, 1.4, and 4.2 goats/ha yearlong) in July 1988. This sampling design permitted evaluating the effect of both goat browsing and crushing on 6 paddocks. The 6 paddocks were sampled at 3 random locations. At each sampling location, samples of soil and litter were collected from beneath each of 3 shrub species—Pringle manzanita, desert ceanothus, and shrub live oak—and on bare interspace areas between shrubs. On each sampling location, litter and humus samples were collected from within a 0.1-m² sampling frame. The 3 cores were collected to a depth of 3.8 cm within the sampling frame at each location. After bulk density had been determined on individual cores, the 3 cores collected at each location were composited for subsequent physical and chemical analyses. An additional 500 g of soil was collected from the 3.9- to 7.6-cm soil depth.

Litter and humus samples were oven-dried, weighed, and ground in a Wiley mill before being analyzed for total nitrogen (N) by the Kjeldahl procedure and total phosphorus (P) following a perchloric acid digestion (Black 1958). Soil samples were oven-dried and weighed to determine bulk density. The dried soil samples were further analyzed for organic carbon (OC) (Walkley-Black), total N (Kjeldahl), total P, total potassium (K), and soil texture (hydrometer). Techniques for determining soil chemical properties are described by Page et al. (1982) and physical properties by Klute (1986).

Statistical Analyses

Vegetation

Shrubs were divided into 4 categories for analyses. Total shrubs and shrub live oak, the only species abundant enough to be tested by itself, were the 2 primary categories. The other categories were based on relative palatability to goats (from utilization measure-

ments): least preferred included Pringle manzanita, broom snake-weed (*Gutierrezia sarothrae* [Pursh.] Britt. and Rusby), and sotol (*Dasylirion wheeleri* Wats.); and the most preferred group included hollyleaf buckthorn, Wrights silktassel, desert ceanothus, menodora (*Menodora scabra* Gray), and birchleaf mountainmahogany (*Cercocarpus betuloides* Nutt.).

Pretreatment shrub data were analyzed with one-way analysis of variance (ANOVA) to test the hypothesis that brush cover was similar among paddocks. If the hypothesis was not rejected, analysis proceeded with two-factor (stocking levels and brush treatments) multivariate analysis of variance (MANOVA), repeated measures design, with time as the repeated measure to test the hypothesis that trends over time did not change with either brush treatment or goat-stocking level. The 7 time periods evaluated did not include pretreatment (11/83) data. Orthogonal polynomial contrasts were used to determine trends and compare responses. Cover for total shrubs and for shrub live oak was tested in this manner. For these groups, an ancillary analysis was done for the last time period (May 1988) by using one-way ANOVA again to test the hypothesis that cover was similar among paddocks to provide a supplemental comparison with the pretreatment test.

The most and least preferred categories had pretreatment differences in cover among paddocks and significant brush treatment \times grazing level interactions, which preclude use of repeated measures. Hence, pretreatment (November 1983) and the May 1988 treatment sets were tested to insure regressions among treatments were homogeneous. They were then analyzed via analysis of covariance to test the hypothesis that there were no differences in cover of these shrub categories on the last sampling date, adjusted for pretreatment conditions, because of brush treatment and/or goat-stocking level. Orthogonal contrasts were used to compare responses.

Herbaceous plant data were combined into 4 categories: perennial and annual grasses, and perennial and annual forbs. No pretreatment data were collected for these groups. Each group was subjected to the same repeated measures test previously described, but significant interactions indicated an invalid procedure. Therefore, each of the 5 sampling times for each of the 4 categories was

Table 2. Density (stems/m²) of herbaceous plants over a 2-1/2 year period on paddocks subjected to 4 goat stocking levels and 2 brush treatments, central Arizona. Data expressed as mean \pm standard error.

Categories/Time		Stocking rates (goats/ha)							
		Brush not crushed				Brush crushed			
		0	1.4	2.4	4.2	0	1.4	2.4	4.2
Perennial grasses	5/86	1.9 \pm 1.0ab**	4.7 \pm 1.4a	0.3 \pm 0.1b	1.9 \pm 0.5ab	0.4 \pm 0.1b	5.1 \pm 1.1a	0.6 \pm 0.1b	1.8 \pm 0.2ab
	10/86	2.2 \pm 0.9b	10.7 \pm 2.0a	0.2 \pm 0.1b	1.9 \pm 0.5b	3.1 \pm 1.0b	2.4 \pm 0.5b	0.5 \pm 0.2b	0.3 \pm 0.1b
	5/87	1.7 \pm 1.6	4.1 \pm 1.3	1.1 \pm 0.3	2.5 \pm 1.0	0.8 \pm 0.4	1.2 \pm 0.4	1.5 \pm 0.4	2.1 \pm 0.2
	10/87	1.5 \pm 0.4	4.5 \pm 2.4	0.3 \pm 0.1	0.9 \pm 0.2	0.5 \pm 0.3	2.6 \pm 1.3	0.9 \pm 0.3	1.0 \pm 0.4
	5/88	2.0 \pm 1.1	2.1 \pm 0.8	0.3 \pm 0.2	1.1 \pm 0.4	0.8 \pm 0.4	2.3 \pm 1.0	0.5 \pm 0.2	0.7 \pm 0.4
Annual grasses	5/86	0.9 \pm 0.2c	7.4 \pm 0.9bc	11.4 \pm 1.3bc	40.5 \pm 13.2ab	52.8 \pm 6.1a	38.0 \pm 6.1ab	47.9 \pm 5.8a	65.4 \pm 12.1a
	10/86	3.0 \pm 1.9c	13.4 \pm 2.3bc	4.8 \pm 2.5bc	33.5 \pm 9.4ab	33.8 \pm 7.5ab	16.6 \pm 3.6bc	26.7 \pm 6.4b	57.9 \pm 8.7a
	5/87	2.8 \pm 1.8b	5.7 \pm 2.7ab	6.2 \pm 0.2ab	10.2 \pm 2.9ab	8.4 \pm 4.6ab	8.5 \pm 2.4ab	13.4 \pm 2.1ab	15.5 \pm 2.0a
	10/87	3.9 \pm 1.8b	3.7 \pm 1.2b	4.7 \pm 1.3b	14.5 \pm 3.9ab	42.4 \pm 9.7a	24.5 \pm 3.4ab	31.2 \pm 14.5ab	23.5 \pm 2.1ab
	5/88	6.7 \pm 1.4c	9.3 \pm 2.2dc	34.8 \pm 3.3bc	41.6 \pm 2.0ab	39.1 \pm 1.4abc	24.5 \pm 4.9cd	38.5 \pm 0.8abc	52.4 \pm 6.1a
Perennial forbs	5/86	0.5 \pm 0.2b	0.3 \pm 0.0b	0.6 \pm 0.2ab	0.8 \pm 0.3ab	0.8 \pm 0.1ab	1.0 \pm 0.3ab	0.6 \pm 0.1ab	1.8 \pm 0.5a
	10/86	0.4 \pm 0.1b	1.8 \pm 0.1ab	0.9 \pm 0.1b	3.6 \pm 0.7a	1.6 \pm 0.5ab	1.4 \pm 0.4b	1.9 \pm 0.1ab	1.9 \pm 0.8ab
	5/87	3.5 \pm 1.9	1.3 \pm 0.7	3.3 \pm 0.7	3.3 \pm 1.1	3.4 \pm 0.6	2.1 \pm 0.6	3.6 \pm 1.5	3.3 \pm 1.4
	10/87	0.9 \pm 0.8	1.2 \pm 1.3	1.9 \pm 1.2	2.2 \pm 1.5	2.3 \pm 1.6	2.7 \pm 2.2	2.7 \pm 1.0	1.8 \pm 1.0
	5/88	3.7 \pm 1.6	1.5 \pm 1.4	1.3 \pm 0.2	3.4 \pm 0.2	2.7 \pm 1.4	2.7 \pm 1.1	3.8 \pm 1.3	2.5 \pm 0.9
Annual forbs	5/86	0.6 \pm 0.1ab	0.2 \pm 0.1b	0.5 \pm 0.1ab	2.3 \pm 0.3a	3.0 \pm 1.1a	0.5 \pm 0.2ab	0.5 \pm 0.1ab	3.2 \pm 0.7a
	10/86	2.3 \pm 0.6b	2.9 \pm 0.3b	1.1 \pm 0.4b	0.6 \pm 0.2b	0.4 \pm 0.1b	1.7 \pm 0.4b	8.5 \pm 1.6ab	15.1 \pm 1.3a
	5/87	0.7 \pm 0.6	3.9 \pm 2.8	3.5 \pm 0.5	4.2 \pm 1.2	2.1 \pm 1.9	4.3 \pm 2.3	5.6 \pm 3.4	3.0 \pm 2.1
	10/87	0.7 \pm 0.6	0.4 \pm 0.2	0.9 \pm 0.2	0.3 \pm 0.2	0.2 \pm 0.1	0.2 \pm 0.1	0.6 \pm 0.1	0.2 \pm 0.1
	5/88	4.0 \pm 1.2b	6.6 \pm 1.0ab	4.6 \pm 1.4ab	11.6 \pm 0.1ab	6.7 \pm 0.7ab	11.2 \pm 3.7ab	12.2 \pm 2.0ab	25.7 \pm 1.5a

*Values within a row followed by the same letter are not significantly different at the 0.10 probability level.

subjected to a two-way (brush treatment \times grazing level) ANOVA to test the hypothesis that there were no differences in density of herbs because of brush treatment or goat-stocking levels at any specific time.

Homogeneity of variances were tested in all cases using Cochran's C. In those cases where mean separation tests were indicated, they were done via Tukey's (HSD). All analyses were accomplished using SPSS/PC+ (Norusis 1988a, 1988b). Those mean separation tests done at $P = 0.10$ also used Tukey but via a program developed by R. King (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.) using Scheffe's (1959) tables.

Soils and Litter

Homogeneity of variance was tested using the Cochran and Bartlett-Box test for soils and litter, respectively. Soil and litter data were analyzed with a two-way ANOVA that treated stocking level and brush crushing as main effects. Statistical differences between means for different stocking levels were determined at the 0.05 level using a Tukey (HSD) test.

Results and Discussion

Vegetation Response

Shrubs

Percentage cover of total shrubs and of shrub live oak was not different ($P > 0.05$) among the 16 study paddocks prior to applying treatments; however, paddocks differed ($P < 0.05$) in amounts of most and least preferred shrubs (Table 1).

Total Shrubs. No interactions ($P > 0.05$) were found involving stocking level, brush treatment, or time for total shrub cover from May 1985 through May 1988. Mean total shrub cover was lower ($P < 0.05$) on paddocks where shrubs were crushed vs not crushed (33 ± 1 and $50 \pm 3\%$, respectively) across stocking levels and times. Paddocks not browsed had higher ($P < 0.05$) total shrub cover percentages than did paddocks that were stocked at light, moderate, or heavy rates (51 ± 2 , 38 ± 1 , $39 \pm 1\%$, and $35 \pm 1\%$, respectively). However, light, moderate, or heavy stocking levels were similar ($P > 0.05$).

Orthogonal polynomial contrasts revealed a quadratic effect ($P < 0.05$) over time. While a linear effect due to goat browsing

might be expected, the parabolic form realized can be attributed to an initial increase in shrub cover from October 1985 to May 1986 (Table 1; group means were 36 ± 4 and $43 \pm 4\%$, respectively). Increases were likely due to a warm, wet 1986 winter, excellent growing conditions for chaparral vegetation. Weather records from Roosevelt, Ariz., indicate January, March, and April 1986 had mean monthly temperatures 2.7, 2.5, and 1.4°C above normal, respectively (February temperature data were missing). February and March precipitation was of 46.2 and 30.0 mm above normal, respectively. Shrub growth during this period and into the following summer apparently negated browsing effects by goats. This trend continued through October 1986 (group mean $45 \pm 4\%$). Thereafter, total shrub cover decreased to $41 \pm 4\%$ by May 1988. These data indicate chaparral growth can be controlled by goats, but effects may be nullified if optimum growing conditions for shrubs are present and stocking levels are not adjusted accordingly.

Crushing brush immediately prior to goat browsing will help maintain reductions in shrub cover. Total cover of crushed shrubs in unbrowsed paddocks was similar ($P > 0.05$) to unbrowsed, uncrushed treatments by the last sampling period (Table 1). Heavily and moderately stocked paddocks had less ($P < 0.05$) shrub cover than did the browsed, uncrushed paddocks ($P < 0.10$). The lightly stocked, crushed areas were similar ($P > 0.05$) to the heavily stocked, uncrushed paddocks but different ($P < 0.05$) from the other uncrushed, moderately and heavily browsed areas. These results confirm one recommendation of Davis et al. (1975) that goats can be effective in suppressing brush, provided that the stand was first treated mechanically, chemically, or by fire.

Shrub Live Oak. There was no stocking level \times brush treatment interaction ($P > 0.05$) for shrub live oak cover. Group means for brush treatments differed ($P < 0.05$), 19 ± 1 and $26 \pm 1\%$ for crushed and not crushed paddocks, respectively. Goat-stocking levels influenced shrub live oak cover. Ungrazed paddocks contained higher ($P < 0.05$) percentages ($31 \pm 1\%$) of live oak than did light, moderate, and heavy browsed plots 22 ± 1 , 20 ± 1 , and $17 \pm 1\%$, respectively). Lightly stocked paddocks contained more oak ($P < 0.05$) than did the heavily browsed ones.

Stocking level \times time and brush treatment \times time interactions

Table 3. The effect of different goat stocking levels on select litter properties under manzanita, shrub live oak, and ceanothus plants and on bare areas. Data expressed as mean \pm standard error.

Litter property	Cover	Stocking levels		
		None	Light	Heavy
Total litter (g/m ²)	Manzanita	3166 \pm 59a*	976 \pm 12ab	1738 \pm 48b
	Ceanothus	1309 \pm 69a	360 \pm 88b	437 \pm 117b
	Shrub live oak	1299 \pm 187a	859 \pm 117ab	764 \pm 92b
	Bare areas	280 \pm 44a	136 \pm 35a	138 \pm 15a
Total nitrogen (g/m ²)	Manzanita	154 \pm 24a	64 \pm 6b	79 \pm 26b
	Ceanothus	138 \pm 5a	32 \pm 10b	75 \pm 8b
	Shrub live oak	138 \pm 24a	106 \pm 20ab	67 \pm 11b
	Bare areas	19 \pm 6a	13 \pm 4a	14 \pm 5a
Percent nitrogen (%)	Manzanita	0.51 \pm .03ab	0.67 \pm 0.7a	0.43 \pm .06b
	Ceanothus	1.07 \pm .08a	0.85 \pm .11a	0.78 \pm .08a
	Shrub live oak	1.05 \pm .07ab	1.21 \pm .08a	0.86 \pm .06b
	Bare areas	0.76 \pm .15a	0.86 \pm .23a	0.95 \pm .20a
Total phosphorus (g/m ²)	Manzanita	32 \pm 8a	25 \pm 10a	12 \pm 2a
	Ceanothus	14 \pm 1a	4 \pm 1b	3 \pm 1b
	Shrub live oak	17 \pm 2	13 \pm 2a	6 \pm 1b
	Bare areas	3 \pm 1a	2 \pm 1	2 \pm 1a
Percent phosphorus (%)	Manzanita	0.10 \pm .01a	0.31 \pm .16a	0.08 \pm .01a
	Ceanothus	0.10 \pm .01a	0.11 \pm .01a	0.08 \pm .01b
	Shrub live oak	0.14 \pm .01a	0.15 \pm .01a	0.08 \pm .01b
	Bare areas	0.09 \pm .02a	0.14 \pm .05a	0.12 \pm .02a

*Any numbers in a row having the same letters (a, b) are not significantly different at the 0.05 level.

were significant ($P < 0.05$), precluding determination of an overall time trend.

Benefits afforded by crushing were not as evident with shrub live oak as with total shrubs, but the recommendations of Davis et al. (1975) are still valid. While there were no differences ($P > 0.05$) in shrub live oak cover prior to any treatment, by the last sampling date the moderately and heavily stocked, crushed paddocks contained less ($P < 0.10$) oak cover than any of the uncrushed paddocks except the heavily stocked ones (Table 1).

Most Preferred Shrubs. The most preferred shrubs were impacted by all stocking levels. Analysis of covariance to adjust for heterogeneous pretreatment conditions failed because the regression was nonsignificant ($P > 0.05$). Therefore, a simple correction for pretreatment heterogeneity was obtained by computing the relative change after treatment as November 1983 percent cover subtracted from May 1988 percent cover, then divided by November 1983 cover. Analysis of this index indicated effects ($P < 0.05$) associated with both browsing and crushing treatments but no interaction ($P > 0.05$) between them. Cover of the most preferred species was reduced 79% on the crushed plots versus 54% on the plots not crushed. The relative changes associated with stocking were decreases of 17, 71, 89, and 90% for 0, 1.4, 2.4, and 4.2 goats/ha, respectively. Browsed plot cover was decreased ($P < 0.05$) compared to unbrowsed plots. Preferred shrub cover decreased ($P < 0.05$) consistently where the brush was not crushed. On crushed plots the preferred species never recovered beyond immediate post-crushing levels (Table 1). Mortality of the preferred shrubs in moderate and heavily stocked paddocks ranged from 16.7% for Wright silktassel to 70.0% for desert ceanothus as compared to 23.1% for shrub live oak by October 1987.

The most preferred species started to recover on crushed plots in unbrowsed paddocks, but the increase in cover of these species culminated during fall 1985, to spring 1986, and thereafter decreased (Table 1). Two reasons for this response are offered: (1) Mortality may have been caused by crushing. The increase noted up to October 1985 may have been due to growth of the survivors. (2) These species are also those most preferred by mule and white-tailed deer (*Odocoileus hemionus* Rafinesque and *O. virginianus* Zimmermann) in this region. Utilization indices on shrubs in paddocks not browsed by goats ranged from 1.00 (Wright silktassel) to 1.35 (hollyleaf buckthorn) as compared to 0.17 for shrub live oak and 0.00 for the least preferred species. Shrub utilization was much less on the unbrowsed, not crushed plots. Presumably this use was by deer and it may have been great enough to impair recovery on the crushed plots.

The most preferred species contributed a high proportion of the decline noted for total shrubs. This is a cause for concern because these species are among those most important to deer in chaparral habitats in Arizona (McCulloch and Urness 1973). Knipe (1983) also noted a decrease in these shrubs and expressed similar concerns.

The decline in cover of preferred shrub species such as desert ceanothus may influence long-term nitrogen cycling in chaparral ecosystems. Desert ceanothus has been reported as an important nitrogen-fixing shrub in California chaparral (Kummerow et al. 1978). If such species are eliminated by continued overutilization, long-term nitrogen cycling could be adversely affected.

Least Preferred Shrubs. There were essentially no changes in percentage cover in the uncrushed paddocks while those in the crushed paddocks increased gradually from November 1983 to May 1988 (Table 1). By May 1988, there were no differences ($P > 0.05$) noted in cover of the shrubs least preferred by goats among stocking levels or between brush treatments.

Herbs

Although there were some differences ($P < 0.10$) in density of perennial grasses among treatments during the two 1986 measurement periods, they were not consistent and did not appear related to treatments (Table 2). No differences ($P > 0.10$) were noted over the last 3 measurement periods. There were no general trends indicating a change in density over time for perennial grasses. May 1988 densities were similar to those noted in May 1986. Perennial forb density appeared higher during May 1987 and May 1988 as compared to May 1986. However, these increases are consistent across all treatments.

Annuals responded to treatments, but the responses appear related to soil surface disturbance, in general, rather than to stocking levels or brush treatments per se. Annual grasses had higher densities ($P < 0.10$) in paddocks that were crushed, regardless of stocking level, and paddocks that were not crushed but received the heaviest stocking rates (Table 2). Annual grasses, primarily red brome, were not homogeneous within paddocks but were concentrated under shrubs or, in crushed paddocks, in shrub litter rather than between shrubs. Soil surface disturbance, whether caused by the Marden crusher or by goat hoof action, combined with higher organic matter contents of the soil in areas previously occupied by shrubs, resulted in high annual grass densities. Less total litter ($P < 0.05$) occurred in bare areas compared to under shrubs (Table 3), which was further reflected in lower organic carbon content of soil in the bare areas (Table 4). The additional organic matter would provide more favorable moisture and fertility conditions. Annual forb densities were higher in paddocks that were crushed and received the highest stocking rates during the first 2 measurement periods, while trends during May 1988 generally followed annual grasses (Table 2).

Litter and Soil Responses

Goat Browsing

Litter. Less ($P < 0.05$) litter accumulated under manzanita, desert ceanothus, and shrub live oak plants on heavily stocked paddocks compared to beneath those plants in unbrowsed paddocks (Table 3). Litter was reduced ($P < 0.05$) under light stocking rates only under ceanothus. Browsing had no effect ($P > 0.05$) on the amount of litter found in bare areas, although less was found on the interspaces of heavily stocked paddocks.

Heavy goat-stocking levels decreased ($P < 0.05$) total N (g/m²) in the litter under manzanita, desert ceanothus, and shrub live oak (Table 3). Stocking levels did not affect ($P > 0.05$) total litter N on bare areas. Lower ($P < 0.05$) concentrations of total percent N were found in the litter of plants on heavily stocked paddocks compared to the lightly stocked paddocks under manzanita and shrub live oak (Table 3). There were no differences ($P > 0.05$) between browsing versus no browsing.

Total P (g/cm²) in desert ceanothus litter was higher ($P < 0.05$) in the unbrowsed paddocks compared to either light or heavy stocked paddocks (Table 3). Under shrub live oak, total P in the litter was less ($P < 0.05$) under heavy stocking compared to light and no goat use. As with N, total percent P of ceanothus plants was lower ($P < 0.05$) in the litter under heavy compared to light stocking rates. Under shrub live oak, percent total P in the litter was less ($P < 0.05$) under heavy stocking compared to light and no goat browsing (Table 3). Browsing had no effect ($P > 0.05$) on the P content of litter under manzanita or in bare areas.

The effect of browsing on both litter and nutrients accumulating under shrubs probably reflected the consumption, by goats, of leaves and twigs that were either retained on the standing plants or that had dropped to the ground and accumulated under the shrub canopies. Although species such as manzanita and shrub live oak are considered less palatable and were not heavily utilized, it

Table 4. The effect of different goat stocking levels on select soil properties in the 0- to 3.8 cm depth under manzanita, shrub live oak, and ceanothus plants and on bare areas. Data expressed as mean \pm standard error.

Soil property	Cover	Stocking levels		
		None	Light	Heavy
Bulk density (g/m ³)	Manzanita	1.27 \pm .06a*	1.37 \pm .08a	1.22 \pm .11a
	Ceanothus	1.23 \pm .05b	1.50 \pm .04a	1.49 \pm .07a
	Shrub live oak	1.25 \pm .09a	1.29 \pm .05a	1.29 \pm .06a
	Bare areas	1.62 \pm .06a	1.71 \pm .08a	1.69 \pm .07a
Organic carbon (%)	Manzanita	3.07 \pm .60a	0.85 \pm .09a	6.67 \pm 2.9a
	Ceanothus	2.92 \pm .72a	0.78 \pm .11b	0.95 \pm .14b
	Shrub live oak	2.20 \pm .43a	2.18 \pm .70a	2.35 \pm .80a
	Bare areas	0.48 \pm .25a	0.44 \pm .19a	0.60 \pm .26a
Total nitrogen (%)	Manzanita	0.09 \pm .10a	0.04 \pm .03a	0.14 \pm .10a
	Ceanothus	0.11 \pm .03a	0.05 \pm .01a	0.07 \pm .01a
	Shrub live oak	0.13 \pm .03a	0.13 \pm .04a	0.17 \pm .04a
	Bare areas	0.06 \pm .02a	0.05 \pm .02a	0.04 \pm .02a
Total phosphorus (%)	Manzanita	0.100 \pm .010a	0.110 \pm .013a	0.089 \pm .016a
	Ceanothus	0.103 \pm .008a	0.125 \pm .007a	0.113 \pm .013a
	Shrub live oak	0.118 \pm .003a	0.133 \pm .007a	0.096 \pm .008b
	Bare areas	0.125 \pm .007a	0.127 \pm .010a	0.085 \pm .013b

*Any numbers in a row having the same letters (a,b) are not significantly different at the 0.05 level.

appears significant amounts of plant leaf and twig material were removed by the goats and, as a result, less litter accumulated on the soil surface. A reduction in litter quality, as indicated by lower percent total N in the litter, suggests that goats are selective for those plant parts containing the highest concentrations of N (e.g., proteins), such as leaves and smaller stems. Decreased litter quality, as indicated by lower concentrations of N and P, was most apparent when comparing heavily stocked to lightly stocked and unbrowsed paddocks.

The effect of goat browsing on litter and nutrient accumulation beneath shrubs has implications on the long-term fertility and productivity of chaparral ecosystems. Chaparral shrubs are typically found on nutrient-poor soils (Hellmers et al. 1955a). One mechanism by which chaparral shrubs have adapted to nutrient-poor soil is believed to be through the accumulation and recycling of nutrients in litter, humus, and soil under shrub canopies. Because chaparral shrubs have extensive root systems they can exploit large volumes of soil for water and nutrients (Hellmers et al. 1955b, Davis and Pase 1977). Nutrients absorbed by shrubs are immobilized in organic matter for several years before they are slowly released into the soil (Schlesinger 1985, Schlesinger and Hasey 1981), suggesting that soil fertility and nutrient availability for plant growth can be enhanced by the accumulation and slow release of plant nutrients through decomposition and mineralization of plant litter. Therefore, any interruption of litter accumulation and decomposition could have important consequences on the long-term stability of chaparral ecosystems. Goats appear to effectively interrupt the accumulation of litter, particularly under preferred shrubs. Presumably this loss of litter and nutrients under shrub canopies reflects a redistribution of the ingested material to either interspaces between shrubs, or in bedding areas. However, there were no detectable differences in interspace litter and nutrients between the different intensities of browsing, suggesting that the litter and associated nutrients that were lost from under shrub canopies were probably concentrated as fecal material in bedding areas.

Soil. Stocking level had no effect ($P>0.05$) on bulk density in the upper soil depth except under desert ceanothus plants where soil bulk density under the light and heavy stocking levels was higher ($P<0.05$) than in unbrowsed paddocks (Table 4). Bulk density was not measured in the 3.8- to 10-cm soil depth. Vegetation utilization and mortality measurements showed that desert ceanothus underwent the highest intensity of browsing (utilization

indices ranged from 2.71 to 3.00), which could have increased ($P>0.05$) the bulk density under this species compared to manzanita (indices from 0.71 to 1.59) and shrub live oak (indices from 1.69 to 2.68).

In soil under ceanothus cover, organic carbon (OC) concentrations were higher ($P<0.05$) under no browsing compared to light and heavy stocking levels. Stocking levels had no impact ($P>0.05$) on OC under shrub live oak, manzanita, and in bare areas (Table 4). There were no effects ($P>0.05$) of stocking level on OC in the 3.8- to 10-cm soil depth (data not presented).

No differences ($P>0.05$) were found in percent N in the surface soil layer under any of the shrub species studied because of browsing (Table 4). Browsing had no effect ($P>0.05$) on the total percent P under Pringle manzanita, desert ceanothus, and in bare areas. However, lower ($P<0.05$) percent total P was present in the soil under shrub live oak that had been browsed heavily compared to light stocking and no goat use (Table 4). Soil N and P at the 3.8- to 10-cm depth were not affected ($P>0.05$) by stocking levels.

The chemical and physical properties of soil were generally less sensitive to goat browsing than was the litter component, and changes were restricted to the upper soil layer (0- to 3.8-cm depth), with no changes ($P>0.05$) occurring in the 3.8- to 10-cm layer. Soil changes in response to grazing disturbance in open shrubland ranges in Australia have been reported to be limited to less than 10 cm from the soil surface (Graetz and Tongway 1986). The decreases in N, P, and OC in response to goat browsing were expected because similar changes have been reported in response to high grazing pressure by sheep on grasslands in Australia (Simpson et al. 1974) and India (Pandey and Sant 1979).

Brush Crushing

Crushing increased ($P<0.05$) the amount of litter, total litter N, and total P under shrub live oak but had no effect ($P>0.05$) under manzanita, desert ceanothus, or on bare areas. Concentrations of N and P in the litter were not affected ($P>0.05$) by brush crushing.

Not many of the soil properties were affected by crushing. Although there was increased soil bulk density under all cover types associated with crushing, the differences were higher ($P<0.05$) only under manzanita, and nonsignificant ($P>0.05$) on bare interspace areas.

Conclusions and Management Implications

The higher levels of goat stocking tested in this study reduced

total shrub cover in Arizona chaparral stands, particularly when done in conjunction with an initial brush crushing treatment. Goat-stocking rates also affected litter accumulation and the underlying soil. These results point out several ramifications that need to be considered when designing a goat-browsing system in Arizona chaparral.

First, perennial herbaceous vegetation did not increase in response to decreasing shrub cover, at least over the 4-1/2 year period of this study and under the condition described. If this trend continues, there will be less plant cover to protect the soil and a greater potential for increased erosion. Although annuals responded to disturbance, their ephemeral nature and distribution pattern (under shrubs and not in interspaces) make them generally ineffective as soil protectors. Because of this, we concur with Knipe (1983)—it may be necessary to reseed perennial grasses in order to obtain an adequate herbaceous cover.

Second, a decline in forage diversity would set the stage for nutritional stress. Those shrubs most affected by goats were those also preferred by native deer. Chaparral habitats are, under normal conditions, nutritionally marginal for deer (McCulloch and Urness 1973). Deer, like goats, are selective feeders and tend to overcome nutritional limitations of forage by selecting the most nutritious parts, within and among plant species. Reducing forage diversity by eliminating the most desired species from the forage base would likely impact these native ungulates. The importance of a diverse forage base for providing nutritionally adequate diets has been noted by Dietz et al. (1962). This was not a problem in Utah where goats were used to control Gambel oak. There, shrubs used (and reduced) by goats were generally those not preferred by wintering mule deer (Riggs and Urness 1989).

Third, goat browsing also affected the litter and underlying soil greatest under a preferred shrub, desert ceanothus. The trampling associated with any level of goat browsing on desert ceanothus was also sufficient to produce changes in some physical and chemical properties of the underlying soil. As a result, it is possible that goat browsing of ceanothus could adversely affect nitrogen cycling not only by interfering with litter accumulation and decomposition but, more importantly, by eliminating this important nitrogen-fixing shrub from the chaparral stand. Ceanothus species have been estimated to comprise about 11.5% of the plant cover in Arizona chaparral stands (Carmichael et al. 1978).

Therefore, it appears the selective browsing of important shrubs, and the associated impacts on the soil, will continually be a problem when designing goat-browsing strategies in Arizona chaparral. Possible solutions may involve more refined management methods designed to reduce selectivity by goats (Savory 1988) or by including perennial forb mixtures in reseeding programs. Either method, using present technology, would be complex. The key, however, may lie in keeping goat operations confined to relatively small proportions of the total landscape.

Our results substantiate Knipe's (1983) conclusions that the successful use of goats to control shrubs in Arizona chaparral will require very intensive levels of management. In the final analysis, it appears that any goat browsing management strategy must be sufficiently comprehensive to protect both the vegetation and soil resource.

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Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities

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Abstract

Utilization patterns of cattle were related to pasture characteristics in a nonrandom and complex manner. Six mixed brush pastures on the Rio Grande Plains (244–356 ha) that were topographically flat and homogeneous in soil type and range sites were studied. Two experiments were conducted: the first experiment was conducted when green forage was abundant and the second under conditions of little vegetative regrowth. A total of 340 random points were characterized for amount, frequency, and greenness of both grasses and forbs, brush and shade tree density, and distance to nearest fence, road, and water. These are variables that can be altered with management practices. When green forage was abundant, factor analysis identified 5 orthogonal factors (green herbage availability, grass quantity, brush abundance, remoteness from roads, and water availability) which accounted for 70% of the communal variation. Six factors (brush abundance, grass quantity, green forb frequency, road location, fence proximity, and water availability) accounted for 70% of the communal variation when herbage was limited. Regression analyses predicting percent utilization from the orthogonal factors indicated that when green forage was abundant, utilization was related largely to green herbage availability, grass quantity, brush abundance, and remoteness ($R^2 = 0.54$, $RSD = 0.114$). Remoteness, brush abundance, green forb frequency, and water availability were the factors associated with utilization when forage was limited ($R^2 = 0.45$, $RSD = 0.152$). Green herbage availability was less important under conditions of limited forage. In mixed brush communities, the actual amount of grass, brush abundance, and remoteness were the major factors affecting utilization.

Key Words: landscape, cattle foraging patterns, pasture spatial utilization

Uniform grazing distribution is desirable for grazing management because of positive impacts on current and potential grazing capacity. A manager must be able to assess, modify, and predict animal use patterns to improve grazing distribution. This requires knowledge of pasture characteristics which affect grazing distribution.

Management techniques proposed to improve grazing distribution include water development, fencing, strategic salt placement, herding, burning or mowing, brush control, and grazing system development (Williams 1954, Dodds 1981, Holechek et al. 1989). The economic feasibility of any of these practices depends on cost and success in altering utilization patterns (Workman and Hooper 1968). However, the impact of these modifications on grazing distribution is not well understood (Senft et al. 1985).

Studies of pasture characteristics which affect utilization patterns have provided descriptive (Mueggler 1965, Cook 1966, Clary et al. 1978, Roath and Krueger 1982) and in some cases predictive (Senft et al. 1983, Senft et al. 1985, Smith 1988) results. Factors affecting cattle utilization patterns vary greatly among studies but because the studies were correlative in nature, the results are localized and are not applicable to areas with radically different terrains

(Senft et al. 1983, Smith 1988). In addition, the majority of landscape use studies were conducted in mountainous regions where topography and range site were important factors affecting utilization patterns (Mueggler 1965, Cook 1966, Senft et al. 1985). Complex topographic and plant community interactions make it difficult to isolate management factors affecting utilization.

Mechanisms governing habitat selection by cattle are complex and largely unknown. From a management standpoint, it is not necessary to produce detailed mechanistic models of livestock distribution if utilization patterns can be adequately predicted from pasture characteristics. Knowledge of pasture characteristics which affect utilization could lead to development of pasture management resulting in increased foraging capacity and uniformity (Smith 1988), and greater control of livestock diet selection and nutrient intake (Senft et al. 1983).

In this study, topography and range site were reduced as sources of impact on grazing pattern by selecting pastures which were uniform in range site and topographically flat. The objectives of this study were: (1) to determine if forage utilization by cattle is spatially random in relatively homogeneous pastures and if not (2) to identify the impact of pasture characteristics which can be controlled by management such as pattern of habitat structure, forage quality and quantity, brush density, shade, and the distance to the closest water, fence, and road on the distribution of utilization.

Materials and Methods

Field Data Collection

The research was conducted on the Texas Agricultural Experiment Station George Lyles Ranch near Uvalde, Texas (29° lat. 99° 52' long.). The study area was on a silty clay loam range site located on nearly level upland with 9.1 m maximum topographic relief. The vegetation of the research area was a low, mixed-brush savannah with a grass understory. The dominant shrubs were mesquite (*Prosopis glandulosa* Torr.), twisted acacia (*Acacia tortuosa* Willd.), cat claw (*Acacia greggii* Gray), and spiny hackberry (*Celtis pallida* Torr.). The dominant grasses were Wrights three awn (*Aristida wrightii* Nash), red grama (*Bouteloua trifida* Thurb.), and buffelgrass (*Cenchrus ciliaris* L.). The distribution of plant species was uniform between all the pastures. Within each pasture, however, the distribution of plants was dependent on previous grazing history and mechanical treatment.

The region's long term annual precipitation averages 57.2 cm, occurring mainly in the spring and fall. An extremely wet spring preceded the study with 59.1 cm of precipitation falling from January to June 1987. However, the study period (July 1987 to April 1988) was dry with only 8.2 cm of precipitation. Thus, vegetation production was high at the beginning of the study but little regrowth occurred subsequently.

Uniform and patterned arrangements of vegetative structure were investigated using 6 pastures (3 uniform and 3 patterned) ranging from 244 to 356 ha. Patterned pastures were developed in 1985 by gridding the pastures in 185 × 750 m areas which were either (1) rootplowed, roller chopped and planted to buffelgrass; or (2) sprayed with .45 kg active ingredient of picloram and clopyralid; or (3) left as native brush. These treatments resulted in reduced

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shrub canopy and increased grass and forb composition for 2/3 of each treated pasture. Uniform pastures were shredded in the early 1980's and regrowth of the shrub component was even-aged and of uniform height. Prior to this experiment the pastures were grazed in a 2 herd-3 pasture system.

The relationship between pasture characteristics and utilization patterns was studied in 2 experiments. Each experiment consisted of a pretreatment vegetation measurement period, grazing period, and a post-grazing period during which utilization was estimated. Pregrazing vegetation measurements were made on ungrazed, current season growth when biomass was high. Pregrazing measurements for the second experiment were made in the same pastures on grazed vegetation with little available regrowth. Pastures were measured and grazed in a sequential manner (Table 1). Pre- and

Table 1. Grazing schedule.

Grazing dates	Spatial arrangement					
	Uniform			Patterned		
	1	2	3	4	5	6
High biomass						
July 20 - September 7	x*			x		
September 7 - October 19		x			x	
October 19 - November 30			x			x
Low biomass						
November 30 - January 18	x			x		
January 18 - February 29		x			x	
February 29 - April 11			x			x

*Grazed during this time.

post-grazing measurements were made within 1 week of the beginning and end of grazing in each pasture. Each pasture was grazed for 7 weeks by a total of 88 cow/calf pairs and yearling heifers. After the first experiment, each pasture was rested for 14 weeks before the second experiment began.

Table 2. Mean and standard error of independent variables and utilization for 6 experimental pastures.

Pasture area (ha) Variables	Spatial Arrangements											
	Patterned						Uniform					
	A	B	C	A	B	C	A	B	C	A	B	C
	337	267	244	356	324	244						
High Biomass												
Utilization (%)	33.3 (2.6)	47.1 (3.1)	58.8 (1.8)	30.9 (2.0)	42.1 (1.5)	57.7 (2.2)						
Grass biomass (kg/ha)	615.8 (126.6)	569.2 (100.2)	522.4 (109.4)	559.9 (97.7)	444.3 (47.4)	274.1 (46.6)						
Forb biomass (kg/ha)	594.3 (96.5)	209.8 (26.1)	60.0 (10.3)	323.7 (57.1)	115.2 (14.7)	60.2 (8.5)						
Grass greenness ¹	4.3 (0.2)	2.8 (0.2)	1.4 (0.1)	4.0 (0.1)	1.8 (0.1)	1.3 (0.1)						
Forb greenness ¹	5.8 (0.1)	5.1 (0.1)	3.6 (0.3)	5.6 (0.1)	4.2 (0.2)	4.1 (0.2)						
Herb greenness ¹	5.1 (0.1)	3.4 (0.2)	1.8 (0.1)	4.5 (0.1)	2.2 (0.1)	1.8 (0.1)						
Grass frequency (%)	25.6 (4.2)	25.8 (2.2)	23.7 (2.1)	34.8 (2.0)	30.9 (1.7)	25.5 (2.8)						
Forb frequency (%)	18.3 (1.8)	8.2 (0.8)	3.7 (0.5)	16.6 (1.6)	4.8 (0.4)	4.6 (0.6)						
n	20	30	30	20	30	30						
Low Biomass												
Utilization (%)	70.4 (2.5)	69.6 (2.0)	29.9 (2.0)	61.2 (1.8)	65.9 (2.1)	50.8 (2.7)						
Grass biomass (kg/ha)	248.7 (62.7)	18.5 (36.3)	167.3 (32.6)	193.8 (37.3)	189.7 (30.2)	127.7 (37.4)						
Forb biomass (kg/ha)	55.6 (37.0)	6.2 (1.6)	25.4 (7.5)	5.1 (1.3)	1.7 (0.7)	12.0 (2.8)						
Grass greenness ¹	1.4 (0.1)	3.3 (0.1)	4.3 (0.1)	1.3 (0.1)	1.9 (0.1)	2.5 (0.2)						
Forb greenness ¹	5.2 (0.1)	5.7 (0.1)	5.9 (0.1)	5.1 (0.2)	4.0 (0.4)	5.8 (0.1)						
Herb greenness ¹	2.6 (0.2)	3.7 (0.1)	4.8 (0.1)	2.4 (0.2)	2.0 (0.1)	3.1 (0.2)						
Grass frequency (%)	17.9 (2.2)	15.6 (1.1)	15.0 (1.4)	18.3 (1.5)	19.7 (1.1)	15.2 (1.8)						
Forb frequency (%)	5.4 (0.5)	3.6 (0.5)	5.5 (0.7)	6.3 (0.8)	1.5 (0.2)	3.1 (0.5)						
n	30	30	30	30	30	30						
High and Low Biomass												
Brush dens. (stems/ha)	4147.0 (300.7)	4092.2 (320.7)	4469.6 (327.9)	6495.7 (298.20)	5027.0 (228.0)	4565.8 (234.9)						
Shade trees (#/1000 ²)	4.4 (1.3)	2.7 (0.56)	5.1 (0.8)	7.2 (1.0)	3.8 (0.4)	12.0 (1.8)						
Distance to fence (m)	257.5 (26.9)	191.7 (19.4)	241.8 (21.4)	187.1 (20.1)	199.2 (17.9)	204.2 (21.1)						
Distance to road (m)	256.5 (22.1)	154.3 (15.8)	173.2 (16.0)	389.2 (28.5)	219.0 (20.9)	147.8 (12.9)						
Distance to water (m)	780.1 (51.7)	605.8 (42.0)	675.0 (25.1)	881.8 (49.9)	901.7 (61.2)	648.5 (37.2)						

¹See text for an explanation of the units in estimating greenness.

Twenty points in each pasture were randomly located during the first sampling period but sample size was increased to 30 thereafter to provide better spatial coverage of the pastures. At the end of both experiments, a total of 340 points had been sampled. Logistical restrictions prohibited sampling more than 30 points per pasture. The same sampling points were used in both experiments and these points were considered the experimental units. Each sampling point was characterized by 12 explanatory variables: grass and forb biomass and greenness, preferred and nonpreferred grass frequency, forb frequency, brush and shade tree density, and shortest distance to nearest fence, road, and water and the dependent variable of utilization (Table 2).

Six, 50-pace (15 m) transects were established radiating at 30° C increments from each sampling point for estimating utilization and percent green biomass. Utilization was defined as the proportion of use on the closest grass species at each paced step based on a subjective estimate dependent upon relative height per unit of basal diameter and categorized into 0, 1-10, 11-30, 31-50, 51-70, 71-90, or 91-100% categories. The same categories of classification were used for greenness as for utilization. Distance to roads, water, fence, and brush and shade tree density were determined for each point at the beginning of the study. All other variables were recorded at the beginning of each grazing period. Brush density of plants <2 m was estimated by counting all shrubs in 3 belt transects (1 × 15 m) which originated at the sampling point. Due to past brush control treatments in the early 1970's, shrubs were of a uniform height although canopy diameter varied according to plant species. Grass species were categorized as being either preferred or not according to known palatability and nutritional value (Blankenship et al. 1982). The number of shade trees (shrubs taller than 2 m) within a 15 m radius of each point was counted.

Grass and forb biomass were estimated in 6 randomly located plots at each point. Biomass was determined using a double sampling technique (Cook and Stubbendeick 1986).

Statistical Analysis

Initial analyses of variance employed a split plot design in which pattern of vegetative structure (patterned vs. uniform structure) was the main plot and experiment (high biomass vs. low biomass) was the subplot. These analyses indicated that distribution of utilization varied greatly among pastures and between experiments but not between vegetative structures. Subsequent analyses were conducted for each experiment separately and designed to determine: (1) if pattern of utilization within these pastures was random and (2) what characteristics of a particular point attracted cattle to utilize vegetation at that point. Nonrandomness was assessed by having a nonzero correlation coefficient associated with a statistically significant model. At the outset, it was hypothesized that the 12 variables listed above could be indications of attractiveness and reasons for nonuniform utilization patterns. Since these variables were interrelated and the list was too long for succinct description of point attractiveness, a factor analysis for each experiment was performed to simplify the description of each point. These analyses provided orthogonal component variables (factors) that accounted for linear relationships among observed variables (Mulaik 1972). Each component variable consists of a linear combination of all 12 explanatory variables. The dominant factor which accounts for most of the variation between the observed variables for each point was determined and ascribed a meaning. Observed variables with high loading scores in the factor are combined to describe that factor. Additional factors were calculated until 70% of the total

variation between observed variables was accounted (SAS 1988). Correlation between the original observed variables allowed factors to be dominated by more than one variable. This technique, although not common, has been used in other ecological research (Moloney 1989, Jensen 1990).

The number of explanatory variables were reduced to a more manageable number of orthogonal factors using this technique. Subsequently, factor scores were calculated for each sampling point and were used as independent variables in regression procedures to explain the sources of variation impacting spatial distribution of utilization by cattle. Percent utilization observations were not normally distributed (Shapiro-Wilk statistic = 0.967, $P < 0.001$) so an arcsine square root transformation was made to conform to regression analysis assumptions of a normal distribution.

Results and Discussion

Pasture Description

Experimental pastures are described in Table 2. Grass and forb biomass was generally much greater during the first sampling period of each pasture (Experiment 1) and thus will be characterized as high biomass. This was the result of large amounts of rain during the 14-week rest period prior to Experiment 1. This rain and rest resulted in not only larger quantities of forbs but a shift in species from that usually found. Annual broomweed (*Xanthoxylum texanum* DC) was the dominant forb under the high

Table 3. Factor analysis of descriptive variables taken under conditions of high and low biomass^a.

	Factors					
	1	2	3	4	5	6
----- High Biomass (Experiment 1) -----						
Ascribed meaning	Green herbage availability	Grass quantity	Brush abundance	Remoteness	Water availability	
Variables						
Grass biomass	0.068	0.857	-0.139	-0.014	0.090	
Forb biomass	0.815	-0.004	-0.043	-0.110	-0.172	
Grass greenness	0.886	0.187	-0.029	0.100	0.106	
Forb greenness	0.722	0.040	-0.150	-0.086	-0.038	
Preferred grass frequency	0.025	0.706	-0.361	-0.248	0.052	
Nonpreferred grass frequency	-0.114	0.612	0.388	0.434	-0.051	
Forb frequency	0.899	-0.167	0.110	0.092	0.069	
Brush density	0.036	-0.054	0.836	-0.015	0.214	
Shade density	-0.114	-0.194	0.647	-0.141	-0.124	
Distance to fence	-0.066	-0.085	-0.093	0.750	-0.270	
Distance to road	0.219	0.001	-0.125	0.638	0.459	
Distance to water	-0.104	0.087	0.082	-0.110	0.842	
Eigen values	2.928	1.836	1.397	1.258	0.961	
Cum portion	0.241	0.161	0.116	0.105	0.080	
----- Low Biomass (Experiment 2) -----						
Ascribed meaning	Brush abundance	Grass quantity	Forb frequency	Road location	Fence proximity	Water availability
Variables						
Grass biomass	-0.350	0.762	0.003	0.007	-0.141	0.009
Forb biomass	-0.284	-0.441	0.068	0.395	0.061	0.005
Grass greenness	-0.301	-0.041	0.486	-0.593	0.178	0.305
Forb greenness	-0.063	0.033	0.845	0.102	0.021	-0.175
Preferred grass frequency	-0.586	0.244	-0.111	-0.012	-0.537	0.130
Non-preferred grass frequency	0.155	0.790	-0.123	0.157	0.141	-0.027
Forb frequency	0.114	-0.240	0.714	0.295	-0.112	0.087
Brush density	0.807	0.176	0.016	0.016	-0.075	0.195
Shade density	0.658	-0.081	-0.059	-0.070	-0.045	-0.075
Distance to fence	-0.112	0.058	-0.066	0.107	0.874	-0.047
Distance to road	-0.097	0.123	0.117	0.790	0.170	0.138
Distance to water	0.040	-0.021	-0.077	0.060	-0.085	0.945
Eigen values	1.860	1.850	1.375	1.226	1.184	0.951
Cum portion	0.155	0.154	0.115	0.102	0.099	0.079

^aRotated factor pattern by the Varimax procedure.

Table 4. Coefficients of partial regression for predicting arcsine of utilization from factors computed.^a

Independent variable	Biomass	
	High	Low
Intercept	.7116	.9027
Green herbage availability	-.0796	(Factor 1)
Green herbage availability ²	+.0178	
Grass quantity	-.0467	(Factor 2)
Brush abundance	-.0688	(Factor 3)
Brush abundance ²	+.027	-.0559 (Factor 1)
Remoteness	-.0495	(Factor 4)
Water availability		-.0392
Water availability ²		-.0208
Green forb frequency		-.0489 (Factor 3)
Road location		+.0668 (Factor 4)
Road location ²		-.0128
Fence proximity		-.0571
Brush abundance × green forb frequency		+.0517
Forb frequency × fence proximity		-.0325
Grass quantity × brush abundance	-.0247	
Road location × fence proximity		+.0358
R ²	.54	.45
RSD	.114	.152

^aThe only variables included are those significant at $P < 0.05$.

biomass experiment whereas western ragweed (*Ambrosia psilostachya* DC) was prevalent when overall biomass was low. This was especially true for the patterned pastures where disturbance had taken place. Utilization was generally lower during the first experiment but more variable than when low biomass was available (Table 2). When cattle have access to large amounts of standing crop, they apparently are more selective and this selectivity results in greater variation in spatial utilization of pastures than when less biomass is available.

