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ARTICLES

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BOOK REVIEWS

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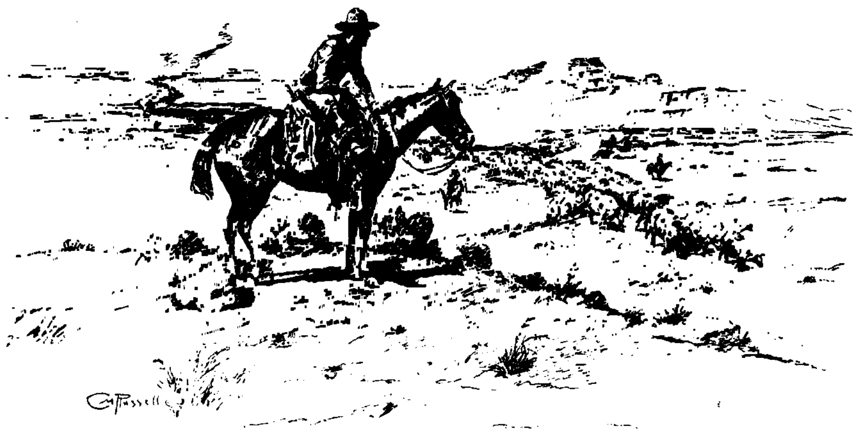
The **Journal of Range Management** serves as a forum for the presentation and discussion of facts, ideas, and philosophies pertaining to the study, management, and use of rangelands and their several resources. Accordingly, all material published herein is signed and reflects the individual views of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

SOCIETY FOR RANGE MANAGEMENT



THE TRAIL BOSS

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

The objectives for which the corporation is established are:

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

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

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

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

—to promote professional development of its members.

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

Contribution Policy

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

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

President's Address

GERALD W. THOMAS

A year in the Presidency of the Society for Range Management goes by with shocking speed when one looks at the *"long"* list of goals and objectives attempted for the year and the *"short"* list of accomplishments. But, then, that's the nature of the process. Officers change; Board members change; but the Society survives and prospers. It prospers because of the continuity in staff (and I want to thank the Denver staff for their excellent service in 1983); the Society survives because of the continuity in long-range plans and objectives. The Society prospers as long as there are *well thought out policies* to help attain the major goals *and well-designed* procedures in place to guide the staff *and the 5,000 or so volunteers who want to help.*

Our January retreat was designed to examine the existing policies of SRM *and look toward a dim but enchanting horizon.* We plowed some old ground on the south 40—but, we also turned over some new sod—Perhaps, I should hasten to add that we even recommended against turning over *any* sod where native rangeland could best serve society.

A year in the Presidency brought me to the full realization, that while we need more members, *those that pay to join are willing and anxious to help. Our members want to contribute to the goals of the Society.* They ask far more frequently, "What can I do to help strengthen the Society?" than "What has the Society done for me lately?"

A year in the Presidency has convinced me that our officers must become more involved in political issues, *whether or not they "feel politically inclined."* We can win 100 battles on the technical front and lose the war in Washington or in the State capitols. However, as we formulate guidelines for political involvement, *we must remember that we are an "international" society* and political issues can develop at any point and at any time. We must keep alert!

A year in the Presidency has demonstrated that the *strength* of SRM and the *effectivness* of SRM rests with the Sections. That's where it happens—*in the field—out on the land!* The Sections generate interest; the Sections enlist new members; the Sections move the Society toward its primary goals. I have been very pleased with our Section leadership this past year.

Presented February 15, 1984, at Rapid City, S. Dak., at the Annual Meeting of the Society for Range Management.

A year in the Presidency has reinforced my belief that we are members of *one of the most unique and challenging societies in the world.* I say "unique" because range management or range science is a "hybrid" field of endeavor, *and we have the hybrid vigor to prove it! Our Society grew out of the void* not covered by the agronomists, the animal scientists, the botanists, the economists, the biologists, the foresters, or even the basic ecologists. While all of these professions contribute to our understanding of the range resource, none of them carry the broad mission of *integrating the art with the science* to emphasize the term "management." *Research, Understanding and Management are our focus-not protection, per se.*

In keeping with the "management" theme, we still need to place more emphasis on service to users of range lands—particularly the livestock sector. We need to demonstrate to the producers of animal products that SRM members have the background and capabilities to assist them with their management decisions. We need more contact—more interaction—more advice from ranchers. *Our own rancher members and our Producer Affairs Committee have helped to carry this message.* I still have a serious concern that the goal of certain environmental interests is to eliminate domestic livestock from public range lands. This concern was elevated with the recent articles in *Outdoor Life,* the *Los Angeles Times,* etc. SRM has the knowledge and the responsibility to help bring these extremist views back into perspective.