Factor Analysis

Five factors explained 70.7% of the communal variation under conditions of high biomass, while 6 factors explained 70.4% of the communal variation in Experiment 2 (Table 3). The relatively large number of factors required to explain 70% of the communal variation is indicative of the complexity of the system. Apparently, these pastures had complex structures not easily defined with a limited set of statements. Also, the factors describing this structure changed as herbage availability decreased: Factor 1 under high biomass conditions had high positive loadings for forb biomass, grass and forb greenness, and for frequency and was defined as a green herbage availability factor, while the factor explaining the most variation under low biomass conditions had high positive loadings for brush and shade density and was defined as brush abundance. Under relatively dry conditions with low biomass, much less variation between sample points existed in green herbage and therefore the most identifiable source of variation in structure was in brush abundance. Even under these relatively dry conditions, however, grass quantity was still an important source of communal variation (Factor 2 under conditions of both high and low biomass, Table 3). Road location, fence proximity, and water availability factors explained less of the communal variation than variables associated with the forage under both biomass conditions.

Factors Influencing Utilization

Regression equations explaining variation in utilization are shown in Table 4. Over half of the variation in utilization was explained by the component factors when herbaceous biomass was high, but under low biomass conditions only 45% of the variation in utilization was explained (Table 4). These significant regression models demonstrate that utilization by cattle was not random but

was associated with measured variables. Randomness (variation from nondefinable sources) apparently increased as biomass declined, as demonstrated by the decrease in the coefficient of determination.

Utilization at random points decreased as remoteness of sampling points (distance to fence and road, Table 3) increased when biomass was high. Most of the fences on these experimental pastures are electric and have been maintained using a road grader to reduce vegetation in the fenceline. The fences therefore act as an avenue allowing access to the pasture. This was expected since ease of access is generally thought to facilitate animal movement (Williams 1954, Workman and Hooper 1968, Roath and Krueger 1982). However, under conditions of low biomass, the relationship between utilization and ease of access was more complicated since distance to road was curvilinearly related to utilization ($P < 0.001$) and green forb frequency interacted with distance to fence. As the distance to a road increased, utilization increased in a curvilinear manner when forage availability within the pasture was limited. This may be the result of 2 equally likely circumstances. First, it is possible that under low biomass conditions the animals were forced further from the roads to utilize remaining forage. An alternative explanation is that there was little vegetation remaining close to the road during the second experiment, and therefore utilization would appear to be low.

Forage quality is generally reported to have a positive effect on utilization when quality is assessed prior to grazing (Hunter 1962, Low et al. 1981, Senft et al. 1985). Utilization of grasses decreased as the distance to the nearest fence increased when biomass was low, but this relationship was affected by the green forb frequency associated with each point. As the frequency of green forbs (Factor 3) increased, utilization of grasses decreased at a faster rate when the distance to a fence was great (Fig. 1). This may have been a result of the livestock switching diet selection to use the abundant green forbs. When the distance to a fence was near the maximum and green forb frequency was high, diet selectivity should have been greatest due to abundant forage and the low concentration of livestock.

When biomass was high (Experiment 1), utilization decreased curvilinearly ($P < 0.05$) as green herbage availability increased but green herbage availability was unrelated ($P > 0.10$) to utilization when biomass was low. The negative relationship of green herbage

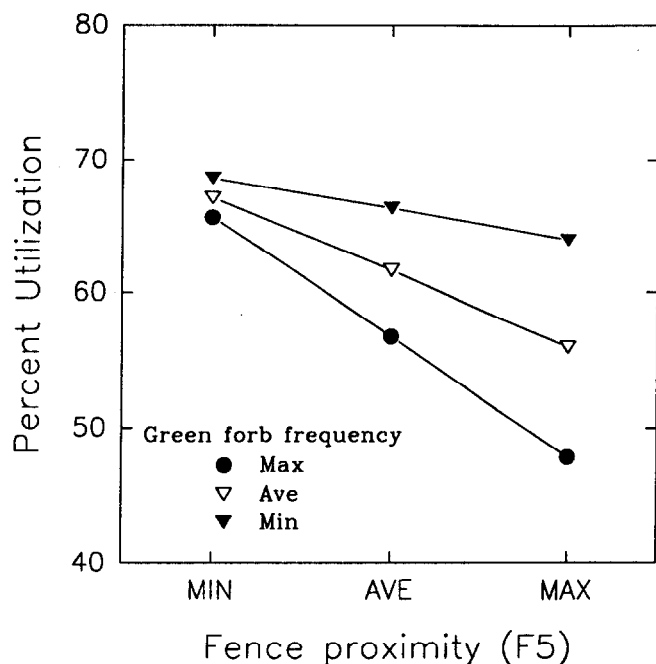


Fig. 1. Influence of Green forb frequency (Factor 2) and Fence proximity (Factor 5) on utilization under conditions of low biomass.

availability to utilization was surprising since most reports indicate that animals are attracted to areas that allow them to maximize biting rate (Hunter 1962, Clary et al. 1978, Low et al. 1981, Senft et al. 1985). Many areas possibly became inaccessible when biomass was high because of relatively dense stands of annual broomweed resulting in reduced utilization. Much of the variation in herbage availability was due to variation in forb availability (i.e., annual broomweed) and since there was sufficient forage in areas of lower forb abundance, ease of access made these relatively attractive areas to graze. Other studies have also shown that cattle avoid sites

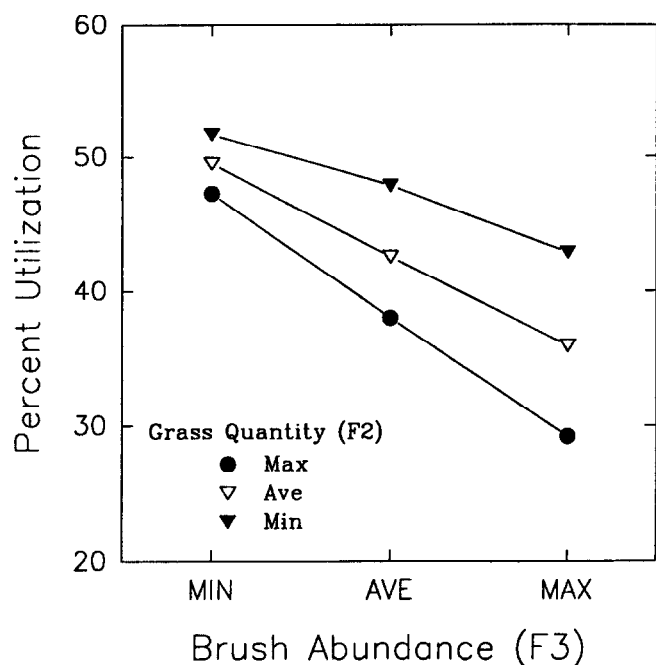


Fig. 2. Influence of Grass quantity (Factor 2) and Brush abundance (Factor 3) on utilization under conditions of high biomass.

with large amounts of nonpreferred plants (Williams 1954, Cook 1966, Senft et al. 1985).

The effect of brush abundance was evident in both the high and low biomass experiments. A slightly curvilinear effect of brush abundance on utilization was evident under high biomass conditions (Table 4). The main impact of brush abundance, however, was evident in the interaction with grass quantity (Fig. 2). As brush abundance increased, utilization of the grasses decreased, most probably due to the physical barrier presented by dense shrublands. Large quantities of grass were required to attract cattle into thick stands of brush whereas in areas low in brush abundance, amount of grass had little impact on utilization (Fig. 2).

The relationship between brush abundance and utilization was affected by green forb frequency under conditions of low biomass (Fig. 3). When green forbs were abundant, utilization of grasses

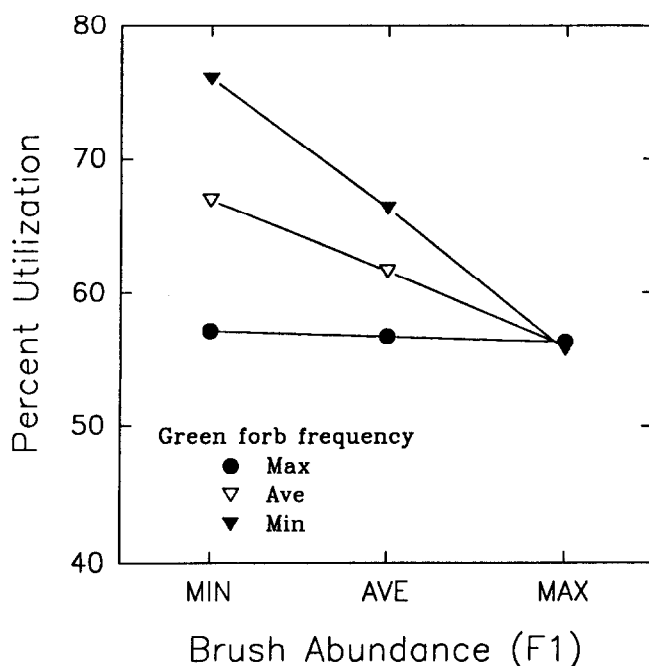


Fig. 3. Influence of Green forb frequency (Factor 2) and Brush abundance (Factor 1) on utilization under conditions of low biomass.

was low regardless of brush abundance. As green forb abundance decreased, utilization of grasses increased probably because animals were less able to be selective. The rate of increase in utilization, however, decreased as brush abundance increased. At very high levels of brush abundance, the frequency of green forbs had no effect on grass utilization (Fig. 3), indicating that when brush stands are dense, increased forb frequency will not attract cattle to penetrate.

Water availability (Factor 5) was not related ($P>0.10$) to utilization under high biomass availability. This was surprising since intense grazing is generally reported around water sources and varies inversely with distance from water (Cook 1966, Clary et al. 1978, Roath and Krueger 1982). The mean distance to water was 816 m but ranged from 40 to 2,140 m. The maximum distance to water was 2,140 but only 12 points had greater distances to water than 1,500 m. These distances may not have been of sufficient magnitude to result in a detectable impact on utilization. Other authors have suggested spacing water points approximately 1,600 m apart in pastures with gentle terrain (Martin and Word 1970, USDA 1976, Holechek et al. 1989).

When biomass was limited, as in the second experiment, water availability became a significant factor affecting utilization (Fig.

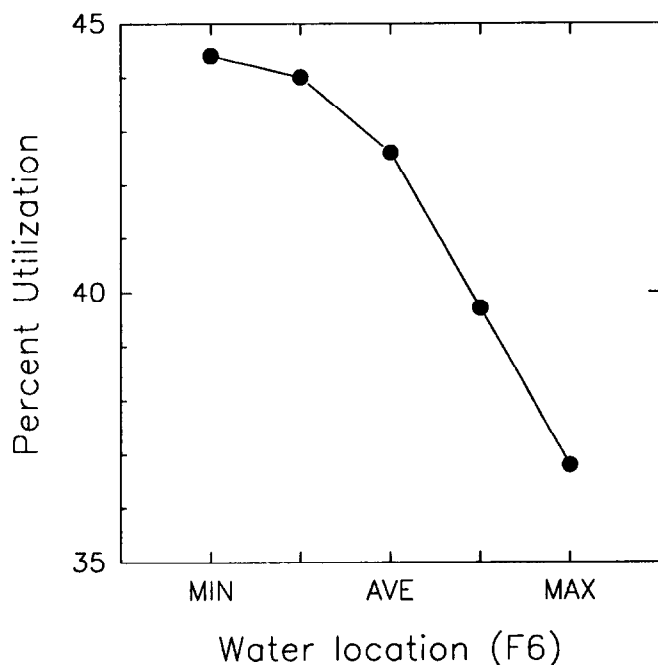


Fig. 4. Utilization of grasses relative to distance from water when biomass is limiting.

4). There was very little effect of water availability up to the average distance from water (816 m) but utilization decreased sharply at greater distances.

Conclusions

Factors which affect utilization changed relative to the amount of herbaceous biomass in the pasture. When biomass was high and forage relatively abundant, the major factors affecting utilization were plant related. Linear combinations (factors) of variables thought to be related to utilization were used to determine that the total amount of vegetation, the amount of grass biomass and brush abundance all contributed to cause a nonrandom use pattern within the experimental pastures.

When total biomass within the pastures was limiting, the physical design of the pasture, as well as the vegetation structure, affected utilization. Road, fence, and water location were the dominant abiotic factors in addition to the biotic factors of frequency of grass and forbs and brush abundance. A smaller portion of the variance could be explained then under high biomass conditions but the utilization pattern did have a nonrandom component. Utilization in these pastures apparently had a nonrandom compo-

nent but the pattern of utilization was related to a complex interplay among pasture and herbage characteristics. The effect of this interplay on utilization patterns was dynamic over time.

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Plant community responses to short duration grazing in tallgrass prairie

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Abstract

A key to management of short duration grazing systems is maintaining proper rest periods for individual pastures, but information on the necessary length of rest periods for tallgrass prairie is limited. Research hypotheses for this study were that tallgrass prairie plant communities would respond differently to grazing schedules incorporating rest periods of varying lengths and that this response would be dependent on stocking rate. Treatments consisted of 3 grazing schedules (2, 3, or 4 rotation cycles per 152 day grazing season) and 2 stocking rates (1.6 and 2.2 times the moderate continuous rate). Plant frequency, standing crop, species composition, and forage utilization were sampled from 1985 to 1989. Precipitation was above average in 4 of the 5 study years. Grazing schedule did not affect any vegetation parameter over time. Stocking rate did not affect plant frequency or species composition. Standing crop was reduced and forage utilization increased at the higher stocking rate but these effects were consistent over time. Frequency of western ragweed [*Ambrosia psilostachya* DC.] and the relative species composition of the forb component increased in all grazed pastures compared to ungrazed pastures. The overall lack of major treatment effects was attributed to favorable precipitation, spring burning, and the initial high-seral successional stage of the experimental pastures.

Key Words: rotation grazing, stocking rate, grazing systems

Short duration grazing (SDG) is a multi-pasture, one-herd grazing system that involves rapid rotation of livestock. A key to management of short duration grazing systems is maintaining proper rest periods for individual pastures. Rest periods should be long enough to allow the most severely grazed plants to recover from grazing before animals re-enter the pasture (Savory 1988). General recommendations have been to allow 30–90 day rest periods with shorter rest periods during rapid plant growth and longer rest periods as plant growth slows.

Most research studies have compared SDG at 1 grazing schedule to continuous grazing. Vegetation response to SDG in such studies has been mixed. Hart et al. (1988), Heitschmidt et al. (1987), and Pitts and Bryant (1987) reported little impact on herbage standing crop or species composition. Thurow et al. (1988) found that SDG at a stocking rate 76% greater than moderate continuous grazing resulted in a shift from midgrass to shortgrass dominance. Only 2 studies have specifically studied different combinations of rest and graze periods within SDG (Denny and Barnes 1977, Tainton et al. 1977). Neither of these studies reported a vegetation response to different grazing schedules.

No research information currently exists for tallgrass prairie ecosystems to determine how long plants need to recover from grazing or how long this time period might vary with season. Practical success has been reported with average grazing cycles of 7

days grazing with 42 days rest (Merrill 1983).

The primary research hypothesis for this study was that tallgrass plant communities would show different plant successional responses when intermittently grazed under schedules with rest periods of varying lengths. An additional hypothesis was that the response to grazing schedule would be dependent on stocking rate.

Study Area

The study area was located on the Oklahoma State University Agronomy Research Range approximately 21 km southwest of Stillwater, Oklahoma (36° 3' N, 97° 14' W). The climate is continental with an average frost-free growing period of 204 days extending from April to October. Average precipitation at Stillwater is 831 mm with 65% falling as rain from May to October. Mean temperature is 15° C with average minimum and maximum temperatures ranging from -4.3° C in January to 34° C in August (Myers 1982).

Soils found on the area are primarily the Grainola and Coyle series, comprising approximately 60 and 35% of the area, respectively. The Grainola series has a loam surface with silty clay loam subsoil and is a member of the fine, mixed, thermic family of Vertic Haplustalfs. The Coyle series has a fine sandy loam surface with sandy clay loam subsoil and is a member of the fine-loamy, siliceous, thermic family of Udic Argiustolls. Range site classification of the Grainola soil is shallow prairie and the Coyle soil is loamy prairie.

The study area was established in 1984 on native tallgrass prairie. The area was dominated by big bluestem [*Andropogon gerardii* Vitman], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and switchgrass [*Panicum virgatum* L.], each comprising approximately 20% of the standing crop by weight in August 1984. Other important species included indiangrass [*Sorghastrum nutans* (L.) Nash], tall dropseed [*Sporobolus asper* (Michx.) Kunth], and western ragweed [*Ambrosia psilostachya* DC.].

Methods

Experimental treatments consisted of 3 grazing schedules under 2 stocking rates. Grazing schedule treatments were based on the number of complete grazing cycles (2, 3, or 4) in an 8-pasture rotation that could be completed during a 152-day spring-summer grazing season. Within grazing schedule treatments, shorter graze/rest periods were used at the beginning of the grazing season when the vegetation was in a rapid growth stage. Graze/rest periods were gradually lengthened during the season as the vegetation matured (Table 1). Each treatment pasture received 19 total days of grazing. Grazing began between 1 April and 1 May depending on the onset of rapid forage growth from year to year. All pastures were burned approximately 4 weeks before the starting dates from 1985 to 1988. The pastures were also burned in late March in 1984, the year before treatments were first applied. Forage levels were low in the spring of 1989 because of drought in the previous summer and the pastures were not burned.

Initial stocking rate treatments were targeted for 1.3 (light) and 1.8 (heavy) times the Soil Conservation Service recommended rate

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

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

¹DG = Days of grazing per cycle.

²DR = Days of rest per cycle.

for the range sites under study. Three animals were grazed on 0.40-ha pastures to obtain the light stocking rate while 5 animals were grazed on 0.48-ha pastures to obtain the heavy stocking rate. Stocker steers and heifers with average summer weights of approximately 315 kg were used in 1985 and 1986. Forage utilization levels were light during these years (Brummer et al. 1988) so dry cows with average weights of 510 kg were used in place of the yearlings in 1987 and 1989. A mixture of cows and yearlings were used in 1988. Poor growing conditions in the summer of 1988 required us to shorten the grazing season which resulted in a reduced stocking rate. Stocking rates for the light and heavy treatments were 99 and 137 animal-unit-days per ha (AUD ha⁻¹) for 1985–86, 159 and 221 AUD ha⁻¹ for 1987 and 1989, and 86 and 116 AUD ha⁻¹ for 1988. Average stocking rates for the entire study were 120 and 166 AUD ha⁻¹ for the light and heavy treatments. Moderate stocking for continuous summer grazing on these range sites is 65–85 AUD ha⁻¹.

Treatments were applied using a simulated 8-pasture short duration grazing system. Pasture number 4 in the rotation was used to determine the mean system effect. Grazing schedules and stocking rates were arranged factorially in a randomized complete block design with 3 replications. In addition, 1 ungrazed pasture was included within each block as a check of plant community responses without the influence of grazing.

Frequency of rooted plants of the major species on the study area was sampled in 100, 0.1-m² plots in all treatment pastures in late July of each year. Species composition was determined in late September each year with the dry-weight-rank method (Gillen and Smith 1986) by sampling 50, 0.1-m² plots in all pastures. Species composition components were big bluestem, little bluestem, switchgrass, indiangrass, other grasses, and forbs. Indiangrass and other grasses were grouped together in 1985 but were separated in the remaining years. Total standing crop was measured by clipping all standing herbage to ground level in 15 of the plots used for composition estimates. Forage utilization was calculated within each block by first subtracting standing crop in grazed pastures from standing crop in the ungrazed pasture and then dividing by standing crop in the ungrazed pasture.

All data were analyzed using analysis of variance techniques for a randomized complete block design with repeated measures (Milliken and Johnson 1984). Grazing schedule and stocking rate were whole plot factors with year as the repeated factor. Pastures were experimental units. The arcsin transformation was applied before the analysis of variance to all dependent variables that were percentages. Grazing treatment (grazing schedule and stocking rate) by year interactions were the main focus of the analysis. If year interactions were not significant ($P = 0.05$), the plant community did not respond to the grazing treatments over time. When significant treatment differences were indicated by the F-tests, treatment means were compared using least significant differences (LSD). In cases where grazing schedule or stocking rate effects were not significant, responses were averaged over all grazing treatments and comparisons were made between grazed and ungrazed treatments.

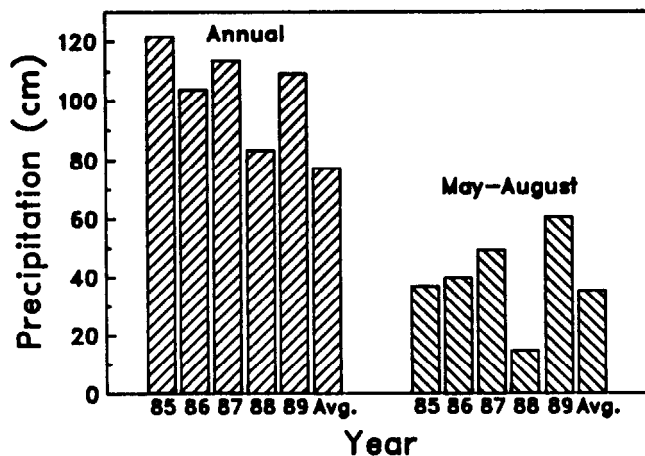


Fig. 1. Precipitation received at the study site from 1985 to 1989. Annual precipitation was totaled on a November to October basis.

Results and Discussion

Precipitation

Precipitation for the entire study period was favorable for plant growth (Fig. 1). Annual precipitation (November to October) was above the long-term average in all years. Precipitation during the main portion of the growing season was also above average except for 1988. Only 2.5–3.0 cm of rain was received per month from May to August 1988. Ungrazed standing crop in September was 2,200 kg ha⁻¹ in 1988 compared to an average of 6,930 kg ha⁻¹ in the other study years. In contrast, May–August rainfall for 1989 was one of the highest amounts on record and was evenly distributed throughout the period.

Standing Crop and Utilization

Standing crop in September was not affected by grazing schedule (Table 2) even though the timing of the grazing periods was quite different. An earlier study conducted at this site (Brummer et al. 1988) showed no short-term effects on growth rates in response

Table 2. Herbage standing crop (kg ha⁻¹) and species composition (%) in September as affected by grazing schedule and stocking rate averaged over years.

Herbage component	Grazing schedule			Stocking rate	
	2-cycle	3-cycle	4-cycle	Light	Heavy
Standing crop	3270	3330	3100	3490 ^{a1}	2970 ^b
Big bluestem	16	16	14	16	15
Little bluestem	20	22	21	23	18
Switchgrass	13	14	13	15	12
Indiangrass	18	15	12	14	16
Other grasses	29	29	33	27	34
Forbs	6 ^a	5 ^a	8 ^b	6 ^x	7 ^y

¹Means within rows and treatment factors with different superscripts are significantly different, $P = 0.05$. Absence of superscripts indicates no significant differences.

to grazing schedules and this response did not change over a longer time period. Tainton et al. (1977) studied rest periods of 20, 40, or 60 days coupled with grazing periods of 2, 10, or 20 days. These treatments had no significant effect on peak standing crop although longer rests and shorter graze periods tended to increase standing crop.

As would be expected from the standing crop results, utilization was also unaffected by grazing schedule. Utilization averaged over years was 45, 44, and 47% for the 2, 3, and 4-cycle grazing schedules, respectively.

The heavy stocking rate significantly reduced September stand-

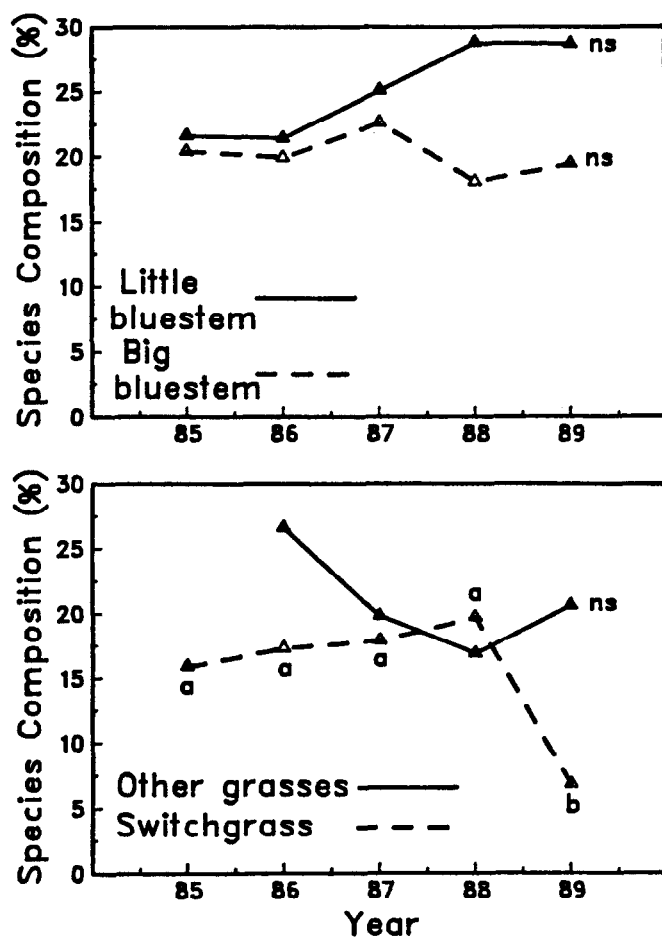


Fig. 2. Species composition responses over years for 4 herbage components. Data points are averages of grazed and ungrazed treatments. Different letters within species indicate year differences, $P = 0.05$. Absence of letters indicates no significant differences between years.

ing crop (Table 2) but this effect was independent of grazing schedule and year. Utilization averaged 41 and 50%, a significant difference, under light and heavy stocking over all years. The heavy stocking rate increased AUD ha⁻¹ by 38% over the light stocking rate but increased utilization by only 22% and reduced standing crop by only 18%. Ralphs et al. (1990) reported that standing crop at the end of the growing season declined in proportion to stocking rate under short duration grazing.

Species Composition

Species composition did not differ among grazing schedules. Forb composition was higher under 4-Cycle grazing (Table 2) but this difference was constant over the 5-year sampling period and, therefore, may have been present before the study began. Denny and Barnes (1977) found no effect on basal cover of vegetation from rest periods ranging from 15 to 140 days. Their experiment covered a 5-year period with 3 dry years followed by 2 wet years.

Composition of grass species was not affected by stocking rate. Forb composition was slightly higher under heavy stocking (Table 2). These differences are probably not biologically significant. Hart et al. (1988) found no response of species composition to stocking rate under short duration or continuous grazing. Ralphs et al. (1990) reported a decline in desirable midgrasses and an increase in poisonous forbs under short duration. The vegetation changes occurred at all stocking rates ranging from 100% to 250% of moderate continuous stocking. Thurow et al. (1988) also observed a decline in midgrasses and an increase in shortgrasses under short

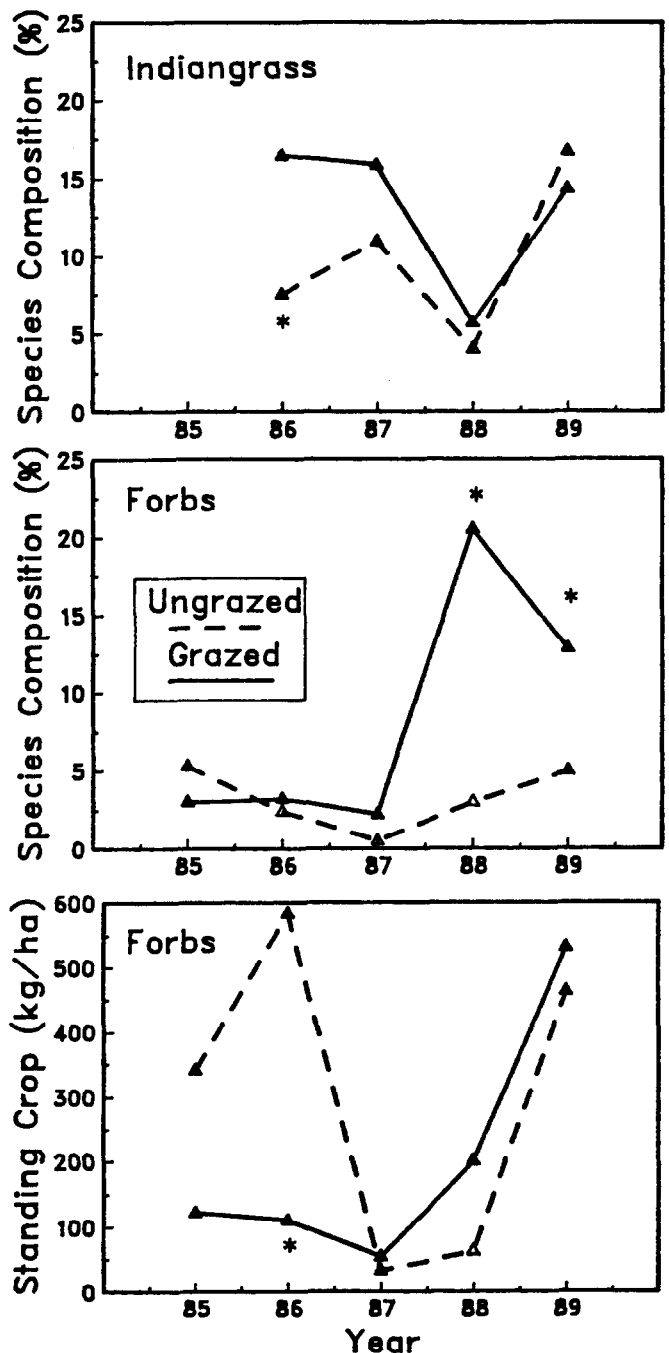


Fig. 3. Relative composition of indiagrass and forbs and standing crop of forbs as affected by the interaction of presence of grazing and year. Asterisks indicate differences between grazing treatments within years, $P = 0.05$.

duration grazing at heavy stocking rates. Butler and Briske (1988) felt that little bluestem would decline under short duration grazing at increased stocking rates because large plants would break up into smaller individuals less able to withstand environmental stresses and interspecific competition.

Big bluestem, little bluestem, switchgrass, and other grasses did not differ between grazed treatments and ungrazed pastures. Of these components, only switchgrass was significantly affected by years (Fig. 2). Switchgrass was apparently seriously reduced by the summer drought of 1988.

Indiagrass was initially lower in the ungrazed pastures but quickly reached a level equal to the grazed pastures (Fig. 3). This

result was due mainly to an increase in the ungrazed pastures rather than a decrease in the grazed pastures. Indiangrass declined dramatically during the drought year but recovered immediately.

Relative forb composition in the grazed pastures increased over six-fold during the drought year but then declined the next year (Fig. 3). Forb composition in the ungrazed pastures increased only moderately in response to wet and dry years. However, actual standing crop of forbs only differed between grazed and ungrazed pastures in 1 year and in that case more forbs were present in the ungrazed pastures (Fig. 3). Much of the increase in forb composition in grazed pastures in 1988 was a reflection of selective use of grasses and heavier than normal utilization on grasses in the dry year. On the other hand, the large increase in forb standing crop in 1989 was due to abundant moisture and was partially offset by increased production of grasses so that percent composition of forbs actually declined in the grazed pastures.

Plant Frequency

Grazing schedule or stocking rate did not account for changes in plant frequency over time for any of the species monitored. Several species exhibited year to year fluctuations in frequency but the changes were similar over all grazing treatments.

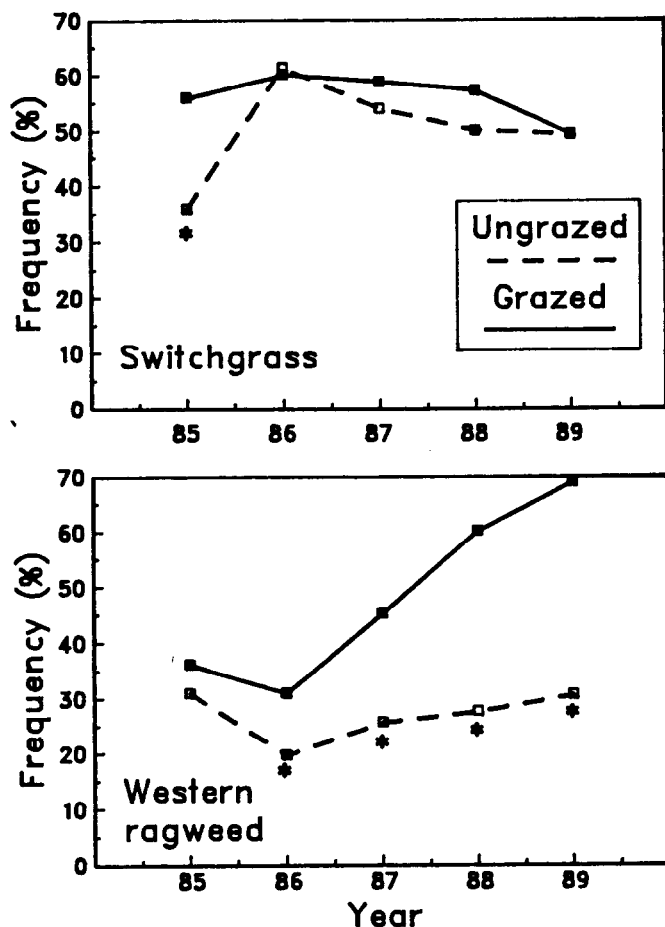


Fig. 4. Plant frequency as affected by the interaction of presence of grazing and year for 2 species. Asterisks indicate differences between grazing treatments within years, $P = 0.05$.

Switchgrass reacted differently in the grazed and ungrazed pastures over years (Fig. 4). Switchgrass was less frequent in the ungrazed pastures in the first year and then increased, but the species remained constant in the grazed pastures. The frequency measurements do not show the same sharp decline in switchgrass in 1989 that was seen in the composition data.

Western ragweed frequency continually increased in the grazed pastures compared to the ungrazed pastures (Fig. 4). This increase occurred even in years such as 1986 and 1987 when forb composition in the grazed pastures was at its lowest point (Fig. 3). Western ragweed contributed 70–80% of the forb component. Such an increase in ragweed frequency would be considered an indication of undesirable species change.

Frequency of all other species monitored was not different between grazed and ungrazed pastures. The response of these species over time (Table 3) should be a gauge of general environmental conditions including the impact of spring burning. An

Table 3. Plant frequency by years averaged over grazed and ungrazed treatments.

Species	Year				
	85	86	87	88	89
Little bluestem	64 ^{bc1}	47 ^a	54 ^{ab}	73 ^c	67 ^{bc}
Big bluestem	56	61	53	56	58
Indiangrass	29 ^a	26 ^a	36 ^{ab}	44 ^b	41 ^b
Tall dropseed	42 ^c	30 ^b	19 ^a	37 ^{bc}	32 ^b
Sideoats grama	11 ^{ab}	7 ^a	18 ^{bc}	16 ^{bc}	22 ^c
Scribner's dicanthelium	53 ^b	27 ^a	58 ^b	61 ^b	66 ^b
Arrowfeather threeawn	18 ^c	8 ^b	2 ^a	4 ^a	3 ^a
Japanese brome	20 ^b	3 ^a	<1 ^a	<1 ^a	<1 ^a
Daisy fleabane	2 ^a	9 ^b	1 ^a	3 ^a	2 ^a
Western yarrow	11 ^b	2 ^a	4 ^{ab}	5 ^{ab}	9 ^b
Catclaw sensitivebriar	7	6	7	8	8
Blackeyedsusan	26 ^b	2 ^a	1 ^a	3 ^a	50 ^c

¹Means within species with different superscripts are significantly different, $P = 0.05$. Absence of superscripts indicates no significant differences.

overall increase in indiangrass and decreases in tall dropseed and arrowfeather threeawn [*Aristida purpurea* Poir.] indicate an increase in range condition (Sims and Dwyer 1965). However, the increase in sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] suggests the opposite. Japanese brome [*Bromus japonicus* Thunb.] was virtually eliminated from the study area after 1986. This cool-season annual grass is particularly susceptible to spring burning (Gillen et al. 1987, Gartner et al. 1978). The biennial blackeyedsusan [*Rudbeckia hirta* L.], 1985 and 1989, and the annual daisy fleabane [*Erigeron strigosus* Muhl. ex Willd.], 1986, illustrate the fluctuations opportunistic species often exhibit in response to specific environmental conditions favorable to their establishment. Little bluestem, Scribner's dicanthelium [*Dicanthelium oligosanthos* (J.A. Schultes) Gould], and western yarrow [*Achillea millefolium* L.] fluctuated over years with no clear direction. Big bluestem and catclaw sensitivebriar [*Schrankia uncinata* Willd.] did not change over years.

Conclusion


Grazing schedule and stocking rate had little effect on the tall-grass prairie plant community in this study. A high seral plant community was maintained under all experimental treatments. This leads to the rejection of the research hypotheses. The lack of stocking rate effect is especially surprising since the stocking rates studied were at least 50% above moderate rates. Three factors probably contributed to these results. First, precipitation was well above average in 4 out of the 5 years of the study. Second, spring burning was applied in the year before treatment initiation and in the first 4 years of treatment application. Spring burning is generally beneficial to tallgrass prairie plant communities and favors higher seral species such as big bluestem that heavy grazing reduces (Towne and Owensby 1984). Third, the plant community was in a high-seral state initially. There was little potential for an upward range trend while the vigor of the dominant species would tend to

buffer any downward trend.

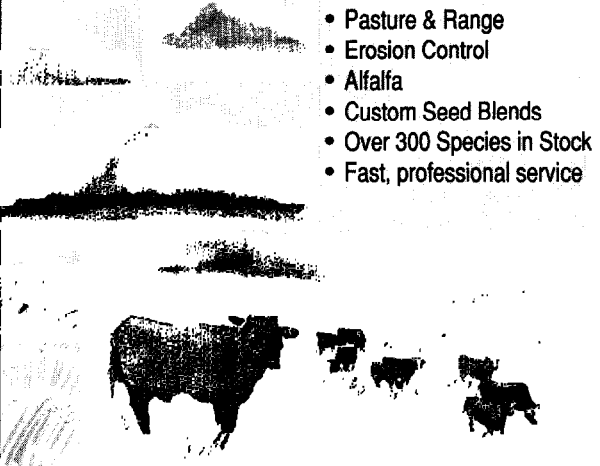
The only indication of an overall grazing effect was the increase in the frequency of western ragweed in the grazed pastures compared to ungrazed areas. The ungrazed pastures are probably the most rigorous standard of comparison possible since they received several spring burns and no grazing during the growing season. However, no major changes in the grazed plant communities could be detected and the grazed pastures remained in a high-seral successional stage. A return to average or below-average precipitation patterns may eventually trigger different vegetation responses.

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Economic relationships of brushpiles, forage production, and California quail hunting

W. PAUL GORENZEL, SONKE A. MASTRUP, AND E. LEE FITZHUGH

Abstract

Harvesting trees for firewood in the oak hardwood rangelands of the western Sierra Nevada foothills creates slash that may be burned to improve livestock forage production or piled into brushpiles for wildlife. The economics of these actions are undocumented. We observed a firewood harvest that created 378 brushpiles averaging 13.6 m² and 1.3 m high, and resulted in a forage loss of 1,807 kg dry weight, equivalent to 4.4 AUM. We projected the present net value of 5 management options concerning the removal or retention of brushpiles during a 15-year period. Inputs included revegetation of burned-brushpile sites, annual forage production on areas with the oak canopy removed, burning and reseeding costs, and income derived from cattle grazing and quail hunting. The options were: (A) burning all brushpiles and reseeding the burned sites; (B) option A without reseeding; (C) burning 235 brushpiles and reseeding, leaving 23 brushpiles/ha for quail; (D) option C without reseeding; (E) leaving all brushpiles. All but option B were economically feasible at a 4% interest rate; at an 8% interest rate, only options C-E were profitable. After 15 years, the accumulated returns per hectare at 4% for options A-E were \$11.67, \$-3.97, \$32.43, \$22.29, and \$23.35, respectively, and at 8%, \$-17.35, \$-25.74, \$8.58, \$3.02, and \$17.98, respectively.

Key Words: *Callipepla californica*, canopy removal, fee hunting, firewood cutting, hardwood rangelands, oaks, *Quercus*.

Hardwood rangelands comprise 3.9 million ha (25%) of the forest land in California and produce about 25% of the total forage available in California (USDA 1972). Grazing by cattle and sheep has been the primary use of hardwood rangelands. Bolsinger (1988) estimated that livestock grazed on 1.2 million ha (60%) of the hardwood range dominated by oaks (*Quercus* spp.) in the early 1980's. Rangeland improvements from 1945 to 1973 reduced the area of oak-dominated hardwoods by about 360,000 ha (Bolsinger 1987). Most oak-woodland owners cite increased forage production as an important reason for cutting oaks (Fortmann and Huntsinger 1987). However, declines in the profitability of the livestock industry forced some ranchers to seek income through firewood cutting and fee hunting. In the past the sale of firewood helped offset the costs of conversion, but recently the income from the sale of firewood alone has become an incentive.

Brush and tree removal to improve forage production or for firewood can reduce California quail (*Callipepla californica*) habitat. Because adult California quail do not like to forage any farther than 15 m into the open (Sumner 1935:194), a clearing as small as 1 ha will remain mostly unused if no brush cover is present. Leaving brushpiles (BP) benefits quail by replacing some of the natural cover that was removed or by creating cover where none previously existed (Leopold 1977). Our objectives were to estimate the costs and benefits of keeping or removing BP and to provide a framework for future analyses.

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Study Area

Three pastures with BP, Scott 14 (S14), Campbell 11 (C11), and Haworth 7 (H7), resulted from clearing operations during the mid-1970's to early 1980's at the University of California Sierra Foothill Range Field Station (SFRFS) in Yuba County. Classified as blue oak (*Q. douglasii*) woodland and blue oak-digger pine (*Pinus sabiniana*) (Mayer and Laudenslayer 1988), the area was representative of western Sierra Nevada foothills. Dominant trees included blue oak, interior live oak (*Q. wislizenii*), valley oak (*Q. lobata*), and digger pine. Elevation ranged from about 140 to 300 m.

Before clearing, tree densities ranged from 120 to 450/ha. Clearing removed shrub cover for quail and reduced tree density to between 25 and 100/ha. The cleared areas were 20 to 45 ha and were dominated by annual grasses (bromes, *Bromus* spp.; fescues, *Vulpia* spp.; wild oats, *Avena* spp.) and forbs (filarees, *Erodium* spp.; clovers, *Trifolium* spp.), with scattered BP or stands of trees. Brushpiles on H7 were burned in December 1985 and reseeded shortly thereafter with a clover and grass seed mix. Brushpiles on S14 and C11 were burned in January 1986 but were not reseeded until mid-October 1986, 9 to 9.5 months later.

A firewood harvest occurred from October 1986 to February 1987 on a fourth, previously uncut area, the Schubert pasture. This area lacked a well-developed shrub component essential for quail cover. Wood cutters removed the oak canopy on 7 separate plots within the 73-ha pasture. Slash from the felled trees was piled to create BP.

Methods

At each harvested plot on the Schubert pasture we mapped the outer boundary and computed area; measured the diameter of all stumps; measured the height and calculated the basal area of each BP. As most BP were circular or elliptical in nature, we measured length (L) and width (W) and computed area (A) as $(3.14) (R)^2$, where $R = (L+W)/4$.

In June 1986 and July 1987, one observer estimated the percent herbaceous-ground cover at burned-BP sites using the plant cramming technique of Hays et al. (1981). We recorded the presence or absence of thistles (*Silybum marianum* and *Carduus tenuiflorus*) at each burned site. Thistles are considered invasive and are unpalatable to cattle (M. Connor, SFRFS superintendent, pers. commun.). Brushpiles are commonly burned on SFRFS to remove thistles growing in and around them.

We calculated forage loss due to coverage by BP (or regained after burning BP) as follows:

$$[(Ar)(FP)] - [(Ar)(RDM)] = AdFR,$$

where:

Ar or total ground area covered by BP = [(number of BP) (average BP basal area in m²)] / (10,000 m²/ha);

FP = average dry forage production in kg/ha at the end of the growing season;

RDM = residual dry matter in kg/ha to remain after grazing;

AdFR = adjusted amount of forage removed by BP in kg/ha.

We used Jansen (1987) and Kay (1987) for estimates of FP after removal of the tree canopy on SFRFS and Clawson et al. (1982) for RDM and AUM forage consumption values. We calculated total dollar value of forage loss as $L = (AdFR/AUM)V$, where AUM = forage equivalent of 1 animal unit month in kg, and V = dollar value of 1 AUM.

We compared the present net worth or value of different management options according to Olson (1986). We calculated the accumulated present values (APV) as follows:

$$APV = \sum_{i=0}^n [(C_n + R_n)(1/(1+I)^n)],$$

where:

C = costs;

R = net income;

n = number of years into the future;

I = discount or interest rate.

We illustrated the calculations at a 4% interest rate and evaluated the sensitivity of the different options to changes in interest rates from 4 to 8%. The management options were: (A) burning all BP and reseeding the burned sites to improve livestock forage production; (B) option A without reseeding; (C) burning 235 BP and reseeding, but leaving 143 BP (24.7 BP/ha) for quail; (D) option C without reseeding; (E) leaving all BP. Field station personnel provided costs for supplies and labor estimates. We valued labor at the California minimum wage rate of \$4.25/hour. Fee hunting for quail was valued at \$2.10/ha/yr (Passof et al. 1985).

Results

Firewood Cutting

Firewood cutters cleared 5.8 ha on 7 plots that averaged 0.8 ha each (Table 1). They cut 1,349 trees ranging in stump diameter

Table 1. Tree and brushpile statistics from 7 plots cleared by firewood cutters on the Schubert pasture, Sierra Foothill Range Field Station, Yuba County, Calif.

Plot	Hec-tares	No. of trees cut	Stump diameter (cm) ($\bar{X} \pm SE$)	Number of brushpiles	Brushpile basal area (m^2) ($\bar{X} \pm SE$)	Brushpile height (m) ($\bar{X} \pm SE$)
1	0.6	100	32.2 \pm 1.2	39	13.8 \pm 1.4	1.1 \pm 0.03
2	0.7	325	22.9 \pm 0.7	52	15.8 \pm 1.4	1.3 \pm 0.03
3	0.4	105	26.6 \pm 1.2	35	9.9 \pm 1.0	1.3 \pm 0.04
4	0.8	182	28.5 \pm 1.1	72	11.2 \pm 0.8	1.2 \pm 0.03
5	0.9	118	33.3 \pm 1.1	58	9.6 \pm 0.7	1.2 \pm 0.02
6	1.1	292	26.2 \pm 0.8	53	16.8 \pm 1.4	1.4 \pm 0.03
7	1.2	227	28.2 \pm 1.0	69	16.8 \pm 1.4	1.3 \pm 0.02

from 2.5 to 95.2 cm. The woodcutters created 378 BP; basal areas ranged from 2.2 to 72.4 m^2 and averaged 13.6 m^2 . Heights ranged from 0.6 to 1.8 m and averaged 1.3 m. BP densities averaged 65.2/ha.

Burned Brushpile Site Revegetation

We examined 44 burned BP on the S14 and C11 pastures and 23 burned BP on the H7 pasture. Herbaceous vegetation was present by the end of the first growing season after burning on all sites, even though none of the burned sites on S14 or C11 were reseeded (Table 2). About 60% of the burned sites on S14 and C11 were in the lowest cover class compared with 30% on the reseeded sites on H7. Otherwise there was little difference between the unseeded and reseeded sites. After the second growing season, all burned sites showed increased cover. On the now reseeded S14 and C11 sites, 89% were in the 51–100% cover classes compared to 91% on H7. There was no difference between the 2 groups in the 3 greatest

Table 2. Number of burned brushpiles on 3 pastures (S14, C11, H7) grouped according to cover class (percent of area covered by herbaceous vegetation) during 2 sampling periods, June 1986 and July 1987, on the Sierra Foothill Range Field Station, Yuba County, Calif.

% Cover class	Location			
	S14 and C11		H7	
	1986	1987	1986	1987
0 – 25	26	0	7	0
26 – 50	10	5	11	2
51 – 75	6	9	3	6
76 – 100	2	30	2	15

cover class frequencies at the end of the second growing season ($X^2 = 0.34$, $df = 2$, $p = 0.84$). In comparison, examination of herbaceous cover on sites adjacent to burned BP indicated all would be in the 76 to 100% cover class.

Most burned sites had thistle, with only minor changes in frequency occurring from the first growing season to the second, from 41 to 39 of 44 sites on S14 and C11, and from 20 to 18 of 23 sites on H7, respectively. Although we did not quantify biomass or percent ground cover for individual grass or forb species, qualitative field observations showed an obvious difference in the abundance of thistle on S14 and C11 compared with H7. Thistle was a major, if not dominant, component of the reestablished herbaceous cover on S14 and C11 burned sites. Although present at 18 to 20 burned sites on H7, thistle was a major component at only 1 site; at the others it was represented by scattered plants.