A year in the Presidency has convinced me of the need to improve our interactions with other professional societies and organizations. *We need to join together when we have mutual interests* but maintain autonomy and independence when our purposes can be served best by acting at our own discretion.

A year in the Presidency has made this "Charter Member" of the Society more and more proud of SRM. The 1984 budget will be tight, but we still hope to keep our new Executive Vice-President *in close contact* with Section field days and programs. *Pete Jackson is providing the leadership necessary to build a strong society.* Please give him your support as well as your suggestions for improving SRM.

Lastly, as the new officers and board members take over, we deliver to them the charge to move the Society to new levels of achievement. I ask you as members to give these new officers and directors your allegiance. With your help, our new President, Dr. Joe Schuster, will make 1984 another great year for SRM. Thank you.

Lightning Fires in North Dakota Grasslands and in Pine-Savanna Lands of South Dakota and Montana

KENNETH F. HIGGINS

Abstract

Lightning strike fires which occurred between 1940 and 1981 were studied in mixed-grass prairie grasslands and in pine-savanna lands in the Northern Great Plains region. A majority (73%) of ignitions occurred during July and August, while a lesser number was recorded in April, May, June, and September. The April-September period is also the average time of the freeze-free period and approximates the average distribution period for thunderstorm activity in this region. The area burned by each of 293 lightning fires (most of which were suppressed) ranged from 0.004-1158.3 ha ($\bar{X}$ = 10.8 ha). The frequency of lightning fires in mixed-grass prairie grasslands averaged 6.0/yr per 10,000 km^2 in eastern North Dakota, 22.4/yr per 10,000 km^2 in southcentral North Dakota, 24.7/yr per 10,000 km^2 in western North Dakota, and 91.7/yr per 10,000 km^2 in pine-savanna lands in northwestern South Dakota and southeastern Montana. The ecological role of lightning-set fires is discussed relative to the development of resource research and management plans and to the interpretation of historical records of natural fire occurrence in the Northern Great Plains region.

Climate and fires are strongly supported in recent reviews as primary agents affecting the origin and development of native grasslands in North America (Vogl 1974, Wright and Bailey 1980). Lightning has for many years been recognized as an important cause of forest fires (Komarek 1966, 1968; Stokes and Dieterich 1980) but there is less agreement about its importance as a natural cause of grassland fires.

Rowe (1969) and Vogl (1974) summarized historical perspectives of the arguments relative to the purported unimportance or absence of lightning fires in North American grasslands. However, authentic instances of lightning-caused fires have been reported in grasslands or steppes in Alberta (Nelson and England 1971), Saskatchewan (Raby 1966, Rowe 1969, Coupland 1973), Kansas (Brock 1925, Malin 1956), Nebraska (Kirsch and Kruse 1973, Wolfe 1973, Westover 1977, Bragg 1978), and Washington (Uresk et al. 1976).

Komarek (1966) reported lightning-caused fires for South Dakota and Nebraska, all of which were associated with forest or forest-savanna vegetative types. Thus, lightning-caused fires are a natural phenomenon in the Central and Northern Great Plains grasslands but there is a paucity of information about their seasonality, frequency, and extent.

The present paper summarizes and characterizes the events of 294 known occurrences of lightning-caused fires in grasslands in North Dakota and in pine-savanna lands of nearby South Dakota and Montana.

The author is wildlife biologist, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Woodworth Station, Woodworth, N. Dak. 58496.

The author would like to thank H.A. Kantrud, A.D. Kruse, G.K. Clambey, R. Komarek, D.H. Johnson, H.D. Wickware, and D.P. Aicher for manuscript review, and K.A. Smith, C.T. Odell, and R. Riddle for assisting with data collection.

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Study Areas

Lightning fire records were obtained for 4 areas within the Northern Great Plains (Fig. 1). These were the Sheyenne National Grasslands of Custer National Forest (1970–81), the brush hills

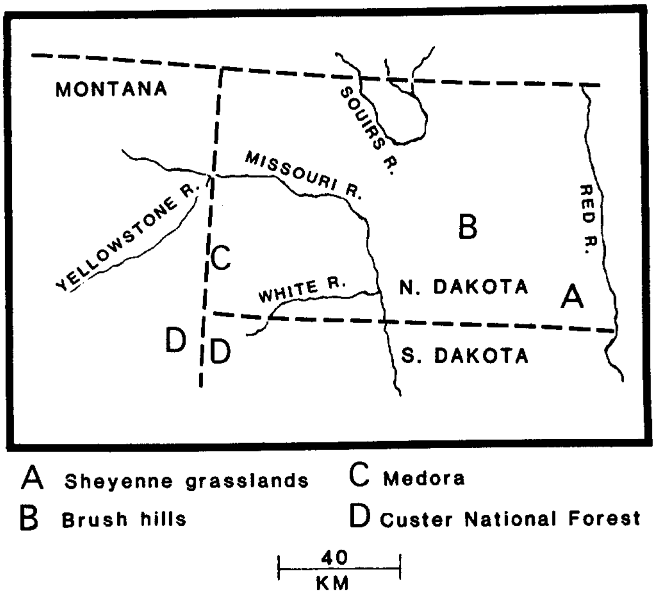

Fig. 1. *Location of study area.*

grassland area on the Missouri Coteau (1959–81), Theodore Roosevelt National Park (1949–81), and the Sioux Ranger District of Custer National Forest (1940–81). Thirteen lightning fires that occurred along the boundary of Theodore Roosevelt National Park were also included as part of the data for that study area.

The Sheyenne National Grasslands of the Custer National Forest in North Dakota are on a geologic formation known as the Sheyenne Delta, a formation at the mouth of the Sheyenne River as it discharged into glacial Lake Agassiz. The grasslands are composed of 4 major habitat associations: choppy sandhills, savanna, dry mixed-grass prairie, and moist mixed-grass prairie. These habitat associations support a variety of plant species representative of tall grass prairie, mixed-grass prairie, and oak-savanna lands. Barker (1974) listed the characteristic species for 9 native plant communities within these habitat associations and described their distribution by soil-moisture relationships.

The brush hills mixed-grass prairie area is privately owned rangeland on the Missouri Coteau in Stutsman County, N. Dak. Major plant species of this area were listed by Küchler (1964). The area is steep to rolling with considerable variation in topographic relief.

The grasslands of Theodore Roosevelt National Park are mostly in the badlands of western North Dakota, an area of extremely rugged topography. These grasslands are typical mixed-grass prairie and were described by Hanson and Whitman (1938) and Dix (1960).

The pine-savanna lands of the Sioux Ranger District of the Custer National Forest are in northwestern South Dakota and southeastern Montana. These savannas have a grass understory composed of mixed-grass prairie species (Hanson and Whitman 1938, Dix 1960) interspersed with scattered stands of ponderosa pine *(Pinus ponderosa)*.

Methods

Records of lightning-caused fires were obtained from published reports, files of public agencies, and from personal observations. Size classes of lightning fires conform to the U.S. Forest Service codes.

Nearly all of the data were from federally owned or managed lands. Presumably, these records are the most consistent because of agency mandates relative to fire records and fire suppression. Personal observations were also included. Because of the doubtful circumstances and generalities in many newspaper accounts, no effort was made to retrieve records from this source. Records from local fire departments were used to substantiate personal observations.

Results and Discussion

Records of 294 lightning-caused fires were obtained in the 4-study areas. The size of 1 lightning fire was undetermined for the brush hills study area. Lightning ignited fires in grasslands and pine-savanna lands during all months from April to September (Fig. 2). Seventy-three percent of lightning ignitions (Fig. 2) and