Canopy Removal, Forage, and Brushpile Relationships

Two studies on SFRFS examined changes in forage production after removal of the oak canopy. Jansen (1987) found that removal of 25, 50, and 75% of blue oak canopies increased forage production during a 7-year period 46% over tree-covered plots to an average of 4,215 kg/ha. During a 21-year period, Kay (1987) noted an average 45% increase in forage on plots with top-killed trees. After year 15, forage production decreased to the levels of tree-covered and open-grassland plots.

With an average basal area of 13.6 m^2 , the 378 BP on the Schubert pasture covered 0.51 ha. Assuming a forage production of 4,215 kg/ha, 2,150 kg of forage was covered by BP. Management practices on SFRFS were based on Clawson et al. (1982) and left a minimum of 672 kg/ha of residual dry matter after grazing. Forage loss adjusted to account for residual dry matter resulted in 1,807 kg of forage unavailable to livestock. At a forage consumption rate of 3% of body weight per day (Clawson et al. 1982) a mature 454 kg cow eats 13.6 kg of forage per day, or 408 kg per month, equivalent to 1 animal unit month (AUM). Calculated forage loss on Schubert from 378 BP was 4.4 AUM. Conversely, if 378 BP were burned, 4.4 AUM would be regained. Following the above procedure, if 235 BP were burned leaving 143 BP, 1,134 kg of forage equivalent of 2.8 AUM would become available to livestock.

Economic Analyses

For the economic comparisons below, the 1,807 and 1,134 kg of forage mentioned above are assumed palatable to cattle and available only if the burned areas are reseeded, as is the normal SFRFS practice.

Although Jansen (1987) and Kay (1987) recorded significant forage increase starting the second growing season after canopy removal, logs and slash were removed (not burned on site) from their plots in a manner that minimized soil disturbance. Our cover surveys (Table 2) of reseeded burned BP on H7 suggested most sites did not achieve the highest cover class rating until the end of

Table 3. Comparison of costs (\$) for burning and reseeding brushpiles, and the value of income derived from forage increases and quail hunting for 5 different management options (A – E) on 5.8 ha, Sierra Foothill Range Field Station, Yuba County, Calif. Positive values represent income, negative values represent costs. Values for forage production and quail hunting are not discounted to present values (see Table 4).

Activity	Option				
	A	B	C	D	E
Burning brushpiles					
Labor ^a	\$-372.52	\$-372.52	\$231.59	\$-231.59	\$ 0
Materials ^b	-189.00	-189.00	-117.50	-117.50	0
Reseeding					
Labor ^c	-69.85	0	-43.42	0	0
Materials ^d	-18.89	0	-11.71	0	0
Forage production					
Year 1 ^e	49.50	37.12	31.50	23.63	0
Years 2–15 ^f	66.00/yr	49.50/yr	42.00/yr	31.50/yr	0
Quail hunting					
Years 1–15 ^g	0	0	12.18/yr	12.18/yr	12.18/yr

^aBased on estimate of 16 hours for 69 brushpiles (M. Connor, SFRFS superintendent, pers. commun.) at \$4.25/hr.

^bBased on 1.9L of diesel fuel per brushpile at \$0.26/L (M. Connor, pers. commun.).

^cBased on estimate of 3 hours for 69 brushpiles (M. Connor, pers. commun.) at \$4.25/hr.

^dBased on seed requirements at 9.2 kg supplied at rate of 17.9 kg/ha, at a cost of \$2.05/kg (M. Connor, pers. commun.).

^eBased on 75% of potential forage production for reseeded sites, an additional 25% reduction for unseeded sites, and \$15/AUM (M. Connor, pers. commun.).

^fBased on 100% of potential forage production for reseeded sites, 75% production for unseeded sites, and \$15/AUM.

^gBased on net income derived from quail hunting at \$2.10/ha/yr (Passaf et al. 1985). No income derived under plans A or B.

the second growing season. We therefore assumed 75% forage production during year 1 and 100% forage production for years 2 through 15. Surveys on S14 and C11 (not reseeded until after the first growing season) showed a similar pattern of revegetation at the end of the second growing season, but dominance by thistles. For the comparisons below, forage production on sites that were burned but not reseeded was reduced an additional 25% relative to reseeded sites to reflect dominance by thistles.

We assumed quail did not benefit from canopy removal and the burning of all BP in options A and B given the lack of brush cover. Hunters would perceive such areas as unsuitable habitat for hunting or leasing. The value of quail hunting was not reduced with the removal of 235 BP in options C and D compared to option E. We assumed hunters would perceive the remaining 24.7 BP/ha as proper habitat management as suggested by existing literature (e.g., Fitzhugh 1983).

The rankings for both initial costs and yearly income were A>B>C>D>E (Table 3). At a 4% discount rate, a positive APV was first achieved for options A and C–E in years 14, 10, 11, and 1, respectively (Table 4). Option B did not achieve positive returns during the 15-year period. Accumulated present values after 15 years ranked C>E>D>A>B. The APV/ha for options A–E were

\$11.67, \$-3.97, \$32.43, \$22.29, and \$23.35, respectively.

The sensitivity analysis of increasing the discount rates from 4 to 8% indicated: (1) all options become less profitable with increasing discount rates; (2) option A became unprofitable at discount rates exceeding about 5.5%; (3) option E was robust to increasing rates, with a decrease in APV/ha of only \$5.37; (4) option E was the most profitable plan at interests rates exceeding about 5.5% (Table 5). The APV/ha for options A–E at an 8% discount rate were \$-17.35, \$-25.74, \$8.58, \$3.02, and \$17.98, respectively.

Table 5. Accumulated present values (\$) of 5 management options (A–E) at different discount rates after 15 years.

Option	Discount rate (%)				
	4	5	6	7	8
A	67.69	19.08	-24.82	-64.57	-100.63
B	-23.05	-59.53	-92.42	-122.27	-149.31
C	188.09	148.14	112.74	79.41	49.78
D	129.29	96.78	67.71	41.37	17.49
E	135.43	126.42	118.30	110.91	104.26

Table 4. Yearly and accumulated present values (\$) at a 4% discount rate for 5 management options (A – E) during a 15-year period on the Sierra Foothill Range Field Station, Yuba County, Calif.

Year	Present value of expected net returns					Accumulated present value				
	A	B	C	D	E	A	B	C	D	E
0	-650.26	-561.52	-404.22	-349.09	0	-650.26	-561.52	-404.22	-349.09	0
1	47.59	35.69	42.00	34.43	11.71	-602.67	-525.83	-362.22	-314.66	11.71
2	61.02	45.77	50.09	40.39	11.26	-541.65	-480.06	-312.13	-274.27	22.97
3	58.67	44.00	48.17	38.83	10.83	-482.98	-436.06	-263.96	-235.44	33.80
4	56.42	42.31	46.31	37.34	10.41	-426.56	-393.75	-217.65	-198.10	44.21
5	54.25	40.68	44.53	35.90	10.01	-372.31	-353.07	-173.12	-162.20	54.22
6	52.16	39.12	42.82	34.52	9.63	-320.15	-313.95	-130.30	-127.68	63.85
7	50.15	37.62	41.17	33.19	9.26	-270.00	-276.33	-89.13	-94.49	73.11
8	48.23	36.17	39.59	31.92	8.90	-221.77	-240.16	-49.54	-62.57	82.01
9	46.37	34.78	38.07	30.69	8.56	-175.40	-205.38	-11.47	-31.88	90.57
10	44.59	33.44	36.60	29.51	8.23	-130.81	-171.94	25.13	-2.37	98.80
11	42.87	32.16	35.20	28.37	7.91	-87.98	-139.78	60.33	26.00	106.71
12	41.22	30.92	33.84	27.28	7.61	-46.72	-108.86	94.17	53.58	114.32
13	39.64	29.73	32.54	26.23	7.32	-7.08	-79.13	126.71	79.81	121.64
14	38.12	28.59	31.29	25.22	7.03	31.04	-50.54	158.00	105.03	128.67
15	36.65	27.49	30.09	24.26	6.76	67.69	-23.05	188.09	129.29	135.43

Given the conditions at SFRFS and the assumptions we made, burning all BP to increase forage production for livestock was profitable only at conservative discount rates of less than about 5.5% and only if the burned BP were reseeded. Leaving all BP for quail management (option E) incurred no initial expenses, thus allowing positive APV starting in year 1. The lower returns of options B and D compared with A and C, respectively, illustrated the beneficial value of reseeding burned BP. The cost savings of not reseeding burned sites was offset by decreased forage production. An integration of cattle and quail management or quail management only (options C-E) gave positive returns during a 15-year period at all interest rates. Despite lower APV than option E at higher discount rates, option C may be the best management strategy. In areas of moderate to high rainfall such as the Coast Ranges and Sacramento Valley foothills, grazing thins dense grass stands, improving access for California quail and permitting the growth of preferred seed-producing forbs (Leopold 1977:178).

Our surveys suggested that the disturbed ground at the burned BP sites was favorable for germination of thistles and that reseeding soon after burning reduced thistle abundance. Thistle seeds are consumed by California quail (Leopold 1977:241, 243, 244) but apparently are not a preferred food if other forbs, especially legumes, are present. On SFRFS the seed mix used on the burned sites and for range improvements in general included rose clover (*Trifolium hirtum*). Rose clover is a highly preferred quail food that represented up to 92% by weight of the fall diet on SFRFS (Kay 1986). Reseeding apparently provides multiple benefits for livestock and quail.

The data and assumptions that were used best apply to the central Sierra Nevada foothills. Local factors and differences between regions must be considered. For example, average forage production and forage response to canopy removal will vary from site to site. Studies in the south-central Sierra Nevada foothills and southern Coast Range found forage production 40–100% greater under blue oaks than in open grassland and forage yields declined after canopy removal to levels comparable to the less productive open grasslands (Holland 1980). The method of canopy removal can affect forage production. Kay (1987) recorded an average forage increase of 66% for root-killed trees using a 2,4-D, but only a 45% increase for top-killed trees. The use of herbicides would increase costs.

Kay (1987) reported a 15-year time limit to forage increases. Time limits for other sites or regions are undocumented. Similarly a decrease in the wildlife value of BP with time is suggested by the popular literature (e.g., Fitzhugh 1983) due to settling and decay. The rate of decay and settling is related to site specific climatic factors and the species of woody materials used in the BP. If a 10-year lifespan is assumed for BP, the order of rankings for plans A-E based on APV at 4% will not change. However, the APV for plans C-E will decrease to \$151.46, \$92.36, and \$98.80, respectively.

The presence of BP may affect other wildlife. The California ground squirrel (*Spermophilus beecheyi*) commonly burrows under and around BP in some regions of California, suggesting BP are a favorable habitat component for squirrels. However, the response of ground squirrels to new BP is not documented. We observed no apparent increase in ground squirrels on the new BP areas on SFRFS. At densities of 8 or more per hectare, ground squirrels can compete with livestock for forage (Fitch and Bentley 1949, Howard et al. 1959). Ground squirrels are quail nest predators; Glading (1938) attributed 30 nests destroyed by ground squirrels from a total of 96 nests found. These losses occurred when ground squirrel density was about 25 squirrels/ha. Brushpiles are attractive to certain nongame birds and may increase deer use of open areas by breaking sight lines and providing hiding cover.

Dollar values of the impacts of BP on other wildlife besides quail are not readily available but may be important in some cases.

Costs and income may vary depending on location. In Texas, gross income from a season hunting lease for bobwhite (*Colinus virginianus*) ranges from \$1.24 to \$16.06/ha, with a net of about \$12.35/ha for the higher price (Guthery 1986). For comparison, Passof et al. (1985) listed an average gross income of \$3.09/ha and a net income of \$2.10/ha for quail hunting in California. The price of a hunting lease depends in part on the quality of habitat, the number of birds present, services and facilities offered, the degree of management, and/or the hunter's perception of that management.

We have provided a framework to calculate the amount of forage covered by BP and to analyze the economics of removing or keeping BP relative to changes in forage production. We applied data obtained on SFRFS to specific cleared areas totalling 5.8 ha, as an example, although it is unrealistic that hunters would lease such a limited area. We assume most quail hunting leases in California involve hundreds of hectares. Over such large areas, patch cuts for firewood that create BP could be perceived by the hunter as improving the habitat for quail in the entire leased area, possibly resulting in a higher lease price for the entire area. The financial impact of the BP would thus be spread over a greater area than the site-limited changes in forage production that would occur with their removal.

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Vegetation changes following brush control in creosotebush communities

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Abstract

Changes in herbaceous plant density and canopy cover of creosotebush (*Larrea tridentata* Sesse & Moc. ex DC) and associated shrubs following brush control treatments were measured in Sonoran and Chihuahuan Desert communities. Treatments were applied in 2 successive years at the Santa Rita Experimental range, Arizona, and 3 locations in Chihuahua, Mexico. Across all locations and years 1.5 kg/ha tebuthiuron [*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea] > 1.0 kg/ha tebuthiuron = disking = disking with furrowing > 2-way railing > 0.5 kg/ha tebuthiuron > land imprinting in reducing canopy cover of creosotebush and associated shrubs. At the Santa Rita Experimental Range annual precipitation was above long-term mean in 1982, 1983, 1984, and 1985; and grass density increased on all treated and untreated plots. Annual precipitation was below long-term mean during 1986 and 1987 and grass density decreased on both treated and untreated plots but did not decrease to pre-treatment densities. Forb densities were less than 3 plants/m² throughout the study, except in 1987 when Russian thistle (*Salsola iberica* Sennen & Pau) increased on all plots. At the Chihuahuan locations, grass densities usually increased during the first year of the study, but very low precipitation throughout the study caused subsequent reductions in grass and forb densities. In dry years brush control treatments did not increase herbaceous plant density.

Key Words: *Larrea tridentata*, disking, land imprinting, Sonoran Desert, Chihuahuan Desert, railing, grass density, shrub cover, tebuthiuron

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Creosotebush (*Larrea tridentata* Sesse & Moc. ex DC) covers about 262,680 km² in the United States (Kuchler 1964) and about 453,250 km² in Mexico (Leopold 1950). According to Gardner (1951) creosotebush increased in both countries from 1910 to 1950, and continues to increase in density and area (Buffington and Herbel 1965, Herbel et al. 1985). As creosotebush and associated woody species increase, forage production decreases (Anderson et al. 1957). Likewise, when woody plant populations are removed or thinned, forage production increases (Morton et al. 1978, Scifres et al. 1979, Jacoby et al. 1982, Herbel et al. 1983). Traditionally, creosotebush has been controlled by mechanical methods: disking, root plowing, roller chopping, shredding, and railing. Disking and root plowing uproot woody plants and are most effective on shallow rooted plants such as big sagebrush (*Artemisia tridentata* Nutt.) and creosotebush (Holechek et al. 1989), but they also destroy most herbaceous plants. Railing, shredding, chaining, land imprinting, and roller chopping remove the tops of plants, but usually kill fewer woody plants than disking or root plowing.

Chemical methods have been developed for creosotebush control with tebuthiuron [*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea] perhaps the most effective. It controls creosotebush and many other woody species on rangelands (Morton et al. 1978, Herbel et al. 1985).

The objectives of this study were to measure changes in herbaceous plant density and canopy cover of creosotebush and associated shrubs in Sonoran and Chihuahuan Desert communities after broadcast applications of tebuthiuron at 0.5, 1.0, and 1.5 kg a.i./ha rates, land imprinting, 2-way railing, disking, and disking with furrowing. Tebuthiuron was applied at 3 rates because results of previous research on creosotebush suggested that control varied with soil depth and texture, and grass and forb responses varied with rate (Jacoby et al. 1982, Herbel et al. 1985).

Disking was included as a standard for comparison with other methods. Disking with furrowing was added to determine if this treatment would aid in water conservation and increase the density of herbaceous plants. Railing and land imprinting were included because they have relatively low energy requirements. Land

Table 1. Monthly and total annual precipitation at Santa Rita Experimental Range from 1981 to 1987 and 11-year monthly mean.

Month	Year						11-year ¹ monthly mean
	1981	1982	1983	1984	1985	1986	
	----- (mm) -----						
January	0	44	11	49	39	0	25
February	0	31	88	0	90	29	2
March	28	36	70	0	26	25	11
April	2	0	0	12	0	4	21
May	0	7	10	4	12	24	29
June	5	10	0	0	0	26	2
July	79	143	102	130	22	22	11
August	9	118	168	184	127	105	65
September	29	58	66	59	48	26	23
October	5	0	191	98	79	0	6
November	0	26	0	0	38	10	17
December	19	55	65	78	24	56	50
Total	176	528	771	614	505	327	262
							359

¹Precipitation from 1977 to 1987.

imprinting is a relatively new method and must be compared with other methods before it can be recommended on rangelands.

Materials and Methods

The study was conducted on the Santa Rita Experimental Range (SRER), 40 km south of Tucson, Ariz., in the Sonoran Desert and at 3 locations in the Chihuahuan Desert of Mexico: Ranchos El Toro, 100 km east of Villa Ahumada; La Reforma, 60 km east of Parral; and Los Pozos, 20 km northeast of Aldama. Elevation is 970 m at SRER, 1,500 m at La Reforma, and about 1,400 m at Los Pozos and El Toro. Long-term mean annual precipitation at SRER, La Reforma, Los Pozos, and El Toro¹ is 359, 428, 328, and 227 mm, respectively. At the Chihuahuan locations 70 to 90% of the annual precipitation occurs June through September (SARH 1982) but is bimodal at SRER, with about 60% occurring June through October and 40% in fall, winter, and spring (Green and Martin 1967). The uneven distribution of precipitation is natural, as is the drought which occurs at most Sonoran and Chihuahuan locations each year during late spring and early summer. Less severe drought in early winter occurs in the Sonoran Desert. The spring drought is usually broken in July and the winter drought by precipitation in December or January (Table 1). Because precipitation in the Chihuahuan Desert occurs primarily in summer months, plants usually undergo stress during early summer before rains begin in June or July (SARH 1982). Rainfall during the study

¹Ing. Sergio Mendez provided 15-year precipitation records from Rancho El Toro and 3 adjacent ranches from which precipitation monthly and annual means were calculated rather than from the 22-year record from Villa Ahumada 100 km to the west.

Table 2. Physical and chemical properties, series, and classification of the upper 20 cm of soils at Ranchos La Reforma, Los Pozos, and, El Toro, Chihuahua, Mexico, and at Santa Rita Experimental Range (SRER), Arizona, United States of America.

Location	Organic matter	pH	Electrical conductivity	Series	Classification ¹
	(%)		(ds/m)		
La Reforma	3.6	6.9	2.9	Kimbrough sandy loam	loamy, mixed, thermic shallow Petrocalcic, Calciustoll
Los Pozos	1.5	7.2	1.3	Jerag sandy loam	loamy, mixed, thermic shallow, Patrocalcic
El Toro	1.1	7.9	1.1	Algerita sandy loam	loamy, mixed, thermic coarse, Ustolic, Typic Calciorthid
SRER	0.7	7.9	1.1	Anthony sandy loam	loamy, thermic, Typic Torrifluvent

¹Soil classification is from Soil Survey Staff (1975).

was measured by individual rain gauges maintained within the study sites at each location.

Slope inclination varies from 2 to 16% at La Reforma, and from 0 to 5% at the other 3 locations. Surface soil textures at the 4 sites are sandy loams underlain by a caliche hardpan that ranges from 5 to 100 cm below the soil surface. Physical and chemical properties, soil series, and classification are shown in Table 2 (Soil Survey Staff 1975).

Creosotebush was the dominant shrub at all locations except La Reforma, where it shared dominance with whitethorn acacia (*Acacia constricta* Benth), shrubby senna (*Cassia wislizeni* Gray), and tarbush (*Flourensia cernua* DC.). Mariola (*Parthenium incanum* H.B.K.), whitethorn acacia, and tarbush were abundant at Los Pozos; javelina brush (*Condalia eriocoides* [A. Gray] M.C. Johnston), and honey mesquite (*Prosopis glandulosa* Torr.) et El Toro; and velvet mesquite (*P. velutina* Woot.) and desert zinnia (*Zinnia pumila* Gray) at SRER. The most abundant native grasses were fluffgrass (*Erioneuron pulchellum* [H.B.K.] Tateoka) at all locations; black grama (*Bouteloua eriopoda* Torr.) at La Reforma and El Toro; threeawns (*Aristida* spp.) at Los Pozos and SRER; bushmuhly (*Muhlenbergia porteri* Scribn.) at Los Pozos, El Toro; and SRER; spike pappusgrass (*Enneapogon Desvauxii* Beauv.) at Los Pozos, and sideoats grama (*B. curtipendula* [Michx.] Torr.) at La Reforma.

Study areas (about 30 ha) at all locations were fenced to exclude livestock in summer 1981 and divided into 2 parts: 1 for treatment in 1981 and 1 for treatment in 1982. Each part was subdivided into 24 plots, 50 by 100 m. The experimental design was a randomized block with 3 replications. The following 8 treatments were applied: broadcast applications of 20% pellets of tebuthiuron at (1) 0.5, (2) 1.0, and (3) 1.5 kg a.i./ha, (4) land imprinting, (5) 2-way rilling, (6) disk plowing, (7) disk plowing with contour furrowing, and (8) untreated check.

Hand application of the tebuthiuron pellets was accomplished by crisscrossing plots 4 times: twice lengthwise using 10 swaths each 5 m wide and twice crosswise on 20 swaths, each 5 m wide. The clay pellets contained 20% a.i. tebuthiuron and were 3.2 mm in diameter and approximately 4.8 mm in length.

The rail consisted of three 2.65-m lengths of railroad steel bolted together to form a triangle and weighted with rock (approximately 770 kg). The rail was pulled over the plot twice in opposite directions. A standard 3-bottom disk plow on a 3-point hitch weighing 500 kg was used at the Mexican sites, and a pull-type 3-bottom disk plow weighing, 1,000 kg was used at the SRER. Both disk plows had 65-cm diameter disks which penetrated soils to 30 cm. A border disk constructed contour furrows at 10-m intervals.

The land imprinter, fabricated from 1.27-cm thick steel plate, consisted of 2 non-directional geometric forms (V-pitter and pit-digger) welded on separate 1- by 1-m cylindrical capsules. Capsules

Table 3. Density (plants/m²) of grasses and forbs measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical control methods and remeasured in 1984, 1986, or 1987 at SRER.

Treatment	1981 Treatments						1982 Treatments					
	Grasses			Forbs			Grasses			Forbs		
	May 1981	Oct 1984	Oct 1986	May 1981	Oct 1984	Oct 1986	May 1982	Oct 1984	Oct 1987	May 1982	Oct 1984	Oct 1987
	(plants/m ²)											
Tebuthiuron, 0.5 kg/ha	1	8	5	1	T ¹	T	0	12	8	3	1	8
Tebuthiuron, 1.0 kg/ha	1	10	8	2	T	T	2	2	4	T	T	21
Tebuthiuron, 1.5 kg/ha	2	10	6	1	T	T	2	8	6	2	T	8
Land imprinting	T	5	3	2	2	1	1	20	4	1	2	36
2-way raiing	3	13	10	1	3	2	2	18	12	3	2	16
Disking	2	4	5	4	3	3	2	7	5	4	1	48
Disking with furrowing	2	4	5	1	3	4	1	23	8	4	1	14
Untreated check	3	6	4	1	4	1	2	13	5	5	1	12
Date average	2	8	6	2	2	1	2	13	8	3	1	20
L.S.D. 0.05	NS ²	7	NS	NS	2	NS	NS	10	5	NS	NS	NS

¹T = Less than 0.5 plants/m²

²NS = No significant difference at the 5% level of probability.

were filled with water and linked on a shaft. Iron boxes located at the front and rear were filled with rock to aid in soil penetration (Dixon and Simanton 1980). Total weight was approximately 4 metric tons.

Mechanical treatments were applied between 14 June and 17 July 1981 and between 26 May and 27 June 1982. Land imprinter treatments were applied at SRER only in 1981 and at all sites in 1982. Tebuthiuron was applied in May of both years.

Prior to treatment, 3 permanent line transects 30 m long were established in each plot. Shrub canopy cover was determined by measuring the canopy that intercepted the transect, and from those values percent canopy cover was calculated. Herbaceous plant density was determined by counting grasses and forbs on belts 30 cm wide on the 30-m transect. Measurements were made before treatment at all locations in May 1981 and 1982. SRER plots treated in 1981 were remeasured in October 1984 and October 1986, and plots treated in May 1982 were remeasured in October 1984 and October 1987. At La Reforma, Los Pozos, and El Toro, plots treated in 1981 were remeasured in May 1982, May 1983, and September 1983, and plots treated in 1982 were remeasured in May and September 1983. Because vegetation changes were very small

at the Chihuahuan locations subsequent to the first year following May treatment, only data from the initial May measurements and the May 1983 remeasurements are shown.

Herbaceous density and shrub cover data were subjected to analyses of variance and, where appropriate, mean separation was performed using the protected LSD mean separation technique to compare cover and density on treated plots with the cover and density on untreated check plots at a location within the year of treatment (Steel and Torrie 1980).

Results and Discussion

Santa Rita Experimental Range

Precipitation

Annual precipitation in 1981 was below long-term mean, but July precipitation was above average (Table 1). In 1982, 1983, 1984, and 1985 annual precipitation was above the long-term mean, but in 1986 and 1987 precipitation was below the long-term mean. In 1985 and 1986 the spring drought was not broken until August. Precipitation was above average in September, October, and November 1985, but was far below average in September, October, and November 1986. During 1987 precipitation was

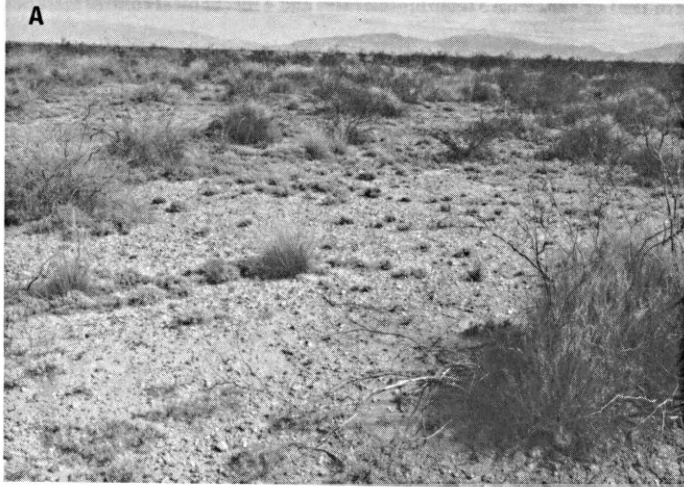
Table 4. Cover (%) of creosotebush and other shrubs measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical control methods and remeasurement in 1986 or 1987 at SRER.

Treatment	1981 Treatments				1982 Treatments			
	Creosotebush		Other Shrubs		Creosotebush		Other Shrubs	
	May 1981	Oct 1986	May 1981	Oct 1986	May 1982	Oct 1987	May 1982	Oct 1987
	(% cover)							
Tebuthiuron, 0.5 kg/ha	25	3	1	1	28	9	8	3
Tebuthiuron, 1.0 kg/ha	22	T ¹	7	2	22	T	8	1
Tebuthiuron, 1.5 kg/ha	22	0	3	1	24	T	10	2
Land imprinting	25	12	3	3	21	11	11	6
2-way raiing	35	10	5	4	20	5	5	6
Disking	18	6	2	4	25	2	8	3
Disking with furrowing	18	2	4	4	30	4	4	4
Untreated check	26	18	5	7	23	17	5	6
Date average	24	6	4	3	24	6	7	4
L.S.D. 0.05	12	8	NS ²	3	8	10	NS	NS

¹T = Less than 0.5% cover

²NS = No significant difference at the 5% level of probability

A



B



Fig. 1. Tebuthiuron plot treated at 0.5 kg a.i./ha in May 1981 at Santa Rita Experimental Range (A) and untreated check plot (B): both photographed October 1984.

below long-term mean throughout the summer and fall.

Grass Density

Perennial grass density averaged about 2.0 plants/m² prior to brush control on both the 1981 and 1982 plots (Table 3). After above-average summer rainfall in 1982, 1983, and 1984, grass densities increased on nearly all plots but there were few differences among treatments when remeasurements were made in October 1984, 1986, or 1987. Fluffgrass and threeawn made up most of the density changes. Bushmulhy plants increased in size on the tebuthiuron plots but density remained about the same (Figs. 1A and 1B). Increased growth of bushmulhy may be related to the higher fertility levels of soil under the dead creosotebush plants, as documented by Cox et al. (1983). The increase in size of bushmulhy was not observed on the land imprinted and 2-way railed plots because these mechanical methods did not kill the shrub plants (Fig. 2). Disking and disking with furrowing killed most of the bushmulhy plants. Spike dropseed (*Sporobolus contractus* Hitchc.) was abundant on the disked and disked with furrowing plots in 1984, 1986, and 1987 but not when treatments were applied (Fig. 3).

The data in Table 3 do not indicate that tebuthiuron lowered grass densities, and they do not show any significant increase in grass density due to water retention by furrows or depressions

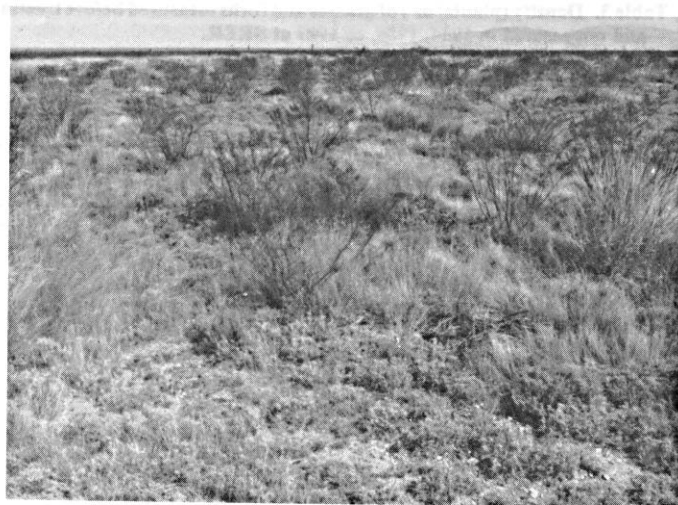


Fig. 2. Two-way railed plot treated June 1982 at Santa Rita Experimental Range and photographed October 1984. Note creosotebush regrowth and abundance of fluffgrass and threeawn plants.



Fig. 3. Disk plowed plot treated June 1982 at Santa Rita Experimental Range and photographed October 1984. Tall grass plants are primarily spike dropseed and short grass plants are threeawns.

created by the border disk or land imprinter. Grass densities were highest and significantly different from the checks on 2-way railed plots. The rail is an implement which tends to smooth rather than increase surface roughness.

Forb Density

Winter forbs were present on all plots before treatment in 1981 and 1982 (Table 3), but density varied within and between plots and averaged 2 and 3 plants/m² in May 1981 and 1982, respectively. Forb density remained about the same between the time of treatment in 1981 or 1982 and remeasurement in 1984. The plants measured in October 1984 were primarily summer annuals but densities of winter forbs measured in the spring of 1983 (data not shown) did not differ significantly from densities in the fall, even though the species were different. Forb density was essentially unchanged between 1984 and 1986 on plots treated in 1981, but

Table 5. Precipitation (mm) at 3 Chihuahuan locations in 1981, 1982, and 1983.

Months/Years	La Reforma	Los Pozos	El Toro
(mm)			
June–September 1981	148	141	198
October–May 1981–82	58	121	28
June–September 1982	38	73	188
October–May 1982–83	28	10	25
June–September 1983	104	93	135
<i>Long-term Mean</i>			
June–September	365	268	171
October–May	63	60	56

there was a dramatic increase in forb density between 1984 and 1987 on plots treated in 1982. Russian thistle (*Salsola iberica* Sennen & Pau) accounted for much of the increase. Russian thistle germinated and became established on all tebuthiuron and mechanically treated plots. Johnsen and Morton (1989) found that 5 years after a 0.9 kg/ha application 5% of the applied tebuthiuron remained in a semiarid soil of northcentral Arizona. They found averages of 21, 88, and 127 g/ha remaining in the 0- to 7-, 7- to 15-, and 15- to 30-cm depths, respectively, after 5 years. Tebuthiuron was found in soil treated at 2 or more kg/ha 11 years after application. This information suggests Russian thistle is tolerant of low amounts of tebuthiuron. Russian thistle establishment apparently was aided by the mechanical treatments as well as the environmental conditions in 1987. While increases in Russian thistle occurred on the untreated check plots of the 1982 treatments, Russian thistle density increases were not detected in 1986 on the 1981 treatments.

Table 6. Density of grasses and forbs (plants/m²) measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical methods and remeasured in 1983 at Rancho La Reforma, Chihuahua.

Treatment	Grasses				Forbs			
	1981 Treatment		1982 Treatment		1981 Treatment		1982 Treatment	
	May 1981	May 1983	May 1982	May 1983	May 1981	May 1983	May 1982	May 1983
	(plants/m ²)							
Tebuthiuron, 0.5 kg/ha	3	2	19	1	48	T ¹	2	0
Tebuthiuron, 1.0 kg/ha	1	1	20	1	44	T	2	0
Tebuthiuron, 1.5 kg/ha	T	1	24	1	82	T	T	0
Land imprinting ²	— ³	—	18	3	—	—	3	0
2-way riling	4	1	21	2	65	1	2	0
Disking	6	T	16	1	83	T	T	T
Disking with furrowing	1	T	28	1	85	T	1	3
Untreated check	T	T	29	2	78	T	3	2
Date average	2	1	22	2	69	T	2	1
L.S.D. 0.05	NS ⁴	NS	NS	NS	NS	NS	NS	NS

¹T = Less than 0.5 plants/m²

²Land imprinting treatments were not applied in 1981 at Chihuahuan locations

³— = No data

⁴NS = No significant difference at the 5% level of probability

Table 7. Density of grasses and forbs (plants/m²) measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical methods and remeasured in 1983 at Rancho Los Pozos, Chihuahua.

Treatment	Grasses				Forbs			
	1981 Treatment		1982 Treatment		1981 Treatment		1982 Treatment	
	May 1981	May 1983	May 1982	May 1983	May 1981	May 1983	May 1982	May 1983
	(plants/m ²)							
Tebuthiuron, 0.5 kg/ha	26	9	9	13	18	20	31	14
Tebuthiuron, 1.0 kg/ha	38	7	13	11	34	19	34	9
Tebuthiuron, 1.5 kg/ha	9	9	11	13	21	11	31	18
Land imprinting ¹	— ²	—	9	11	—	—	28	31
2-way riling	19	7	8	10	75	28	32	59
Disking	8	2	9	3	68	36	25	36
Disking with furrowing	5	3	7	4	48	34	34	29
Untreated check	33	9	7	11	33	42	34	28
Date average	20	7	9	10	42	28	31	28
L.S.D. 0.05	NS ³	NS	NS	3	NS	17	NS	21

¹Land imprinting treatments were not applied in 1981 at Chihuahuan locations

²— = No data

³NS = No significant difference at the 5% level of probability

Table 8. Density of grasses and forbs (plants/m²) measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical methods and remeasured in 1983 at Rancho El Toro, Chihuahua.

Treatment	Grasses				Forbs			
	1981 Treatment		1982 Treatment		1981 Treatment		1982 Treatment	
	May 1981	May 1983	May 1982	May 1983	May 1981	May 1983	May 1982	May 1983
	(plants/m ²)							
Tebuthiuron, 0.5 kg/ha	4	7	17	8	49	5	3	4
Tebuthiuron, 1.0 kg/ha	6	7	16	9	58	4	3	3
Tebuthiuron, 1.5 kg/ha	6	4	16	8	69	3	1	3
Land imprinting ¹	— ²	—	—	9	—	—	—	6
2-way raiing	7	12	—	1	63	14	—	6
Disking	4	4	—	T ³	66	11	—	5
Disking with furrowing	5	6	—	T	48	11	—	2
Untreated check	6	15	14	18	49	5	4	1
Date average	5	8	16	6	56	8	2	4
L.S.D. 0.05	4	6	NS ⁴	7	NS	4	NS	3

¹Land imprinting treatments were not applied in 1981 at Chihuahuan locations

²— = No data

³T = Less than 0.5 plants/m²

⁴NS = No significant difference at the 5% level of probability

Table 9 Canopy cover of shrubs (%) measured before treatment in 1981 or 1982 with 3 tebuthiuron rates and 4 mechanical methods and remeasured in 1983 at Ranchos La Reforma, Los Pozos, and El Toro, Chihuahua.

Treatment	La Reforma				Los Pozos				El Toro			
	1981 Treatment		1982 Treatment		1981 Treatment		1982 Treatment		1981 Treatment		1982 Treatment	
	May 1981	May 1983	May 1982	May 1983	May 1981	May 1983	May 1982	May 1983	May 1981	May 1983	May 1982	May 1983
	(% Cover)											
Tebuthiuron, 0.5 kg/ha	35	7	37	12	19	6	19	10	18	2	19	4
Tebuthiuron, 1.0 kg/ha	42	10	32	8	20	4	20	5	15	1	28	4
Tebuthiuron, 1.5 kg/ha	32	1	34	7	14	2	22	1	19	T ¹	22	2
Land imprinting ²	— ³	—	30	5	—	—	—	5	—	—	—	4
2-way raiing	28	5	37	2	21	5	—	2	14	2	—	2
Disking	36	4	38	4	18	3	—	2	16	1	—	1
Disking with furrowing	26	5	35	6	13	3	—	2	11	1	—	1
Untreated check	28	29	38	21	19	21	20	17	11	13	20	18
Date average	32	9	35	8	18	7	20	6	15	3	20	4
L.S.D. 0.05	NS ⁴	13	NS	4	10	11	NS	10	9	4	NS	8

¹T = Less than 0.5% cover

²Land imprinting treatments were not applied in 1981 at Chihuahuan locations

³— = No data

⁴NS = No significant difference at the 5% level of probability

Creosotebush and Other Shrub Cover

Creosotebush canopy cover was lower 6 growing seasons after treatment compared to untreated check except on plots where land imprinting and 2-way raiing were applied in 1981 and where land imprinting and tebuthiuron at 0.5 kg/ha were applied in 1982 (Table 4). Tebuthiuron at 1.0 and 1.5 kg/ha, disking, and disking with furrowing reduced creosotebush canopy cover by about 21%.

All treatments reduced cover of other shrubs when plots were remeasured in 1982 (data not shown); but cover, due to regrowth on land imprinted and 2-way railed plots, was equal to or near pre-treatment levels in 1986 (Table 4). Land imprinting was not effective in reducing desert zinnia cover from 1981 to 1986 when applied to wet soil but did in 1982 when soil was dry (data not shown). Between 1984 and remeasurements in 1986 or 1987, cover of other shrubs did not change or increased only slightly.

Chihuahuan Desert Locations

Precipitation

June to September precipitation was below the long-term mean at La Reforma and Los Pozos throughout the study (Table 5). In

1981 summer precipitation was only about 50% of the long-term mean at both locations but it was evenly distributed throughout the growing season. Summer precipitation during 1982 was very low at both locations. The only significant rainfall at La Reforma in 1983 was 80 mm in August. At Los Pozos, October to May 1981–1982 precipitation was about twice the long-term mean, but the June to September precipitation in 1982 and 1983 was far below the long-term mean. At El Toro the June to September precipitation was slightly above long-term mean in 1981 and 1982 but October to May precipitation was about half the long-term mean each year.

Grass and Forb Density

At La Reforma grass density before treatment in May in 1981 and May 1982 averaged 2 and 22 plants/m², respectively (Table 6). Sideoats grama, black grama, and fluffgrass were the most abundant species. The higher density in May 1982 was probably due to grazing exclusion during the previous year and the relatively even distribution of precipitation during the 1981 June to September period, which permitted the establishment of perennial grass seedlings. Grass density decreased on all treated and untreated plots

from May 1982 to May 1983 during a period of very low precipitation. All grass species on all treatments were adversely affected by low precipitation in 1982 and 1983. Cool-season forb density before treatment in May 1981 averaged 69 plants/m² and included 37 different species. By May 1982 forb density had dropped dramatically on both treated and untreated plots. Below-average precipitation continued during 1982 and 1983 and forb densities were low until the study was terminated in October 1983.

At Los Pozos grass density before treatments were applied averaged 20 and 9 plants/m² on the 1981 and 1982 treatments, respectively (Table 7). Grass density usually decreased on the 1981 treatments between 1981 and 1983. There were slight increases on the 1982 0.5 and 1.5 kg/ha tebuthiuron, land imprinted, 2-way railed, and check plots, but decreases occurred on the disked and disked with furrowed plots. Forb density decreased on all the 1981 treatments except the 0.5 kg/ha tebuthiuron and decreased on all the 1982 treatments except the land imprinted, 2-way railed, and disked plots.

At El Toro black grama was the most abundant grass species; however, saltgrass (*Distichlis stricta* [Torr.] Rydb.), fluffgrass, and bushmuly were also numerous on most of the plots (Table 8). Slight increases occurred in the density of grasses on most of the 1981 plots. Decreases occurred in the density of grasses on the 1982 tebuthiuron plots due to toxicity of tebuthiuron to black grama. A slight increase in density occurred on the untreated check. Forbs were abundant before brush control treatments were applied in May 1981, but their density decreased on all treated and untreated plots during the study. The decrease was probably due to the very low precipitation during the October to May periods of 1981–1982 and 1982–1983, which would have prevented establishment and growth of winter annual forbs (Table 5).

Creosotebush and Other Shrub Cover

Creosotebush canopy cover at the time of treatment averaged 3% on the 1981 and 1982 plots at La Reforma, but other shrubs averaged 29 and 32% on the 1981 and 1982 plots, respectively. Thus, total shrub cover was higher at La Reforma than at the other 2 Chihuahuan locations and the SRER (Tables 4 and 9). All tebuthiuron and mechanical treatments applied in both years at the Chihuahuan locations reduced shrub cover except the 0.5 kg/ha tebuthiuron treatment in 1982 at Los Pozos. There were small changes in shrub canopy cover on the untreated check plots during the study. The decreases were usually associated with low precipitation. Increases were mostly associated with growth of individual plants.

Conclusions

Over all locations and years, the treatments reduced shrub canopy cover in the following order: 1.5 kg/ha tebuthiuron > 1.0 kg/ha tebuthiuron = disking = disking with furrowing > 2-way railing > 0.5 kg/ha tebuthiuron > land imprinting. During the 6-growing-season study in the Sonoran Desert community, grass density increased in all treatments when precipitation was above normal, but density decreased when precipitation was below average. However, grass densities remained above their pre-treatment levels on all treatments. In contrast, forb densities did not increase except in 1987, the second year of below-average precipitation, and then the increase was due primarily to Russian thistle. Because of

very low precipitation at the Chihuahuan locations, grass and forb densities decreased below pre-treatment levels after an initial 1-year increase.

Furrowing and land imprinting are treatments designed to increase amounts of water retained in the soil (Anderson et al. 1957, Dixon and Simanton 1980). In arid areas furrowing and land imprinting should reduce runoff and retain water for use by plants on the treated site. At SRER grass densities on plots receiving disking with furrowing were not greater than on plots disked only. Grass densities were highest and significantly different from the checks on 2-way railed plots. The rail is an implement which tends to smooth rather than increase surface roughness. Data from this study suggest that furrowing and land imprinting are not effective in increasing grass or forb densities in a Sonoran Desert creosotebush community. When precipitation was below average, brush control treatments did not increase herbaceous plant density.

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Effect of fertilizer on plant biomass distribution and net accumulation rate in an alpine meadow in central Himalaya, India

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Abstract

The objective of this study was to observe the effect of nitrogen application on the plant biomass and rate of net aboveground accumulation in an alpine grassland of Central Himalaya, dominated by the grass *Danthonia cachemyriana*, Jaub. and Spach. Nitrogen was applied in the form of urea at the rate of 250 kg ha⁻¹ in late May 1984 and late April 1985. Aboveground and belowground biomass from both fertilized and control plots were measured from a day before fertilization and at 30-day intervals throughout the growing season in 1984 and 1985. The aboveground net accumulation (ANC) in 1984 was 409 g m⁻² for the control and 450 g m⁻² for treated plots, and in 1985 it was 382 g m⁻² in the control and 458 g m⁻² in the treated plots. The differences in ANC between control and fertilized plots were significant at $P < 0.05$ for 1984 and $P < 0.01$ in 1985. The belowground net accumulation (BNA) in 1984 was slightly greater in the treated plots (314 g m⁻²) compared to the control (207 g m⁻²), but in 1985 the BNA was significantly ($P < 0.05$) higher (328 g m⁻²) for the control plots compared to treated plot (222 g m⁻²). Results indicate that this alpine meadow is less nitrogen limited than the grasslands studied elsewhere. Nitrogen fertilization had more effects on the pattern of biomass allocation than on total production.

Key Words: fertilizer, plant biomass, net primary productivity

Nutrient availability limits growth of most tundra plants, as shown by fertilization experiments in many locations throughout the arctic (Babb and Whitfield 1977; Mckendrick et al., 1978, 1980; Shaver and Chapin 1980, 1986; Shaver et al. 1986). The availability of nitrogen, more than any other element, is the critical determinant of both the structure and productivity of grassland communities (Date 1973). Henry et al., (1986) found, for the tundra plant communities, the response to nitrogen to be weaker in the more mesic and wet-mesic locations compared to desert communities.

The present study deals with the effect of nitrogen application on plant biomass and net dry matter accumulation rates in a Central Himalayan alpine grassland, dominated by the grass *Danthonia cachemyriana* Jaub and Spach. In this grassland, plant growth during the favorable growth period (May–September) seems not to be limited by moisture. Sufficient soil moisture is provided by the snow-melt from May to mid-June and rainfall is quite high from mid-June to mid-September due to the monsoon (Ram et al. 1988). We hypothesized that because of the favorable moisture, nutrient release from litter of the previous year should be adequate for the growing season so that plant productivity would not be limited by a shortage of nitrogen.

Methods and Materials

The study site Rudranath, lies between 30° 28' N lat. and 79° 20' E long., at an average elevation of 3,600 m. The mean daily temperature in 1984 ranged from 5.0 and 21.2° C and the mean

daily minimum between 2.0 and 10.5° C from April to November. The low values occurred in November and the high in June. During May–October the site received 1,586 mm rainfall. The soil is a residue from crystalline silty loam in texture with a mean depth of 30 cm. The pH ranged between 4.5–5.3, Kjeldahl nitrogen ranged between 0.4–0.9%, and available phosphorus between 0.001–0.007% (Ram et al. 1989).

The effect of nitrogen application was studied during the snow-free period (from May to September) of 1984 and 1985. Six physiognomically similar plots each of 10 × 10 m area were selected for the study. Three of these plots were maintained as control (Co), while the remaining 3 were fertilized once in 1984 (F₁) and again in 1985 (F₂) in a randomized block design. Each plot was divided into 1 × 1-m subplots. Nitrogen in the F₁ and F₂ plots was applied in the form of urea at the rate of 250 kg/ha⁻¹ in late May 1984 and late April 1985.

The aboveground and belowground plant biomass from both fertilized and control plots were measured. Starting from a day before the fertilization, sampling was done at 30-day intervals through 30 October each year. For aboveground biomass, three 1 × 1-m subplots were harvested at random from each treatment plot on each sampling date. No subplot was harvested more than once. The harvested material from each subplot was separated into live shoots and dead shoots. Litter was collected from each subplot subsequent to its harvest.

The belowground plant material was collected using one monolith (25 × 25 × 30 cm) from each harvest subplot after the aboveground components had been sampled. Roots were washed free of soil particles using a thin jet of water. All plant samples were dried at 80° C and weighed.

The aboveground net accumulation (ANC) was the peak live shoot biomass of the community. The belowground accumulation, was the difference between maximum and minimum biomass values during the study period.

The rate of biomass increment was calculated on the basis of live shoot dry weight as follows:

$$\text{Increment rate} = W_2 W_1 / t_2 - t_1$$

where, W_1 and W_2 are the shoot dry weights (g m⁻²) at the beginning (t_1) and at the end (t_2) of the sampling period. The interval $t_2 - t_1$ is in days.

Results

Aboveground Biomass

The time-series biomass of live shoots, dead shoots, litter, and belowground parts for both treatments are shown in Figure 1 for the 2 study years. The data were subjected to Analysis of Variance using the SPSS (New Version) programme (SPSS Inc. Chicago, Illinois).

In 1984 the live shoot biomass increased from 100 g m⁻² in May to 409 g m⁻² in August in the control plots (CO₈₄) and from 94 g m⁻² in May to 450 g m⁻² in August in the fertilized plots (F₁). Thereafter the live shoot biomass declined and reached a minimum (33 and 34 g m⁻²) in October.

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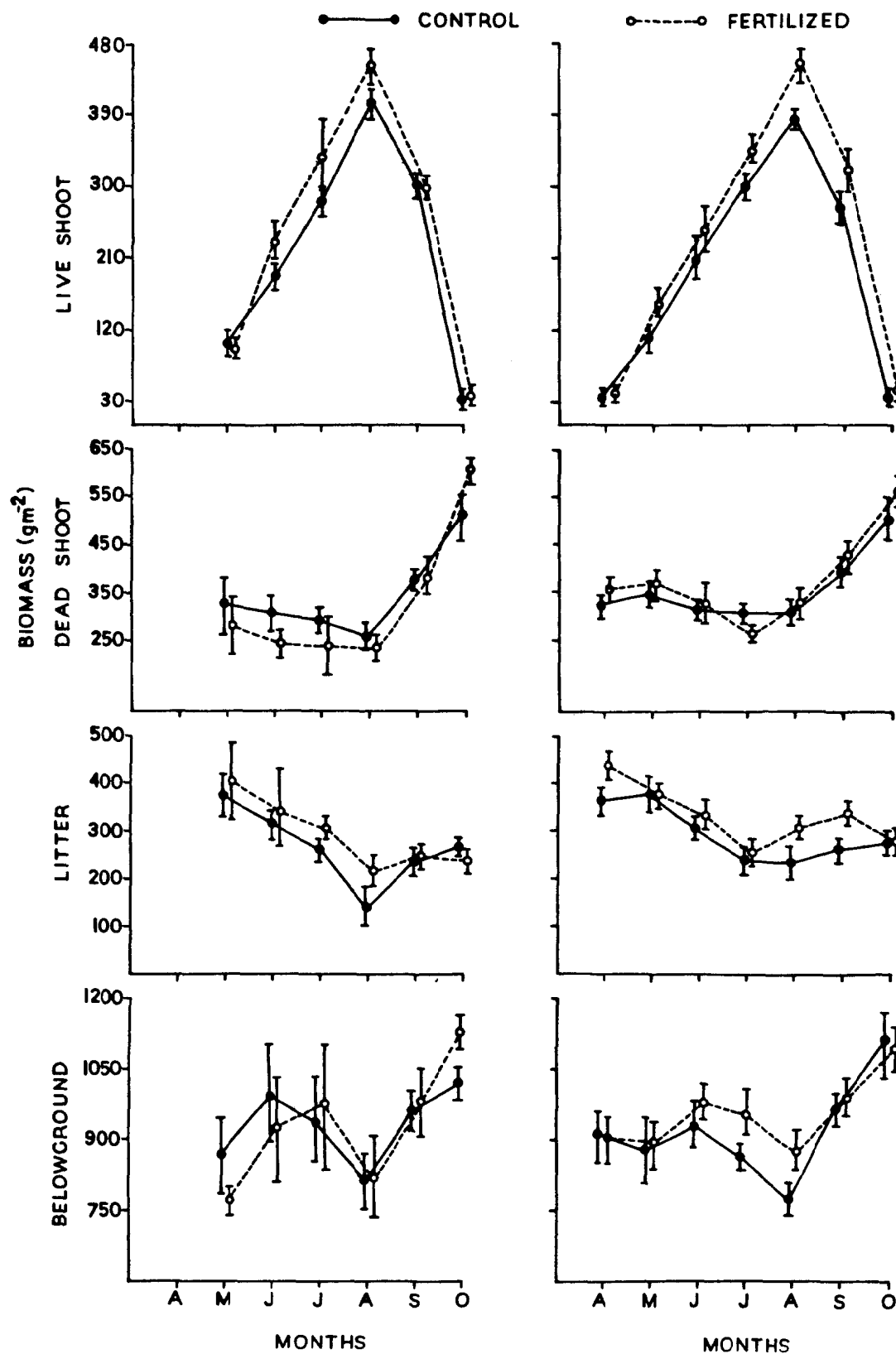


Fig. 1. Variation in the biomass of various primary producer compartments in an alpine meadow of Central Himalaya. The solid line is for control and broken line is for fertilizer treatment. Vertical bars represent ± 1 SE.

In 1985, the biomass increased from 43 g m⁻² in April to 458 g m⁻² in August in the fertilized plots (F₂), compared to 33 g m⁻² in April and 382 g m⁻² in August in the control plots (Co₈₅). The differences due to month were significant ($p < 0.01$) but not due to year. The peak biomass was significantly higher in fertilized plots than in control plots in both years, ($p < 0.05$ in 1984 and $p < 0.01$ in 1985).

The dead shoot biomass declined from May to August each year in both the control and fertilized plots. Values were 323 g m⁻² in May and 286 g m⁻² in August in Co₈₄ and 275 g m⁻² in May and 235 g m⁻² in August in the fertilized plot. After August the dead shoot biomass increased and attained a peak (509 g m⁻² and 500 g m⁻² in control plots and 610 g m⁻² and 559 g m⁻² in fertilized plots in 1984 and 1985, respectively) in October. The differences due to year were not significant but those due to months ($p < 0.01$) and due to fertilization ($p < 0.01$) were significant.

The litter mass declined from May to August in both the control and fertilized plots in both the years. The seasonal patterns of dead biomass and litter in fertilized plots were similar to that in the control plots both years. However, peak values were significantly ($p < 0.01$) different (375 g m⁻² vs 404 g m⁻² in 1984 and 376 vs 443 g m⁻² in 1985). The differences due to months were also significant for both years ($p < 0.01$).

Belowground Biomass and Root:Shoot Ratio

The seasonal patterns of the belowground biomass were similar for control and fertilized plots and the differences due to months were significant ($p < 0.05$). Fertilization did not show a significant effect on the peak biomass of belowground components.

The root:shoot ratio decreased from April and May to August, increasing in September–October. It ranged from 1.1 : 1 (August) to 2.6 : 1 (May) in control and from 1.1 : 1 (August) to 2.3 : 1 (May) in the fertilized plots during the 2 years of study.

Effect of Fertilizer on Net Aboveground Biomass Accumulation

The aboveground net accumulation (ANC) was 409 g m⁻² for Co₈₄ and 450 g m⁻² for F₂ treatment and 382 g m⁻² for Co₈₅ and 458 g m⁻² for F₁ treatments (Fig. 2). The ANC was significantly different between the control and the treated plots ($p < 0.05$ in 1984 and $p < 0.01$ in 1985).

The belowground net accumulation (BNA) was slightly but not significantly higher in F₁ (314 g m⁻²) than in Co₈₄ (207 g m⁻²). However, in 1985 the BNA was 328 g m⁻² in Co₈₅ and 222 g m⁻² in F₂ plots ($p < 0.05$). Obviously, double fertilization brought about a

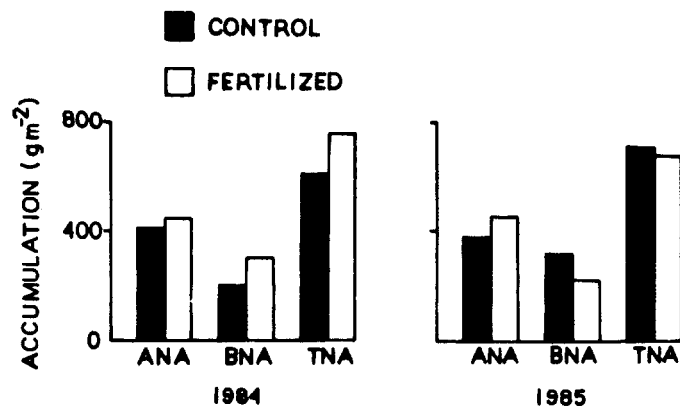


Fig. 2. Effect of fertilizer on aboveground net accumulation (ANA), Belowground net accumulation (BNA) and total net accumulation (TNA) in 2 years of study.

change in allocation of biomass to plant parts, causing a dramatic increase in accumulation of biomass in shoots partly at the expense of roots.

Discussion

Lorentz and Rogler (1973a) have reported that spring growth can be stimulated by application of fertilizer nitrogen. Earlier initiation of spring growth and accelerated growth rate early in the season following application of nitrogen have also been observed by others (Rogler and Lorentz 1965, Johnston et al. 1967) as well. In a study of mixed prairie, Lorentz and Rogler (1973b) have reported that subsequent to fertilization the cool-season species found in the mixed prairie begin growth early in the spring, a time when low soil temperature restricts natural nitrification processes. Therefore, response to application of nitrogen early in the growing season is sizeable, even on soils relatively high in total nitrogen.

The increase in the live shoot biomass after application of fertilizer was significantly different from the control during both years of study. The litter mass was significantly greater in the second year of the study, evidently as a consequence of induced production. These results indicate net accumulation in the Central Himalayan alpine meadow is somewhat nutrient limited, but far less than that of the tussock tundra, Alaska (Table 1). For, the latter Shaver and Chapin (1986) reported that fertilization caused an increase in total

Table 1. Effect of fertilizer on aboveground biomass and production, and comparison with other Alpine studies.

	Biomass (g m ⁻²)				Production (g m ⁻²)		Vegetation type	Source
	Once fertilized Control	fertilized	Twice fertilized Control	fertilized	Control	Fertilized		
Mt. Washington Alpine (44° N)	146.0	151.4	—	—	146.0	151.4	<i>Carex meadow</i>	Bliss (1966)
Toalik Lake, Alaska (68°)	155.6	278.7	—	—	70.1	131.1	<i>Eriophorum vaginatum</i>	Chapin and Shaver (1985)
Eagle Creek Alaska (65°)	212.1	330.6	—	—	—	—	<i>E. vaginatum</i>	Shaver and Chapin (1986)
Kuparuk Ridge (68°)	151.7	169.4	—	—	—	—	<i>E. vaginatum</i>	Shaver and Chapin (1986)
Kuparuk Ridge (68°)	139.6	152.3	139.6	206.3	—	—	<i>E. vaginatum</i>	Shaver and Chapin (1986)
Sagwon (69°)	—	—	161.7	288.1	—	—	<i>E. vaginatum</i>	Shaver and Chapin (1986)
Rudranath Himalaya (30° N)	409.0	450.0	382.0	458.0	382.0–409.0	450–458	<i>Danthonia cachenmyriana</i>	Present study

community aboveground production up to 300% and aboveground biomass 110%. In this study total net biomass accumulations in F₁ and F₂ plots were 15 to 20% greater than the control plots (Table 1).

The effect of nitrogen fertilization during the first year on the net accumulation of belowground biomass was conspicuous in the later part of the season (September–October), the value being 140 g m⁻² compared to 67 g m⁻² in the control plot. It seems that this large accumulation of biomass in the belowground component in fertilized plots supports a particularly faster growth of shoots in the first month of the second year of the study than occurred in control plots. A part of this increase in shoot growth was at the expense of the belowground parts. We suggest that the retranslocation of nutrients from the belowground component to growing shoots made plants relatively independent of the soil nutrient pool. The effect of fertilization when soil temperatures are lower is likely to be insignificant on shoot growth for low temperatures would limit the nitrogen uptake by physiologically inactive plants.

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Herbage response following control of honey mesquite within single tree lysimeters

R.K. HEITSCHMIDT AND S.L. DOWHOWER

Abstract

Justification for controlling honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) on rangelands has been traditionally related to enhanced livestock production from increased herbage production. More recently, however, it has been hypothesized that control would also increase off-site water yield. The objective of this 3-year study was to quantify the effects of control of individual honey mesquite trees inside nonweighable lysimeters on herbage standing crop, leaf area, and aboveground production. Utilizing frequent harvest techniques, estimated aboveground net primary production (ANPP) in intact tree lysimeters averaged 235 g/m². Estimated ANPP in the treated lysimeters averaged 349 g/m². The increased ANPP, following removal of the trees, resulted in significantly greater amounts of herbaceous leaf area and standing crop. The increase in ANPP was relatively uniform regardless of distance from the trunk of removed trees and was the result of increased production by those herbage species present at time of control rather than a shift in species composition. The dominant species in both treatments was Texas wintergrass (*Stipa leucosthrica* Trin. & Rupr.). Sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] was a subdominant. The results, in combination with concurrent water yield studies, suggest control of honey mesquite will not enhance water yields dramatically in this region in the absence of livestock grazing.

Key Words: aboveground net primary production, Texas wintergrass, sideoats grama, leaf area index

Justification for controlling honey mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.) in the Rolling Plains of Texas has been related traditionally to the enhancement of livestock production as a result of increased forage production (Scifres and Polk 1974, Dahl et al. 1978, McDaniel et al. 1978, Brock et al. 1978, Scifres 1980, Jacoby et al. 1982, Bedunah and Sosebee 1984, Heitschmidt et al. 1986). However, it has been suggested recently that control of honey mesquite will also dramatically enhance off-site water yield (Griffin and McCarl 1989) primarily through increased subsurface flow. Unfortunately, this claim has been made in the absence of any definitive supportive and/or refutable data. Moreover, this claim is founded on the underlying hypothesis that water losses via evapotranspiration processes are greater in honey mesquite-dominated grasslands supporting a sparse stand of herbaceous species than a honey mesquite-free grassland dominated by a dense stand of herbaceous species.

The objective of this study was to quantify the effects of honey mesquite control on herbaceous growth dynamics and aboveground net primary production (ANPP). This study was but one of several (Carlson et al. 1990, Hicks et al. 1990, Ansley et al. 1990) designed to quantify the potential effects of honey mesquite control on water yield in the Rolling Plains.

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Materials and Methods

Study Area

The study area was the Wagon Creek Spade Ranch located (33° 20'N, 99° 14'W) on the eastern edge of the Rolling Plains in Throckmorton County. Climate is continental and semiarid. Average annual precipitation is 682 mm and bimodally distributed (Fig. 1) with peaks in May (96 mm) and September (118 mm).

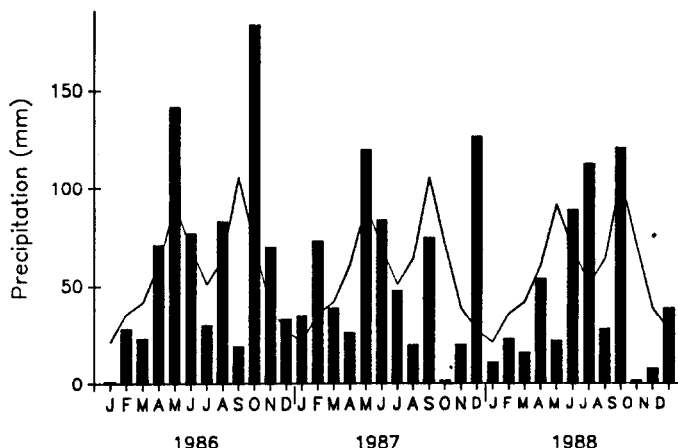


Fig. 1. Monthly precipitation (mm) during 3-year study and 28-year average (continuous line) at Texas Experimental Ranch located 1 km from study site (from Heitschmidt et al. 1985).

Average maximum daily temperatures range from 11.4° C in January to 35.8° C in July. Average minimum daily temperatures range from -2.4° C in January to 22° C in July. The average frost-free growing season is 220 days. Elevation is about 450 m.

The vegetation of the region is mixed grass prairie under an overstory of sparse to dense stands of honey mesquite. Dominant midgrasses are sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], a warm-season perennial, Texas wintergrass (*Stipa leucosthrica* Trin. & Rupr.), a cool-season perennial, and Japanese brome (*Bromus japonicus* Thumb.), a cool-season annual. Dominant shortgrasses are buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] and common curlymesquite [*Hilaria berlandieri* (Steud.) Nash], both warm-season perennials. The dominant forbs are Texas broomweed [*Xanthocephalum texanum* (DC.) Shinners], a warm-season annual, and heath aster (*Aster ericoides* L.), a warm-season perennial.

The study site was located inside a 15-ha livestock enclosure of single-stemmed honey mesquite trees. Soils were Nuvalde clay loam (fine, silty, mixed thermic Typic Calciustolls), a deep, well-drained, slowly permeable soil located on gently sloping (1-3%) uplands. The silty clay loam surface is about 28 cm thick. The silty clay loam subsoil is about 56 cm thick. The underlying alluvial parent material is silty clay with 30-60% calcium carbonate. Range site classification is clay loam. For a more detailed description of

the regional climate, soils and vegetation, see Heitschmidt et al. (1985).

Treatments

Six nonweighable lysimeters were installed in July 1985 around similar sized honey mesquite trees (mean trunk basal diameter = 18 cm, mean canopy area = 10 m²). Trenches were cut around each tree to a depth of 2.5 m about 1 m beyond the drip line (mean area/lysimeter = 21.3 m²). Trench walls were lined with impervious plastic and filled with soil. A fiberglass border was installed to channel surface flow into a runoff trough. Three of the trees were then harvested at 20 cm above the soil surface and stumps treated with 1 liter of diesel oil to prevent regrowth. The thrice replicated treatments are hereafter referred to as herbaceous (H) or herbaceous plus honey mesquite (H+M). For a more detailed description of the installed treatments, see Carlson et al. (1990).

Data Collection, Summarization, and Analyses

Herbaceous standing crop was estimated at various time intervals (Fig. 2) during the 3-year study using nondestructive point-sampling techniques and regression analyses. Number of hits per pin, 10 pins per vertical frame, was recorded by species/species group (hereafter referred to as species) and tissue (i.e., green lamina, senesced lamina, and stem) on each sample date. Sample frames were located at 0.5-m intervals along 4 permanent line transects radiating from the base (H+M treatment) or remaining stump (H treatment) of each tree to the lysimeter border (mean number of sample frames/lysimeter = 18). All plots were mowed to a height of about 5 cm in January of each year.

To establish biomass to frequency of hits and leaf area to biomass relationships, ten 0.25-m² quadrats were located in representative stands of vegetation outside the lysimeters a total of 10 times during 1986 and 1987. Samples were collected whenever a major change in the phenological growth pattern of the dominant species occurred. Each quadrat was sampled with 3 frames (i.e., 30 pins) prior to clipping the standing crop by species at ground level. Live and dead lamina and stem areas of hand separated subsamples were estimated using a digitized leaf area meter. All biomass was dried at 60° C to a constant weight before weighing.

Various linear and curvilinear functions were examined for goodness of fit for biomass to frequency of hits and leaf area to biomass relationships prior to selecting the simple linear relationship of $y = bx$. To determine the effect of species, class of tissue and date on biomass/frequency of hits and leaf area/biomass ratios, a series of least squares analysis of variance (AOV) models were used. When significant ($P < 0.05$) effects were found, data sets were repeatedly subdivided and re-analyzed until no significant differences were present. The final regressions used are presented in Tables 1 and 2.

Various repeated measures AOV models were used to assess differences between treatments, dates, and distance from tree or remaining stump in herbage standing crop, leaf area index (LAI), species composition, and aboveground net primary production (ANPP) which was calculated in 3 manners: (1) summation of positive increases in total standing crop; (2) summation of peak standing crop by species/species group; and (3) peak total standing crop. The error term for detecting treatment differences was replication within treatment. The error term for assessing differences among tissue categories was replication within treatment by category. The residuals were used to test for date and/or year effects. Tukey Q procedures were used for mean separation where appropriate.

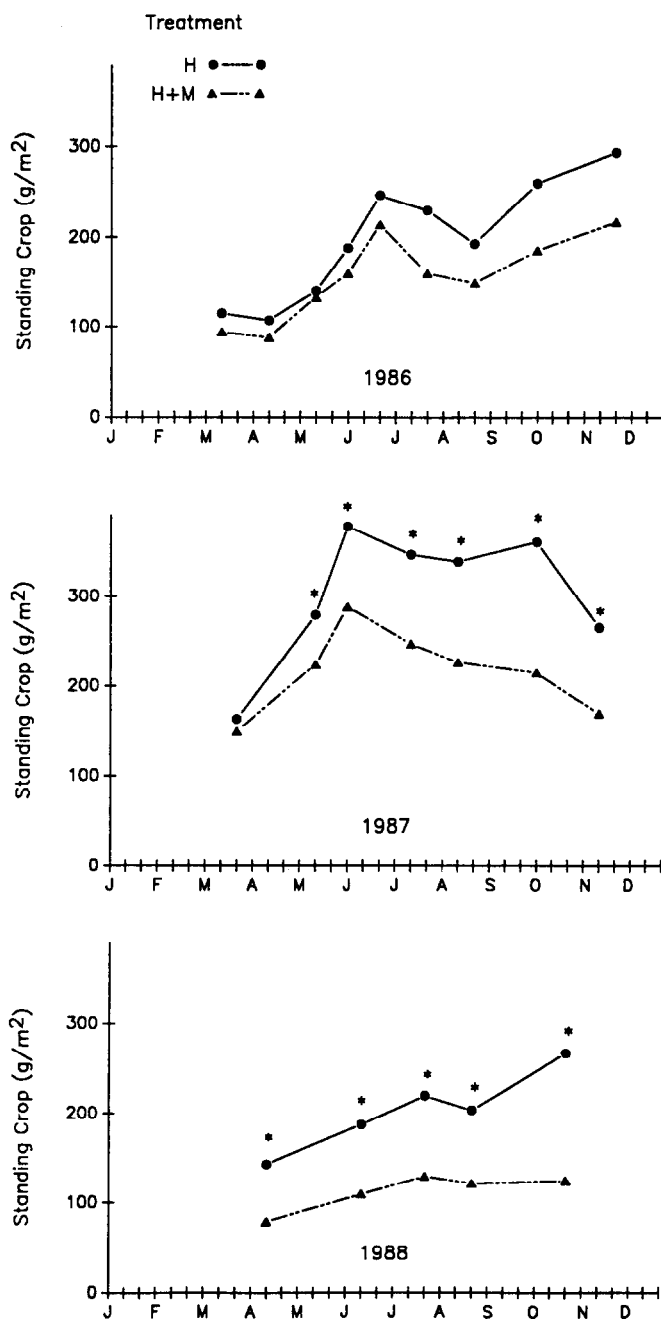


Fig. 2. Herbage standing crop (g/m²) in herbaceous (H) and herbaceous plus honey mesquite (H+M) treatments during 3-year study. Asterisks identify dates when treatment means were significantly different at $P < 0.05$.

Results

Biomass Dynamics

Biomass dynamics (Fig. 2) during the 3 years of study were linked closely to seasonal patterns of precipitation (Fig. 1). Growth during 1986 was slow during early spring, as a result of below normal winter precipitation, near normal during late spring and early summer, and rapid during fall as a result of above average fall rains. There were no significant ($P = 0.16$) differences between treatment standing crops although biomass in the H treatment was greater on all dates than in the H+M treatment. Peak standing crop occurred in November and averaged 294 g/m² in the H plots and 217 g/m² in the H+M plots. The date by treatment interaction was

Table 1. Linear regressions used to estimate herbage standing crop as a function of frequency hits.

Species/species group	Coefficient ¹	Tissue ²	Dates ³	r ⁴	n ⁵
Annual grasses	68.3	1+d+s	4	.86	21
Annual grasses	137.4	1+d+s	2	.96	13
Sidecoats grama	124.6	1+d	10	.96	57
Sidecoats grama	300.4	s	10	.85	53
Shortgrasses ⁵	117.3	1+d+s	10	.97	50
Texas wintergrass	120.6	1+d	10	.96	82
Texas wintergrass	59.5	s	3	.93	20
Texas wintergrass	197.0	s	2	.92	16
Texas wintergrass	146.3	s	5	.93	39
Other midgrasses	157.7	1+d+s	5	.99	8
Forbs	120.5	1+d+s	8	.87	61

¹y = bx where y = g/m² and x = frequency of hits (%).

²l = live (green) lamina, d = dead (senesced) lamina and s = stem.

³Number of dates and total n values vary as a result of variation among sample dates in presence or absence of certain species and/or class of tissue.

⁴All regressions were significant at $P < 0.01$.

⁵Buffalograss and common curlymesquite.

not significant ($P = 0.24$).

Biomass dynamics in 1987 (Fig. 2) varied from 1986 in that early spring growth was more rapid and fall regrowth was limited. The rapid growth during spring was the result of ample fall and winter precipitation during 1986 and near normal spring precipitation (Fig. 1). Biomass in the H treatment was significantly greater than in the H+M treatment on all dates except March. Peak standing crops occurred in early June and averaged 378 and 288 g/m² in the H and H+M treatments, respectively.

Table 2. Linear regressions used to estimate leaf area as a function of tissue biomass.

Species/species group	Coefficient ¹	Tissue ²	Dates ³	r ⁴	n ⁵
Annual grasses	87.7	l	4	.93	38
Annual grasses	161.9	d	2	.99	8
Annual grasses	69.9	d	3	.99	17
Sidecoats grama	88.1	1+d	6	.98	58
Sidecoats grama	107.3	1+d	4	.99	40
Sidecoats grama	32.0	s	10	.97	90
Shortgrasses ⁵	93.7	d	10	.99	96
Shortgrasses ⁵	82.0	l	10	.98	96
Shortgrasses ⁵	36.6	s	10	.96	87
Texas wintergrass	49.0	l	3	.96	23
Texas wintergrass	92.6	l	8	.97	87
Texas wintergrass	67.5	d	2	.99	19
Texas wintergrass	101.4	d	2	.99	20
Texas wintergrass	80.8	d	7	.98	77
Texas wintergrass	40.9	s	10	.99	101
Other midgrasses	53.0	1+d+s	5	.98	6

¹y = bx where y = cm/m² and x = g of tissue.

²l = live (green) lamina, d = dead (senesced) lamina and s = stem.

³Number of dates and total n values vary as a result of variation among sample dates in presence or absence of certain species and/or class of tissue.

⁴All regressions were significant at $P < 0.01$.

⁵Buffalograss and common curlymesquite.

Biomass dynamics in 1988 were similar to 1986 although growth rates and peak standing crops during the spring and fall of 1988 were much less than in 1986. Differences were related primarily to differences in amounts and temporal distribution of precipitation (Fig. 1). Biomass in the H treatment was significantly greater on all dates than in the H+M treatment. Peak standing crop in the H treatment occurred in November and averaged 267 g/m². This was in contrast to the H+M treatment wherein peak standing crop of 130 g/m² occurred in July.

The gradual delineation of treatment effects over years (Fig. 2) was the result primarily of changes in the absolute abundance of all species. This was evidenced in that species composition changed

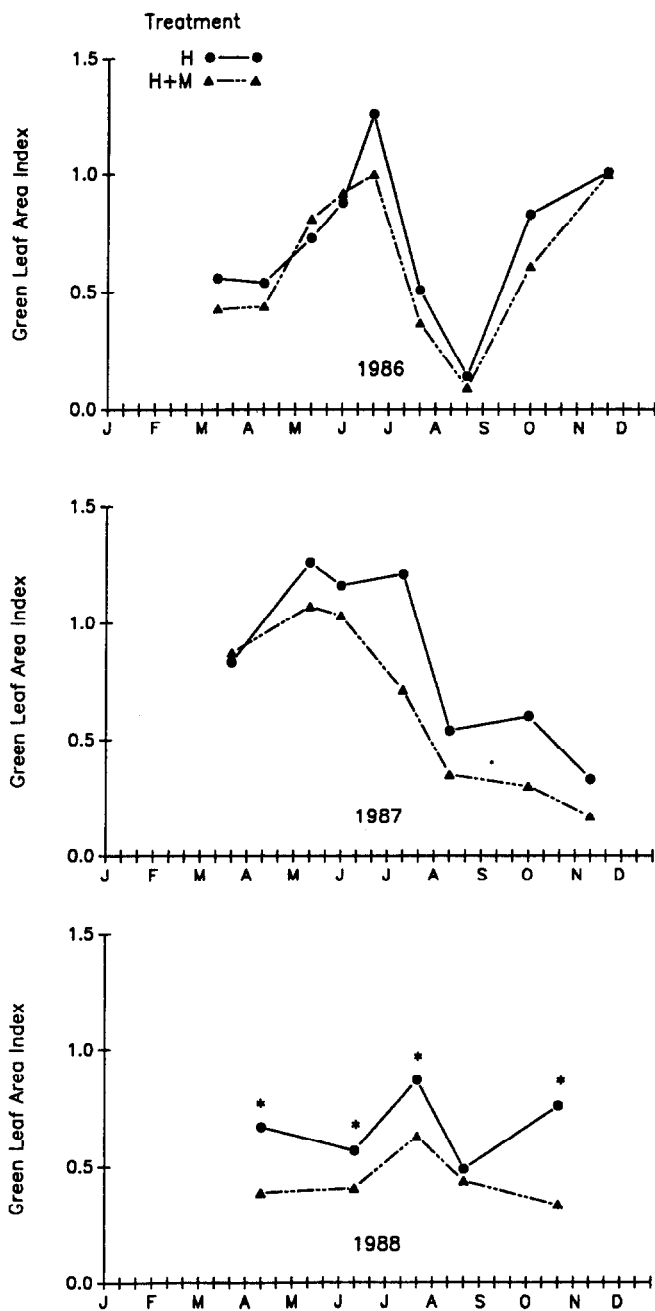


Fig. 3. Green (live) leaf area index for grasses in herbaceous (H) and herbaceous plus honey mesquite (H+M) treatments during 3-year study. Asterisks identify dates when treatment means were significantly different at $P < 0.05$.

little from 1986 to 1988 within a given distance from a tree (H+M treatment) or stump (H treatment) (see ANPP section).

Leaf Area Index (LAI)

The dynamics of total (live lamina + dead lamina + stem) surface area indices were similar (data not presented) to total biomass dynamics (Fig. 2). Likewise, live (i.e., green) biomass dynamics (data not presented) were similar to live leaf area dynamics (Fig. 3). Live leaf area indices did not vary significantly between treatments in either 1986 ($P = 0.43$) or 1987 ($P = 0.15$) although differences were considerable on most dates in 1987. However, in 1988 there was a significant difference in LAI between treatments in that LAI in the

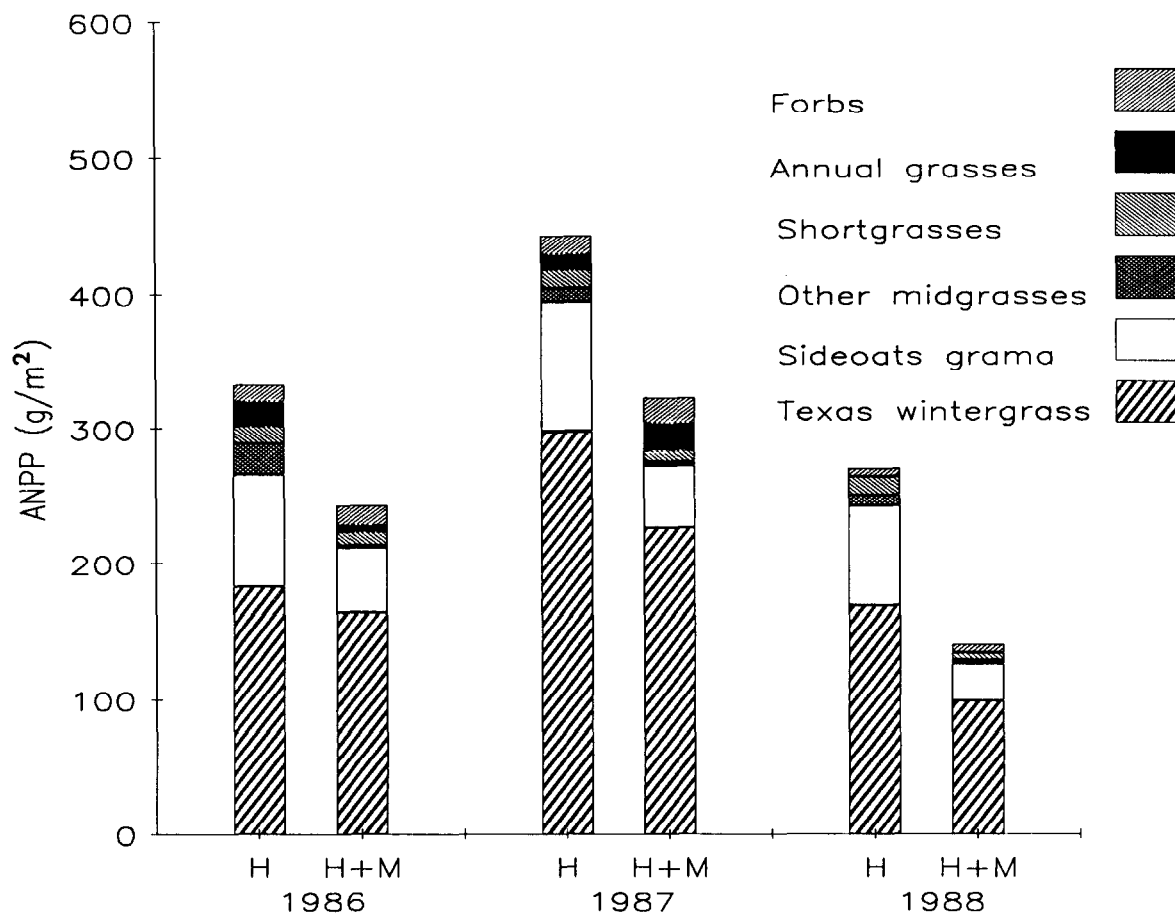


Fig. 4. Estimated aboveground net primary production (ANPP) in herbaceous (H) and herbaceous plus honey mesquite (H+M) treatments during 3-year study. Differences among years (1987>1986>1988) were significant at $P<0.01$. Differences among treatments (H>H+M) were significant at $P=0.08$. Year by treatment interaction effect was not significant ($P=0.67$).

H treatment was significantly greater than in the H+M treatment on all dates except 24 August. The absence of a significant difference in August was most likely related to difference between treatments in soil water in that water in the top 130 cm of the soil profile was generally less during summer in the H than H+M plots (Carlson et al. 1990). As a result, rates of senescence during periods of drought, such as August 1988 (Fig. 1), were usually greater in the H than H+M treatment. This is reflected by the rather dramatic decline in live LAI in the H treatment from 18 July to 24 August 1988.

Aboveground Net Primary Production (ANPP)

Aboveground net primary production was significantly ($P<0.10$) greater in the H than H+M treatment in all years regardless of method of calculation. Likewise, ANPP was significantly ($P<0.05$) greater in 1987 than 1986 and in 1986 than 1988. Utilizing the summation of species' peak standing crop method (Fig. 4), estimated ANPP averaged 349 g/m² in the H treatment and 235 g/m² in the H+M treatment. Estimates for 1986, 1987, and 1988 were 289, 383, and 205 g/m², respectively.

There were no major shifts in species composition during the 3 years regardless of treatment. Texas wintergrass was the dominant species in both treatments and sideoats grama the subdominant. In 1986, percent composition in the H treatment was 55% Texas wintergrass, 25% sideoats grama, and 20% other species. By 1988, composition had shifted only slightly to 62% Texas wintergrass, 27% sideoats grama, and 11% other species. Likewise only minor shifts were noted in the H+M treatment in that percentage compo-

sition of Texas wintergrass changed from 67 to 71%, sideoats grama from 20 to 19% and other species from 13 to 10%.

Examination of the effects of distance from tree (H+M treatment) or remaining stump (H treatment) revealed significant ($P<0.01$) year, distance, and year by distance interaction effects (Fig. 5). The year effects were similar to those reported for the entire plots (1987>1986>1988) (Fig. 4). Greatest production occurred within 0.5 and 1.0 m of the trees (distances 1 and 2) and averaged 367 and 337 g/m², respectively. This was significantly ($P=0.05$) greater than estimated ANPP (245 g/m²) within 0.5 m of the borders of the lysimeters (distance 4). Estimated ANPP between 1.0 m of the trees or stumps and 0.5 m of the lysimeter border (distance 3) averaged 323 g/m² and was not significantly different from the 3 other locations. We attribute the reduced ANPP near the lysimeter borders primarily to disturbance factors associated with the installation of the lysimeters. This was evidenced by the absence of any significant differences in ANPP among the 4 areas (Fig. 5) 3 years after treatment installation. The absence of significant treatment by distance ($P=0.17$) and treatment by year by distance ($P=0.57$) interaction effects showed responses were similar in both treatments.

The dominant species in all zones was Texas wintergrass (Fig. 5) regardless of the presence or absence of honey mesquite. The subdominant was sideoats grama and there were only minor changes in composition during the 3 years of the study regardless of location (Fig. 5). A notable exception to this was the area nearest the border of lysimeters which had a subdominance of annual forbs during the first year (1986). We believe this subdominance was a

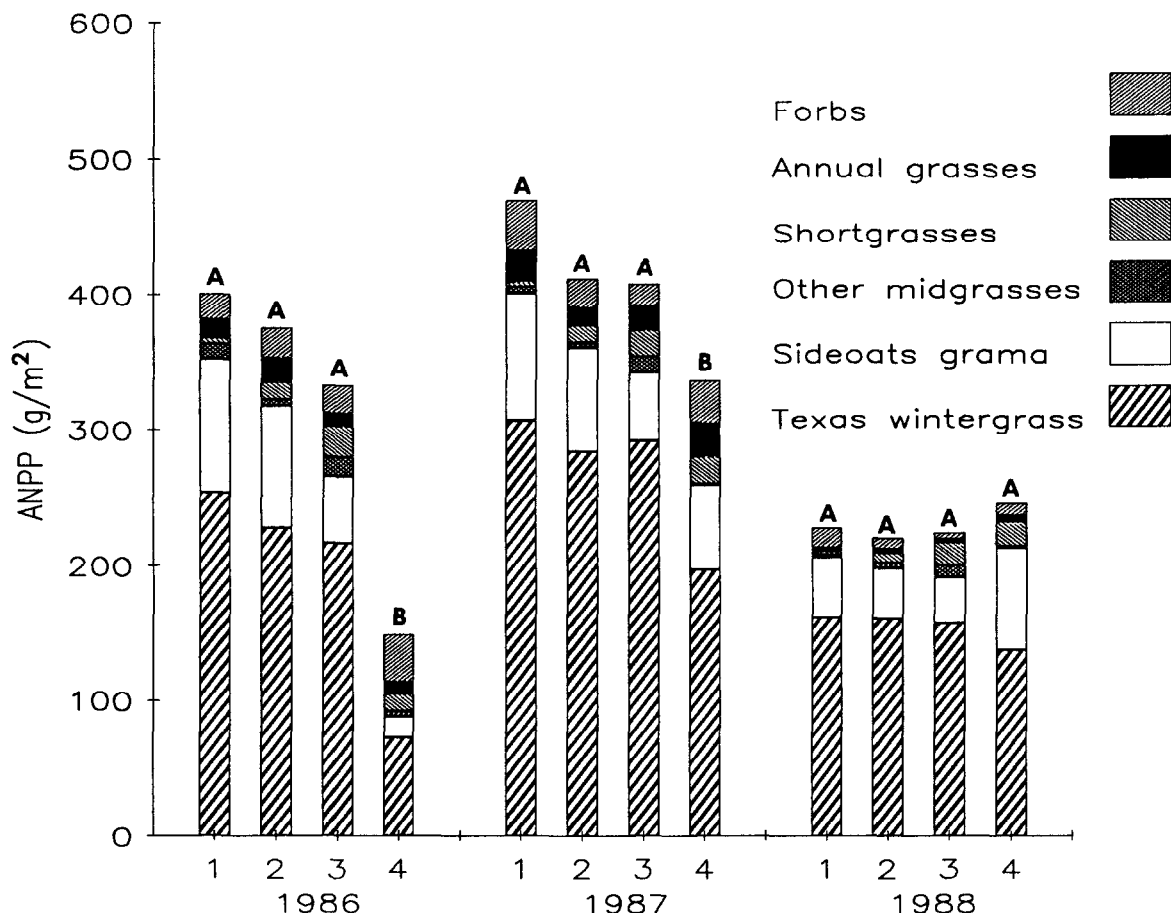


Fig. 5. Estimated aboveground net primary production (ANPP) in herbaceous (H) and herbaceous plus honey mesquite (H+M) treatments during 3-year study at various locations from trunks of trees (1=0.5 m, 2=1.0) to edge of lysimeters (3=1.0–4.0 m, 4=within 0.5m of edge). Histograms within a year superscripted by different letters are significantly different at $P < 0.05$.

reflection of the disturbances incurred during installation of the lysimeters because by 1988, forbs were only a minor component in this area and ANPP was equal to that in the other zones.

Discussion and Conclusions

The results of this study show aboveground herbage production increased following control of individual honey mesquite trees (Fig. 4). This increase was relatively uniform regardless of distance from the trunk of removed trees (Fig. 5) and was the result of increased production by herbage species present at time of control rather than a shift in species composition.

These results are in general agreement with the findings of others examining the effects of honey mesquite control on herbage production (Scifres and Polk 1974, Dahl et al. 1978, Brock et al. 1978, McDaniels et al. 1978, Jacoby et al. 1982, Bedunah and Sosebee 1984). Moreover, the absence of a major shift in species composition within the canopy area is in general agreement with the findings of Jacoby et al. (1982), in the Trans Pecos region of Texas, and with Brock et al. (1978) on a study site located about 60 km from our study area. Jacoby et al. (1978) reported a minor shift in species composition 3 years post-treatment as leatherweed croton [*Croton pottsii* (Croizat) Muell. Arg.], a warm-season perennial forb, decreased from 41 to 24% and hooded windmillgrass (*Chloris cucullata* Bisch.), a warm-season perennial grass, increased from 26 to 34%. Although Brock et al. (1978) suggested a major shift in species composition had occurred by 3 years post-treatment, close examination of their data provides minimal support for such a conclusion. For example, they suggested species composition had

shifted from a Texas wintergrass dominance to a warm-season midgrass dominance. This conclusion was based, however, on end-of-summer standing crop estimates, which probably substantially underestimate ANPP of Texas wintergrass because peak standing crop of Texas wintergrass seldom occurs during late summer in this region. For example, in our study Texas wintergrass peak standing crops of 169, 260, and 132 g/m² peaks were recorded in late November 1986, early June 1987, and late October 1988, respectively. These estimates were in contrast to late summer estimates of 134, 196, and 114 g/m² in 1986, 1987, and 1988, respectively. Moreover, McDaniels et al. (1978), working in cooperation with Brock et al. (1978), concluded from standing crop estimates collected during spring that Texas wintergrass increased on the area following control.

Variation between treatments in growth dynamics (Fig. 2) and LAI (Fig. 3) among seasons and years was minimal in this study because differences between treatments in species composition were minor. These results, in combination with ANPP estimates (Figs. 4 and 5), emphasize that the major factors affecting herbage production within the canopy area of honey mesquite are climatic factors, particularly precipitation, rather than presence or absence of honey mesquite. This is in agreement with previous research in this region, which has shown patterns of post-treatment rainfall and grazing intensity affect both the magnitude and duration of herbage response following control of honey mesquite (Scifres et al. 1974, McDaniels et al. 1982, Heitschmidt et al. (1986).

The results of this study also reveal why removal of honey mesquite may not dramatically alter off-site water yields in this

region. Concurrent research in these same lysimeters showed annual 3-year average evapotranspiration losses were 2.4% greater (95.0 vs. 97.4%), surface runoff 3.0% less (4.6 vs. 1.6%), and deep drainage 0.6% greater (0.4 vs. 1.0%) in the H than H+M lysimeters (Carlson et al. 1990). Presumably, the absence of any major effects on water yields following removal of the honey mesquite was in part related to the increased standing crop (Fig. 2) and photosynthetically active (i.e., green) leaf area (Fig. 3) stemming from the increased herbage production (Fig. 4). Other research at this study site showed transpirational water loss by Texas wintergrass (Hicks et al. 1990), the dominant herbaceous species, and honey mesquite (Ansley et al. 1990) are similar on a per unit area of leaf surface basis. Moreover, these data in combination with knowledge of the regional effects of amount of herbage standing crop on water infiltration rates and surface runoff (Wood and Blackburn 1981, Pluhar et al. 1987), infer that heavy livestock grazing may be required to effectively increase water yields in this region following removal of honey mesquite. Caution should be exercised, however, in any attempt to extend these data to other regions because: (1) growth form of the honey mesquite trees was single-stemmed rather than multi-stemmed regrowth; (2) study was conducted in the absence of any livestock grazing; and (3) no attempt was made to determine herbage response in the interstitial areas.

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Response of cottontail rabbit populations to herbicide and fire applications on cross timbers rangeland

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Abstract

Knowledge of how resident wildlife populations respond to brush management strategies is especially limited for rangelands in the cross timbers vegetation type of Oklahoma. We examined how cottontail rabbit (*Sylvilagus floridanus*) density and habitat use were influenced by applications of tebuthiuron or triclopyr, with and without annual burning, on cross timbers rangeland. Line transect flush-counts, mark-recapture live trapping, and fecal pellet counts were used to evaluate seasonal differences in population density among 5 brush control treatments. Cottontail rabbits ($n = 225$) were flushed along 362 km of line transects during 5 census periods. Density in winter was consistently lower than summer for all treatments, except for the untreated control in winter 1987. Line transect density estimates varied from 0 to 1.875 rabbits/ha and suggested that herbicide and annual burning treatments had a positive influence on cottontail rabbit populations compared to untreated controls. Mark-recapture density estimates did not differ among treatments. Fecal pellet counts were greater on herbicide-treated pastures than an untreated control in both spring and fall. Prairie-eastern redcedar (*Juniperus virginiana* L.) and forest-prairie ecotone habitats were utilized greater than expected by cottontail rabbits. Mature hardwood overstory and mixed-brush habitats were avoided. Tebuthiuron and triclopyr effectively decreased hardwood overstory and increased preferred habitats for cottontail rabbits.

Key Words: cottontail rabbit, *Sylvilagus floridanus*, population dynamics, tebuthiuron, triclopyr, brush control, habitat use

The cross timbers land resource area covers nearly 5 million ha of Oklahoma (SCS 1981), and with the remainder of the oak-hickory forest of the Ozark Plateaus represents about 19 million ha of land in the central United States (Garrison et al. 1977). Livestock production from these oak-dominated rangelands is relatively low, but appropriate brush management can increase forage and livestock production from these areas (Scifres and Mautz 1978, Stritzke 1980, Scifres et al. 1981). The likelihood of improved cattle production after removal of woody vegetation has promoted increased utilization of herbicides, fire, and mechanical control methods. Continued conversion of oak-dominated rangelands to increase livestock production is anticipated.

Increased interest in wildlife as an additional economic resource (Eltringham 1984) warrants an evaluation of the impacts of any brush management on animal populations. Range improvements that alter vegetation can modify habitat quality for many game species (Beasom and Scifres 1977). In particular, modifications that influence cover or food can change the suitability of a rangeland for wildlife (Borrecco et al. 1974, Darr and Klebenow 1975, Fagerstone et al. 1977, Tanner et al. 1978, Scifres and Koerth 1986).

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Our objective was to evaluate responses of cottontail rabbit (*Sylvilagus floridanus*) populations to 4 brush management strategies in the cross timbers of central Oklahoma. We evaluated applications of soil-applied tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N'-dimethylurea) and foliage-applied triclopyr ([[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), in combination with and without prescribed burning, to control overstory hardwoods. Prescribed burning was used as a maintenance treatment to prolong the effective life of the initial herbicide treatment. Responses of cottontail rabbit populations to brush management in the cross timbers are currently unknown.

Methods

Study Area

Our study was conducted on the Cross Timbers Experimental Range (CTER), which is located in Payne County 13 km southwest of Stillwater, Oklahoma. The CTER was established in 1983 to compare vegetation and livestock responses to brush management. This area is located in the western cross timbers forest and occupies a rugged landscape that is dissected by ephemeral and intermittent stream drainages with steep slopes. Soils of the region were described by Gray and Stahnke (1970), and a pre-treatment vegetation inventory of the CTER was completed in 1982 (Ewing et al. 1984).

The dominant vegetation type is upland forest, which is dominated by blackjack (*Quercus marilandica* Muench.) and post oak (*Q. stellata* Wangenh.), with tallgrass prairie interspersed on fine-textured soils, some of which are naturally revegetating following cropland abandonment (Ewing et al. 1984). The upland forest varies from an open hardwood overstory with productive herbaceous understory to a closed overstory with negligible understory production. Bottomland forest occupies rather restricted positions along drainages. In general, blackjack and post oak composed more than 70% of the overstory; post oak is about twice as abundant as blackjack oak.

Experimental Design

The CTER includes twenty 32.4-ha (0.42×0.83 km) fenced experimental pastures, representing 4 replications of 4 brush management treatments, using combinations of herbicide and annual prescribed burning, and an untreated control (Fig. 1). This provides an experimental design consisting of 4 replications of 5 treatments. The 5 experimental treatments include: (1) tebuthiuron applied aerially at 2.2 kg/ha in March 1983; (2) tebuthiuron applied as in treatment #1 with prescribed burning in April 1985, 1986, and 1987; (3) triclopyr applied aerially at 2.2 kg/ha in June 1983; (4) triclopyr applied as in treatment #3 with prescribed burning in April 1985, 1986, and 1987; (5) untreated control. Pastures with similar amounts of tallgrass prairie and upland forest habitat were assigned to a replication. All 20 experimental pastures were grazed seasonally by stocker cattle from April through September in 1985, 1986, and 1988, and from mid-March to mid-August in 1987.