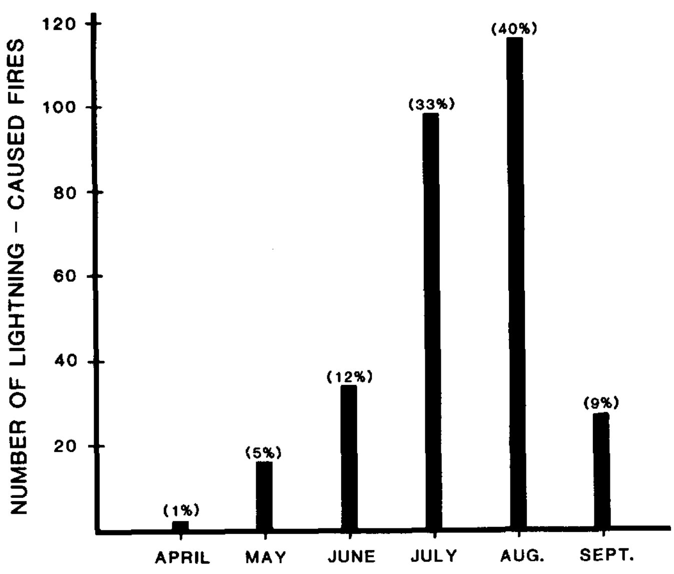

Fig. 2. *Monthly distribution of 293 lightning-caused fires in the Northern Great Plains.*

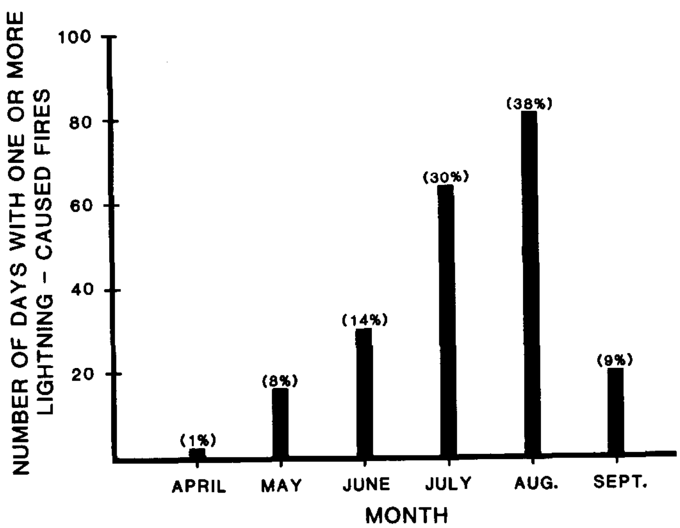

Fig. 3. *Monthly distribution of 213 days with one or more lightning-caused fires in the Northern Great Plains.*

68% of the days with fires (Fig. 3) occurred during July and August with lesser numbers in April, May, June, and September. Multiple ignitions (more than 1 fire in 1 area on a single calendar day) occurred in all months from June–September. Eighty-six percent of the days (n = 44) with multiple ignitions occurred from July 1–August 31.

The area burned by each of 293 grassland lightning fires ranged from 0.004–1158.3 ha ($\bar{X}$ = 10.8 ha). Eighty-eight percent of these fires burned an area of 3.64 ha or less (Fig. 4). Mean monthly sizes of these fires are shown in Table 1. The largest mean area burned occurred in July, followed by May, August, June, September, and April. Fires of 40.5 ha or larger occurred in all months from May–August. Only 2 fires burned more than 405 ha; both occurred in July.

Frequency of lightning fires averaged 6.0/yr per 10,000 km^2 in eastern North Dakota grasslands, 22.4/yr per 10,000 km^2 in south-central North Dakota grasslands, 24.7/yr per 10,000 km^2 in western North Dakota grasslands, and 91.7/yr per 10,000 km^2 in pine-savanna lands in northwestern South Dakota and southeastern Montana (Table 2). Fires caused by lightning strikes were about 4 times more frequent in pine-savanna lands than in grasslands with few trees. Although the period of record is relatively short (n = 12 years) for eastern North Dakota, fires caused by lightning strikes seemingly occurred more frequently west of the Missouri River in North Dakota than east of the river.

The mean size of 4 lightning fires where no suppression was applied was less than 8.1 ha (Table 3). This sample may not reflect the expected mean size of unsuppressed fires for northern grasslands but it represents all the information currently available.

These data demonstrate that lightning is a common cause of fires in northern mixed-grass prairie grasslands. Fire records from 42 years (1940–81) show that lightning strikes caused periodic grassland fires in all months during April–September. This period coin-

Table 1. Sizes of 293 lightning-caused fires in North Dakota grasslands and in nearby pine-savanna lands in South Dakota and Montana by months.

Variables	April	May	June	July	August	September	Total
Number of fires	2	16	34	98	116	27	293
Total hectares burned[a]	1.22	252.51	109.41	1884.38	905.18	32.21	3184.91
Mean fire size (hectares)[a]	0.61	15.78	3.22	19.23	7.80	1.19	10.87

[a]These figures are minimal because nearly all fires were subject to suppression.

Table 2. Frequency of lightning-set fires in North Dakota grasslands and in pine-savanna lands in nearby South Dakota and Montana.

Variables	Sheyenne National Grasslands in southeastern ND	Privately-owned grasslands in south-central ND	Theodore Roosevelt National Park in western ND	Sioux Ranger District in northwestern SD & southeastern MT
Area (ha)	28,423	3,888	28,350	66,015
Vegetative type	Tall grass prairie	Mixed-grass prairie	Mixed-grass prairie	Mixed-grass prairie/ponderosa pine
Period of record	1970–81 (12 years)	1959–81 (23 years)	1949–81 (33 years)	1940–81 (42 years)
Number of lightning-set fires	2	2	36	254
Fire frequency (no/yr)	0.17	0.09	1.09	6.05
Fire frequency (no/yr/10,000 km²)	5.985	22.377	38.477	91.717

cides with the freeze-free period at these latitudes and approximates the average distribution period for thunderstorm activity in this region (Jensen 1972).

Table 3. Size of lightning fires in North Dakota grasslands when suppression was not applied.

Year	Month	Size (ha)	Means of extinguishment
1971 or 1972[a]	July or Aug.	6.1–8.1	Unknown
1973[a]	Aug. or Sept.	≃8.1	Unknown
1978[a]	July	≃8.1	Rain
1981[b]	May 2	≃4.05	Natural burn out

[a]Records from Karen Smith, Manager, Lostwood NWR, ND.
[b]Observations by the author.

The incidence of grassland fires from lightning strikes in this study was greatest during July and August (73%), with lesser numbers in April, May, June, and September. This is understandable because (1) the fine fuels of grasslands are usually dry during this period, (2) July is the peak month for thunderstorms although they occur nearly as often in June and August (Jensen 1972), and (3) the highest average temperatures occur during July and August (Jensen 1972).

Other reports also support the premise that the probability of lightning-caused fires in grasslands is greatest but not exclusive to the summer and late-summer season in the Northern Great Plains. A 1792 quote from the journal of Peter Fidler (Nelson and England 1971) stated of the Canadian grasslands, "...lightning in the spring and fall frequently lights the grass." Rowe (1969) noted the occurrence of over 40 ignitions of grassland by lightning on 21 different dates in southwestern Saskatchewan and the nearby United States; all ignitions occurred during July, August, and September.

A very conservative perspective of the extent of lightning-set fires was demonstrated by the data in the present study because some degree of suppression was applied to nearly all of the fires on record. Nevertheless, if the assumption is made that equal initial suppressive efforts were applied to all of the fires, then the pattern of fire sizes should be somewhat reflective of their natural potential. Consequently, relative fire sizes were greatest during July, the month with the highest mean temperature and peak numbers of thunderstorms. Furthermore, even with suppessive actions, 2 lightning-set fires in grasslands exceeded 405 ha, both in July. A limited number (n = 4) of lightning fires free of suppressive actions averaged slightly less than 8.1 ha.

Lightning fires in the past century have been largely affected by cultural obstacles and practices—mainly roads, cultivated fields, heavy grazing, and new suppression techniques. Even with numerous obstacles, lightning has caused fires of considerable extent. Rowe (1969) listed 2 large grassland fires (3, 110 and 4,666 ha) for southwestern Saskatchewan, and Wolfe (1973) reported a May lightning fire in Nebraska that originated on a prairie and burned over 7,290 ha of rangeland and forest. This fire skipped across the valley and Middle Loup River, a railroad right-of-way, and a highway right-of-way (Komarek 1966). These examples demonstrate that extensive grassland fires of lightning origin can occur even during recent times despite advanced suppressive techniques and cultural obstacles, if fuel and weather conditions are dry and winds are high. Large fires like these occur infrequently. Records indicate that the size of lightning fires in northern grasslands is frequently limited because of rain shortly after the frontal passage of a thunderstorm system.