Line Transect Counts

Transects are routinely used for estimating rabbit populations over large areas (Tiemeir 1965, Smith and Nydegger 1985, Wywiakowski and Stoddart 1988). We employed a similar technique to estimate cottontail rabbit densities on 2 replications of the 5 brush

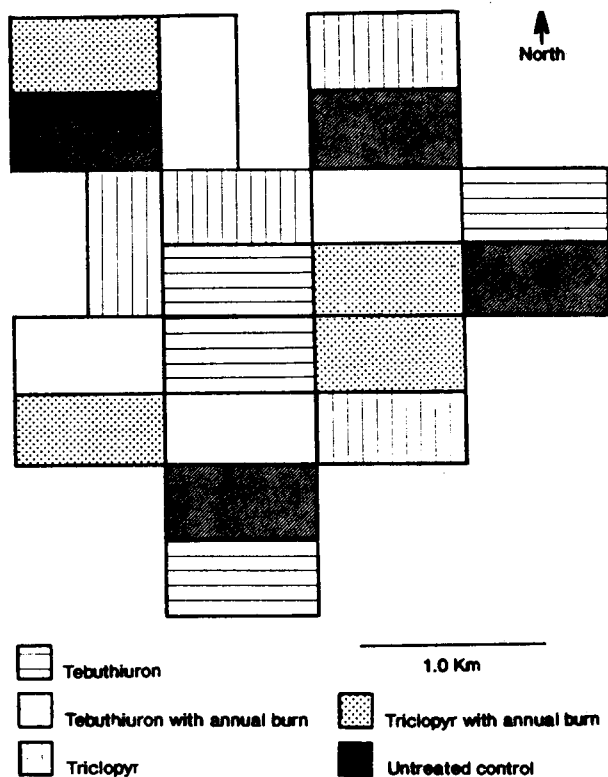


Fig. 1. Map of the Cross Timbers Experimental Range, Payne County, Oklahoma; 20 experimental pastures represented 4 replications of 4 brush management strategies and an untreated control.

treatments. Three 0.8-km permanent line transects were established on each of 10 pastures. The 3 line transects were spaced systematically and were separated at least 100 m from boundary fences as well as each other. Each transect was walked 3 times between 0600 and 0900 hours in July (summer) and February (winter) from 1986 to 1988, which resulted in censusing 14.5 km on each treatment and 72.5 km for all treatments within a season. Observers measured the perpendicular distance from the transect line to the point where a cottontail rabbit flushed (Wywiałowski and Stoddart 1988). Cottontail rabbit density was estimated for each treatment from the frequency distributions of perpendicular distances using the Fourier Series estimator in program TRANSECT (Burnham et al. 1980).

Mark-Recapture Census

Density of cottontail rabbit populations is determined in part by availability of adequate nesting and escape cover (Chapman et al. 1982). Therefore, more intensive monitoring with mark-recapture censusing was conducted on 3 adjacent pastures (untreated control, triclopyr only, and a tebuthiuron with fire treatment) that differed substantially in the amount and type of post-treatment cover that was available to cottontail rabbits. Untreated control pastures were characterized by a dense woody canopy with little herbaceous cover and moderate amounts of woody understory; triclopyr-treated pastures contained little overstory with moderate amounts of herbaceous cover and dense understory of herbicide-resistant woody species; and, tebuthiuron with fire treatments possessed very little overstory, dense herbaceous cover, and very little woody understory (Engle et al. 1987, Stritzke et al. 1987).

These 3 treated pastures were censused by a mark-recapture technique using single-door box traps (90 × 30 × 30 cm) placed at 75-m intervals in a 8 × 4 grid pattern (32 traps/pasture) that was centered on each pasture. Each trap location on the grid was marked with a permanent wood stake. Traps were baited with

Table 1. Seasonal TRANSECT (Burnham et al. 1980) estimates of cottontail rabbit density (rabbits/ha) on 5 brush control treatments on the Cross Timbers Experimental Range, Payne County, Oklahoma; summer 1986 to summer 1988.

Year	Season	Brush treatment	Mean ¹	Standard error	95% confidence interval
1986	Summer	Tebuthiuron	0.414 ^a	0.230	-0.178-1.006
		Tebuthiuron w/fire	1.404 ^b	0.340	0.521-2.287
		Triclopyr	1.117 ^c	0.220	0.352-1.882
		Triclopyr w/fire	1.327 ^{bc}	0.182	0.386-2.667
		Control	0.858 ^{abc}	0.354	0.015-1.701
1987	Winter	Tebuthiuron	0.000 ^a	0.000	0.000-0.000
		Tebuthiuron w/fire	0.460 ^b	0.230	-0.132-1.052
		Triclopyr	0.019 ^g	0.089	-0.213-0.251
		Triclopyr w/fire	0.000 ^a	0.000	0.000-0.000
		Control	1.875 ^c	0.718	0.027-3.720
1987	Summer	Tebuthiuron	0.622 ^{abc}	0.325	-0.215-1.459
		Tebuthiuron w/fire	0.816 ^b	0.279	0.096-1.535
		Triclopyr	1.058 ^b	0.269	0.365-1.750
		Triclopyr w/fire	1.606 ^b	0.551	0.188-3.023
		Control	0.207 ^c	0.075	0.012-0.402
1988	Winter	Tebuthiuron	0.000 ^a	0.000	0.000-0.000
		Tebuthiuron w/fire	0.061 ^b	0.027	-0.009-0.131
		Triclopyr	0.043 ^{ab}	0.043	-0.068-0.154
		Triclopyr w/fire	0.009 ^{ab}	0.054	-0.112-0.130
		Control	0.001 ^{ab}	0.163	-0.301-0.303
1988	Summer	Tebuthiuron	0.846 ^a	0.179	0.385-1.306
		Tebuthiuron w/fire	0.511 ^{ab}	0.244	-0.117-1.139
		Triclopyr	0.838 ^a	0.267	0.150-1.525
		Triclopyr w/fire	0.471 ^{ab}	0.183	0.000-0.942
		Control	0.062 ^b	0.014	0.026-0.098

¹Means within a season followed by different letters are significantly different ($P < 0.100$).

Table 2. Structure characteristics of 5 habitat types on the Cross Timbers Experimental Range, Payne County, Oklahoma (measured in October, 1987).

Habitat variable	Mature hardwood overstory		Prairie-eastern redcedar		Forest-prairie ecotone		Prairie-s snag overstory		Mixed brush-s snag overstory	
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE
Woody plant density (stems/0.0016 ha)	34	7	2	1	15	6	5	2	24	5
Herbaceous canopy cover (%)	10	3	79	3	64	8	78	4	62	5
Woody understory canopy cover (%)	21	3	6	3	12	7	3	1	24	4
Overstory canopy cover (%)	61	3	8	3	19	7	18	3	27	5
Lateral foliage density ¹										
0–0.5 m	3.2	0.2	2.9	0.2	3.5	0.4	3.4	0.2	3.8	0.2
0.5–1.0 m	3.4	0.1	2.4	0.3	3.4	0.4	2.6	0.2	3.4	0.2
1.0–1.5 m	3.1	0.2	2.2	0.2	3.2	0.3	2.3	0.2	3.0	0.3
1.5–2.0 m	3.6	0.1	2.2	0.2	3.1	0.4	2.2	0.2	3.0	0.3

¹Density classes: 1 = 0–20%; 2 = 21–40%; 3 = 41–60%; 4 = 61–80%; 5 = 81–100%

apple and alfalfa and set for 10 consecutive days during late October (fall) and late April (spring) from fall 1986 to fall 1988. Initially, each captured cottontail rabbit was marked with a unique ear tag and released. Recaptures were recorded and released. Mark-recapture data were analyzed using program CAPTURE (Otis et al. 1978) to estimate seasonal abundance for each pasture. We estimated the effective trapping area by adding one-half of the mean maximum recapture distance to the periphery of each grid. Cottontail rabbit density was estimated by dividing the estimated abundance by the effective trapping area (Otis et al. 1978). No cottontail rabbits marked on a pasture were subsequently recaptured on adjacent pastures.

Habitat Use

Both treated and untreated pastures contain a mosaic of habitat types. We identified 5 post-treatment habitat types on the mark-recapture trapping grids: (1) mature hardwood forest, (2) prairie with eastern redcedar, (3) forest-prairie ecotone, (4) prairie with snag overstory, and (5) mixed-brush with snag overstory. Each trap station was assigned to 1 of these habitat types. We measured habitat use by fecal pellet counts (Wolff 1980, Litvaitis et al. 1985) on existing mark-recapture trapping grids. All pellets were counted and removed within a 1-m radius of the trap stake 1 week before each trapping period in October and April from fall 1986 to fall 1988.

Structural characteristics of vegetation were assessed at each pellet plot in early October 1987. Woody plant density in the understory was measured by counting the number of stems with a diameter <7.5 cm and a height >0.5 m within a 16 m² (4 × 4 m) plot centered on each stake. Canopy cover of herbaceous plants, woody understory plants, and trees was ocularly estimated within each plot. Lateral foliage density, an index of visual obstruction provided by understory vegetation, was measured at 0.5-m intervals from 0 to 2 m above ground using a vegetation profile board (Nudds 1977) centered on each stake. The observer viewed the board 15 m from the plot in each of 4 quadrats and a mean value determined for each plot. Measurements were assigned to 1 of 5 density classes based on proportion of the board obstructed from vision (i.e., 1 = 0–20% covered, 2 = 21–40% covered, etc.).

Statistical Analysis

Density estimates derived from line-transect and mark-recapture censuses were compared within each season using Z statistics (Brownie et al. 1978, Wywiałowski and Stoddart 1988), with significance indicated by $P < 0.10$. Pellet counts within a study pasture were grouped by season prior to analysis. To correct for deviations

from normality, we performed logarithmic transformations on pellet counts and shrub density counts and arcsin transformations on cover measurements (ground, shrub, canopy) (Sokal and Rohlf 1969). We used chi-square and Bonferroni Z statistics (Neu et al. 1974) to compare availability and use of habitat types. Pairwise correlation coefficients were used to detect vegetation variables that influenced habitat use by cottontail rabbits.

Results and Discussion

Rabbit Densities

Cottontail rabbits ($n = 225$) were flushed along 362 km of line transects during the 5 census periods. Rabbit density in winter was consistently lower than summer for all treatments, except for the untreated control in winter 1987 (Table 1). Although visibility for observing rabbits was excellent on all treatments in winter, no rabbits were counted along transects in several treatments. Density estimates varied from 0 to 1.875 rabbits/ha in winter. Low over-winter survival and dispersal of juveniles (Chapman et al. 1982) probably accounted for most of the seasonal decline in density.

A gradual decline in rabbit density was observed from summer 1986 to summer 1988 on all treatments, except the tebuthiuron treatment, where mean summer densities increased from 0.414 to 0.846 rabbits/ha. The mean estimated density of cottontail rabbits for all treatments declined from 1.024 rabbits/ha in summer 1986 to 0.545 rabbits/ha in summer 1988. Decline in rabbit densities during our study could have been due to the periodic cyclic tendencies of this species (Bailey 1968). Although we did not quantify the degree of predation, we frequently noticed predator scats and rabbit kill-sites along transects during 1986 and 1987. Very few signs of predation were evident in 1988.

Line transect censuses suggested tebuthiuron and triclopyr herbicides and burning can have a positive influence on population density of cottontail rabbits (Table 1). Density was significantly greater on triclopyr than unburned tebuthiuron treatments, and burned tebuthiuron pastures supported a greater density than unburned tebuthiuron pastures, in summer 1986. Densities on treated pastures, except for unburned tebuthiuron, were significantly greater than untreated controls in summer 1987. Unburned tebuthiuron and triclopyr treatments also supported greater densities than controls in summer 1988.

Although line transect densities were low in winter, treatment differences were evident in both 1987 and 1988 (Table 1). Densities were greater on controls and burned tebuthiuron pastures compared to other brush treatments in winter 1987 and greater on

burned than unburned tebuthiuron treatments in winter 1988. No cottontail rabbits were observed on the tebuthiuron treatment in winter 1987 and 1988. We do not think cover availability adequately explained the lack of winter observations on tebuthiuron treatments. Several other treatments also supported few rabbits, despite greater amounts of cover on those treatments.

We captured 164 individual cottontail rabbits on 204 different occasions. The number of cottontail rabbits that were recaptured was not great: only 7.3% of individuals caught were recaptured within the same season. Large seasonal fluctuations in mark-recapture estimates of density were observed (Fig. 2), similar to the

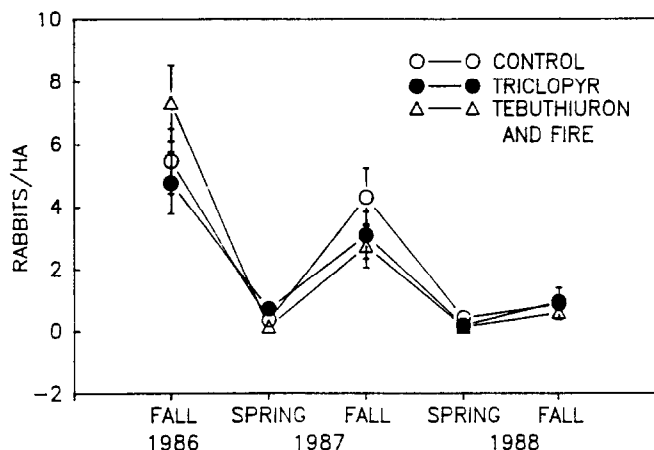


Fig. 2. Estimates of population density (rabbits/ha \pm SE) by mark-recapture census of cottontail rabbits in 3 experimental pastures using program CAPTURE (Otis et al. 1978). Populations were sampled in fall and spring from fall 1986 to fall 1988.

fluctuations observed in line transect estimates (Table 1). Mark-recapture estimates of density were greatest in fall 1986 with 7.32 rabbits/ha on the tebuthiuron with fire treatment. Fall mark-recapture estimates of population density declined during the study and reached their lowest in fall 1988. Mark-recapture estimates for fall 1988 were similar to the estimates derived from line transect censuses, despite the fact that line transect estimates were determined in summer and winter. Fall density estimates should reflect an additional 3 months of recruitment into the population compared to line transect estimates for summer. Spring estimates also could include recruitment into the overwinter population, as the breeding season begins between January and March (Barkalow 1962, Pelton and Provost 1972). This suggested that recruitment was low for all pastures in 1988, possibly in response to lower than normal herbage production which persisted through most of the summer (unpublished data).

Differences in mark-recapture estimates of population density among treatments were not significant ($P > 0.10$) for any fall season because of large standard errors associated with our estimates (Fig. 2). Statistical comparisons among treatments were not performed for spring estimates because no rabbits were recaptured on several treatment pastures. The lack of adequate recaptures during our censuses may have been caused by a large trap-shy component in populations or ineffective baiting techniques.

In contrast to mark-recapture estimates, the seasonal frequency distribution of fecal pellets differed among the 3 trapping grids (Fig. 3). The Bonferroni intervals showed that pastures treated with triclopyr and tebuthiuron with fire were utilized greater than expected ($P < 0.05$) and the control pasture was utilized less than expected ($P < 0.05$) in fall (3 sample periods pooled). A similar trend was observed for spring (sample periods pooled) when the tebuthiuron with fire pasture was utilized greater than expected and the control pasture was utilized less than expected. These

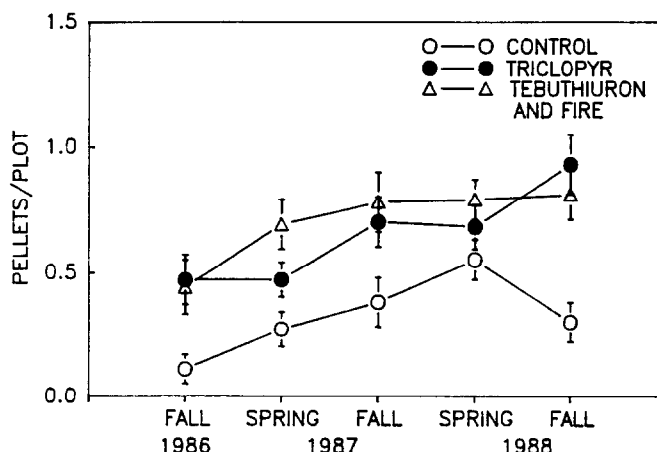


Fig. 3. Fecal pellet density (pellets/plot) on 3 experimental pastures from fall 1986 to fall 1988. Pellet counts were subjected to a $(x + 1)$ logarithmic transformation prior to calculating $\bar{x} \pm SE$.

results agreed more closely with line transect estimates than to mark-recapture results. Our data support the conclusion that brush treatments had a positive influence on cottontail rabbits, but remarkable differences in rabbit density did not exist among treatments. Undoubtedly some of the discrepancy between population indices was a reflection of differences in sensitivity among techniques.

Habitat Use

The 5 habitat types identified on trapping grids differed markedly in their structural attributes (Table 2). Prairie-eastern redcedar and prairie-sag overstory habitats were characterized by minimal woody understory and overstory canopy, moderate lateral foliage density, and high herbaceous cover. Conversely, mature hardwood and mixed brush-sag overstory habitats had high woody understory cover and lateral foliage density, and low amounts of herbaceous cover. Forest-prairie ecotones occurred less frequently on the grids and represented an intermediate or transitional habitat type. Habitats of mature hardwood overstory or prairies with a sag overstory were the 2 prominent types on our trapping grids (Table 3).

Table 3. Total captures of cottontail rabbits in 5 habitat types on the Cross Timbers Experimental Range in fall (1986–88); observed captured totals for each habitat type did not differ ($P > 0.10$) from expected.

Habitat type	n	Pro- portion of area	Total fall captures	
			Observed	Expected
Mature hardwood overstory	75	0.26	42	45.2
Prairie-eastern redcedar	51	0.18	39	31.3
Forest-prairie ecotone	21	0.07	13	12.2
Prairie-sag overstory	87	0.30	58	52.2
Mixed brush-sag overstory	54	0.19	22	33.1

¹Represents no. of sample plots \times replicates.

Cottontail rabbits are habitat generalists and no universal type appears to be preferred (Chapman et al. 1982). We used live capture and fecal pellet count distributions to assess preferential habitat use on the CTER. Both techniques have been used previously to assess patterns of habitat use by lagomorphs (Adams 1959, Wolff 1980, Litvaitis et al. 1985). Availability of habitat types relative to frequency of live captures of cottontail rabbits (Table 3) showed no preferential utilization of habitats ($P > 0.10$) on the

Table 4. Cottontail rabbit utilization of 5 habitat types within the Cross Timbers Experimental Range, Payne County, Oklahoma as indicated by the distribution of pellets in fall (1986–88) and spring (1987–88). Observed fecal pellet totals greater (+) or less (–), and no different (NS) than expected for each season are indicated ($P < 0.10$).

Habitat type	Fall pellet distribution				Spring pellet distribution			
	<i>n</i> ¹	Observed	Expected	Use	<i>n</i>	Observed	Expected	Use
Mature hardwood overstory	75	67	830	—	50	183	329	—
Prairie-eastern redcedar	51	1142	574	+	34	472	228	+
Forest-prairie ecotone	21	644	224	+	14	113	89	+
Prairie-s snag overstory	87	1007	958	NS	58	364	380	NS
Mixed brush-s snag overstory	54	332	606	—	36	135	241	—

Represents no. of sample plots × replicates.

CTER. In contrast, frequency distributions of fecal pellets showed that prairie-eastern redcedar and forest-prairie ecotone habitats were used more than expected ($P < 0.05$) and habitats with a mature hardwood overstory or mixed brush-s snag overstory were used less than expected ($P < 0.05$) (Table 4). Pairwise correlation coefficients (Table 5) suggested that rabbits select for habitats with adequate herbaceous cover and against those with heavy canopy cover. Overstory cover of untreated blackjack and post oak effectively reduced herbaceous cover and thus food availability. Herbicide treatments, particularly tebuthiuron, promoted greater herbaceous cover compared to controls.

Differences between pellet counts and live captures to determine habitat preferences are partially related to the lack of adequate numbers of captures. The basic assumption of both indices is that captures should increase with the amount of time rabbits spend within a habitat type (Litvaitis et al. 1985). In most seasons, we had few recaptures which hindered our ability to detect time spent within a habitat type. Live trapping may have provided different results on habitat use if a large proportion of each population was captured (trap-shy component) or more individuals were recaptured. Live trapping and pellet counts can provide similar information on habitat use (Litvaitis et al. 1985).

Conclusion

Our objective was to evaluate the impacts of brush management on cottontail rabbit populations in the cross timbers of Oklahoma. Our results indicate that triclopyr and tebuthiuron herbicide applications used in combination with and without prescribed fire (annual) have no adverse impacts on resident populations. Although results were not always consistent, line transect censuses, fecal pellet counts, and habitat preference evaluations suggested that treated areas supported higher densities of cottontail rabbits and

provided more preferred habitat types than control areas. Line transect censuses also suggested that prescribed burning had a positive impact on density of cottontail rabbit populations. Habitat preference evaluations indicated that the pasture treated with tebuthiuron provided more favorable habitat types for cottontail rabbits than the pasture treated with triclopyr.

Successional and climatic changes occurred on treated pastures during the study, and undoubtedly influenced cottontail rabbit numbers and responses to treatments among seasons and years. Herbicide applications were completed in 1983 and prescribed burning was initiated in 1985. Our study began in 1986; we therefore, have no information on population responses immediately following brush control. However, the higher mark-recapture estimates in 1986, followed by a gradual annual decline to 1988, suggests that populations increased after the first year of treatment.

Applications of tebuthiuron and triclopyr, either with or without prescribed fire, provide a useful management option for increasing the diversity of habitats and increasing preferred habitat types of cottontail rabbits. Our comparisons among 3 pastures suggests that tebuthiuron applications provide more suitable habitat types than applications of triclopyr.

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Table 5. Pairwise correlation coefficients between cottontail rabbit pellet density or capture frequency and structural characteristics of habitats on the Cross Timbers Experimental Range, Payne County, Oklahoma.

Treatment pasture	Index	Habitat variable						
		Shrub density	Ground cover	Smilax ¹ cover	Shrub cover	Canopy cover	LSF1 ²	LDF4 ³
Control	Pellets/plot	-0.32**	0.80***	-0.14	-0.41**	-0.66***	-0.25	-0.38*
	Rabbits/plot	-0.24	0.07	-0.18	-0.12	-0.07	-0.14	0.09
Triclopyr	Pellets/plot	-0.12	0.20	-0.03	-0.29	-0.53***	-0.11	-0.34*
	Rabbits/plot	-0.29	0.06	-0.32*	-0.07	0.02	0.16	0.07
Tebuthiuron with fire	Pellets/plot	0.02	0.51**	-0.15	-0.14	0.06	-0.19	0.13
	Rabbits/plot	-0.16	-0.01	-0.35*	-0.22	-0.02	-0.05	0.23
All treatments	Pellets/plot	-0.31***	0.68***	-0.10	-0.41***	-0.62***	-0.08	-0.36***
	Rabbits/plot	-0.22*	0.04	-0.26**	-0.11	0.03	-0.02	0.10

¹Percent canopy cover attributed a greenbriar (*Smilax* sp.).

²Lateral foliage density at 0–0.5 m.

³Lateral foliage density at 1.5–2.0 m.

* $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***).

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Water relations and transpiration of honey mesquite on 2 sites in west Texas

CHANGGUI WAN AND RONALD E. SOSEBEE

Abstract

Transpiration rates and internal water relationships of honey mesquite (*Prosopis glandulosa*) were investigated weekly during May through September 1986 on sandy loam and clay loam, both upland sites in west Texas. Average transpiration rates peaked at approximately $7 \text{ mmol m}^{-2} \text{ s}^{-1}$ at 1100 hr during wet periods and reached a plateau between 4 and $5 \text{ mmol m}^{-2} \text{ s}^{-1}$ between 1200 and 1400 hr. During dry periods, the average transpiration rates reached their maximum plateau of $2 \text{ mmol m}^{-2} \text{ s}^{-1}$ at 1000 hr and declined between 1200 and 1600 hr. The transpiration rates ranged from an average of $3.28 \pm 2.05 \text{ mmol m}^{-2} \text{ s}^{-1}$ for trees on a sandy loam site to an average of $3.85 \pm 1.94 \text{ mmol m}^{-2} \text{ s}^{-1}$ for those on a clay loam site. Stomatal closure in midsummer caused a substantial increase in leaf temperature. Mesquite has developed other means, such as leaf orientation, wax accumulation, and reduction in canopy development, to avoid drought. Stomatal conductance of mesquite is very responsive to soil water availability and dryness of the air, and is less responsive to internal water status. This research further substantiates that mesquite behaves like a facultative phreatophyte in west Texas.

Key Words: *Prosopis glandulosa*; leaf conductance; xylem water potential; facultative phreatophyte; water stress; drought avoidance.

Honey mesquite has been described as an extravagant water user. Early research has shown that honey mesquite takes 1,725 kg water to produce 1 kg of phytomass (McGinnies and Arnold 1939). Nilsen et al. (1983) reported that the average transpiration ratio for honey mesquite was about 800 g water for 1 g aerial phytomass produced. Therefore, large quantities of water are required to maintain the high productivity of honey mesquite (Nilsen et al. 1983).

The aboveground net primary production of mesquite is higher than one would expect from classical relationships between precipitation and productivity (Whittaker 1978). Virginia and Jarrell (1983) suggested that enhanced productivity seems to be decoupled from limitation by surface water resources. Nilsen et al. (1983) stated that desert phreatophytes, such as honey mesquite, can have high summer productivity in the Sonoran Desert because water loss is not curtailed. Nilsen et al. (1987) also found that seasonal growth of mesquite was not influenced by precipitation or temperature. However, irrigated mesquite trees produced more foliage and had considerably higher transpirational water loss than nonirrigated trees in west Texas (Easter and Sosebee 1975).

Like desert xerophytes, mesquite can acquire soil water that is held at rather high matric forces. Haas and Dodd (1972) recorded soil water potential of -1.5 MPa to at least 150-cm depth. Mesquite can survive under soil water potential as low as -3.0 MPa , by reduction in leaf area, increase in thickness of the leaf cuticle and almost complete cessation of growth (Fisher et al. 1972). Mesquite maintains a positive net photosynthesis at water potentials less than -4.0 MPa (Strain 1970).

Nilsen et al. (1983) stated that when growing in a wash woodland of the Sonoran Desert where the water table was 4 m deep, honey mesquite avoided drought by using available groundwater. Conse-

quently, mesquite maintained leaf conductances greater than 6.5 mm s^{-1} throughout the growing season and a considerable amount of water was lost through transpiration. In some semiarid areas of west Texas where the water table is 8 m deep, or deeper, one could ask "Do mesquite trees exhibit the same drought avoidance mechanisms as shown in the wash woodland?" This research was conducted to study transpiration rates and plant water relations of honey mesquite growing on 2 sites of a semiarid west Texas rangeland with focus on drought avoidance mechanisms.

Methods and Materials

The study was conducted on mesquite infested rangeland located on the Texas Tech University campus, Lubbock. Honey mesquite trees were selected on 2 sites, sandy loam and clay loam. The sandy loam site is characterized by an Amarillo fine sandy loam soil (fine-loamy, mixed, thermic Aridic Paleustalfs) and the clay loam site is characterized by an Olton clay loam soil (fine, mixed, thermic Aridic Paleustolls). The clay loam site has a higher water holding capacity; therefore, it is more mesic. Climate of the area is semiarid with an average annual precipitation of 450 mm. Monthly and annual precipitation vary considerably with May and June being the wettest months. The average frost-free period is 211 days, from early April to early November. Vegetation in the area has a shrub stratum of honey mesquite and a herbaceous stratum dominated by buffalograss (*Buchloe dactyloides*), blue grama (*Bouteloua gracilis*), and broom snakeweed (*Xanthocephalum sarothrae*).

Mesquite xylem water potential was measured daily at dawn and hourly to bihourly from 0800 to 1700 hours using a pressure chamber (Scholander et al. 1965). Petioles were excised from the plants and measurements were made with time lapse of less than 1 minute. Pressure was applied to the chamber at a moderate rate ($0.05 \text{ MPa sec}^{-1}$) to avoid error. Soil water content was determined with a neutron attenuation technique at 15-cm increments in the profile of 30 to 165 cm. Soil moisture measurements were taken once a week; 3 replications were used for each measurement. A pressure membrane plate apparatus (Gardner 1965) was used to develop a soil water retention curve with water potentials as low as -1.5 MPa . Soil matric potential data were derived from soil water contents by using the water retention curve.

Stomatal conductance, transpiration, air, and leaf temperature, photon flux density, and relative humidity were measured with a Li-Cor 1600 steady-state porometer. A cylindrical chamber was installed on the porometer and used to accommodate the sample leaves. Leaves with an area of 3 to 5 cm^2 were placed in the chamber when the measurements were taken. Measurements were taken on trees growing on the 2 sites 7 to 8 times a day from 0800 until 1700 hours on both sites with a time interval of 15 minutes between measurement on trees of the 2 sites. Three replications were made for each measurement and the averages are reported. Ten mesquite trees (replications) were randomly selected on each site. Measurements were taken weekly on clear days May through September, 1986. The data were subjected to regression analyses and t-test.

The actual diffusive resistance (R_1) was determined from the following equation:

$$R_1 = (R_d + 0.15) (TA/LA) - R_b$$

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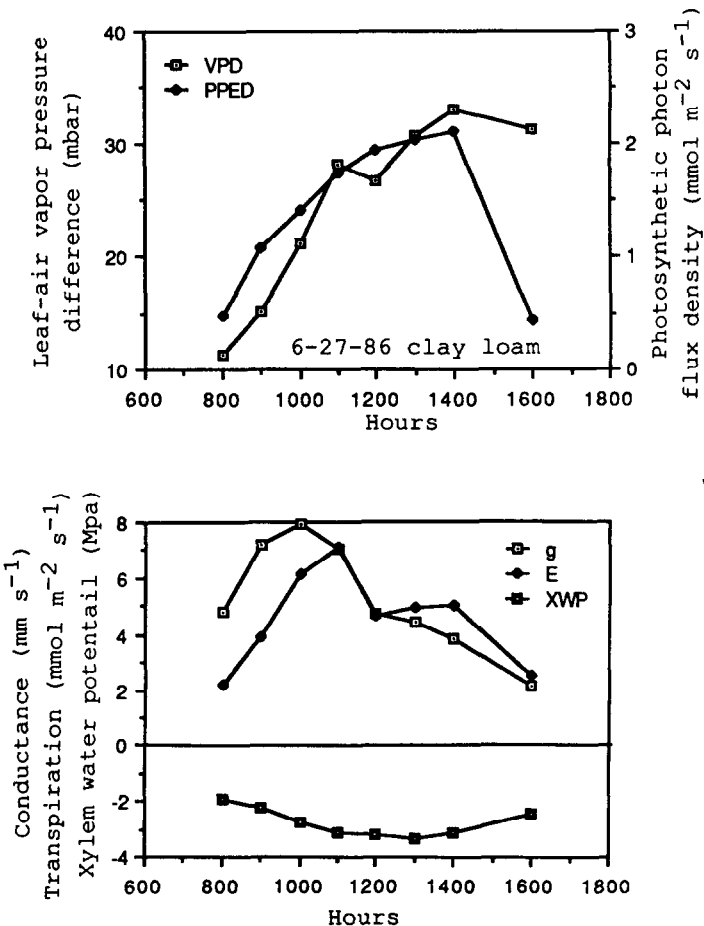


Fig. 1. Leaf-air vapor pressure difference (VPD) transpiration (E), leaf conductance (g), photosynthetic photon flux density (PPFD) and xylem water potential (XWP) in a representative mesquite tree during a wet day (27 June 1986, soil matric potential -0.03 MPa) on Texas Tech campus, Lubbock.

where:

Rd = diffusive resistance displayed by the porometer,
 TA = true area of the sample leaf and,
 LA = leaf area entered into the Li-Cor 1600,
 Rb = boundary layer resistance. In Li-Cor 1600, a default value of Rb was set at 0.15 s cm^{-1} .

The average boundary layer resistance (Rb) of mesquite leaves was calculated to be 0.149 to 0.160 s cm^{-1} , using the equation (Cowan and Milthorpe 1968):

$$Rb = 1/[0.294(u/b)^{1/2}],$$

where:

u = wind speed, cm s^{-1} and,
 b = the surface dimension of the leaf (about 0.4 – 0.5 cm for mesquite leaves). The calculated Rb was very close to the default value of Rb in the Li-Cor 1600 porometer. Rb was much smaller than stomatal resistance ($>1 \text{ s cm}^{-2}$) and was not a major resistance in transpirational water loss.

The actual stomatal conductance was determined as the reciprocal of actual diffuse resistance and actual transpiration rate was the product of measured transpiration rate and LA/TA.

Results and Discussion

Leaf conductance and transpiration of mesquite declined during the drought of July as compared to a wet June (Fig. 1 and 2). Six-fold reduction in daily average leaf conductance (from 5.23 to

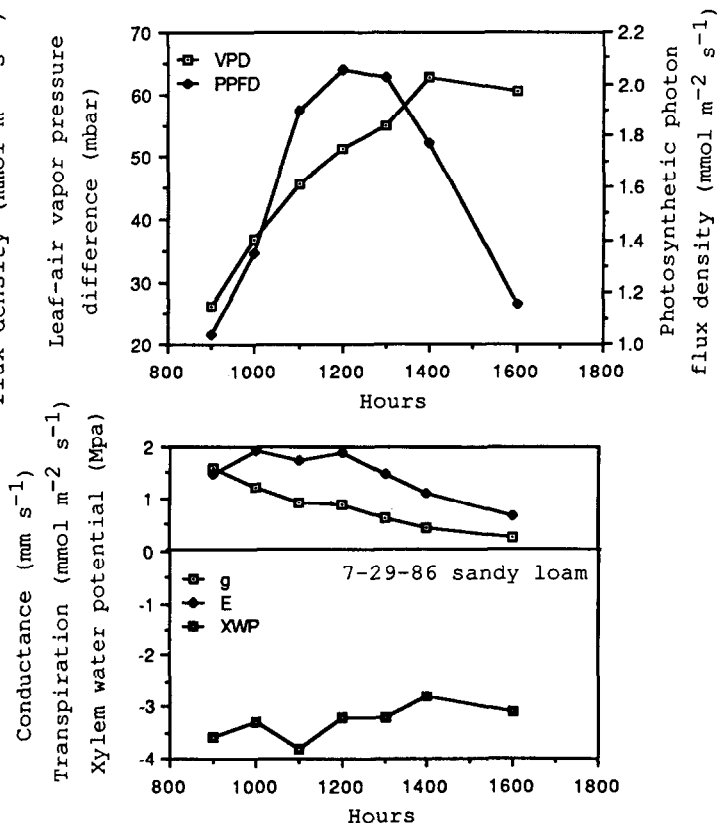


Fig. 2. Leaf-air vapor pressure difference (VPD), photosynthetic photon flux density (PPFD), transpiration (E), leaf conductance (g) and xylem water potential (XWP) in a representative mesquite tree during a drought day (29 July 1986, soil matric potential -1.5 MPa) on Texas Tech campus, Lubbock.

0.84 mm s^{-1}) in the summer was a reflection of reduced soil water availability. When soil water was less available, mesquite trees did not transpire as much as those receiving ample water (daily average transpiration 1.46 vs. $4.54 \text{ mmol m}^{-2} \text{ s}^{-1}$), regardless of the atmospheric evaporation demand. Coupling of stomatal conductance with soil water availability was more obvious for trees growing on the different soil types. The seasonal trend of daily average transpiration rate on the 2 sites follows the same pattern as soil water potential (Fig. 3). Before mid-June, soil matric potential of the clay loam was considerably higher than that of the sandy loam; so were the transpiration rates. From 13 June to 8 July, the soil matric potentials were high (>-0.5 MPa) on both sites, and greater transpiration rates were found on the sandy loam, indicating a greater uptake from that site. A related study has shown that mesquite taps deep horizons sooner on the sandy loam as compared to the clay loam site. In July, water content in 30 to 165 cm profile was 57% of field capacity on the sandy loam, while it remained 80% on the clay loam (Wan 1987). Consequently, stomatal conductance and transpiration were over 2-fold greater for trees on the clay loam site in midsummer because the soil water content was higher (Fig. 4).

In late July, mesquite trees had similar xylem water potentials on both clay loam and sandy loam sites in spite of different amounts of available soil water. However, they transpired at different rates (Fig. 5). From 29 July to 6 August, trees on the clay loam transpired 59 to 125% more water than trees on the sandy loam site with similar leaf areas.

When soil water was most available, as on 6 June, the trees transpired more water (more than 2-fold) than on 31 July when soil water was limited. Yet, the xylem water potential was higher on 6

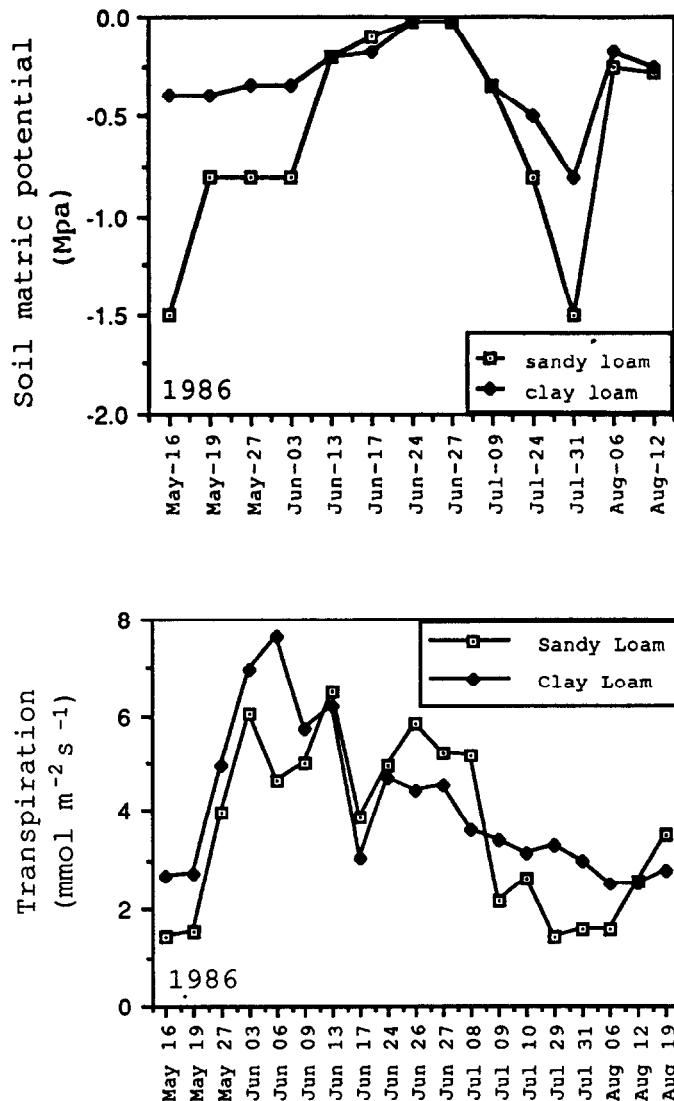


Fig. 3. Seasonal changes in soil matric potential (MPa) (upper figure) and daily average transpiration rate (lower figure) on the sandy loam and the clay loam sites. Soil matric potential was derived from soil water content at 60-cm depth based on water retention curves.

June (-3.1 MPa) than that in late July (-3.8 MPa). Through an efficient water transport system, the plant with ample water supply (6 June) can maintain higher xylem water potentials with increased transpiration rates, and thus avoid water stress (Hall and Schulze 1980). In contrast, when the soil is dry, the trees greatly restrict transpirational water loss in the afternoon through stomatal closure. Thus, water potential recovered or became less negative in the afternoon (Fig. 1 and 2) because transpirational water loss declined. Slopes of the curves in Figure 4 represent resistance to water flow which is largely dominated by soil water availability for a particular plant species (Schulze and Hall 1982). When dawn xylem water potential decreased to about -2 MPa in trees on the sandy loam soil, resistance increased and transpiration was greatly reduced.

Stomata respond sensitively to changes in VPD. Stomatal closure is sufficient to reduce transpiration rate even when mesquite is subjected to higher evaporation demands. On 26 June 1986, as VPD increased from 18.8 mbar at 1100 hours to 25.8 mbar at 1500 hours, the transpiration rate decreased by 38% (from 10.6 to 6.5 μg

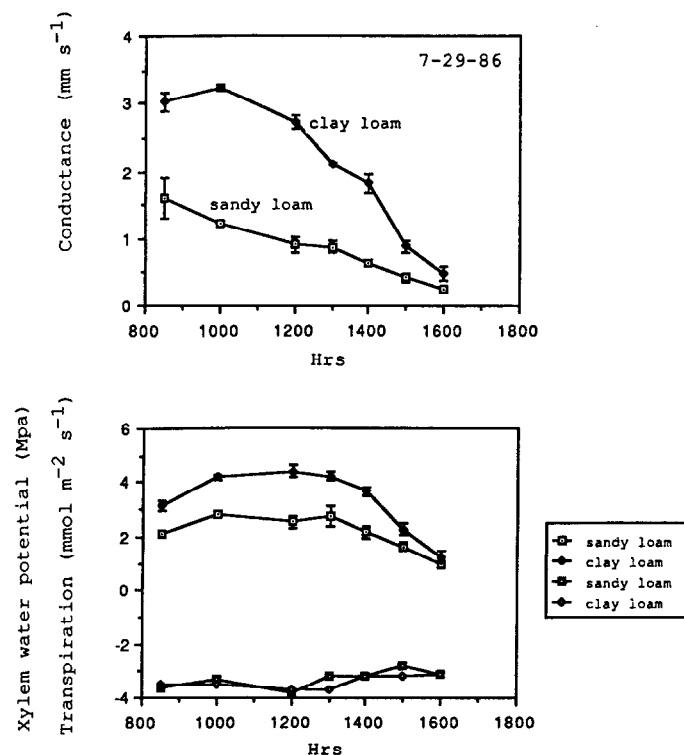


Fig. 4. Diurnal changes in leaf conductance, transpiration and xylem water potential in mesquite trees on 29 July 1986. The measurements were taken on trees growing on 2 sites on the Texas Tech campus, Lubbock. The error bars represent standard error of means. The average soil water content in 30-165 cm profile was 10.6% and 6.6% for the clay loam and sandy loam, respectively. Soil matric potential at 60-cm depth (highest matric potential in the profile) was -0.7 MPa and -1.5 MPa for the clay loam and sandy loam, respectively. Differences in conductance and transpiration between the 2 sites were significant ($P < 0.01$).

$\text{cm}^2 \text{s}^{-1}$), which otherwise would have increased by 37% if the stomatal conductance had remained the same. This response represents a feedforward control. It can prevent water potential from declining as evaporative demand increases. The plant water potential remained stable at -3.1 MPa in the afternoon as a result

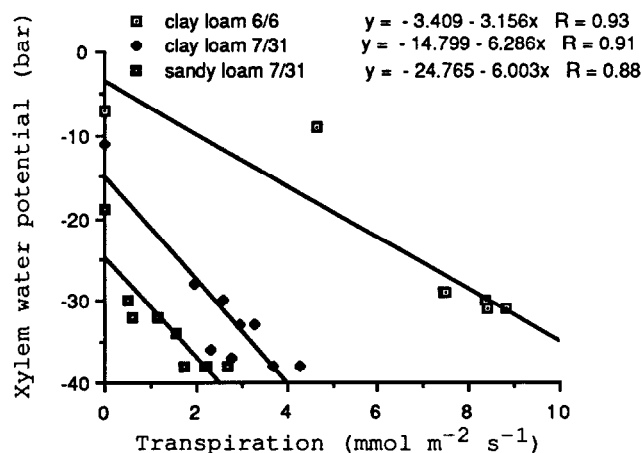


Fig. 5. Relationship between xylem water potential and transpiration in mesquite trees growing on Texas Tech campus, Lubbock, Texas May through September 1986. The intercept on Y axis is dawn xylem water potential. Soil matric potential at 60-cm depth was -0.4 MPa on 6 June and was -0.7 MPa and -1.5 MPa for the clay loam and sandy loam, respectively, on 31 July.

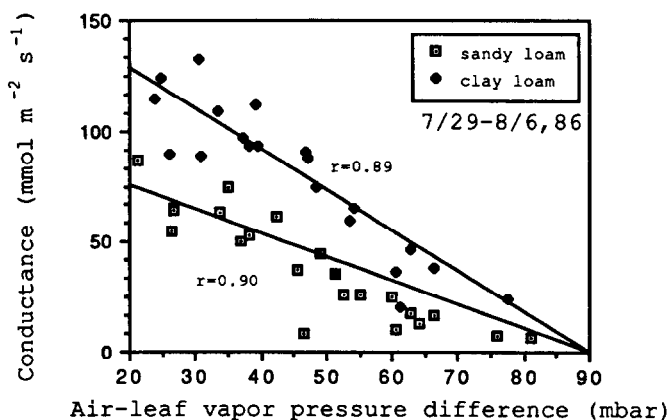


Fig. 6. Leaf conductance of mesquite on 2 sites as a function of air-leaf vapor pressure difference. The measurements were made from 3 trees on each site 29, 1 July, and 6 August 1986 on the Texas Tech campus, Lubbock. Soil matrix potential at 60-cm depth was -0.7 MPa on the clay loam and <-1.5 MPa on the sandy loam.

of stomatal closure. A linear response of stomata to VPD was observed during a drought period on the 2 sites (Fig. 6).

Stomatal aperture is not only affected by VPD, but also by soil water status. Previous work (Easter and Sosebee 1975) has shown that mesquite trees on a xeric site did not transpire as much as those on a more mesic site when environmental conditions (except soil water potential) were the same. Our data indicate that maximum daily stomatal conductance is linearly ($P < 0.01$) correlated with soil water status on both the fine sandy loam ($r = 0.88$) and the clay loam soil ($r = 0.67$) (Fig. 7). As soil water was depleted, daily maximum stomatal conductance was greatly reduced. Hence, in June when soil water was most available, the trees had daily maximum stomatal conductances of 2.8 to 6-fold higher than in midsummer.

Stomatal conductance of mesquite is less responsive to internal water status. In midsummer, leaf conductance exhibited a continuous decline from morning until afternoon, but xylem water potential dropped to the lowest level at midday and increased in the afternoon (Fig. 4). In the wet season, however, midday stomatal closure was probably caused by lower xylem water potential (Fig. 1).

On a typical sunny day on the Texas Tech campus in the summer, total solar radiation was about 1000 W m^{-2} in the afternoon. If the soil is wet and stomata are open, mesquite can transpire $7.5 \text{ mmol m}^{-2} \text{ s}^{-1}$. Under these conditions latent heat transfer plays a significant role in the plant's energy balance and about 33%

Table 1. Diurnal change in air and leaf temperature on a typical summer day. Each number is an average of 3 measurements. Data were collected on 31 July 1986.

Hour	Sandy loam		Clay loam	
	Air	Leaf	Air	Leaf
800	27.8	27.7	27.4	26.8
1000	31.5	31.4	30.1	30.0
1100	35.4	34.7	33.4	32.9
1200	36.1	36.1	35.8	35.7
1300	38.4	38.9	37.6	37.3
1400	39.8	40.3	39.7	39.9
1500	41.5	42.1	39.9	40.2
1700	42.9	43.5	42.5	42.6
\bar{x}	36.7	36.8	35.8	35.7

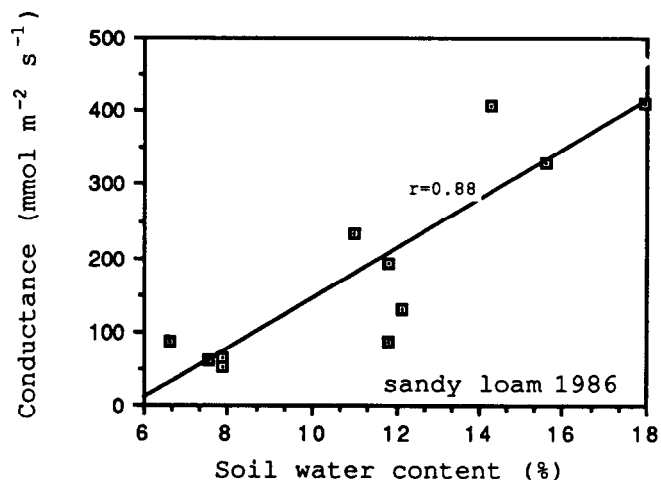
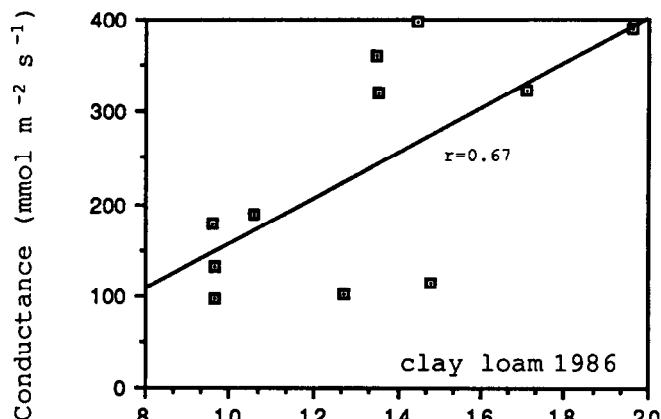


Fig. 7. Relationship between daily maximum leaf conductance and soil water content (w/w). Leaf conductance is an average of 3 measurements. Soil water content represents an average of the 30 to 60 cm profile ($n = 9$). $P = 0.0064$ for the clay loam and 0.0068 for the sandy loam soils. Soil water content declined from June to early August.

of incident radiation can be dissipated by transpirational cooling ($43.78 \text{ J mmol}^{-1} \times 7.5 \text{ mmol m}^{-2} \text{ s}^{-1} / 1000 \text{ W m}^{-2}$). Mesquite's highest average daily rate of transpiration was only $7.64 \text{ mmol m}^{-2} \text{ s}^{-1}$, which is much lower than cultivated pasture species such as alfalfa (*Medicago sativa*) (Sosebee 1980). Some desert species, such as *Phragmites communis* growing in a moist habitat, but under high evaporative demands, can transpire at much higher rates than mesquite trees, thus bringing leaf temperatures to 8°C lower than the ambient temperature (Percy et al. 1974). For our trees, leaf temperatures of 1°C lower than ambient were uncommon. In most cases, leaf temperatures were higher than ambient temperatures even when the soil water was readily available (through midday stomatal closure). This indicates that a mesquite tree is a conservative plant in consumptive water use. It maintains its leaf temperature close to the ambient, instead of several degrees below (Table 1). In the latter case, extra water has to be transpired, which represents wasted water, especially when the leaf temperature is within the optimum range for photosynthesis. This dehydration avoidance mechanism may not bring any benefit to mesquite trees, since on the native rangeland, water saved may be used by the competitive plant species or lost through evaporation. However, dehydration avoidance allows conservation of water since deep

water sources can only be exploited by deep-rooted plants such as mesquite.