Except for fire frequency, the temporal patterns of lightning-set fires were very nearly identical between the mixed-grass prairie grasslands in Theodore Roosevelt National Park and the ponderosa pine-savanna lands of the Sioux Ranger District. Fires caused by lightning strikes were slightly more than 4 times as frequent in the pine-savanna lands than in grasslands with few trees or shrubs. Lightning-set fires occurred as frequently as once in 12 years on 3,888 ha of privately owned pastureland in southcentral North Dakota, once in 6 years on 28,423 ha of grazed Forest Service

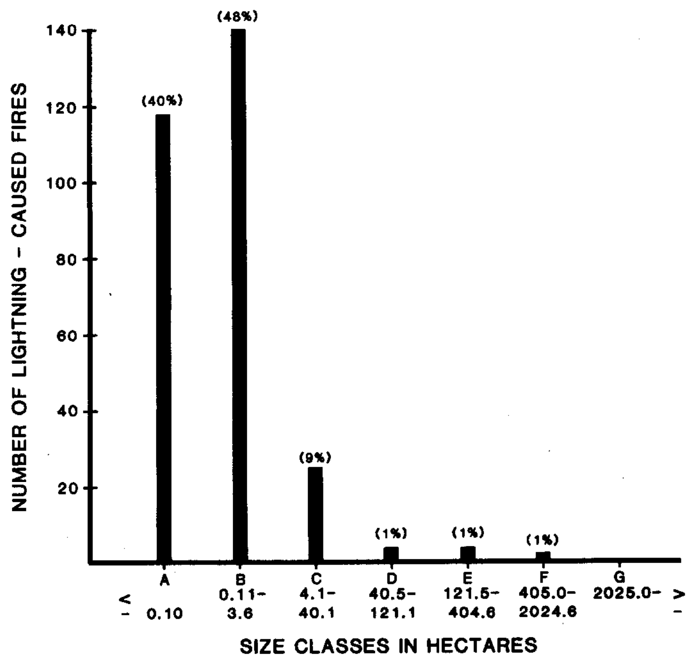

Fig. 4. *Distribution of 293 lightning-caused fires in the Northern Great Plains by size classes.*

grasslands in eastern North Dakota, and once per year on 28,350 ha of mixed grasslands on National Park Service lands in western North Dakota. In earlier studies in mixed grasslands in western North Dakota, Quinnild and Cosby (1958) gave evidence that fire had not occurred for 16–17 years, and the study areas of Dix (1960) were believed free from fire for at least 20 years. In pine-savanna lands in northwestern South Dakota and in southeastern Montana, lightning-set fires occurred on an average of 6 times per year or once a month during the season for lightning fires (April–September) on 66,015 ha of Forest Service lands. These data suggest that lightning-set fires occur at a higher frequency in the western part than in the eastern part of the region. The western parts of North Dakota and South Dakota and eastern parts of Montana are also more xeric than the eastern parts of the Dakotas.

Most fires in the pine-savanna lands were caused by lightning-to-tree strikes (D. Aicher, pers. comm.), whereas most fires in Theodore Roosevelt National Park and the Sheyenne National Grasslands areas of North Dakota were lightning-to-grass strikes (H. Wickware and R. Riddle, pers. comm.). Fires in the park were initiated most frequently on or near the tops of grassy buttes.

The ecological ramifications of fires in northern grasslands are multiple. However, if we accept the concept that for the past few hundred years northern grasslands have occupied their present ranges and that weather conditions have been fairly arid during this period (Will 1946, Dix 1964, McAndrews et al. 1967, Shay 1967, Wells 1970), then some ecological deductions can be made relative to past and present occurrences of lightning fires in grasslands of the Northern Great Plains regions of the United States and Canada:

(1) Nearly all fires during the fall-winter period (October--March) reported in journals and letters from the Northern Great Plains region since ca. 1750 were probably caused by sources other than lightning strikes, most likely man. This is an important interpretation factor relative to the cause and historical occurrence of natural fires in northern grasslands.

(2) A greater percentage and size of lightning-set fires during summer and early fall would tend to favor grasslands over woodlands (except on areas of rougher and more dissected topography), mid to short graminoid vegetation over taller species, and cool-season species of graminoids over warm-season species. The natural vegetation type was probably very similar to that described by Hanson and Whitman (1938) and Küchler (1964).

(3) The frequency and extent of lightning fires have been confounded by the cultural features of recent years. They were also confounded in the historic past by the patterns of grazing animals that unevenly reduced the fuel loads. However, the frequency and extent of historic lightning fires would probably be higher and greater than in the post-bison era because of continuum of fuel, regardless of height or density.

(4) Although historic journals dating back to ca. 1750 give many descriptions of accidental and intentional use of fire by American Indians, there are no records of fire suppression efforts by these peoples except to save occupied camp sites. Thus, lightning and cultural fires of pre-settlement times probably proceeded without event until interrupted by precipitation, cool atmospheric temperatures, natural barriers of streams and wetlands, interruptions in fuels caused by grazing of wild herbivores, or by significant changes in topographic relief.

Many studies substantiate that the native flora and fauna of northern grasslands and savannas are strongly adapted to an ecosystem with fire acting frequently as a functional entity in the evolutionary processes. These data suggest that the occurrence of lightning ignition was sufficient to produce ecological adaptions to lightning-set fires if they ocurred similarly during historic time. Even though the data identify general patterns of lightning-set fires, resource managers should keep in mind that different management objectives may also require different prescribed fire frequencies even on the same area.

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Livestock Grazing Influences on Community Structure, Fire Intensity, and Fire Frequency within the Douglas-fir/Ninebark Habitat Type

G. THOMAS ZIMMERMAN AND L.F. NEUENSCHWANDER

Abstract

Influences of livestock grazing on community structure, fire intensity, and normal fire frequency in the Douglas-fir/ninebark *(Pseudotsuga menziesii/Physocarpus malvaceus)* habitat type were studied at the University of Idaho's experimental forest in northern Idaho. Livestock grazing caused increased tree numbers, decreased production, cover, and frequency of major palatable grasses, and altered dominance of shrub and forb species. Grazing influences on community structure were increased accumulation of downed woody fuel in every size class, increased forest floor duff, and decreased herbaceous fuels. Livestock grazing influences were discussed in light of their significance in potential fire intensity and fire frequency in Douglas-fir forest communities.

Historically, fire exerted a strong influence on the ecology of western forest communities, and the history has been widely studied. Arno (1976) reported the significance of fire in forest development. However, little information was available on the frequency and intensity of fires in the Douglas-fir/ninebark *(Pseudotsuga menziesii/Physocarpus malvaceus)*[1] habitat type. Wellner (1970) reported that these forests experienced fires that caused slight to extreme damage. Arno (1976) stated that fires in Douglas-fir forests of western Montana were frequent prior to 1900 (mean fire-free periods ranged from 7 to 19 years), and fire damage was usually not extreme. Fire was a major force in stand development, but during the last 50 years, its role has been reduced to one of minor significance because of effective fire suppression and logging activities.

Since different animals have different food preferences, seasons of use, and grazing intensities, they influence the forest community structure differently. Changes in overstory structure and in shrubby and herbaceous density and composition can affect the intensity and frequency of fires in forest communities. Grazing has exerted strong influences on the ecology of forest communities (Daubenmire 1968). Livestock grazing has been effective in reducing the fire hazard in the forests of the western United States (Adams 1975, Ingram 1931) since the early part of this century (Hatton 1920). Range managers have shown that grazing has influenced vegetal development and that it can change the path of secondary succession. Long-term interactions of livestock grazing wildfire, however, have not been reported.

Authors are graduate research assistant and associate professor, College of Forestry, Wildlife, and Range Science, University of Idaho, Moscow.

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[1]All scientific and common names follow Hitchcock and Cronquist (1973).

Cholewa (1977) and Froeming (1974) discussed the importance of the Douglas-fir/ninebark habitat type. These communities support vegetation which provides adequate summer forage for livestock, summer and winter browse, and both visual and thermal cover for big game. Characteristically, this vegetation is dry in late summer, creating a fuel layer of high continuity and flammability. If an adequate supply of dry fuel particles in 1-centimeter and smaller size classes is available, fire can be ignited easily and spread rapidly (Dodge 1972). Livestock grazing has eased fire ignition and spread by removing herbaceous undergrowth and reducing the number of fuel particles and by hastening decay of litter through trampling (Hatton 1920).

This study was designed to determine influences of livestock use in the Douglas-fir/ninebark habitat type of northern Idaho. Specifically, the goal was to determine changes in community structure, composition, and distribution of fuel caused by livestock grazing, and to assess the extent to which these changes modify fire frequency and intensity.