In summer drought, latent heat transfer of mesquite on the sandy loam site was reduced such that only a few percent of incident solar radiation was dissipated by transpiration (daily average transpiration was $1.7 \text{ mmol m}^{-2} \text{ s}^{-1}$; $1.7 \text{ mmol}^{-2} \text{ s}^{-1} \times 44 \text{ mmol}^{-1} \div 1000 \text{ W m}^{-2} = 7.48\%$). Net photosynthesis in the late afternoon was reduced to zero at a leaf temperature of 43.5°C (Wan 1987). The corresponding transpiration was only $0.52 \text{ mmol m}^{-2} \text{ s}^{-1}$, one-fourth of the value for trees on the clay loam site. It appeared that higher leaf temperatures and increased water stress in trees on the sandy loam site were responsible for reduced metabolic activity. Since transpirational cooling was not sufficient to dissipate the extra energy load, mesquite has developed other means to cope with water and high temperature stresses. There are some prominent features the plant employed for this adaptation:

1. Change leaf angle: In spring when soil was wet and VPD was low, changes in leaf orientation were not observed. On hot summer afternoons, the plant turned its leaves parallel to the sun rays, so energy absorption was reduced.

2. Increase in wax and pubescence as the season progresses. Scanning electromicroscope photographs of leaf surfaces exhibit sunken stomata surrounded by a wax layer and hairs. Hydrophobic wax and hairs not only prevent water escape from leaf surfaces but also reflect a considerable amount of solar radiation.

3. Increase in leaf thickness and decrease in leaf size. The specific leaf weight increased from 4 mg cm^{-2} in April to 17 mg cm^{-2} in August. By this means, the leaf surface area was reduced, and less energy was absorbed. As leaves became smaller, air turbulence was favored and more energy was dissipated through convection.

4. Reduced canopy development. Mesquite has 2 types of leaves: early leaves, which emerge at budbreak and reach full maturity around mid-May, and late leaves, which appear later in the growing season and complete their expansion after May. A mild water stress in early to mid-June exerted different influences on expansion and growth in the 2 types of mesquite leaves. More late leaves appeared on trees growing on the mesic clay loam than on the sandy loam site. In mid-June, 1986, 14% of mesquite trees on the clay loam had late leaves, whereas, only 5% of trees on the sandy loam site had late leaves. Like many plants, drought deciduous species in particular, honey mesquite also sheds some of its leaves in droughts.

On the sandy loam site, trees are shorter and the canopy is smaller compared to trees on the more mesic clay loam site. This is an important desiccation avoidance mechanism. It gives the plant a better change to survive a severe drought. Carter (1964) reported that during the severe drought from 1950 through 1956, many mesquite trees died in south Texas. However, the hardest hit stands occurred on clay soils. Most mature trees were killed, but young trees or trees with several stems resulting from pruning were largely unaffected. These observations imply that a small canopy is a mandatory modification for the plant to cope with water stress because it results in increased water supply relative to the demand, leading to an improved plant water balance.

It is difficult to make an universal estimate of water consumption for trees in different environments. In semiarid west Texas, in a wet year with annual precipitation of 530 mm, on an upland site that characteristically has limited soil water supply, the average transpiration rate was $3.85 \pm 1.94 \text{ mmol m}^{-2} \text{ s}^{-1}$ for trees on the clay loam site and $3.28 \pm 2.05 \text{ mmol m}^{-2} \text{ s}^{-1}$ for trees on the sandy loam site May through September. These values are based on 130 paired measurements in different periods. Trees on the clay loam site had greater stomatal conductance and transpiration rates ($P < 0.01$) than those on the sandy loam site.

On the southern High Plains of Texas, honey mesquite avoids

desiccation by stomatal closure and greatly reduced transpirational water loss in midsummer. Daily maximum leaf conductance was only 1.6 mm s^{-1} for trees on a sandy loam site and 3.2 mm s^{-1} for trees on a clay loam site. Stomatal closure creates some problems in leaf energy balance in midsummer. Leaf temperatures as high as $42\text{--}43^\circ \text{C}$ were recorded on some trees, which led to complete cessation of photosynthesis. However, mesquite has developed various means to avoid high energy absorption. The very common response of mesquite trees to water stress is restricted late leaf development and reduction in canopy size. This reduction in transpiring area, together with stomatal closure, helps reduce water loss in the summer. Because the sandy loam is drier in the summer and the stomata of the trees are more tightly closed, it seems that herbicide would have to be applied earlier in the year on the sandy loam compared to the clay loam site.

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Evaporation from rangeland with and without honey mesquite

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Abstract

The Bowen ratio/energy balance technique was used to estimate evaporation (E) from honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) as the difference in total E (plant and soil) between that of adjacent mesquite-dominated and mesquite-free rangeland areas near Throckmorton, Tex. After treatment with diesel in July 1988 to defoliate the honey mesquite, E from the treated area decreased to a minimum value of about 40% of that from the untreated area. In 1989, seasonal E totals from the untreated and treated areas were, respectively, 190 and 176 mm—a 7% reduction in E due to mesquite defoliation. Total E for the herbaceous and honey mesquite vegetation in 1989 in the untreated area was 117 and 73 mm, respectively. Honey mesquite foliar cover was 15% in the untreated area, but it accounted for 38% of the total E. These honey mesquite E data were supported by independent measurements of sap flow. While honey mesquite used substantial amounts of water, E from the rangeland from which it was removed was just slightly lower due to increased herbaceous evaporation associated with increases in standing crop. Under the circumstances of low grazing intensity and low runoff potential, honey mesquite removal would provide little if any additional water for off-site uses in the short-term and, therefore, the removal of this species for purely hydrological purposes would not be justified. Increases in off-site water availability may, however, result from honey mesquite control under grazing regimes which preclude accumulation of additional herbaceous standing crop or at site with greater runoff potential.

Key Words: *Prosopis glandulosa*, transpiration, evapotranspiration, sap flow, Bowen ratio/energy balance

As the demand for water increases (Anderson 1983), a critical question involves the effect of land management practices such as brush control on the water balance of rangelands. To understand how brush control might affect on-site water use efficiency and water availability for off-site uses, it is important to identify the effects of land management practices on rangeland hydrologic processes.

Evaporation (E), which includes plant and soil evaporation (Monteith 1985), is the largest water loss from rangelands and accurate E data are critical for evaluating the effect of management practices on rangeland hydrologic processes. However, few E data are available for rangelands, especially for brush species which compete with herbaceous vegetation for water.

Evaporation data for the widespread woody plant, honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*), are highly variable, depending, in part, upon the depth to available soil water (Thomas and Sosebee 1978). The data suggest that it is a facultative xerophyte. The limited evidence supporting the premise that this species competes for water that could be used for other purposes fosters the assertion that its removal would significantly increase water availability for other uses (McGinnies and Arnold 1939, Rechenthin and Smith 1967, Mosely 1983) even though the data

are inconclusive (Griffin and McCarl 1989).

The objective of this study was to calculate honey mesquite E as the difference between E, measured using the Bowen ratio/energy balance technique (Tanner 1960), from adjacent mesquite-dominated and mesquite-free areas. These E values were compared with honey mesquite sap flow rates measured by heat balance gauges (Baker and van Bavel 1987).

Materials and Methods

Site Description and Experimental Design

This experiment was conducted during 1988 and 1989 at the Texas Experimental Ranch, 16 km north of Throckmorton (33° 20'N, 99° 14'W, elevation = 450 m). The slope of this upland site was < 1%. The predominant soil at the site (Heitschmidt et al. 1985) was a Nuvalde clay loam (fine silty, mixed, thermic Typic Calciustolls). Grazing intensity was 4 ha AUM⁻¹. Honey mesquite trees at the ranch had been chemically treated in 1979 and were characterized by a multi-stemmed regrowth pattern.

Evaporation measurements were made in 2 adjacent areas. One, termed untreated, had a mix of herbaceous vegetation and honey mesquite. The other, termed treated, had only herbaceous vegetation after the diesel application which defoliated all of the honey mesquite. On 27 July 1988, about 1 liter of diesel fuel was applied to the base of each honey mesquite tree in the 6-ha treated area (200 m east-west by 300 m). The untreated area was immediately to the south of the treated area and, for vegetation sampling purposes, was considered to be 200 by 200 m, although similar vegetation extended for more than 1 km in all directions.

Vegetation Sampling

On 28 May 1988, herbaceous standing crop in each area was estimated by clipping plants in 6 randomly positioned, 1- by 1-m quadrats at a height of 10 mm. On 25 Apr., 30 May, 6 July, 7 Aug., and 5 Sep. 1989, standing crop was clipped by species, except on the last day, from three 1-m square quadrats at 5 sampling locations in both areas (n = 15). Samples were dried and weighed. On 5 Sep. 1989, density of woody plants in both areas was estimated by the point centered-quarter method (Cottom and Curtis 1956) at 25 points uniformly distributed across each area, and canopy height and diameter of 100 individual honey mesquite trees in the untreated area were measured.

Photosynthetically active radiation (PAR) above and below the honey mesquite canopy was measured on 13 Apr., 10 May, and 29 July in 1988 and on 25 Apr., 14 July, and 22 Sept. in 1989 using a Model LI191SB sensor (LiCor Corp., Lincoln, Neb.). Four, 30-m long transects were established in both areas at 30-m intervals. Measurements of below-canopy PAR were made within 2 hours of solar noon for 60 s each at 1-m intervals along each transect with the sensor centered upon and normal to the transect at a height below the honey mesquite and above the herbaceous canopy.

Bowen Ratio/Energy Balance

Existing mesquite E data are based primarily upon measurements of gas exchange on small leaf samples or soil water content. Gas exchange measurements may be inaccurate or unrepresentative because of the effect of the sensor on the leaf boundary layer and because of the need to extrapolate to the whole plant over the day measurements made on small portions of a canopy during brief periods of time. The E estimates from soil water measurements,

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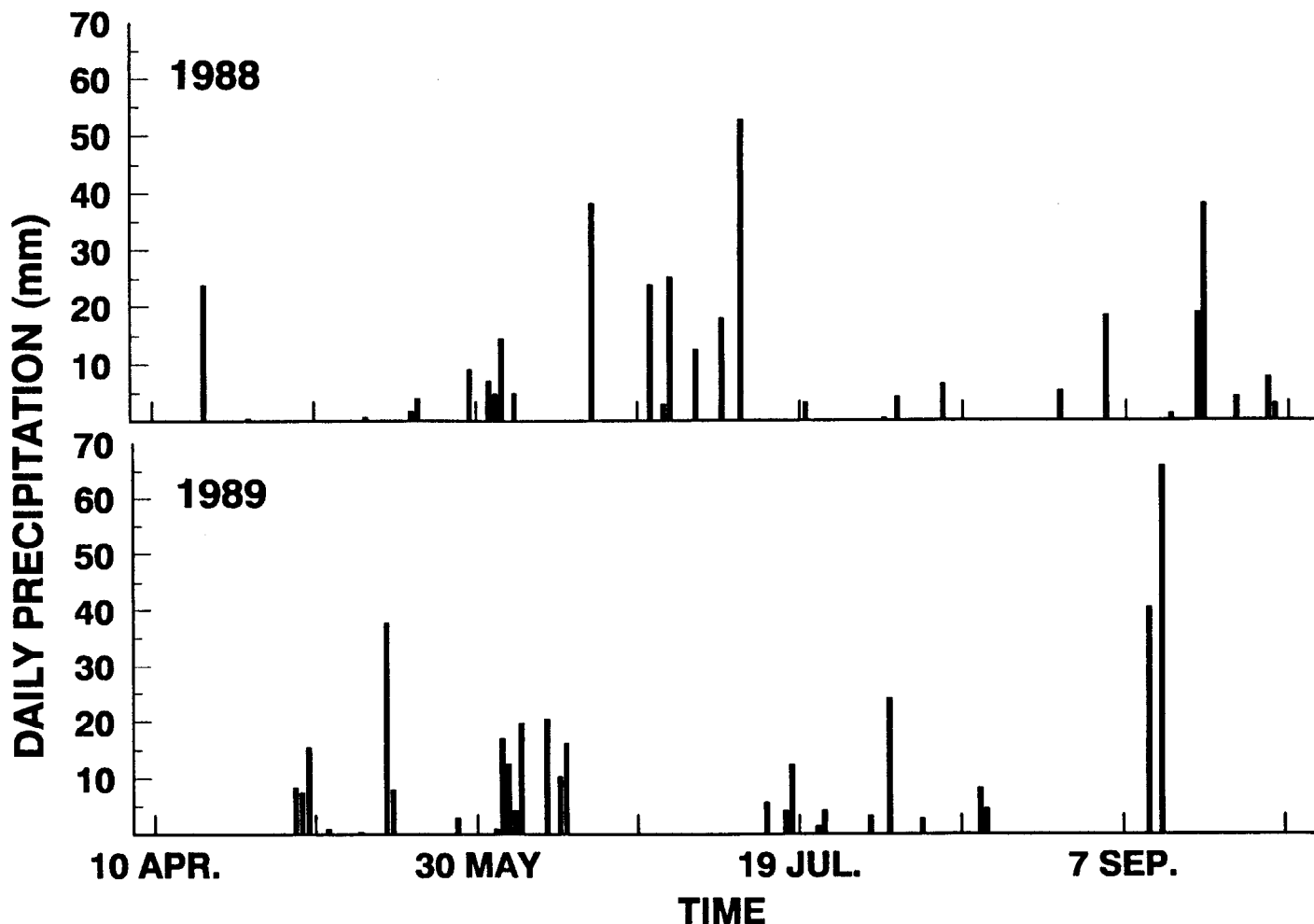


Fig. 1. Daily precipitation in 1988 and 1989 at the experimental site near Throckmorton, Texas.

calculated as a residual from the water balance, include the measurement error of other hydrologic components, which can be large, and are inaccurate for short periods. Neither method necessarily provides representative *E* measurements for extensive stands (Waisel 1960, Van Hylckama 1974, Thomas 1976). However, the Bowen ratio/energy balance (BREB) technique can provide accurate, continuous measurements of *E* over an extensive area. Its use requires a long upwind distance of uniform conditions (fetch); this is typically not limiting on rangelands.

In 1988, BREB measurements were made during 3 periods: 11 April through 27 May, 26 July through 19 August, and 7 through 30 September. In 1989, BREB measurements were made during 2 periods: 25 April through 13 July, and 23 August through 25 September.

The energy balance of the 2-dimensional earth's surface, ignoring the very small amount of energy used in photosynthesis, can be described by:

$$R_n = LE + H + G \quad (1)$$

where *R_n* is the net radiation, *L* is the latent heat of vaporization, and *H* and *G* are the sensible and soil heat fluxes, respectively. The sign convention used herein was that *R_n* toward the surface and *LE*, *H*, and *G* away from the surface were positive.

If temperature (*T*) and specific humidity (*q*) measurements are made at a minimum of 2 heights with the same vertical distance

between the sensors, the Bowen ratio (*BR*) can be calculated as

$$BR = (C_p/L) * (K_h/K_w) * (dT/dq) \quad (2)$$

where *C_p* is the specific heat of dry air at constant pressure and *K_h* and *K_w* are the transfer coefficients for heat and water vapor, respectively. If it is further assumed that (1) *K_h* = *K_w*, (2) the vertical profile shapes of *T* and *q* are similar, and (3) the vertical flux is constant over the heights where *T* and *q* are measured, equations (1) and (2) can be combined into the following

$$E = [(R_n - G)/(1 + BR)]/L \quad (3)$$

Except in extremely unstable or stable atmospheric conditions, assumption 1 is usually valid (Rosenberg et al. 1983). Assumptions 2 and 3 are typically not violated if measurements are made at appropriate heights above the surface. Adequate accuracy of the BREB technique has been demonstrated by comparison with *E* measurements from lysimeters (Tanner 1960, Denmead and McIlroy 1970, Blad and Rosenberg 1974) and the technique has been successfully used in natural communities (McNaughton and Black 1973, Gay and Holbo 1974, Gay and Fritschen 1979, McCaughey and Brintnell 1984).

The *R_n* was measured at both a base station and a mobile station in each area. The *R_n* in 1988 was measured with 1 Model 6220 and 3 Model 6211 net radiometers (Science Associates, Princeton, N.J.) at heights of about 3 m. The mobile station in the treated area did not have a net radiometer for the last 2 measurement periods in

1988. In 1989, 1 Model 6220, 2 Model 6211, and 1 Model Z002886 (REBS, Seattle, Wash.) radiometers were used. The 6220 was on the base station in the untreated area in both years and measurements from it were used in the LE calculations for all stations [Eq. (3)] because the relationship between it and R_n measured at other stations was consistent (see below).

Near each base station, soil heat flux was calculated from measurements from 4 soil heat flux plates buried at 0.1 m (1988) or 0.05 m (1989), and from storage above this depth. Storage was calculated from soil temperature and heat capacity above the plate depth. Plate measurements were corrected for plate shape and differences in soil and plate conductivity (Philip 1961). Three plates were buried away from and 1 plate was buried under a honey mesquite tree in each area. Soil temperature was measured with spatially averaging, copper/constantan thermocouples buried 0.2 m from each plate. The heat capacity was determined from bulk density and gravimetric soil water content measurements of 75-mm diameter soil cores (4 to 6 per area) taken about every week.

Measurements of dT and dq were made on both base and mobile stations with systems similar to the design of Tanner et al. (1987) and Bingham et al. (1987). The dT was measured at heights of approximately 2.8 and 4.0 m above the ground by 2 pairs of unshielded, unshielded, differentially wired, chromel/constantan thermocouples (wire diameter at junction = 25.4 μ m). The dq values were calculated from dew point temperature (T_{dp}) measured on air drawn from each air temperature height to a Model DEW 10 cooled-mirror, dew point hygrometer (General Eastern, Watertown, Mass.). The T_{dp} was converted to q (Geiger 1973). The air stream from each height was switched to pass over the hygrometer every 60 s.

Measurements of dT and T_{dp} were made during the last 30 s of 60-s periods using a data logger that sampled every 2 s. Two 30-min means of the BR were calculated from the mean value of 2 dT measurements and from the difference in the mean q value for each height. Thus, there were 2 E values per station, with the R_n , G, and dq values common to each [Eq. (3)]. Daylight E totals were summed from half-hour E values. Daylight periods were typically 0800 through 1900 h Local Standard Time. This encompassed the time during which almost all the E occurred.

The base station in the treated area was located about 50 m south of the center of the northern border. The base station in the untreated area was located about 20 m south of the southern border of the treated area. In the treated area, this provided about 300 m of fetch for the predominantly southerly winds. This fetch distance is adequate for these Bowen ratio/energy balance calculations of E (Heilman et al. 1989).

To describe the spatial variability of the BR and R_n measurements, the mobile station in each area was moved about every 4 days to a different location. The mobile station was moved from 5 to 20 m each time in all directions and it remained within about 60 m of the base station. All stations were in the treated area until 29 April 1988.

Daylight totals of herbaceous E from the untreated area were calculated as the product of the mean E from the treated area ($n = 4$, 2 values/station) and the ratio of the herbaceous standing crop in the untreated and treated areas. Daily standing crop ratios were linearly interpolated from values calculated on sampling dates. This calculation of mesquite E assumes that herbaceous E was proportional to the standing crop. Honey mesquite E in the untreated area was the difference between the total E and herbaceous E in the untreated area.

At the base station in the untreated area, half-hour averages of wind direction were measured. Half-hour totals of precipitation were measured at all stations. Wind direction and precipitation were recorded for the same periods that BREB measurements were

made. Daily precipitation was also measured throughout the year with a nonrecording raingage located approximately 300 m west of the base station in the treated area.

Honey Mesquite Sap Flow

Another technique applicable for honey mesquite E measurements is the constant-power heat balance gauge where sap flow rate through a stem is determined by a heat balance. From 27 July through 9 Aug. 1988, 2 sap flow gauges (Model SGA16, Dynamax, Houston, Tex.) were placed on 2 honey mesquite stems with diameters of about 17 mm on a tree near the base station in the treated area. In 1989, sap flow was measured near the base station in the untreated area on 9 honey mesquite stems from 26 April through 13 July and on a different set of 9 stems from 23 August through 25 September. For both periods, 8 of the 9 stems had diameters from 15 to 20 mm (gauge Models SGB16 and SGB19) and 1 had a diameter of 35 mm (Model SGA35).

Gauge signals were sampled every 15 s, and 30-min averages were calculated by a data logger. Daylight totals of mass flow were summed from 30-min sap flow values calculated following the procedures described by Dugas (1990). Gauges provide accurate measurements of sap flow rates of agronomic (Dugas 1990) and woody plants (Steinberg et al. 1989).

Prior to use in the field, sap flow measurements using gauges were validated in the glasshouse by comparison with mass measurements from a potted honey mesquite plant whose soil surface was covered to eliminate soil evaporation. Measurements were made at Temple, Tex., for 4 days in February 1988. Total measured mass loss and calculated sap flow were 1,335 and 1,387 g, respectively. The root mean square error (RMSE) of the daily losses was 25 g. These results confirmed the method accuracy for honey mesquite.

On 14 July 1989, the area of all leaves on each gauged stem was estimated. All leaves were stripped from each stem and approximately 10% of the leaf area was measured with a photo-electric leaf area meter. Leaves were dried and the total leaf area for each stem was calculated from the ratio of leaf area to leaf mass of the subsample and the mass of the remainder of the leaves.

Results and Discussion

Vegetation

Honey mesquite responded immediately to the diesel application on 27 July 1988. Leaves wilted within 2 days of application, and about 90% of the trees were completely defoliated by 7 September. Honey mesquite density in the treated and untreated areas was 380 and 486 trees ha^{-1} , respectively. In the untreated area, average tree height and crown diameter were both 1.99 m, and honey mesquite foliar cover was 15.5%. On 5 September 1989, 4% of the honey mesquite plants in the treated area exhibited a small amount of regrowth. In the treated and untreated areas, lotebush [*Condalia obtusifolia* (Hook.) Weberb.] made up 1 and 5% of the woody species, respectively. Surviving honey mesquite and lotebush were retreated in the fall of 1988 and the spring of 1989. The likely small contribution of the honey mesquite regrowth and lotebush to E was ignored.

The minimum ratio of PAR below the honey mesquite canopy to that above was 0.85 in the treated area (before diesel application) and 0.9 in the untreated area. The ratio in the treated area in 1989 was about 1.0. Thus, a relatively small amount of energy was intercepted by the honey mesquite in both areas and essentially no energy was intercepted by honey mesquite stems in the treated area after diesel application.

In 1988, herbaceous standing crops in the treated and untreated areas (Table 1) were not significantly different ($P \leq 0.01$) and it was assumed that herbaceous E in the treated and untreated areas was

Table 1. Herbaceous standing crop in an area treated to defoliate honey mesquite and an untreated area in 1988 and 1989.

Area	Date					
	1988	1988	1988	1989	1989	1989
	28 May	25 Apr.	30 May	6 July	7 Aug.	5 Sept.
	(kg ha ⁻¹)					
Treated						
avg	1020	632	1029	1152	715	928
SD	100	190	205	242	155	135
Untreated						
avg	830	477	692	613	461	797
SD	340	150	164	251	188	312

equal. In 1989, however, standing crop in the treated area was significantly greater on all sampling dates except the last, and herbaceous E in the untreated area was calculated as described above.

Texas wintergrass [*Stipa leucotricha* Trin. & Rupr.], buffalo-grass [*Buchloe dactyloides* (Nutt.) Englem.], and sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] contributed 80 to 90% of the above-ground herbaceous biomass in both areas. The species composition in each area was similar in 1989. On 25 April, the difference between the 2 areas in percentage composition (by mass) was 2, 8, and 4% for these 3 species, respectively. On 7 August, differences were 8, 1, and 13%, respectively.

Bowen Ratio/Energy Balance

Precipitation totals for the periods defined by the beginning and ending dates of the BREB measurements (11 April and 30 September 1988, and 25 April and 25 September 1989) were 378 and 363 mm in 1988 and 1989, respectively. The long-term average precipitation at Throckmorton for the period from April through September is 457 mm. In 1988, larger daily precipitation totals occurred in late June and early July, while in 1989 the larger totals were in late May, early June, and mid September (Fig. 1). Daily precipitation totals varied significantly, occasionally by a factor of 2, between the 4 BREB stations, especially on days with large totals.

In 1988, wind direction was consistently from the south and southeast, especially during the second and third measurement periods. In 1989, wind direction was from the south and southeast during the first period. It was consistently from the south during the first 10 days of the second period and from the north or south during the last 15 days of the second period. These wind directions provided adequate fetch on almost all days to ensure that dT and dq measurements were representative of the respective areas.

In 1988, mean daylight Rn at the base station in the untreated area for the 3 measurement periods was 12.2, 12.0, and 8.9 MJ m⁻², respectively. In 1989, Rn for the 2 measurement periods was 12.4 and 8.7 MJ m⁻².

The ratios of Rn from the radiometers on the 2 mobile stations and on the base station in the treated area to the Rn from the radiometer on the base station in the untreated area (considered a 'standard' in this experiment) were used to evaluate the spatial variability of Rn and, in 1988, the effect of defoliating honey mesquite on Rn. The magnitude of the Rn ratios (Fig. 2) varied because of different radiometer designs. The variability of the ratio was small and comparable for all sensors; the C.V. of the ratios varied from only 3 to 6%. There was as much variability in the ratio of the radiometer on the base station in the treated area as for the radiometers on the 2 mobile stations, which, as a result of movement, 'viewed' different surfaces. This suggests that there was little spatial variability of Rn at this location. Because of the small

variation in this Rn ratio for each sensor and of the large difference in the absolute Rn values for the different sensor designs, the Rn from the radiometer on the base station in the untreated area was used in all LE calculations [Eq. (3)].

There was no significant effect of honey mesquite defoliation on Rn in the treated area. After diesel application in 1988, Rn ratios increased for the mobile station in the untreated area, where no diesel was applied, and for the base station in the treated area (Fig. 2).

The soil heat flux was a relatively large percentage of Rn. In 1988, daylight G totals for the last 2 periods in the untreated area averaged 1.9 and 1.4 MJ m⁻², while the comparable values in the treated area were 2.0 and 1.8 MJ m⁻². In 1989, averages for the 2 periods were 2.0 and 1.6 MJ m⁻² in the untreated area and 2.4 and 1.8 MJ m⁻² in the treated area. The lower G values in the untreated area were caused by greater interception of Rn by the honey mesquite leaf area. These G differences are significant considering the magnitude of the E differences between the treated and untreated areas (see below).

Daylight E values from the base and mobile stations in the treated and untreated areas were essentially equal for the 2 years (Fig. 3). The slopes of linear regression of the mobile station E vs. base station E were not significantly different from 1.0 in either year for the untreated area ($P \leq 0.01$; Neter et al. 1985), but were significantly less than 1.0 in the treated area. The latter suggests that E values from the base station in the treated area may have been biased high. This would tend to have lowered the estimate of mesquite E. The E differences between the base and mobile stations were, however, quite small. In 1989, average E from the base and mobile stations differed by less than 0.08 mm d⁻¹ for both areas. The RMSE between the E values from the base and mobile stations was 0.36 and 0.26 mm d⁻¹ for the untreated and treated areas, respectively. The greater variation in E from the untreated area was likely due to the presence of honey mesquite.

In both years, early-season E values were most variable, primarily due to varying Rn, and total E values from the treated and untreated areas were essentially equal (Fig. 4). Early-season E values were lower in 1988 than in 1989 because of less precipitation (Fig. 1) and increased in both years following significant precipitation events. Maximum E was about 5 mm d⁻¹ (Fig. 4). The E approached zero in both areas in 1988 and equaled zero in the treated area during dry conditions late in the 1989 growing season. The E rates on these mesic rangelands were low relative to those reported from agronomic crops (Tanner 1960, Blad and Rosenberg 1974), averaging slightly less than 2 mm d⁻¹ over the 2 growing seasons.

For days in 1988 when BREB measurements were made, seasonal E totals were 119 and 106 mm from the untreated and treated areas, respectively. After diesel application in 1988, the values from these 2 areas were 62 and 45 mm, a 28% reduction in E in the treated area. For days in 1989 when BREB measurements were made, seasonal E totals were 190 and 176 mm from the untreated and treated areas, respectively, a 7% reduction in E. The lower reduction in 1989 of E in the treated area relative to that from the untreated area is attributed to higher E in the treated area associated with the increased herbaceous standing crop following elimination of competition by honey mesquite (Table 1). Damage to the herbaceous vegetation in the treated area under mesquite trees in 1988 caused by diesel application and trampling by the dozen individuals applying the diesel may also have been a factor. The 7% difference in E measured in this study between brush-dominated and brush-free rangelands is about one-half of the difference measured in a previous study (Richardson et al. 1979), but is similar to the difference measured for 2 years in south Texas from nonweighing lysimeters (Weltz 1987).

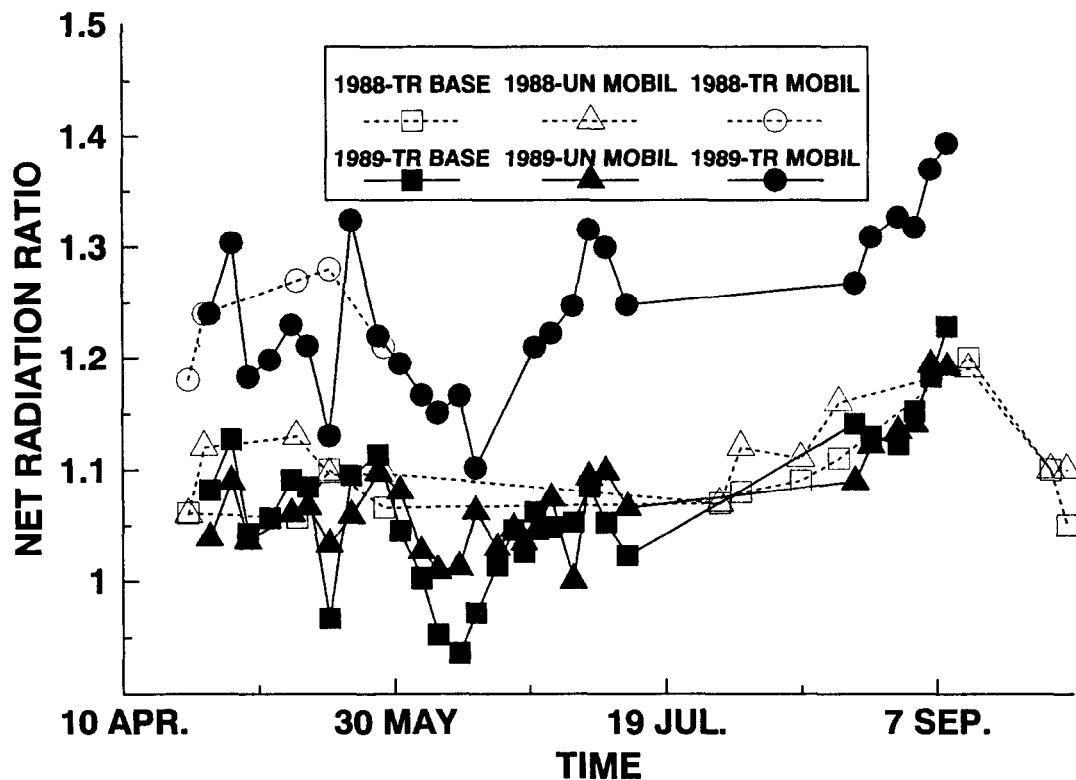


Fig. 2. Ratio of daylight net radiation from net radiometers on mobile stations in the treated (TR) and untreated (UN) areas and on the base station in the treated area to the net radiation from a radiometer on the base station in the untreated area in 1988 and 1989. Ratios were calculated for periods defined by mobile station movements (see text).

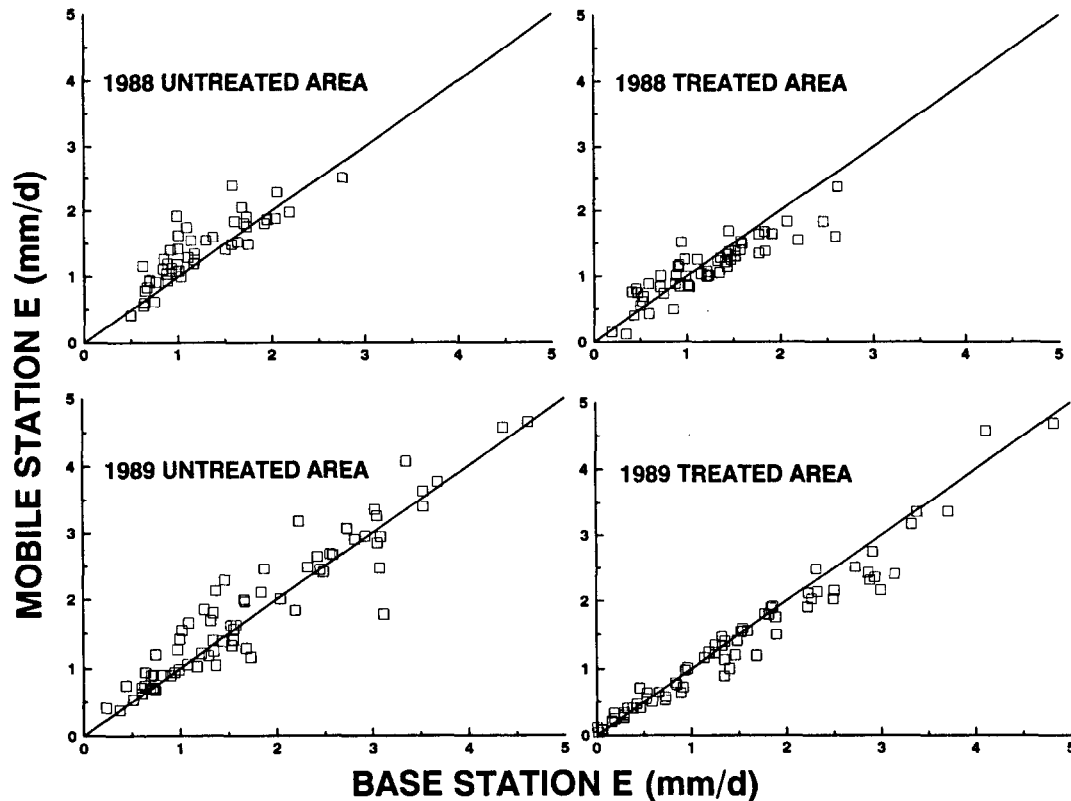


Fig. 3. Daylight totals of evaporation (E) from base and mobile stations in treated and untreated areas in 1988 and 1989. The 1:1 line is shown.

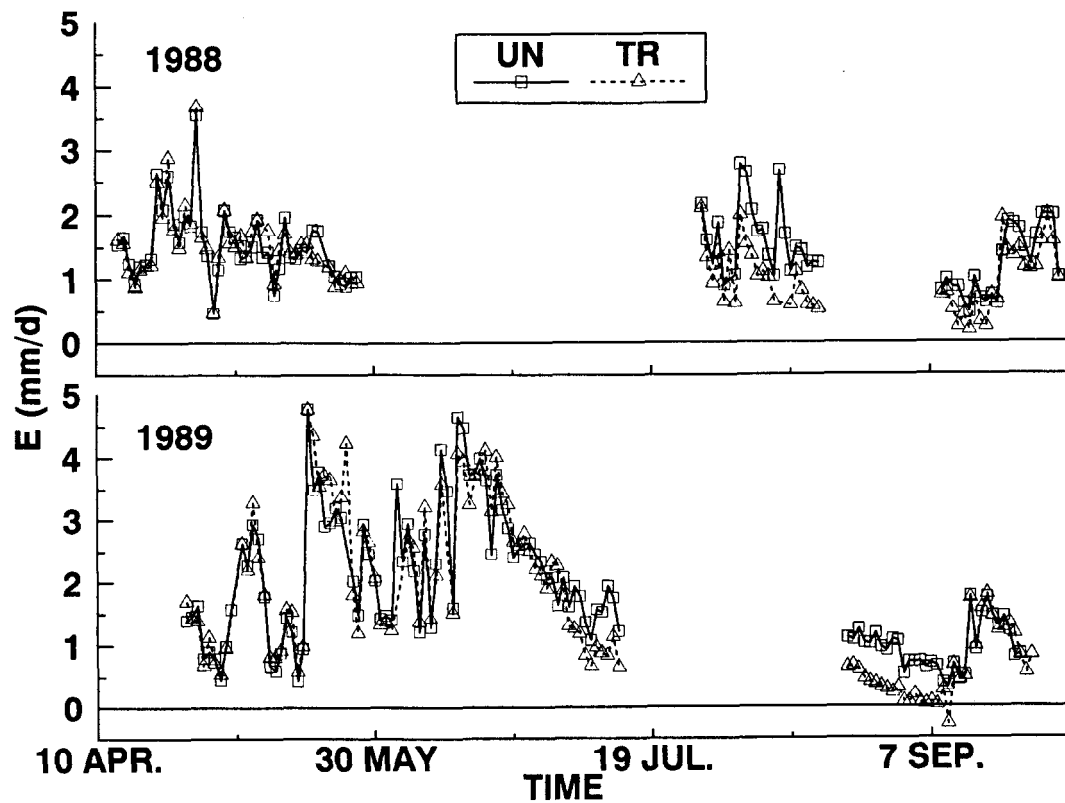


Fig. 4. Daylight totals of evaporation (E) in treated (TR) and untreated (UN) areas in 1988 and 1989.

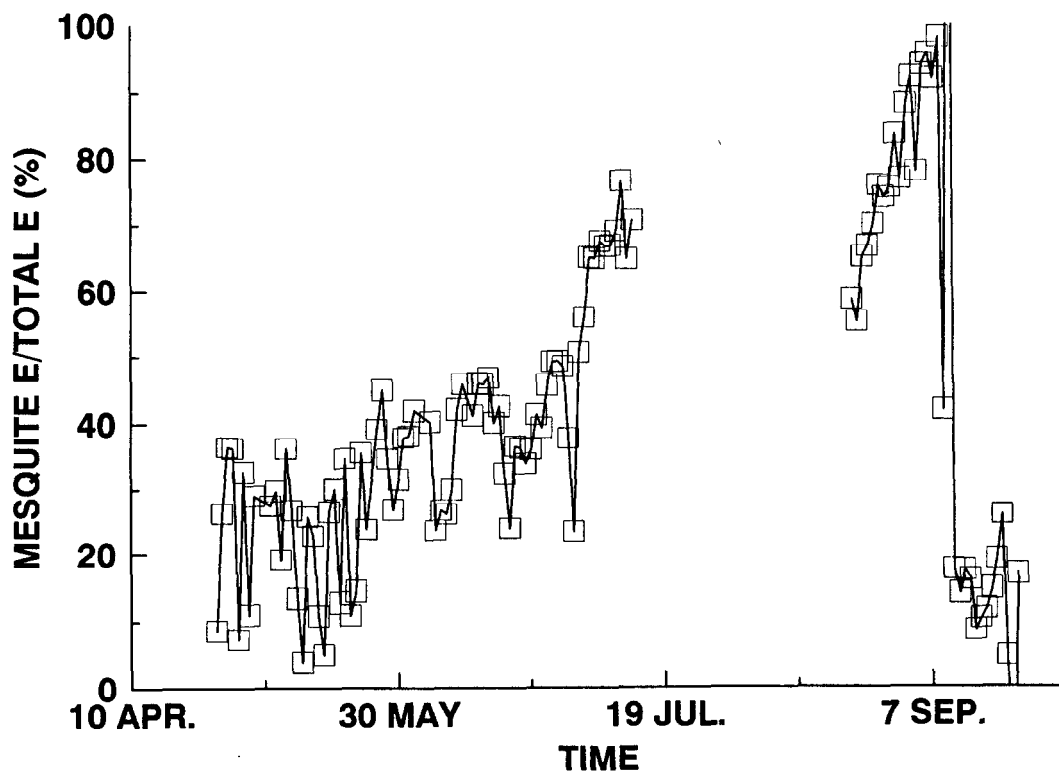


Fig. 5. Daylight evaporation (E) from honey mesquite expressed as a percentage of total E from the untreated area in 1989.

Honey mesquite E was consistently a smaller percentage of total E from the untreated area for the first half of the first measurement period and for the last 10 days of measurements in 1989 (Fig. 5). Increasing percentages from approximately 22 June to 14 July coincided with E values linearly decreasing (Fig. 4) in association with the lack of precipitation (Fig. 1), and may reflect the relatively low sensitivity of honey mesquite and high sensitivity of herbaceous vegetation to decreasing water availability in the upper soil profile. Honey mesquite E remained a high percentage of the total E throughout the beginning of the second measurement period until the heavy precipitation around 12 September. In 1989, total E for the herbaceous and honey mesquite vegetation in the untreated area was 117 and 73 mm, respectively. Even though honey mesquite had only 15% foliar cover and intercepted an even smaller percentage of the light, it contributed 38% of the seasonal E, and, during dry periods, up to 100% of E (Fig. 5). This relatively high contribution of honey mesquite to the total E may reflect its deep rooting pattern (Heitschmidt et al. 1988), which enables it to explore a large volume of soil for water.

The consistency of the E measurements from the BREB instrumentation and the effect of honey mesquite defoliation on E can be seen by examining the ratio of E from the treated area to that from the untreated area (Fig. 6). The E ratio varied ± 0.1 from 1.0 through 28 April 1988, when all 4 stations were near the base station in the treated area, and the ratio varied ± 0.2 from 1.0 for the remainder of the first period when there were 2 stations in each area, but before the diesel had been applied. Thus, the 4 Bowen ratio stations measured the same E when they were in the same area and the E values from the 2 areas were essentially equal before diesel application. For the first measurement period in 1988, the slope of the E ratio regressed against time was not significantly different from zero (two-tailed *t* test, $P \leq 0.005$; Neter et al. 1985). Subsequent to diesel application, the ratio dropped rapidly to a value of about 0.4. During the last period in 1988, the ratio was consistently less than 1.0 again, but fluctuated more than it did during the second period, likely because of larger precipitation totals (Fig. 1) and a concomitantly larger relative contribution of herbaceous vegetation to the total E (Fig. 5).

In 1989, the ratio of E from the 2 areas varied ± 0.2 from 1.0 for the first part of the season (Fig. 6). Beginning on about 29 June the ratio dropped rapidly to about 0.5 on 14 July, indicating the evaporation from the treated area was 50% of that from the untreated area. This period of rapid decrease coincided with declining soil water levels due to the lack of precipitation (Fig. 1) and with the increase in the honey mesquite E as a percentage of total E (Fig. 5). During the last measurement period in 1989, the ratio approached zero as the herbaceous component of E dropped to zero (Figs. 4 and 5). The maximum absolute difference in E between the 2 areas was approximately 0.6 mm d^{-1} and was also greatest during the last part of the first measurement period and the first part of the second period. The ratio again approached 1.0 after heavy precipitation.

Honey Mesquite Sap Flow

The rapid effect of diesel application on sap flow rate was evident in the daylight flow totals measured by the 2 gauges on a tree that had diesel applied to the base of it on 28 July (Fig. 7). Sap flow through the stem with the first gauge decreased from 700 g d^{-1} to less than 100 g d^{-1} within 9 d. The decrease is also reflected in data from the other stem. These data support the rapid decrease in E from the treated area, relative to that from the untreated area, as measured by the Bowen ratio instrumentation (Fig. 6).

In 1989, daylight stem flow totals from honey mesquite (Fig. 8) mirrored the E from the untreated area (Fig. 4). Both increased markedly on about 20 May in association with 50 mm of precipitation (Fig. 1) and both declined for the last 20 days of the first

period. Sap flow declined markedly from the beginning of the second period until precipitation on about 12 September. The average sap flow through each stem was $1,368 \text{ g d}^{-1}$. Assuming sap flow through each stem was $1,000 \text{ g d}^{-1}$ for the 40 days between the 2 sap flow measurement periods in 1989 (Fig. 8) and an arbitrary but representative 8 stems tree^{-1} , a total seasonal (150 days) water use of about 1,600 liters tree^{-1} was calculated from the sap flow measurements. Using the 73 mm of honey mesquite E for the period of BREB measurements and the density of 486 trees ha^{-1} , and assuming that honey mesquite used 60% of an estimated 1 mm d^{-1} from the untreated area for the period between the BREB measurements (Figs. 4 and 5), calculated total seasonal honey mesquite E from the BREB measurements was 2,000 liters tree^{-1} . These estimates of mesquite E agree reasonably well with each other, but are substantially greater than the value of 80 liters tree^{-1} calculated for upland range sites (Sosebee 1980).

Sap flow data also compare favorably with the seasonal E value of 100 liters m^{-2} of mesquite leaf area of Nilsen et al. (1983). Division of the average sap flow for each stem for the first measurement period by the total leaf area (both sides) yielded a mean E value for mesquite of 1.1 liters $\text{d}^{-1} \text{ m}^{-2}$ leaf area. This value was biased slightly because the leaf area was likely lower in the early part of the season than on the day leaf area measurements were made. This value was prorated for the entire 1989 season based upon the ratio of the mean daily E from the untreated area for the first measurement period to the mean daily E for the total season. This 'adjusted' sap flow per unit leaf area was 0.9 liters $\text{d}^{-1} \text{ m}^{-2}$ leaf area, which, for a 150-day season, resulted in a total water loss of 135 liters m^{-2} leaf area, a value slightly higher than that of Nilsen et al. (1983). As an additional comparison, using the assumed 8 stems tree^{-1} and the measured value of 1.88 m^2 of leaf area stem^{-1} , the seasonal sap flow total of 1,600 liters is equivalent to 106 liters m^{-2} of leaf area.

As a final comparison between the sap flow and BREB E values, mean daylight sap flow totals were converted to a unit area basis, assuming 4,000 stems ha^{-1} (500 trees ha^{-1} and 8 stems tree^{-1}) and was divided by the total E from the untreated area. There were similarities between this sap flow/E ratio (Fig. 9) and the honey mesquite E expressed as a percentage of total E (Fig. 5). Both curves show a steep slope for the last half of the first measurement period, high values for the first half of the second period, and a rapid drop after the precipitation on about 12 September. Thus, the sap flow and BREB E measurements were in agreement.

Conclusions

Daily total evaporation (E) from rangeland was highly variable, differing by as much as a factor of 5 on successive days. Mesquite E was equally variable, whether estimated by Bowen ratio/energy balance or sap flow techniques. Mesquite E varied by as much as an order of magnitude on successive days and commonly varied by a factor of 3 or 4. Such extreme short-term variability has implications regarding the representativeness of E values estimated with methods that depend upon a limited number of measurements, each made over a brief period of time, such as porometry.

After diesel application in 1988 to defoliate all honey mesquite in the treated area, total E from the untreated and treated areas was 62 and 45 mm, respectively. In 1989, seasonal E totals from the untreated and treated areas were 190 and 176 mm, or a 7% reduction in E in the area without mesquite. Even though honey mesquite foliar cover was only 15% and it intercepted a small percentage of the light, honey mesquite E was 38% of the seasonal total in a year of average rainfall. During dry periods, honey mesquite E increased to 100% of that total. Both percentage and absolute differences in E between the treated and untreated areas were greatest under dry conditions and were essentially zero immed-

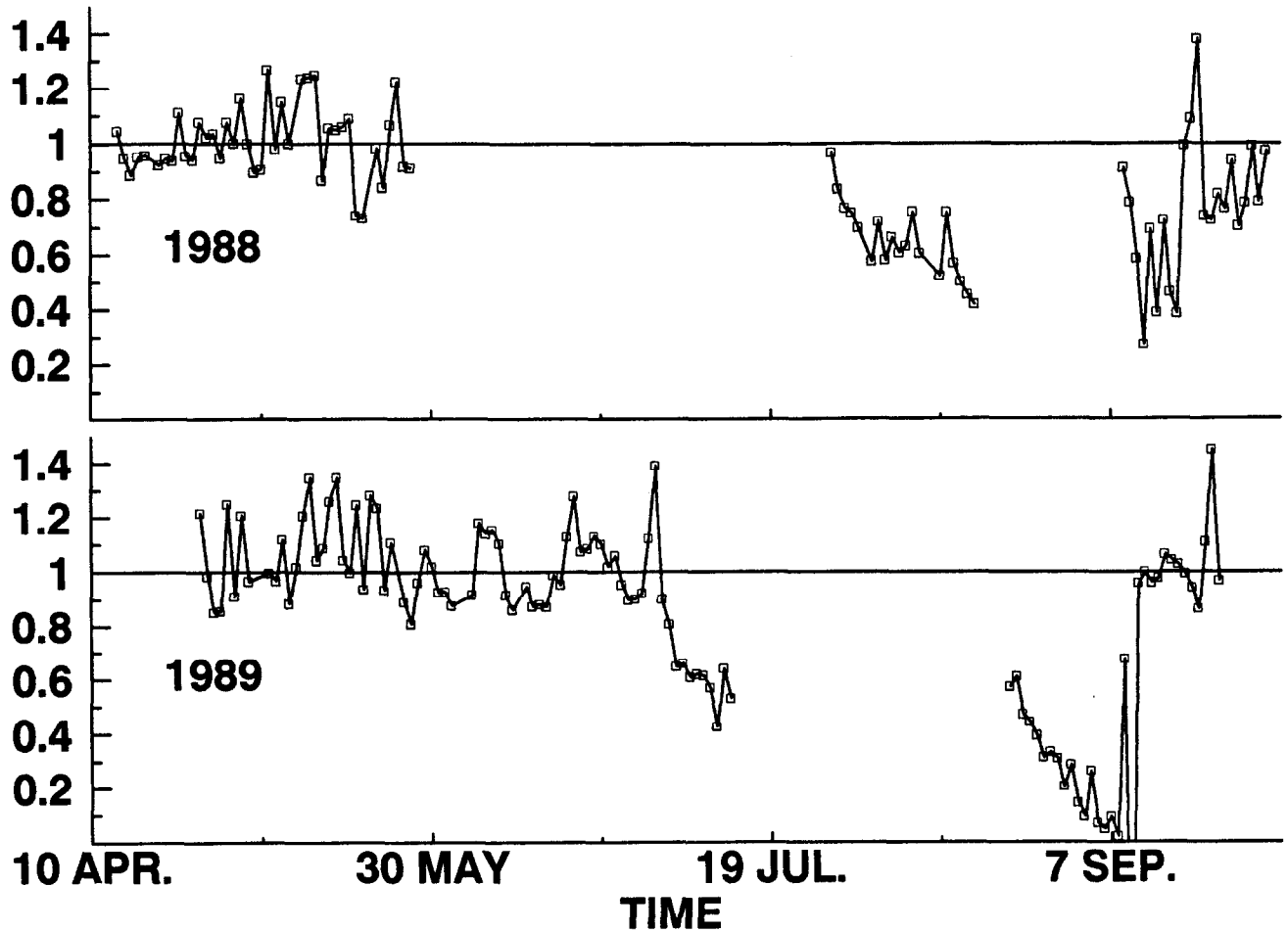


Fig. 6. Ratio of evaporation (E) from the treated area to the E from the untreated area in 1988 and 1989.

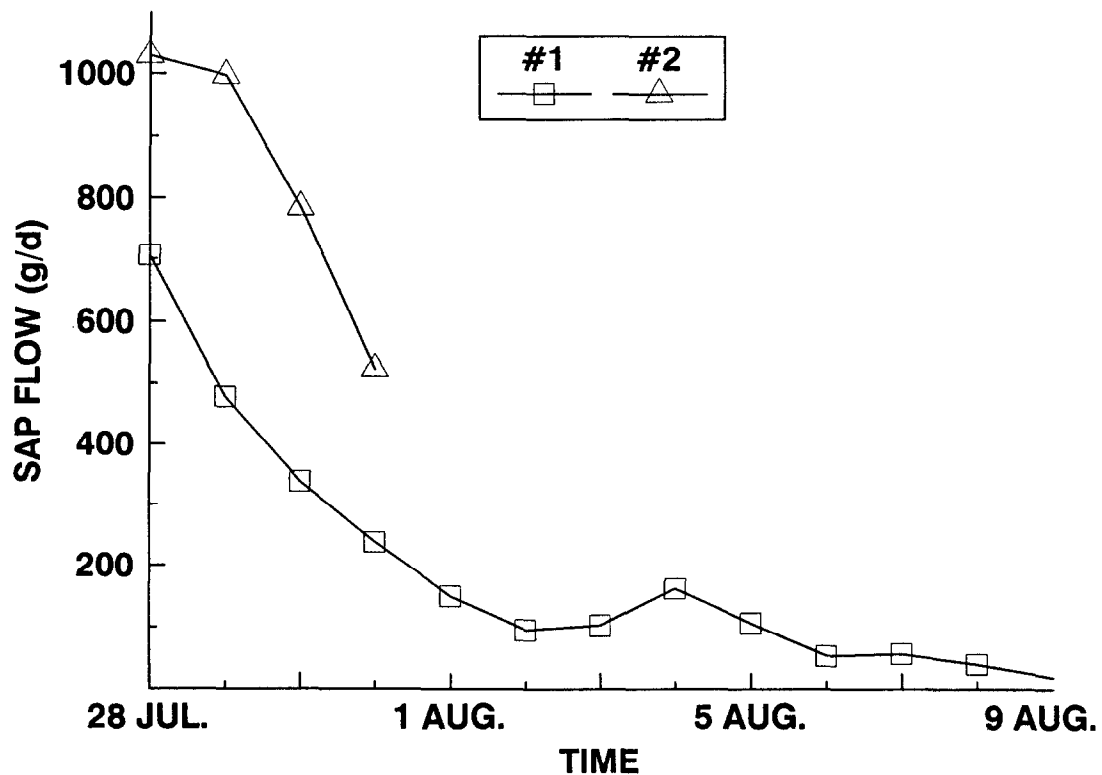


Fig. 7. Daylight honey mesquite sap flow from 2 gauges on 2 stems on a tree that had diesel applied to it on 28 July.

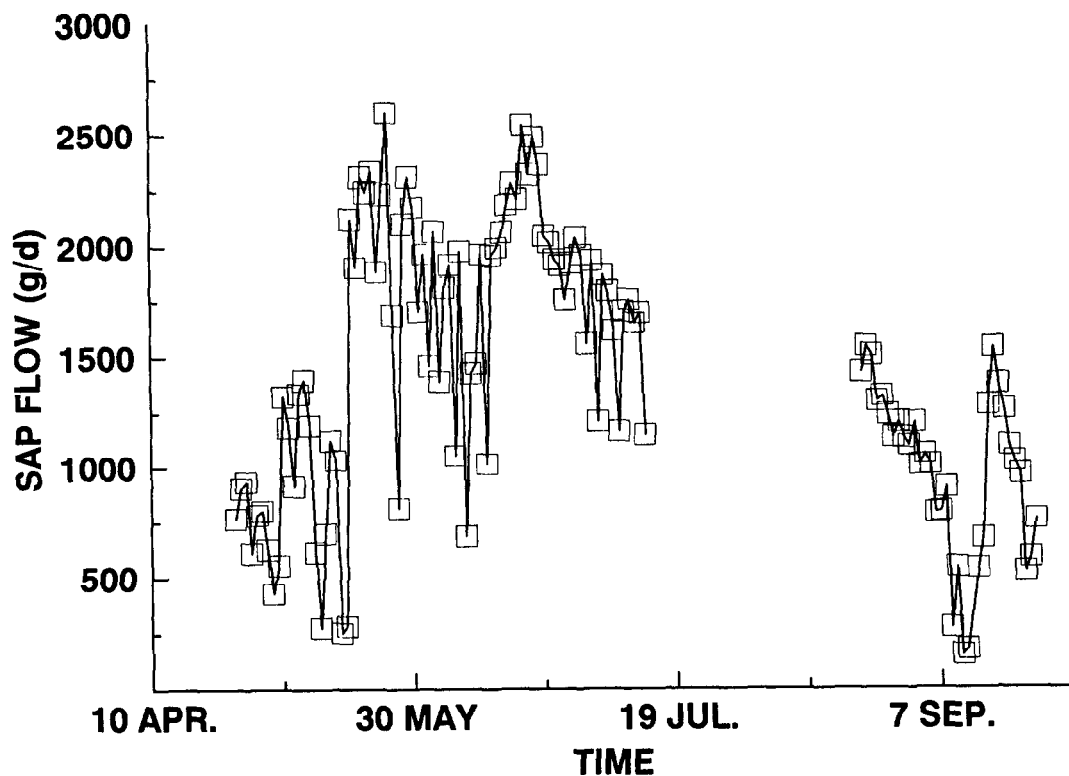


Fig. 8. Mean daylight mesquite sap flow from 9 stems in the untreated area in 1989.

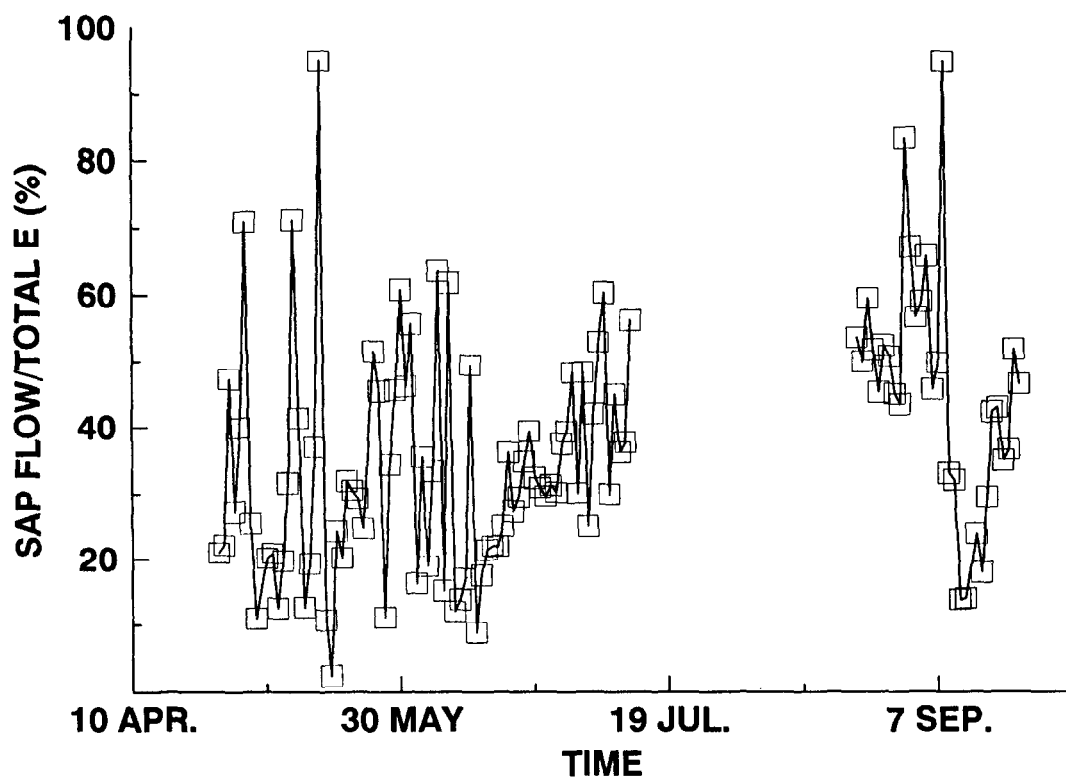


Fig. 9. Mean daylight honey mesquite sap flow expressed as percentage of the evaporation (E) from Bowen ratio instrumentation in the untreated area in 1989. A density of 4,000 stems ha^{-1} was used to convert the sap flow to daily rates of evaporation.

ately after precipitation, when soil water availability was high.

While honey mesquite used substantial amounts of water and increased E, the E from the rangeland without it was just slightly lower than E from a rangeland with it due to an increase in herbaceous E associated with increased standing crop following mesquite control. In this environment, which had a low potential for runoff and deep percolation, removal of honey mesquite would not be expected to increase availability of water for off-site uses because water not transpired by mesquite in subsequent years would be utilized by grasses. If so, brush control for purely hydrological purposes would not be justified. Increases in forage production following mesquite control equalling or exceeding those measured in this study have been reported at several locations in the same geographic area (Dahl et al. 1978, Jacoby et al. 1982, McDaniel et al. 1982, Bedunah and Sosebee 1984). However, differences in E or increases in off-site water availability as a result of honey mesquite control may occur under a grazing regime which precludes accumulation of additional herbaceous standing crop or for different soils.

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Effects of seedbed preparation and cattle trampling on burial of grass seeds

VON K. WINKEL, BRUCE A. ROUNDY, AND DAVID K. BLOUGH

Abstract

Location of seeds in the seedbed may affect germination and seedling establishment of range grasses. Our objective was to determine the effects of trampling by livestock and mechanical seedbed preparation on burial of grass seed on a sandy loam seedbed. Plots were root plowed or ripped then broadcast seeded, or broadcast seeded then lightly or heavily trampled by cattle or land imprinted before summer rains. Seedbeds were sampled by extracting soil plugs with plastic vials, splitting the plugs, and determining seed location with a dissecting scope. Sampling occurred after treatment, after summer thunderstorms, and after seedling emergence. An average of 75, 42, 17, and 7% of seeds found were buried immediately after heavy trampling, land imprinting, light trampling, and no disturbance, respectively. After summer thunderstorms an average of 78, 72, 63, 40, and 29% of seeds found were buried on plots root plowed or ripped, heavily trampled, imprinted, lightly trampled, and undisturbed, respectively. Although high percentages of seeds were buried on plots heavily trampled, imprinted, and root plowed or ripped, many of these seeds were too deep for seedling emergence. Smaller-seeded blue panic (*Panicum antidotale*) and the lovegrasses (*Eragrostis lehmanniana* Nees and *Eragrostis lehmanniana* Nees \times *E. trichophora*) were buried by treatment and rain better than sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.].

Key Words: seed location, seed depth, seedbed preparation, revegetation, root plowing, land imprinting, sideoats grama, blue panic, Lehmann lovegrass, Cochise lovegrass

Reasons for failure of some seedlings on semiarid rangelands may include insufficient soil water and soil coverage of seeds, and unfavorable temperature (Vallentine 1989); lack of radicle entry (Campbell and Swain 1973, Sheldon 1974, and Cox and Martin 1984); ant, bird, and rodent predation (Howard 1950, Nelson et al. 1970); and excessive seed burial (Mutz and Scifres 1975).

Drilling is the preferred method for sowing seeds on most rangelands. Drilling distributes and covers seeds more uniformly and places seeds at a desired depth more accurately than broadcasting (Vallentine 1963, Jordan 1981). However, drilling is not always practical and broadcast seeding must be used on steep slopes and rough terrain.

Broadcast seeding of small-seeded species on prepared seedbeds before summer rains has produced similar seedling emergence as drilling in the southwestern United States (Cox et al. 1986). Chaining, ripping, plowing, and imprinting have all been used to help prepare seedbeds (Allison and Rechenthin 1956; Tiedemann and Schmutz 1966; Haferkamp 1987; and Clary 1988, 1989). It has been assumed that these treatments help to bury seeds. Livestock trampling following broadcast seeding has also been suggested as helping to bury seeds (Plummer 1955, Hormay 1970, Vallentine 1989, Pearson and Ison 1987). Little information is available on where

trampling or mechanical seedbed preparation of rangeland soils places seeds in the seedbed.

Our objective was to determine the effects of cattle trampling, land imprinting, root plowing or ripping, and summer thunderstorms on location of broadcast grass seeds.

Methods

The study was conducted on the Anvil ranch, about 65 km southwest of Tucson, Ariz., in conjunction with a seedling establishment study. The soil at the site is a sandy loam (fine, mixed, thermic Ustollic Haplargids).

The experimental design of the study was a randomized block with 4 grass species \times 5 seedbed treatments applied to each of 3 blocks on each of 2 years (1987 and 1988).

Seedbed treatments applied to 6- by 6-m plots included light cattle trampling (approximately 10 hoofprints per m²), heavy cattle trampling (5 cattle herded inside the plot for 20 minutes to thoroughly disturb the upper 4 cm of soil), land imprinting, root plowing (1987) or ripping (1988), and no disturbance. Land imprinting consists of pulling water-filled metal cylinders with welded angle forms which imprint a furrow about 5–10-cm deep (Dixon and Simanton 1980).

Plots were seeded after root plowing or ripping, but were seeded prior to all other seedbed treatments. Two 1-m² subplots within each 6- by 6-m treatment plot were intensively broadcast seeded with 'Vaughn' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), 'A-130' blue panic (*Panicum antidotale* Retz.), 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees), or Cochise lovegrass (*Eragrostis lehmanniana* Nees \times *E. trichophora* Coss and Dur.).

The volume of seeds of each species necessary to completely cover the soil surface of the 1-m² subplots with a single layer of seeds were determined. Seeds were evenly broadcast across the subplots by using a grid and seeding each of 16, 1/16-m² areas. The soil surface was then protected with cotton cloth, the seedbed wetted, and 3.5- by 5.0-cm soil plugs extracted with plastic vials. Samples were taken to the laboratory, split in half, and seeds were located with a dissecting microscope (Winkel and Roundy 1991a). Four samples were collected from each subplot for a total of 480 samples per sample period and 24 samples per treatment-species combination per sample period. Data were recorded as percent of seeds found at particular depths in the seedbed.

Seedbeds were sampled immediately after treatment application (1987 and 1988), a few weeks later after the first major thunderstorm (1987 and 1988), and after seedling emergence (1987 only for blue panic, Cochise and Lehmann lovegrass, and 1988 only for sideoats grama). Root-plowed or ripped plots were not sampled after treatment because of the heterogeneous nature of the seedbed, but were sampled after rain and seedling emergence. Seed distribution was sampled after a 20-mm rain in 1987 and after a 35-mm rain in 1988.

Repeated measures analysis of variance was performed on the soil depth at which cumulative percentages of seeds were found, and p-values were adjusted with Greenhouse-Geisser statistics (Morrison 1976). This analysis was used to determine differences in seed distributions in the seedbed after treatment and after summer

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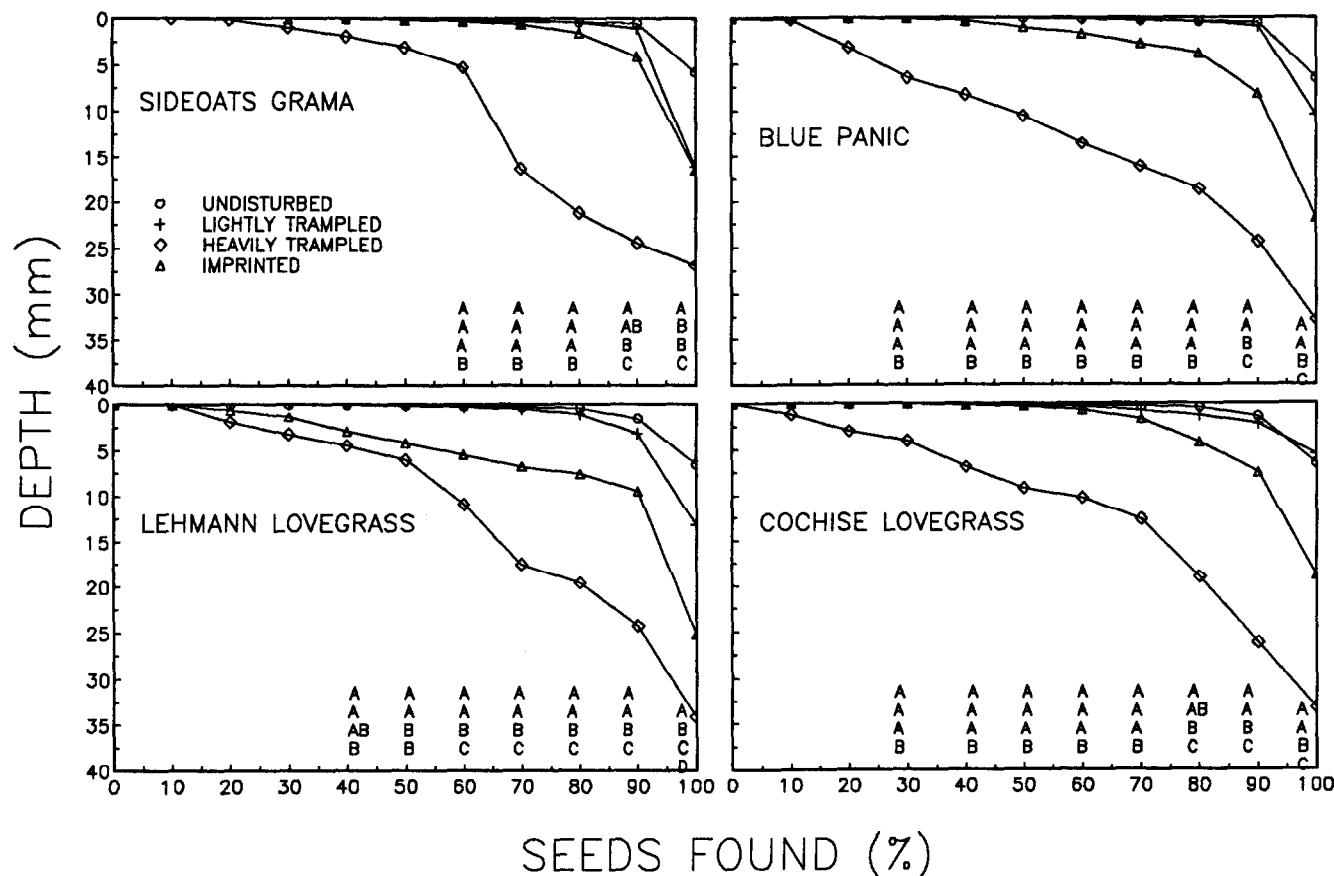


Fig. 1. Vertical distribution of broadcast sideoats grama, blue panic, and Cochise and Lehmann lovegrass seeds in a sandy loam soil immediately after seedbed treatment in 1988. Columns having the same letters are not significantly different ($P>0.05$).

thunderstorms among years, species and treatments, as well as differences in depth of seedling emergence among species and treatments. The biological limit of each species was determined by plotting and regressing the cumulative percentage of seeds that produced emergent seedlings on seed depth.

Analysis of variance was used to determine differences in percentages of seeds found on the soil surface, within the biological limit and below the biological limit in relation to the treatments.

Results and Discussion

Various interactions of year, species, and seedbed treatment were significant ($P<0.01$) for depth at which seeds were buried immediately after treatment and after rainfall (Table 1). Seed distribution of all 4 species immediately after treatment showed

Table 1. Repeated measures analysis of variance of depth at which cumulative percentages of broadcast seeds were found for 4 grass species immediately after seedbed treatment and after at least 20 mm of rain.

Source	df	F-values		rain
		After treatment	After df	
Percentage \times Year	9	3.98 **	9	0.25
Percentage \times Species	27	2.64 **	27	5.97 **
Percentage \times Treatment	27	51.15 **	36	6.78 **
Percentage \times Year \times Species	27	4.10 **	27	0.91
Percentage \times Year \times Treatment	27	5.81 **	36	2.20 **
Percentage \times Species \times Treatment	81	1.21	108	1.18
Percentage \times Year \times Species \times Treatment	81	0.86	108	1.49

**Significant at the 0.01 level.

similar trends between the 2 years, with the exception that seeds from all species were buried deeper by heavy trampling in 1988 (Fig. 1).

Heavy trampling was the most effective treatment in burying sideoats grama seeds, followed by imprinting, light trampling, and no disturbance. Heavy trampling buried seeds to a depth of 27 mm, compared to 17 mm for imprinting, 16 mm for light trampling and only 6 mm for no disturbance.

Blue panic seed burial followed trends similar to sideoats grama burial. However, the smooth, more spherical blue panic seeds were found deeper than grama seeds in the seedbed. Heavy trampling buried seeds to 33 mm, imprinting to 22 mm, light trampling to 11 mm and no disturbance to 7 mm.

Seeds of the 2 lovegrasses showed similar distribution and depth of seed burial, with the exception that imprinting buried more Lehmann than Chochise lovegrass seeds. Again, heavy trampling buried most seeds, followed by imprinting, light trampling, and no disturbance. Heavy trampling buried seeds of both species to depths of more than 30 mm, followed by imprinting near 20 mm, light trampling near 10 mm, and no disturbance to 7 mm.

Seed location after summer thunderstorms was highly variable between years and among species, but generally thunderstorms increased seed burial. The trend of increased burial with increased seedbed disturbance seen in seed placement after treatment, continued after rainfall. However, in many cases, more seeds in root-plowed or ripped plots were buried than seeds in other treatments. Root plowing or ripping produces a highly fragmented seedbed and natural soil sloughing may help bury seeds.

There was a significant ($P\leq 0.01$) interaction between depth at which seedlings emerged and species, but not seedbed treatment. This indicates that different species emerged from different depth

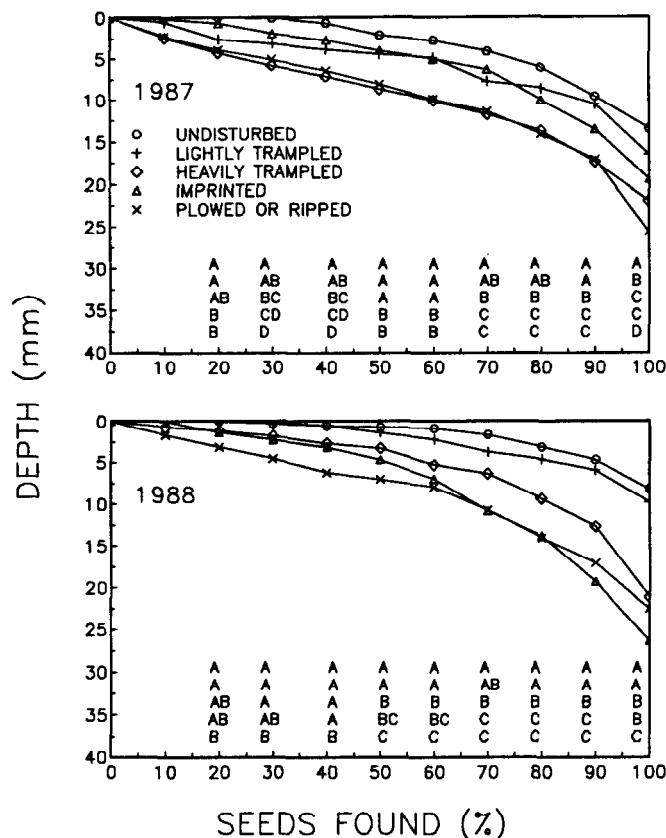


Fig. 2. Vertical distribution of sideoats grama, blue panic, and Cochise and Lehmann lovegrass seeds in a sandy loam soil after summer thunderstorms in relation to seedbed treatment. Columns having the same letter are not significantly different ($P>0.05$).

intervals, but that each species had similar depth intervals of emergence for all seedbed treatments.

Blue panic seedlings emerged from greater depths than the other 3 species, followed by sideoats grama, then Cochise lovegrass and then Lehmann lovegrass (Fig. 3). All blue panic, sideoats grama, and Cochise and Lehmann lovegrass seedlings emerged from above 18, 16, 10, and 9 mm, respectively. Nearly all seedlings from all species emerged from buried seeds, even though after rain, many seeds remained on the soil surface. Either seeds on the surface did not germinate, or many were buried between sampling after rain and seedling emergence. Some seedlings of sideoats grama, blue panic, and Cochise lovegrass emerged from 30 mm, 30 mm, and 20 mm, respectively, in a greenhouse study (Winkel 1990). Differences between these data and the field data may have been a result of higher bulk density in the field or differences in germination conditions.

Seeds of blue panic and sideoats grama emerged from greater depths in the seedbed than the small-seeded lovegrasses, possibly due to greater seed size and more seed reserves. Blue panic seeds are about 1 by 2 mm and sideoats grama seeds are 1 by 5 mm, compared to seeds of Cochise and Lehmann lovegrass which are about 0.5 by 0.75 mm. The recommended sowing depth for blue panic and sideoats grama is 12 mm and that for the lovegrasses is 7 mm (Jordan 1981). The results of this study confirm these recommendations. Based on this study and other observations, we suggest that on coarse-textured soils in southern Arizona, it may be practical to broadcast lovegrass seeds on undisturbed seedbeds. Seeds will then either establish on the surface or be buried after summer thunderstorms.

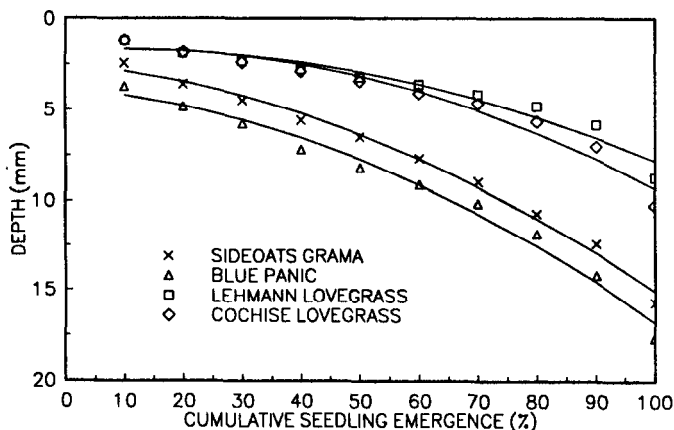


Fig. 3. Cumulative seedling emergence of sideoats grama, blue panic, and Cochise and Lehmann lovegrass in relation to depth in the seedbed on a sandy loam soil.

About 90% of the seedlings emerged from seeds that were within 6, 7, 12, and 14 mm from the soil surface for Lehmann lovegrass, Cochise lovegrass, sideoats grama, and blue panic respectively (Fig. 3). These depths were considered the biological limit of emergence for these species in this soil. Analyses of variance on percent of seeds found after treatment and after rain on the soil surface, and within and below the biological limit produced 2 and 3 factor interactions of year, species, and treatment (Table 2). In

Table 2. Analysis of variance of percentage of seeds of 4 grass species found in different depth categories in relation to time of sampling and seedbed preparation treatment.

Source	df	Surface	F-values	
			Within biological limit	Below biological limit
After treatment				
Year	1	0.06	1.96	1.02
Species	3	9.38 **	9.57 **	7.15 **
Treatment	3	115.45 **	76.68	86.71 **
Year \times Species	3	0.35	0.94	2.14
Year \times Treatment	3	2.08	11.33 **	4.71 **
Species \times Treatment	9	0.89	3.96 **	2.95 **
Year \times Species \times Treatment	9	1.07	1.71	0.44
After rain				
Year	1	13.34 **	3.81 *	5.27 *
Species	3	12.52 **	3.44 *	7.67 *
Treatment	4	22.16 **	6.13 **	17.09 *
Year \times Species	3	0.19	0.81	0.82
Year \times Treatment	4	3.07 *	1.20	2.00
Species \times Treatment	12	0.80	0.66	0.78
Year \times Species \times Treatment	12	2.29 *	1.68	1.78

* significant at the 0.05 level.

**significant at the 0.01 level.

general, greater soil surface disturbance (heavy trampling, land imprinting, and root plowing or ripping) buried more seeds, but also placed more seeds below the biological limit (Table 3).

All species generally responded similarly to the treatments with the exception that fewer sideoats grama seeds were buried than seeds of the other species. This was probably because these seeds were larger, and most were still contained in spikelets. This prevented seeds from being easily sifted through the seedbed. Heavy trampling was the most successful in burying sideoats grama seeds.

Summer thunderstorms (20 mm of rain in 1987, 35 mm in 1988)

Table 3. Percent of seeds found on the soil surface, within the biological limit, and below the biological limit in relation to year, sampling time, species and seedbed treatment.¹

Species treatment	1987						1988					
	Immediately after treatment			After rain (20-mm)			Immediately after treatment			After rain (35-mm)		
	Surface	Within biol. limit	Below biol. limit	Surface	Within biol. limit	Below biol. limit	Surface	Within biol. limit	Below biol. limit	Surface	Within biol. limit	Below biol. limit
----- % -----												
Sideoats grama												
Undisturbed	100.0 a ²	0.0 c	0.0 b	88.1 a	6.3 c	5.6 ab	95.3 a	4.7 c	0.0 b	81.1 a	13.3 ab	5.6 b
Light trampling	98.2 a	0.9 c	0.9 b	72.5 ab	25.4 bc	2.1 b	88.7 a	8.3 bc	3.1 b	79.6 a	20.4 ab	0.0 b
Heavy trampling	25.5 c	58.1 a	16.4 a	8.5 c	68.6 a	23.0 a	42.1 b	26.7 a	31.3 a	75.0 a	15.5 b	9.5 ab
Land imprinting	77.1 b	22.9 b	0.0 b	75.5 ab	14.6 bc	10.0 ab	79.9 a	17.6 ab	2.6 b	67.9 a	23.3 ab	8.9 ab
Root plowing	—	—	—	51.4 b	32.2 b	16.5 ab	—	—	—	27.8b	43.3 a	28.9 a
Blue panic												
Undisturbed	97.7 a	2.1 c	0.2 b	36.1 a	42.8 a	21.1 a	93.4 a	6.6 b	0.0 b	84.3 a	15.7 b	0.0 b
Light trampling	70.4 b	29.3 b	0.3 b	38.9 a	34.1 a	27.1 a	91.0 a	9.0 b	0.0 b	66.7 a	33.3 ab	0.0 b
Heavy trampling	14.4 c	65.7 a	19.9 a	3.6 b	56.2 a	40.2 a	15.6 c	48.8 a	35.7 a	22.9 b	57.1 a	20.0 b
Land imprinting	52.9 b	37.7 b	9.3 a	20.5 ab	58.3 a	21.1 a	57.0 b	39.8 a	3.2 b	18.8 b	37.5 ab	43.8 a
Root plowing	—	—	—	12.1 ab	44.4 a	43.5 a	—	—	—	3.1 b	25.0 ab	71.9 a
Lehmann lovegrass												
Undisturbed	90.3 a	9.4 c	0.3 b	78.7 a	18.4 ab	2.9 b	86.6 a	13.4 a	0.0 c	55.6 a	22.2 a	22.2 a
Light trampling	78.6 a	21.2 bc	0.1 b	59.3 ab	8.2 b	32.5 a	79.1 a	18.1 a	2.7 c	54.5 a	38.8 a	6.8 a
Heavy trampling	26.9 b	48.9 a	24.1 a	12.3 b	46.0 a	41.7 a	26.6 b	19.9 a	53.5 a	69.3 a	22.1 a	8.6 a
Land imprinting	44.9 b	24.5 b	30.7 a	35.0 b	38.6 a	26.4 a	47.9 b	23.7 a	28.4 b	37.5 a	35.0 a	27.5 a
Root plowing	—	—	—	6.7 b	35.5 a	57.9 a	—	—	—	40.8 a	26.0 a	33.2 a
Cochise lovegrass												
Undisturbed	96.1 a	3.3 c	0.5 b	59.0 a	25.1 a	15.9 bc	86.0 a	13.9 b	0.1 c	81.6 a	18.2 a	0.2 b
Light trampling	81.1 a	15.7 b	3.2 b	58.1 a	36.1 a	5.8 c	80.4 a	19.4 b	0.2 bc	52.5 ab	23.7 a	23.8 a
Heavy trampling	23.6 b	43.3 a	33.1 a	5.6 b	50.1 a	44.3 ab	23.5 c	31.5 a	45.0 a	24.4 b	43.7 a	31.9 a
Land imprinting	44.8 b	35.3 a	20.0 a	17.4 b	44.0 a	38.6 ab	60.9 b	31.9 a	7.2 b	25.1 b	23.6 a	51.3 a
Root plowing	—	—	—	6.8 b	43.5 a	49.7 a	—	—	—	28.8 b	32.4 a	38.8 a

¹Percent of seeds on the surface, and within and below biological limit may not add to 100 due to rounding of numbers.

²Means in a column with a species followed by the same letter are not significantly different ($P>0.05$).

effectively buried more seeds for all treatments, including no disturbance (Table 3). In fact, after rain, similar percentages of lovegrass and blue panic seeds were buried within and below the biological limit regardless of the treatment. Rain was less effective in burying sideoats grama seeds. Once again, more sideoats grama seeds were buried in the heavily trampled plots.

Greater seedling emergence in heavily disturbed plots in some cases may have been due to greater seed burial by these treatments. On a wet year (1987) there was generally similar emergence of small-seeded lovegrasses among all treatments, but greater seedling emergence of blue panic was associated with greater seedbed disturbance and seed burial by heavy trampling, imprinting, and ripping (Winkel and Roundy 1991b). On a moderately wet year (1988) greater seedling emergence of all grasses was associated with greater seedbed disturbance and seed burial by heavy trampling, imprinting, and ripping. Since many seeds from less-disturbed plots were still on the surface after rain, the fact that nearly all seedlings sampled after emergence came from buried seeds suggests that seeds remaining on the surface on undisturbed plots did not germinate or were washed away by rain.

All 4 species tested in this study have shallow biological limits. Also, their adventitious roots are initiated from the coleoptilar node, which is nearly always within 1 to 2 mm of the soil surface. Adventitious root initiation requires 2–4 days of optimal soil water conditions (Olmsted 1942, Wilson and Briske 1979, Winkel 1990). Soil water from the top 3 cm of soil in this study is depleted from -0.03 to -0.1 MPa matric potential within 1 to 4 days after a rainstorm (Roundy, unpublished data Univ. of Arizona). Seeds buried deeper within the shallow biological limits of these species probably do not have a significantly longer period of available water than those at a more shallow depth under the rapid drying

conditions of the Southwest. A greenhouse study (Winkel 1990), indicated that seedling emergence and primary root lengths of sideoats grama, blue panic, and Cochise lovegrass can decrease with increased planting depth.

decrease with increased planting depth.

Soil disturbance by cattle trampling or mechanical treatments definitely can bury seeds at a desirable depth for emergence. However, summer rains can bury many small seeds even on unprepared seedbeds. Seed burial increases seedling emergence probably by increasing seed-soil contact and water flow to the seed (Collis-George and Sands 1959). Seedling emergence of species with shallow biological limits depends on successive storms to maintain available water in the seedbed. Treatments used to help bury seeds would not necessarily be expected to increase seedling emergence of these species in a dry year due to a lack of available water above the biological limit. In a wet year, soil movement associated with rain will bury many small seeds. However, seedbed treatments increase the numbers of seeds buried and increased seed burial before summer rains may help reduce seed predation and thereby increase seedling emergence. Treatments which highly disturb the seedbed, such as heavy trampling, imprinting, rootplow or ripping, may also bury many seeds too deep for emergence. Seedbed treatments are probably more essential to help bury large than small-seeded species broadcast on the soil surface.

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Effects of cattle trampling and mechanical seedbed preparation on grass seedling emergence

VON K. WINKEL AND BRUCE A. ROUNDY

Abstract

Cattle trampling has been recommended to bury seeds and encourage seedling establishment but has not been compared with traditional seedbed preparation techniques. We compared seedling emergence of broadcast-seeded 'Vaughn' sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], 'A-130' blue panic (*Panicum antidotale* Retz.), 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees), and 'Cochise' atherstone lovegrass (*Eragrostis lehmanniana* Nees \times *E. trichosperma* Coss and Dur.) on lightly and heavily trampled seedbeds with that on undisturbed, land imprinted, and root-plowed or ripped seedbeds. We seeded and applied the treatments prior to summer rains on a sandy loam soil in southern Arizona for 3 years. In a wet year (1987) when surface soil water was estimated to be available for at least 24 consecutive days, heavy trampling and land imprinting increased emergence of blue panic and land imprinting increased emergence of Cochise lovegrass. In that year, lovegrass emergence was high even on undisturbed plots. In a moderately wet year (1988), surface soil water was available for periods of 6–9 days during seedling emergence and greater disturbance, either by heavy trampling, land imprinting and/or root plowing or ripping produced higher emergence than light trampling and nondisturbance. In a dry year (1989), surface soil water was available for periods of 2–3 days and seedling emergence was low and generally similar for all treatments. Sideoats grama emergence was low all 3 years, but was highest in 1988 when initial thunderstorms were followed closely by subsequent storms. Seedbed disturbance by cattle and mechanical methods may enhance revegetation in the Southwest in years of moderate precipitation but may be unnecessary in wet years or futile in dry years, depending on species and soils.

Key Words: land imprinting, root plowing, sideoats grama, blue panic, Lehmann lovegrass, Cochise lovegrass, range revegetation

Livestock trampling has been recommended as a way to help bury seeds and increase seedling emergence in rangeland revegetation (Plummer et al. 1955, Hormay 1970, Pearson and Ison 1987, Vallentine 1989). However, there are few data available to evaluate the use of livestock as a seedbed preparation technique. In Nevada, moderate trampling increased emergence of perennial grasses, but decreased emergence of perennial forbs on specific seedbed microsites (Eckert et al. 1986). Heavy trampling decreased perennial grass emergence, but increased emergence of sagebrush and annual forbs on certain microsites.

Comparisons between trampling and other techniques are needed to determine if it is a viable seedbed preparation technique. Mechanical seedbed preparation techniques used in the Southwest include root plowing and land imprinting. Rootplowing has been successful in controlling woody plants (Fisher et al. 1959) and produces a highly disturbed seedbed which may bury broadcast seeds (Jordan 1981). Revegetation success on root-plowed seedbeds has been reported by Allison and Rechenbush (1956), Fisher et al. (1959), Herbel et al. (1973) and Nelson and Gabel (1987).

The land imprinter was developed to increase revegetation success on semiarid rangelands by concentrating soil water in furrows (Dixon and Simanton 1980). Few studies have been conducted which compare land imprinting with other seedbed preparation techniques. In southern Arizona, land imprinting resulted in fewer broadcast or drill-seeded grass plants than did rilling or disking, probably because it did not reduce competition from creosotebush [*Larrea tridentata* (DC.) Coville] (Cox et al. 1986). Haferkamp et al. (1987) reported seedling emergence of crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Shult.) was nearly twice as high with imprinting compared to drilling on loose, disked seedbeds, but 2–4 times more seedlings emerged from drilling than imprinting on firm, unprepared seedbeds. Clary (1989) reported greater density, cover and production of seeded species from imprinting a burned sagebrush community as compared to seeding with a rangeland drill. He suggested the difference was related to increased bulk densities or imprinted soil, decreased wind erosion, and greater seed-soil contact. Our objective was to compare the effects of light and heavy cattle trampling, rootplowing, land imprinting or ripping, and nondisturbance on seedling emergence of warm-season grasses.

Methods

Study Area

The study was conducted on the Anvil ranch, about 65 km southwest of Tucson, Ariz. The study site is on the east slopes of the Baboquivari mountains at an elevation of 1,027 m. The soil is a sandy loam (fine, mixed, thermic Ustollic Haplargids). The site is on the edge of the Chihuahuan semidesert grassland subresource area (Jordan 1981), with major plant species consisting of mesquite (*Prosopis juliflora* Swartz), snakeweed (*Gutierrezia sarothrae* Pursh), various cacti, and native grasses including Arizona cotton-top [(*Digitaria californica* (Benth.) Henr.)] and purple 3-awn (*Aristida purpurea* Nutt.).

The climate is characterized by hot summers and cool winters. Average annual precipitation for the past 30 years, obtained 17.7 km from the site, is 328 mm, of which 60–70% falls between July and November (U.S. Dept. Commerce 1987).

Treatment Application

The experiment was a split plot with 5 seedbed treatments and 4 species applied in 4 blocks on each of 3 years. Years were randomized within blocks and each block per year included 20 plots, which were randomly assigned the 20 treatment-species combinations.

All plots used in a particular year were treated with a combination of picloram (4-amino-3,5, 6-trichloropicolinic acid) at 0.6 kg/ha and 2,4,D [(2, 4-dichlorophenoxy) acetic acid] at 2.2 kg/ha to kill snakeweed, and glyphosate [(N-(phosphonomethyl)] glycine at 2.2 kg/ha to kill native grasses. Scattered mesquite trees were cut and removed.

Five seedbed preparation treatments were applied in June or early July (before summer rains) on 6 by 6-m plots: (1) no disturbance, (2) light cattle trampling, (3) heavy cattle trampling, (4) land imprinting, and (5) root plowing or ripping. Lightly trampled plots were treated by leading a 300–500 kg steer or heifer around each plot until a density of about 10 hoof prints per m² was obtained.

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Heavily trampled plots were enclosed with an electric fence, and five 300–500 kg steers or heifers were herded around each plot for approximately 20 minutes. Plots were land imprinted with a Dixon land imprinter composed of 1 directional and 1 nondirectional-geometric angle iron form welded on separate 1 by 1-m cylinder capsules. Total weight of the imprinter was approximately 5 metric tons and it produced imprints approximately 5–7-cm deep in this soil.

Root-plowed plots were treated with a root plow in 1987 that was pulled through each plot at a depth of 15–20 cm. Because of root plow breakage in 1988 and 1989, plots in those years were treated with a ripper. The ripper had 3 shanks about 60-cm apart and was pulled through the soil in each plot 5 times at a depth of 15–20 cm to thoroughly disturb the seedbed. The composition of the seedbeds with root-plowed and ripped plots was similar. Seedbeds were prepared between 1 and 8 July in 1987, 14 and 17 June in 1988, and 29 May and 5 June in 1989.

Seeds of 'Vaughn' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), 'A-130' blue panic (*Panicum antidotale* Retz.), 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees), and 'Cochise' atherstone lovegrass (*Eragrostis lehmanniana* Nees \times *E. trichophora* Coss and Dur.) were either sown with a hand-held 'Cyclone' seeder, or mixed with No. 60 blasting sand and hand broadcast onto all plots at a rate of 1.2 million pure live seeds per hectare. All plots except plowed plots were seeded before treatment application while plowed plots were seeded immediately after treatment.

Data Collection

Seedling densities were recorded when seedlings were about 2–4-cm tall. This corresponded with 18 August 1987, 1 August 1988, and 22 August 1989. Each plot was sampled with 1/16-m² quadrats uniformly spaced across the plot in 2 transects of several quadrats each. Number of quadrats (subsamples) varied from 20–40 per plot for the lovegrasses, and 40–80 quadrats for sideoats grama and blue panic. Quadrat numbers were increased for a given species and year when densities were low and decreased when densities were high.

Percent cover of indigenous forbs, annual and perennial grasses, and bare ground and litter was recorded beginning on 15 September 1987, 26 September 1988, and 8 September 1989. Each plot was sampled with a 10-point pin frame uniformly spaced across the plot in 2 transects of 5 placements each, for a total of 100 points per plot. Frequency data were derived from density data to determine differences in distribution of the seeded species.

Soil water in the top 1–3 cm was measured in selected undisturbed, imprinted, and heavily trampled plots with Colman soil moisture cells (Colman and Hendrix 1949) in 1988 and 1989. Precipitation was measured on site with a tipping-bucket rain gauge, and soil water and precipitation data were recorded with a Campbell Scientific Instruments CR-10 datalogger. Soil from the top 20 cm of several plots was analyzed for percent water content at –0.03, –0.10, –0.30, and –1.50 MPa matric potential with a pressure plate. Soil water was considered available for germination and growth when volumetric water content was above 0.09, which corresponds to a matric potential of –0.1 MPa.

Statistical Analysis

Because numbers of quadrats or subsamples counted varied among years for some species, seedling density data were analyzed initially for significance of main effects and interactions by calculating approximate F ratios according to the procedure of Steel and Torrie (1980). Significant ($P < 0.01$) year-species-treatment interaction justified analysis of variance and LSD mean separation ($P < 0.05$) of treatments separately for each species for each year. In those analyses, conventional F ratios were calculated since the

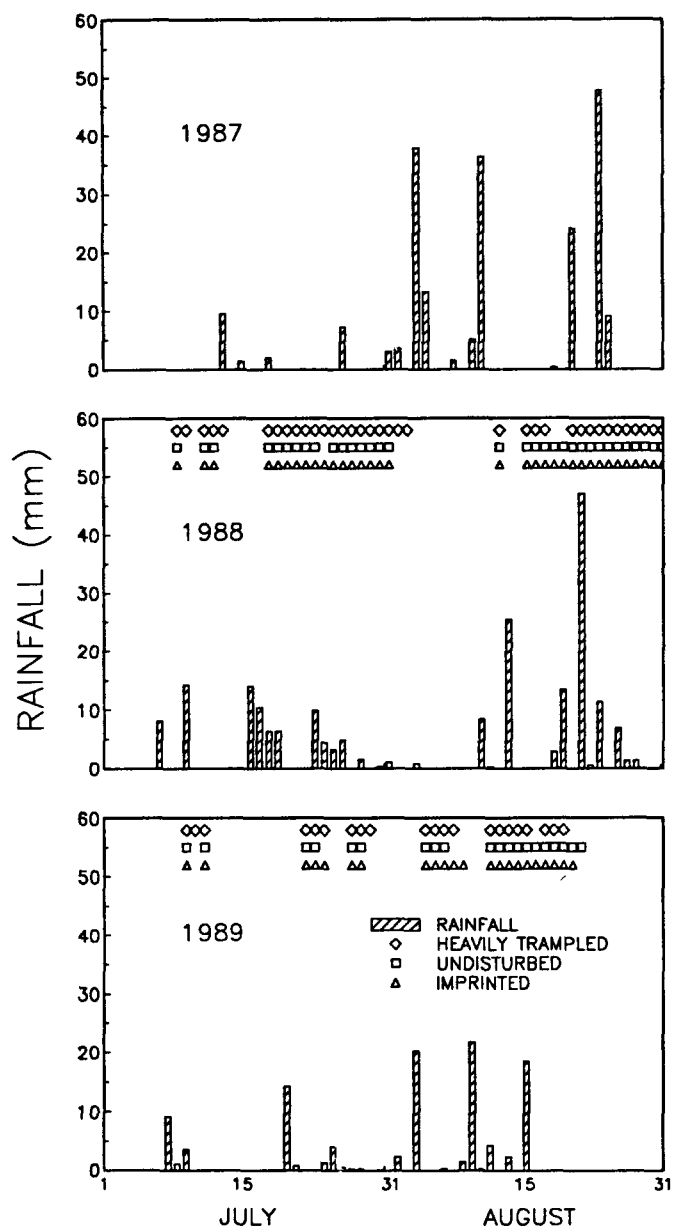


Fig. 1. Daily rainfall (vertical bars) for July and August 1987, 1988, and 1989 at the Anvil Ranch, southern Arizona; and lengths of wet and dry periods in the upper 1–3 cm of the seedbed in relation to year and seedbed preparation treatment. Periods of soil water content (vol/vol) ≥ 0.09 (> -0.1 MPa matric potential) are indicated by symbols and dry periods are represented by blank spaces between symbols.

total number of subsamples were equal for a given year and species. Analysis of variance was performed on the arcsin square root of percentage data both for cover and frequency.

Results

1987

Consistent summer rainfall began on 21 July and continued with high frequency and intensity until 25 August (Fig. 1). Although no soil water data were collected during 1987, the surface soil remained wet from approximately 4 to 28 August. All species had high emergence except sideoats grama (Fig. 2). Blue panic had little emergence on undisturbed and lightly trampled plots, moderate emergence on root-plowed plots, and high emergence on heavily trampled plots. The lovegrasses had high emergence for all treat-

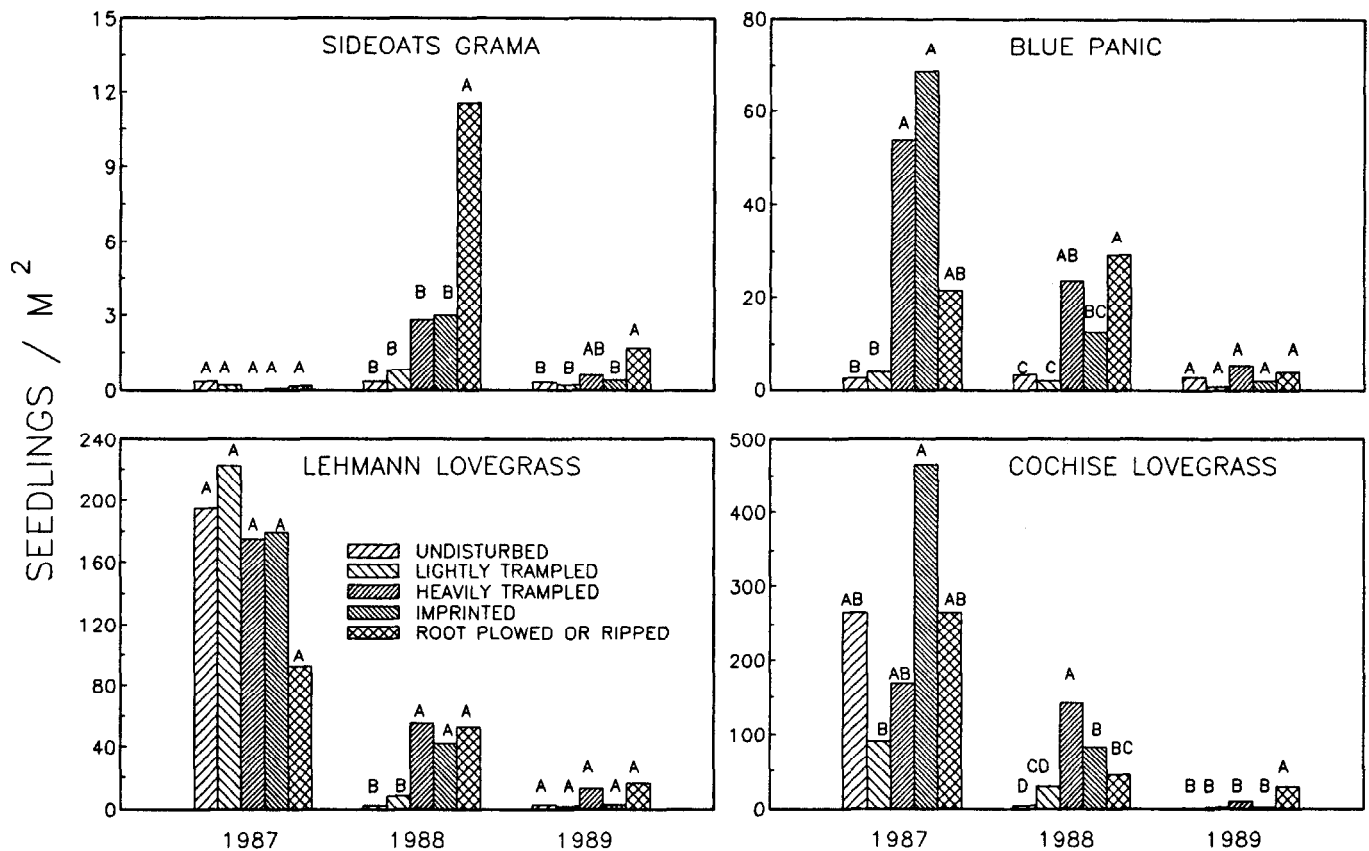


Fig. 2. Seedling density of broadcast-seeded sideoats grama, blue panic and Lehmann and Cochise lovegrass in relation to seedbed preparation treatments done on 3 years on a loamy upland range site in southern Arizona. Means for a species within a treatment year with the same letter are not significantly different ($P > 0.05$).

ments but responded to them differently. Lehmann lovegrass had a trend toward lower emergence on root-plowed plots than on the other treatments. Cochise lovegrass had greatest emergence on imprinted plots, lower emergence on undisturbed, heavily trampled, and root-plowed plots, and least emergence on lightly trampled plots.

1988

Thunderstorm activity began on 7 July and continued with fairly high frequency until 28 August (Fig. 1). Although number of days with rainfall during July and August was higher in 1988 (15 in 1987, 25 in 1988), storms were generally smaller and the seedbed did not stay wet as long as in 1987. Starting on 17 July, soil water was available in the surface soil for about 6 days, unavailable for a day or less and then available for another 6–9 days. Most seedlings emerged during these wet periods. Heavily trampled and imprinted plots generally had available water for 1 to 2 days longer than undisturbed plots.

Seedling densities were generally higher on heavily trampled, imprinted, or ripped plots than on undisturbed or lightly trampled plots (Fig. 2). Sideoats grama density was highest on ripped plots. Blue panic density was highest on ripped and heavily trampled plots followed by imprinted plots. Lehmann lovegrass densities were similar on ripped, imprinted, and heavily trampled plots. Cochise lovegrass densities were highest on heavily trampled plots, followed by imprinted and ripped plots. The lovegrasses had much higher emergence than blue panic and sideoats grama for all disturbance treatments.

1989

Summer rainshowers in 1989 were less frequent and intense than in either 1987 or 1988 (Fig. 1). Initial and subsequent storms in July

were separated by a 10-day dry period. Periods of surface-soil water availability during emergence in July were only 2–3 days long. Heavily trampled and imprinted plots had similar periods of available water in the surface soil that were up to 14 hours longer than in undisturbed plots. Emergence was low for all species and generally similar for the different seedbed treatments (Fig. 2). Ripping slightly increased emergence of sideoats grama and Cochise lovegrass over that of the other treatments.

Seedling Frequency

There was a significant interaction between year and treatment for frequency of seeded species (Table 1). Seedlings were most evenly distributed on seedbeds prepared by heavy trampling, imprinting and root plowing or ripping. Distribution was moderate on undisturbed and lightly trampled plots in 1987, and limited in 1988 and 1989. Distribution across treatments was greatest for the lovegrasses, followed by blue panic and then sideoats grama.

Cover of Indigenous Grasses

Analysis of variance for both bare ground and litter cover indicated significant ($P < 0.05$) treatment and year effects but the treatment-year interactions were not significant ($P < 0.05$). Root plowing or ripping and heavy trampling resulted in more bare ground than the other treatments (Table 2). More bare ground was exposed in 1989 than in 1988 (Table 3). Heavily trampled, imprinted and root-plowed or ripped plots had significantly less ($P < 0.05$) litter cover than lightly trampled and undisturbed plots. There was significantly more litter in 1989 than in the other 2 years, probably as a result of a gradual build-up of litter associated with cattle exclusion.

The 4 most common indigenous grasses on the plots included an annual lovegrass (*Eragrostis arida* Hitchc.), feather fingergrass

Table 1. Frequency (% occurrence in subsample quadrats) of broadcast-seeded sideoats grama, blue panic, and Lehmann and Cochise lovegrass in relation to year of seeding and seedbed preparation treatment on a loamy upland range site in southern Arizona.

Year and seedbed treatment	Species			
	Sideoats grama	Blue panic	Lehman lovegrass	Cochise lovegrass
----- Frequency (%) -----				
1987				
Undisturbed	2 a ¹	11 c	64 ab	63 b
Lightly trampled	1 a	12 c	61 ab	63 b
Heavily trampled	0 a	74 a	71 ab	61 ab
Land imprinted	0 a	66 a	81 a	90 a
Root plowed	1 a	37 b	50 b	75 ab
1988				
Undisturbed	2 bc	13 b	11 b	12 c
Lightly trampled	3 b	10 b	21 b	36 bc
Heavily trampled	13 b	48 a	64 a	82 a
Land imprinted	11 b	34 a	51 a	56 ab
Ripping	30 a	53 a	61 a	55 ab
1989				
Undisturbed	1 b	9 a	5 b	3 b
Lightly trampled	1 b	4 a	9 b	5 b
Heavily trampled	3 ab	16 a	39 a	21 a
Land imprinted	3 ab	20 a	15 ab	8 b
Ripping	6 a	18 a	36 a	45 a

¹Means in a column within a year with the same letter are not significantly different ($P>0.05$).

(*Chloris virgata* Swartz), sixweeks needle grama (*Bouteloua aristoides* (H.B.K.) Griseb.), and Rothrock grama (*Bouteloua rothrockii* Vasey). There was no significant ($P>0.05$) difference in cover for these species for any of the seedbed treatments (Table 2). There was less annual lovegrass and feather fingergrass in 1989 than in 1987 and 1988 (Table 3).

Discussion

Differences in seedling emergence among years and treatments were related to precipitation patterns and periods of available water. Seedling emergence was highest for all species except sideoats grama in 1987 when surface-soil water was estimated to be available for about 24 consecutive days. The lovegrasses had high emergence from all treatments in that year while blue panic had greater emergence on the more disturbed seedbeds. The low density of sideoats grama in 1987 may be related to its rapid germination (24–48 hours—Simanton and Jordan 1986) and possible desiccation during the 12-day drying period after initial rainstorms (Fig. 1). The other species require a longer period of available water to germinate and apparently only germinated in early August during consistent rainfall.

The greater emergence of the small-seeded lovegrasses com-

Table 3. Percent cover of bare ground, litter, and 4 indigenous grasses in 1987, 1988, and 1989 on a loamy upland range site in southern Arizona.

Parameter	Year		
	1987	1988	1989
----- Cover (%) -----			
Bareground	45 ab ¹	33 b	54 a
Litter	12 b	16 b	33 a
Annual lovegrass	10 a	11 a	0 b
Feather fingergrass	5 a	9 a	0 b
Six weeks grama	2 a	4 a	1 a
Rothrock grama (seedlings)	1 a	0 b	1 a

¹Means in a row with the same letter are not significantly different ($P>0.05$).

pared to the larger-seeded blue panic on the undisturbed plots and the greater emergence of blue panic on the more disturbed seedbeds in 1987 may have been due to greater seed-soil contact. Heavy trampling, land imprinting, and root plowing buried more seeds than nondisturbance or light trampling (Winkel et al. 1991). However, many seeds were buried by summer rains, even on undisturbed and lightly trampled plots. Seedling emergence from surface-sown seeds on bare ground in a greenhouse study was much greater for Cochise lovegrass than for sideoats grama and blue panic (Winkel 1990). A lower trend in emergence of Lehmann lovegrass on root-plowed plots in 1987 may have been related to excessive seed burial. Root plowing buried at least 60% of the Lehmann lovegrass seeds too deep for seedling emergence (Winkel et al. 1991).

Greater seedbed disturbance by heavy trampling, land imprinting, or ripping produced greater seedling emergence than no disturbance or light trampling in a moderately wet year (1988). That was the only year that sideoats grama produced an acceptable stand of seedlings, and this occurred on the ripped plots. Ripping buried twice as many sideoats grama seeds at a depth from which seedlings could emerge than did the other treatments (Winkel et al. 1991). Successful emergence of sideoats grama in this year was probably related to more consistent initial rainfall and soil water availability at the start of the rainy season than occurred in 1987 or 1989. The greater seedling emergence of all species on the more disturbed seedbeds in 1988 was probably related to greater seed burial on these seedbeds (Winkel et al. 1991) and a slightly longer period of available water, at least for the imprinted and heavily trampled plots. In 1988, there were significant correlations between percentage of seeds buried immediately after treatment (Winkel et al. 1991) and seedling emergence for blue panic ($r^2 = 0.99$, $P = 0.003$), Lehmann lovegrass ($r^2 = 0.99$, $P = 0.006$) and Cochise lovegrass ($r^2 = 0.97$, $P = 0.017$). There were also significant correlations between percent of seeds buried after a 35-mm rain and seedling emergence for sideoats grama ($r^2 = 0.99$, $P = 0.001$) and blue panic ($r^2 = 0.80$, $P = 0.004$). None of these correlations were significant ($P<0.05$) in 1987 when soil water was available for a longer

Table 2. Effects of seedbed treatment applied before summer rains on a loamy upland range site in southern Arizona on percent cover of bare ground, litter and 4 indigenous grasses after the summer rainy season. Values are means of 3 years (1987, 1988, 1989).

Parameter	Seedbed treatment				
	Undisturbed	Lightly trampled	Heavily trampled	Imprinted	Root plowed or pitted
----- Cover (%) -----					
Bare ground	36 b	36 b	52 a	41 b	55 a
Litter	27 a	27 a	16 b	19 b	15 b
Annual lovegrass	5 a	7 a	8 a	9 a	7 a
Feather fingergrass	3 a	4 a	5 a	5 a	6 a
Six weeks grama	3 a	2 a	2 a	2 a	2 a
Rothrock grama (seedlings)	1 a	0 a	1 a	0 a	1 a

¹Means in a row followed by the same letter are not significantly different ($P<0.05$).

period of time than in 1988, except for blue panic emergence, which was positively correlated ($r^2 = 0.89$, $P = 0.016$) with percentage of seeds buried above 12 mm.

Low emergence on all treatments in 1989 was related to inconsistent rainfall and only 2–3 days of available water in the surface soil in July. More consistent rainfall and longer periods of available water occurred later in August, but these did not produce a cohort of seedlings. Seeds may have initiated germination after initial rains and desiccated during the subsequent dry periods in July. All of the seeded species have subcoleoptile internode elongation that places their adventitious roots near the soil surface and makes them susceptible to desiccation without recurrent rainfall.

Emergence of indigenous annual and short-lived perennial grasses was apparently affected much more by precipitation patterns than seedbed treatments. These grasses were not observed to emerge until after a period of consistent rainfall. Evidently they are adapted to emerge from a variety of seedbed microsites as long as soil water is available.

Analysis of past seedings is difficult because daily precipitation, temperature, humidity (Cox et al. 1982), and soil water availability are seldom measured. This study documents that seedling emergence is highly related to the pattern of soil water availability. With the exception of sideoats grama, seedling density of all species was highest during a wet year (1987), intermediate during a moderately wet year (1988), and limited during a dry year (1989). Greater seedling emergence from more disturbed seedbeds was most evident in a moderately wet year. A slightly longer period of soil water availability and increased seed burial associated with seedbed disturbance by heavy trampling, imprinting, root plowing, or ripping help to explain their higher seedling emergence compared to non-disturbance and light trampling. In this study, increased seedling emergence was more highly associated with increased percentage of seeds buried on a moderately wet year than on a wet or dry year. Seed burial may increase emergence by increasing seed-soil contact and water flow to the seed (Collis-George and Sands 1959), increasing radial penetration (Dowling et al. 1971, Cox and Martin 1984) and reducing predation (Nelson et al. 1970, Campbell and Swain 1973).

Seedling establishment of small-seeded lovegrasses may not require seedbed preparation on coarse-textured soils during wet years in southern Arizona. Sideoats grama and blue panic appear to require seedbed preparation for seedling establishment. Heavy trampling, imprinting and root plowing, or ripping all provided adequate seedbed preparation for burial and emergence during wet or moderately-wet years. During dry years these seedbed treatments would not be expected to increase seedling emergence.

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Viewpoint: Range science and range management are complementary but distinct endeavors

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Range management and *range science* are complementary but distinct endeavors. *Range management* is an attempt to optimize returns from rangelands in combinations desired by and suitable for society through the manipulation of range ecosystems (Stoddart et al. 1975). As such, range management is a planning process in which alternative management options are exposed to the decision-maker's values, and the option with the highest value is selected. *Range science* is the body of scientific knowledge upon which range management should be based. As such, range science should be the set of concepts and ideas that agree or are consistent with how natural processes operate. Both are necessary for wise use of range resources. The purpose of this paper is to discuss the roles of planning and science in range management, to provide examples of biological processes important in range management, and to discuss the role of range science in understanding those processes.

Planning and Science

Planning and science are different kinds of decision making (Romesburg 1981). Planning examines alternative images of a future possible world and selects the image with the highest value. The images in planning are composed of scientific knowledge, common sense, rule-of-thumb knowledge, untested theories, and hunches. Managers must plan with the best knowledge and thought at hand, regardless of their true value. Indeed, in many cases the planning involved in range management is based on common sense, rule-of-thumb knowledge, hunches, and untested theories, rather than scientific knowledge of biological processes.

Science exposes alternative theories to facts and selects the theory that agrees most closely with the facts. Of the 3 main methods of science, range scientists rely primarily on induction, to a limited extent on retroduction, and rarely on hypothetico-deduction (see review in Romesburg 1981). Lack of the use of retroduction and hypothetico-deduction to study the processes of most importance to range management has resulted in the lack of a conceptual and scientific basis for range management.

Induction is useful for finding laws of association between classes of facts. For example, if we observe over many trials that herbivores prefer to select green rather than dead plant parts, we are using induction if we declare a law of association. Induction has a limitation: it can only give knowledge about possible associations among classes of facts. Induction can be useful in planning, provided the associations always hold, but it cannot give knowledge about the processes of nature. Hence, induction can be used repeatedly without explaining "how?" or "why?". When we ask "how?" or "why?" we are asking for an explanation, an abstract process that provides a reason for the facts.

Retroduction is useful for finding research hypotheses that are explanations for facts. For example, if we observe herbivores ingesting the most nutritious plant parts available on a range and our best guess for the reason for this behavior is that herbivores can relate the tastes of foods with their gastrointestinal consequences, we would be using retroduction to provide an explanation (research hypothesis) for the observed facts relating to the process of diet selection. Retroduction is essential for elucidating alternative research hypotheses, but retroduction alone is not a reliable source of knowledge because alternative explanations can often be

given for the same set of facts.

Hypothetico-deduction complements retroduction by subjecting alternative explanations to experimental verification. Starting with research hypotheses, predictions are made about other classes of facts that should be true if the research hypotheses are actually true. For example, one way to explain the preference of herbivores for some foods over others is to argue that preferred foods are immediately pleasing to the senses of taste, smell, and touch (Provenza and Balph 1990). An alternative explanation is that herbivores develop preferences for or aversions to foods as a result of their postingestive effects, and that taste and odor primarily enable animals to discriminate among different food items (Provenza and Balph 1990). To test these alternative explanations, the taste of a flavor could be paired with gastrointestinal consequences that are either positive or negative. The hypothesis that herbivores select food based on gastrointestinal consequences is supported if herbivores subsequently form preferences for or aversions to the flavor. If experiments are well-designed and carefully controlled (Platt 1964, Hurlbert 1984), the hypothetico-deductive method of science can evaluate the reliability of the research hypotheses generated by retroduction, and is the primary means of increasing the reliability of knowledge about natural processes.

Processes Important in Range Management

Many biological processes are important in range management. Plant autecology and synecology, as well as diet and habitat selection by herbivores, are of particular importance to grazing management. I use these as examples of processes that we must understand if we are to manage rangelands wisely.

Plant autecology is the study of a single organism or of a single species. Its importance to management lies in its ability to provide insights into characteristics that enable plants to tolerate or avoid disturbances such as grazing, cutting, and fire. Historically, much effort has gone into *describing* the responses of different plant species to factors such as season, intensity, and frequency of grazing (Stoddart et al. 1975). Genetic variation among and within plant species, as well as soil moisture and nutrient status and season, intensity, and frequency of disturbance, affect the ability of plants to tolerate or avoid grazing. To the extent that we can understand the mechanisms that underlie tolerance and avoidance, we can better manage rangelands (Caldwell 1984, Malechek et al. 1986, Bryant et al. 1987). Thus, range scientists must determine how and why plants tolerate or avoid disturbances.

Plant synecology is the study of the interactions among different plant species within plant communities. The importance of synecology to grazing management lies in its ability to predict changes in the abundance of different plant species as a result of management practices (Stoddart et al. 1975). Historically, much scientific effort has gone into *describing* existing vegetation and changes in vegetation. The concepts of range site and range condition and trend have developed as an outgrowth of these efforts (Stoddart et al. 1975). Future scientific endeavors must be directed at developing the conceptual and experimental basis for understanding the dynamic nature of plant population and community level processes to determine how and why vegetation exists as it does, and to relate the results to spatial and temporal scales appropriate for management (Archer and Tieszen 1986, Westoby et al. 1989). Such research will lead to important insights into the structure and function of plant communities, and enhance the abilities of range

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managers to intervene in ways that are wise.

Diet selection by herbivores affects both the production of herbivores and range condition. Animal nutrition depends on diet selection, as does the relative abundance of different plant species on rangelands (Stoddart et al. 1975). Research on diet selection has described the physical and chemical characteristics of plant species herbivores select and led to recommendations on when to graze and when to supplement on rangelands. It has not, however, provided understanding of how or why herbivores select some plant species and avoid others. To the extent that we can understand how and why herbivores select or avoid the plant species they do, we increase our potential to manipulate diet selection. Learning apparently plays a major role in the process of diet selection by herbivores (Provenza and Balph 1990, Provenza et al. 1990). If so, discovering how herbivores learn could let managers manipulate diet selection to increase use of supplements, feedlot rations, and unpalatable plant species, and to decrease use of poisonous plants, seedlings in forest plantations, and tree seedlings in orchards and conifer plantations (Provenza and Balph 1987).

Habitat selection by herbivores affects both the production of herbivores and range condition. Herbivores' production is affected because carrying capacity is dependent on animal dispersion. Range condition improves when herbivores disperse widely, and declines when they overutilize locations such as riparian zones. Grazing of public lands has become an increasingly contentious issue in the West, one that is likely to persist as a coalition of recreational users and environmentalists draws strength from a burgeoning urban population. The foraging behavior of livestock often raises the ire of recreational users of the same lands. One problem is that cattle and sheep tend to prefer the lush vegetation next to streams, a habit which can lead to overuse of these highly visible, ecologically sensitive areas. The grazing habits of livestock might be malleable enough that they can be trained to graze elsewhere. Different subgroups of herbivores differ in use of the same range, apparently learn habitat preferences, and transfer these preferences from generation-to-generation (Hunter and Milner 1963, Key and MacIver 1980, Zimmerman 1980, Roath and Krueger 1982). It might be possible to select animals that utilize upland habitats and cull those that favor riparian areas, thus enhancing dispersion on rangelands (Provenza and Balph 1987). We will not understand why herbivores use areas of the range differentially, however, if researchers continue to *describe* how factors such as temperature, relative humidity, forage availability, water location, and topography are correlated with affect the distribution of herbivores (Stoddart et al. 1975).

The Role of Range Science

As a science matures, it passes through several stages (Wiegert 1988). In the beginning, the science is largely descriptive and concern rests with determining *what* is there. During this stage the method of induction is used to establish laws of association between classes of facts. Once a large body of fact has accumulated, much energy is devoted to seeking order and pattern in the facts. Scientists then become more concerned with *how* things are arranged and how they function. Finally, scientists endeavor to explain *why* natural processes function as they do. During these latter 2 stages of development, the methods of retrodution and hypothetico-deduction are used extensively. It is time for range science to make the transition from the *what* to the *how* and *why* stages of development.

Traditionally, range scientists have *described* components of range ecosystems in an attempt to provide information for managers. This has been an extremely important first step in the development of range science, and most management recommendations are currently based on information generated by such efforts.

Nonetheless, it is often difficult to differentiate the role of the manager (planner) from that of the researcher (scientist), because researchers are often more intent on solving problems and providing management recommendations than on providing fundamental understanding of process important in range management.

An important role for range scientists now and in the future is to provide the scientific knowledge upon which planners can manage rangelands, and to a lesser extent to conduct research that in essence attempts to plan for the planners. Range scientists can no longer afford to describe and monitor rangelands in an attempt to plan for range managers. This is not to say that management is not important or that range scientists should not be involved in range management. Rather, scientists and managers have separate roles to play in wise use of natural resources. Scientists should be concerned with understanding the processes of nature that are important for management of natural resources; managers should use that understanding as the basis for managing rangelands.

If scientists continue to focus on solving problems, range as a discipline will be dead. Without a thorough understanding of the biological processes on which to base management, range managers have no more basis for decision making than do politically active special-interest groups. Range scientists must thoroughly understand the biological processes underlying range management to provide range managers with a firm basis for their decisions, and to provide them with credibility. If not, management of rangelands will be based on findings from disciplines that do have a firm scientific basis.

To develop scientifically, a discipline must have a conceptual basis. Conceptual models provide a focal point for research that is designed to understand processes in nature, and they help us organize the vast number of facts and observations related to processes. A discipline without a conceptual basis is like a boat without oars. Several factors are important if there are to be conceptual bases for the many biological facets of range science. First, range scientists must develop conceptual models of how we think important biological processes operate. Second, we must use retrodution to develop numerous alternative explanations for our conceptual models. Third, we must use hypothetico-deduction to test the alternative explanations. Fourth, we cannot make any assumptions about how or why processes, operate; rather, we must think of alternative explanations for every facet of every process, and we must design experiments that eliminate those explanations that are inaccurate. No stone can be left unturned. This will facilitate the movement of range science from the *what* to the *how* and *why* stages of development.

Range science is an integrative discipline. As such, range scientists are in an ideal position to organize multidisciplinary research. Indeed, the processes important to range scientists and managers can only be studied by drawing upon expertise from many disciplines. Scientists from other disciplines are interested in pursuing questions that interest range scientists, and range scientists should serve as a focal point for this kind of research. Thus, for example, the study of diet selection will involve disciplines as diverse as natural products chemistry, animal physiology, pharmacology, toxicology, psychology, nutrition, and neural biology to name a few. Range scientists should provide the leadership in developing a strong conceptual basis for processes that are important for range management.

Conclusion

The role of contemporary range scientists is to develop an understanding of the processes that are important for the wise management of rangelands. Clearly, in some cases there is information available on the structure and functioning of ecosystems that is simply not being used in management, either because the informa-

tion is relatively new and has not yet been incorporated into management programs or because managers do not know how to apply the information. In such cases, the problem is not so much that the science is lacking, but that the pure science has not been translated into practical application. It is equally true, however, that range scientists have not endeavored to understand processes that are important for the management of rangelands through careful analyses of the biological systems and processes. To provide a scientific basis for the management of rangelands will require research to understand the significant biological process, and research to apply that understanding to development of new technologies and management. The next major advances in range management will occur when researchers turn their attention from describing what occurs on rangelands to understanding the hows and whys of biological processes important to range management. As we do, the titles of our textbooks will change from "Principles of Range Management," to "Principles of Range Science and Their Application to Range Management."

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Technical Notes

The effect of light on adventitious root formation in blue grama

RAKSHAN ROOHI, DONALD A. JAMESON, AND NASSER NEMATI

Abstract

Formation of adventitious roots in blue grama seedlings requires that the node between the subcoleoptile and the coleoptile be exposed to light at the 3-leaf or later stages of development. Thus, adventitious root formation will occur only at or near the soil surface. With continuous light, the subcoleoptile approximated zero length, but for those developed in darkness the usual length was about 1 cm. Under usual range conditions, the time between germination and the 3-leaf stage of development is such that it is rare that both of these events will occur with moist soil conditions, and seedling survival will be infrequent.

Key Words: light response, subcoleoptile, adventitious roots

When a grass seed germinates, it first develops a primary root. During early development of the seedling, adventitious roots develop at the lower node of the shoot axis. In most mature grass plants, the root system consists entirely of adventitious roots. Survival of a grass seedling depends upon its ability to develop adventitious roots.

In the common perception of grass seedling development, the adventitious root node forms at essentially the same location as the origin of the primary root. Thus, a seed planted at 1-cm depth will originate adventitious roots at this depth. A lower planting depth may result in more soil moisture available for root development, and planting depth is ordinarily constrained only by the ability of the seedling to produce a coleoptile sufficient to reach the surface. For many grass species, improved seedling establishment can be obtained by selecting for larger seeded varieties that allow for deeper plantings.

In certain grasses, such as blue grama (*Bouteloua gracilis*), the commonly perceived development does not occur. Instead, there is a subcoleoptile or internode between the point of emergence of the primary root from the caryopsis and the origin of the coleoptile (Hyder 1974). For these species, the adventitious roots do not begin at the seeding depth, but at a higher, and generally drier, point in the soil profile.

Blue grama is difficult to establish by seeding (Weaver and Albertson 1943; Riegel et al. 1963; Wilson and Briske 1978, 1979). The relationship of drought and adventitious roots has been studied by Wright (1971), Sims et al. (1973), Briske and Wilson (1977, 1978, 1980), Hassanyar and Wilson (1978), Wilson and Briske (1977, 1978), and Wilson et al. (1976). Because blue grama seedlings quickly elevate their subcoleoptiles (Stubbendieck and Burzlauff 1971, Hyder et al. 1971, Hyder 1974, Sluijs and Hyder 1974, Wilson et al. 1976), the adventitious roots typically begin formation in dry soil, and seedling mortality results. The primary or seminal root provides only about 2 ml of water per day (Wilson 1976), which is insufficient for seedling survival. However, if a seedling can develop just 1 adventitious root, this root can supply up to 10 ml of water per day (Wilson 1976).

For blue grama, the usual research approach of selecting larger

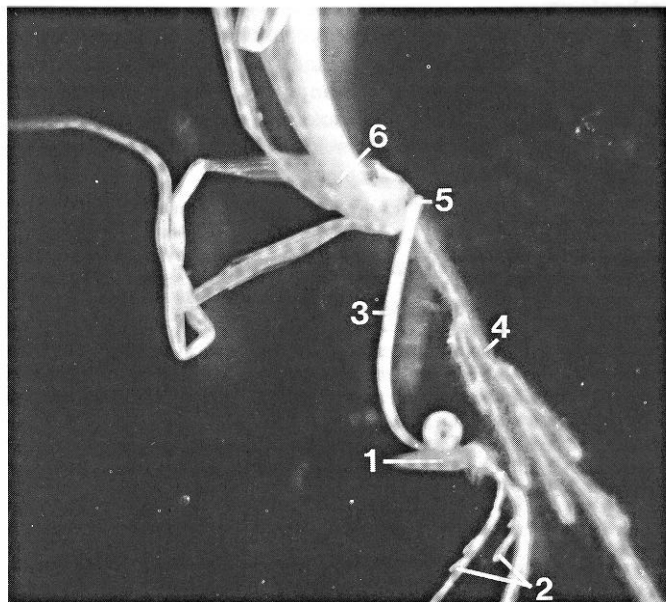


Fig. 1. Blue grama seedling developed in agar culture with 4 days of darkness followed by light: (1) caryopsis, (2) primary root, (3) internode, (4) adventitious root, (5) node, and (6) shoot.

seeded varieties will not be productive if the adventitious roots still form in the upper, and usually drier, soil layers.

Materials and Methods

Initial studies on the effect of light on subcoleoptile lengths were conducted in agar culture. Agar was prepared for test tubes using 6.5 gm agar per liter of half strength MS nutrient solution (Murashige and Skoog 1962). The pH was adjusted to 5.7. Seeds of the Hachita variety (provided by the Soil Conservation Service Plant Materials Center, Las Lunas, New Mexico) were dehulled with a Woodward Laboratory Air-Seed apparatus (Dewald and Beisel 1984). Adequate sterilization was provided by immersing the seeds for 30 seconds in 70% ethanol, followed by 20% bleach for 3 minutes. Twenty replicated tubes with 3 seeds each were either placed in continuous light (21 watts/m²), or in complete darkness for 4 days and then in the light.

For greenhouse studies, caryopses were prepared as for the agar culture studies. Planting was done in pots containing fine sandy loam soil. The caryopses were placed on the soil surface, and later covered with 1 cm of fine sand. Ten replicate pots with 20 caryopses each were prepared for treatment as follows: (1) covered immediately after sowing, (2) covered after 24 hours, (3) covered after 48 hours, (4) covered after 72 hours, (5) covered after 96 hours, and (6) uncovered. Water content of the pots was maintained by subirrigating to a predetermined pot weight that approximated field capacity.

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Results

For seedlings grown in agar culture and continuous light, all the seedlings had essentially zero subcoleoptile length. The adventitious roots and primary roots grew from the same locations, and it was frequently difficult to distinguish between primary and adventitious roots. Seedlings kept in the dark for 4 days and then moved to continuous light developed elongated internodes, usually about 1 cm length (Fig. 1). Thus, light obviously was an important factor in controlling the length of the subcoleoptile and the point of formation of adventitious roots.

Even within the Hachita variety, the greenhouse-grown seedlings exhibited considerable morphological variation and had both upright and decumbent growth forms as reported by Painter (1987). However, this degree of variation did not extend to behavior of the subcoleoptile and development of adventitious roots; all of the seedlings that were covered with sand after sowing, regardless of the time of exposure, developed elongated internodes and the adventitious roots originated near the sand surface. Seedlings in pots that were left uncovered had internodes of essentially zero length, and adventitious roots originated at the surface of the original soil layer. This behavior was subsequently investigated in several studies with various seed covering treatments, using thin layers of sand at different stages of seedling development. Regardless of the covering treatment, adventitious root developed when the node at the subcoleoptile-coleoptile junction was exposed to light at the 3-leaf or later stages. Any earlier exposure to light, followed by darkness, was insufficient to develop adventitious roots. However, prolonged exposure of seeds on the soil surface did reduce overall survival even in the relatively moist conditions of the greenhouse.

Discussion and Conclusions

These studies clearly show that continuous exposure of developing blue grama seedlings to light prevents growth of the subcoleoptile. A similar response has been reported for oat seedlings (Mandoli and Briggs 1981, Schafer et al. 1982, Schafer and Haupt 1983). The reduction in internode length is probably controlled by the phytochrome system (Salisbury and Ross 1985). Exposure of the coleoptile to light did not change the development of the subcoleoptile, which suggests that the response mechanism cannot be developed in one portion of the plant and translocated to another part. In addition, the response mechanism was not stored, i.e., even exposure of the developing seedling to light for 96 hours did not modify development. Without exposure to light at the 3-leaf or later stages, adventitious roots of blue grama simply do not form. These results support the observations of Newman and Moser (1988) for other species. In our study material, there was no genetic variation in this behavior. Regardless of seed size and planting depth, adventitious roots in our material formed only when the node was close enough to the soil surface that light was received directly on the node. The practical implications of these findings are that blue grama seedlings will only form adventitious roots at the soil surface. The usual time interval between planting and development of the 3-leaf stage is typically a few weeks; under usual range conditions, this also means that adventitious roots are initiated mostly in dry soil, and seedling mortality results.

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Emergence of several Triticeae range grasses influenced by depth of seed placement

T. LAWRENCE, C.D. RATZLAFF, AND P.G. JEFFERSON

Abstract

Seed of 8 Triticeae species was planted in petri dishes (depth = 0) and 2, 4, 6, and 8 cm deep in soil in the greenhouse. Total emergence at 6 weeks after planting declined significantly with increased depth and the species by depth interaction was significant ($P < 0.001$). Dahurian wildrye (*Elymus dahuricus* Turcz. ex Griseb.) and tetraploid Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski) exhibited similar emergence from deep seedings and were superior to all other species except Altai wild ryegrass (*Leymus angustus* [Trin.] Pilger). The better emergence of the tetraploid Russian wildrye entry compared to diploid cultivar suggests that the establishment of the tetraploid cultivar will be less affected by poor seed depth control. Newly released cultivars of Dahurian wildrye will be less affected by variable seed depth than several of the species currently recommended for seeding rangelands.

Key Words: Dahurian wild ryegrass, Altai wild ryegrass, Russian wild ryegrass, slender wheatgrass, intermediate wheatgrass, crested wheatgrass, Nuttall's alkali grass

Variable seed depth is a major cause of establishment failure on semiarid rangelands and may result from inadequate depth control of seeding equipment (Lawrence and Dyck 1990), rough microtopography, or poor seedbed preparation. Emergence of seedlings from seed depths greater than 2.5 cm would be an advantageous trait in dryland grasses. 'Tetracan', a newly released tetraploid (2N = 4X = 28) Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski) cultivar has larger seed mass and greater emergence from 4.5 cm depth of seeding than diploid cultivars (Lawrence et al. 1990b). The emergence of Tetracan from deeper seeding has not been documented. Dahurian wildrye (*Elymus dahuricus* Turcz. ex Griseb.) is a recently introduced species with high establishment year forage yield that has been identified for seeding in mixtures with slower establishing species in semiarid locations in Western Canada (Lawrence and Ratzlaff 1985, Lawrence et al. 1990a). The present study was conducted to determine the response of these new cultivars to increasing seed depth relative to other grass species.

Authors are research scientist (retired), grass breeding technician, and research scientist, Research Station, Research Branch, Agriculture Canada, Box 1030, Swift Current Saskatchewan S9H 3X2, respectively.

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Methods

The experiment was conducted over a 6-week period in a greenhouse with temperature maintained at approximately 25° C in a 16-hour photoperiod with surface applied water as required. One hundred viable seeds in single rows constituted individual plots. The experimental design and treatments were as follows:

Design—4 replicate split plot.

Main Plots—8 grasses: Altai wildrye (*Leymus angustus* [Trin.] Pilger) 'Prairieland'; Dahurian wildrye 'James'; Russian wildrye-diploid 'Swift'; Russian wildrye-tetraploid 'Tetracan'; slender wheatgrass (*Elymus trachycaulus* [Link] Gould ex Shinnars) 'Revenue'; intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth and D.R. Dewey subsp. *intermedium*) 'Clarke'; crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Schultes) 'Summit'; and Nuttall's alkali grass (*Puccinellia tenuiflora* Schribn. & Merr.) Sc 186169 (an accession from People's Republic of China via S. Smoliak, Lethbridge Research Station).

Split-plots—Five seeding depths: 0 (in petri dishes), 2, 4, 6, and 8 cm, using methods outlined by Lawrence (1979).

Soil Mix—loam: with 41.5% sand, 21.6% clay and 36.9% silt.

Data Analysis—Emergence (%) was determined 6 weeks after planting. Emergence at all depths was adjusted to correct 0 depth data to 100%. Analysis of variance based on the split plot model and regression of entry means on depth were computed with SAS General Linear Models procedure.

Results and Discussion

The final emergence of the 8 grass species decreased with increasing depth of seeding (Table 1). The species, depth, and species by depth interaction effects were all highly significant ($P < 0.001$). First or second order regression equations with depth as the independent variable accounted for more than 90% of the variability in emergence for all species. Altai wildrye was least affected by deep seed placement as previously reported (Kilcher and Lawrence 1970). The tetraploid Russian wildrye had greater emergence than the diploid Russian wildrye. This conclusion indicates that seedling establishment of the new cultivar Tetracan should be less variable than has been observed for previous diploid cultivars. Dahurian wildrye exhibited excellent emergence to 6 cm depth and was less affected by seed depth than crested wheatgrass or diploid

Table 1. Mean emergence (%) of 8 grasses (n = 4), 6 weeks after planting at 5 depths and regression equation of mean emergence on depth.

Grass	Depth (cm)					Regression	R ²	SEE ¹
	0	2	4	6	8			
	----- (%) -----							
Dahurian wildrye	100	95.3	86.3	68.7	17.6	97.4+ 4.92Depth-1.81Depth ²	0.98	3.77
Russian wildrye-tetraploid	100	93.1	75.5	48.3	21.3	101.0- 3.01Depth-0.89Depth ²	0.98	1.09
Russian wildrye-diploid	100	73.6	47.4	10.2	0.3	98.9-13.14Depth	0.98	1.09
Altai wildrye	100	85.1	66.9	63.9	48.7	97.7- 6.19Depth	0.97	0.67
Intermediate Wheatgrass	100	64.5	45.0	27.6	12.7	98.4-16.73Depth+0.77Depth ²	0.99	1.82
Crested Wheatgrass	100	76.1	25.5	2.8	0.6	105.6-23.79Depth+1.27Depth ²	0.96	6.56
Slender Wheatgrass	100	91.4	64.4	36.4	15.7	106.3-11.18Depth	0.98	0.98
Nuttall's Alkaligrass	100	13.2	0	0	0	92.0-37.34Depth+3.33Depth ²	0.92	9.44

¹SEE = Standard error of estimate for first order regression coefficient.

Russian wildrye. The higher seedling vigor (Lawrence et al. 1990b) of this species and its better emergence from deep seed placement than current dryland grasses are agronomic advantages for seeding on semiarid rangelands. The very low emergence of Nuttall's alkali grass from 2 cm depth indicates that if this species is used in reclaiming wet saline soil seeps, broadcast seeding will be required.

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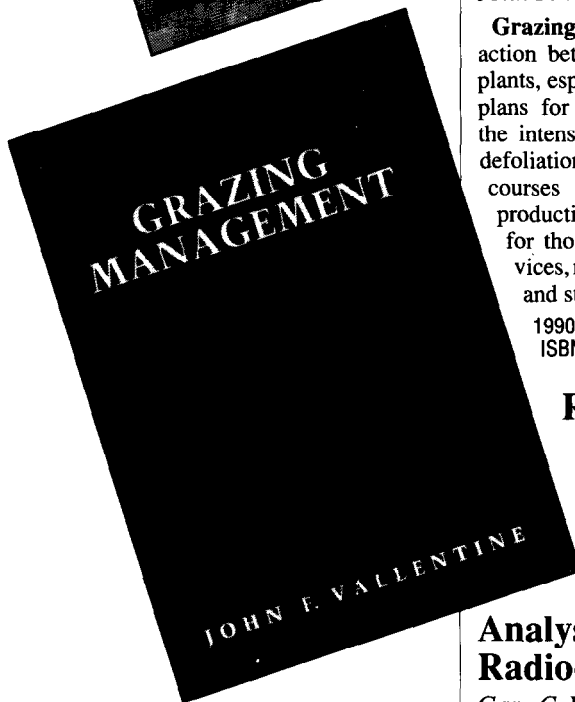


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Book Reviews

Range Management. Jerry L. Holechek, Rex D. Pieper, and Carlton H. Herbel. 1989. Prentice Hall, Englewood Cliffs, New Jersey. 501 p. US \$48.00.

Current students and instructors in range management should welcome this new textbook. Recent classes in the principles of range management have previously been limited to the outdated 1975 edition of *Range Management* by Stoddart, Smith, and Box. Need of an updated textbook has existed for some years, and this book fills that need admirably.

Range Management is organized into 17 chapters covering the broad subject discipline. Chapter titles in order are: 1. Rangeland and Man; 2. Rangeland Physical Characteristics; 3. Range Management History; 4. Description of Rangeland Types; 5. Range Plant Physiology; 6. Range Ecology; 7. Range Inventory and Monitoring; 8. Considerations Concerning Stocking Rate; 9. Selection of Grazing Methods; 10. Methods of Improving Livestock Distribution; 11. Range Animal Nutrition; 12. Range Livestock Production; 13. Range Wildlife Management; 14. Range Management for Multiple Use; 15. Manipulation of Range Vegetation; 16. Range Management in Developing Countries; and 17. Computer Applications and the Future. The text draws and cites a larger list of published research papers than have previous textbooks.

This book may be considered the first of the second generation range management textbooks. Earlier texts were authored by those who founded the discipline or at least lived through its founding and early development. This new book shows more evidence that authors learned more of the subject, and possibly experienced less of it. The content is slightly more technical in places than its predecessors. Its format is more a set of class notes put into book form than an array of experiences and approaches put to text.

As a range management textbook, much favorable may be said. The writing and editing are excellent. The style is concise. Sentences are short and clear. Needless words have been omitted. The result is a high density of information and easy reading. Because of the conciseness, the book is exceptionally thorough in its coverage without being overly long. It really does present many principles and practices, and does so more directly than earlier textbooks.

The book lacks some introspection and philosophy, but these shortcomings may contribute to the strength of the book as a class text for undergraduates. It contains little agonizing over difficult concepts and approaches, few of the thoughtful discussions of Heady's *Rangeland Management*. The book is a black and white, all business textbook of management which most students will appreciate. Because of its seeming origin in notes, it is an ideal book for students to condense into notes.

Range Management has a stronger livestock emphasis than its namesake by Stoddart, Smith, and Box. The chapters on range livestock management are expanded, updated and much improved. The flavor is more of Texas, the Southwest, and Intermountain West, and instructors in some Western states may find too many cattle and sheep here. But Holechek, Pieper, and Herbel convey no doubt that they know what the discipline of range management is worldwide, and without livestock, its identity is fragmented at best. That sense of identity tied to domestic livestock is much like that found in the second edition of *Range Management* by Stoddart and Smith, and is partly what distinguishes it from the 1975 third edition of that same book. Aside from one chapter, it contains less emphasis on international aspects of range management. The

techniques and references are weighted toward North America.

Range Management will be a welcome addition to the libraries of all those involved with rangelands at any level. Because of its conciseness, it is a good reference book, although its index is sparse. Students and instructors in introductory classes in range management will find it a pleasure to read. It will save the latter group considerable work—David L. Scarnecchia, Washington State University, Pullman, Wash.

Weeds and Poisonous Plants of Wyoming and Utah. Edited by Tom D. Whitson, with 6 text contributors. 1987. University of Wyoming Cooperative Extension Service, P.O. Box 3313, Laramie, Wyo. 82971-3313. 282 p. \$13.50 spiral bound.

The first requirement in weed control or vegetation management programs is recognition of the species followed by information concerning life cycle and means of reproduction and spread. *Weeds and Poisonous Plants of Wyoming and Utah* is a regional guide to identification of a representative cross-section of common agronomic, range, and non-crop weeds. The definition of a weed used as a criterion for including plants in the book was "a plant that interferes with management objectives for a given area of land at a given point in time." I was grateful that the editors did not subject us to the usual "plant out of place" and "plant whose virtues have not yet been discovered" routine. Their definition allows the inclusion of native as well as introduced species, and the text indicates why and under what conditions each species may be considered weedy.

The book describes 133 species in 36 families. There are 3 quality color photos of each weed, a large one (12 × 17.5 cm) of the entire plant and 2 smaller ones (5 × 7.5 cm) showing key characteristics of identification such as fruits, flowers, seedlings, rosettes, and leaf or spine details. The text consists of a brief description of the plant, life span and reproduction method(s), origin (native or source of introduction), customary habit(s), toxicity, mechanisms for spread, useful properties and other items of interest such as whether it is an alternate host for crop pests. There are some general comments on control, usually indicating relative difficulty. Because no special herbicide recommendations are made, the book is applicable over a wide area and will not become rapidly out-of-date.

The plants are arranged by family, based on the 1980 Cronquist system, beginning with ferns and ending with monocots. Common and scientific names follow the Weed Science Society of America's official list. One weakness of the book is that it lacks a key to identification, but it does have an index with both scientific and common names. It also lists 20 references for additional information and for species not included in this book. There is a glossary (not illustrated) for botanical terms although it probably won't receive much use because technical terminology is kept to a minimum in the text.

I highly recommend *Weeds and Poisonous Plants of Wyoming and Utah* to homeowners, farmers and ranchers, extension agents, land managing agencies, weed control professionals, and anyone who would like a book of beautiful color photos of plants. For plant identification, it is much better than the average wildflower guide; and the price is a real bargain.—Cindy Talbott Roché, Department of Natural Resource Sciences, Washington State University, Pullman, Wash.

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