Study Area

The study was conducted in the forested hills along the western slope of the Bitterroot Mountains on the University of Idaho Experimental Forest located approximately 20 km (12 mi) northeast of Moscow in Latah County, Idaho.

Elevation of the area ranged from approximately 853 m (2,800 ft) to near 1,006 m (3,300 ft) with slopes varying from 5 to 40%. The area contained 2 main soil series. Areas with 5 to 20% slope, comprised of deep, moderately well-drained soils formed in deep loess, were classified as Carlinton silt loams. Steeper slopes, moderately well drained throughout, formed from granodiorite residuum with some loess influence, were classified as Uvi silt loams.

Vegetation of the area was characteristic of Douglas-fir/ninebark habitat type as described by Daubenmire and Daubenmire (1968). Vegetation was cover mapped by Basile (1954) and updated by Thilenius (1960). Overstories were a mixture of Douglas-fir and ponderosa pine *(Pinus ponderosa)*. Understories varied greatly but were generally dominated by ninebark *(Physocarpus malvaceus)*, oceanspray *(Holodiscus discolor)*, and snowberry *(Symphoricarpos albus)*. Graminoids, comprised primarily of pinegrass *(Calamagrostis rubescens)*, elk sedge *(Carex geyeri)*, bluebunch wheatgrass *(Agropyron spicatum)*, and Idaho fescue *(Festuca idahoensis)*, combined with an abundant number of forbs, formed the ground layer.

"High grade" logging occurred on the study area in 1925. Cutting practices ranged from light, selective cutting to clearcutting, and most of the merchantable timber was harvested regardless of species (Basile 1954). During the early 1940's, unregulated grazing by both cattle and sheep occurred on the area. Construction of the enclosure excluded livestock, but at various locations the fence fell into disrepair and did not consistently restrict big game use of the area. Observations showed that whitetail and mule deer and elk utilized areas both inside and outside the enclosure throughout the year. From 1945 to 1967, the area was utilized by a large number of domestic livestock, and it was grazed very heavily. During this period, for 5 months each year, the stocking rate was nearly double the herbaceous carrying capacity.[2] In 1969 a management plan was written that provided for gradual reduction in animal numbers and for shortening the grazing season to 4 months. Currently, the area surrounding the enclosure is grazed by cattle during the spring, summer, and fall.

Utilization of the graminoids for the last 20 years averaged 85% (one animal per 13 ha) with a maximum of 99% in 1966 and a minimum of 43% in 1972 (U.S. Forest Service). Prior to 1968, utilization exceeded 90%, based on U.S. Forest Service records. Grazing records were incomplete prior to 1959 and grazing was not uniform across the study area, but the area was very heavily grazed. Browsing by big game was probably never very high in the study area and had been insignificant for the last 20 years (Thilenius and Hungerford 1967).

Organized fire protection has been provided in the area since sometime in the 1920's. The only fire on record was a wildfire that burned a small portion, about 18 ha, of the study area in 1963. Fire scars on many mature ponderosa pines were evidence that periodic, low intensity fires historically occurred in the area about every 22 years. Fire frequencies were not adequately determined for these specific stands, but in similar Douglas-fir stands of western Montana the mean fire frequency was 19 years (Arno 1976).

Methods

Vegetation was sampled in the Douglas-fir/ninebark habitat type using a series of macroplots established both inside and outside the enclosure during 1978. Each pair of grazed and ungrazed macroplots were on the same slope, aspect, and soil series. At least a 3-m distance was maintained as the minimum buffer width between plots and the enclosure fence to eliminate any bias associated with the fence right-of-way. A total of eighteen 15 × 25-cm (375 m^2) macroplots were sampled. Variables measured included cover, frequency, production, number of trees, basal area, shrub density, and accumulation of downed woody fuels.

Each macroplot was further subidived into three 5 × 25-m (125 m^2) sections. Along the central section, fifty 20 × 50-cm (.1 m^2) microplots were placed at 1-m intervals. In these microplots, the parameters of cover, frequency, and production were measured. Cover was estimated using 6 cover classes for plants inside the microplots (Daubenmire 1959). Rooted frequency was determined for all species. Herbaceous plant species in every third microplot were clipped, oven dried, weighed, and converted to kilograms per hectare to obtain production values. Grazing was unrestricted for the grazed plots, but very few animals were observed in the stands prior to the sampling period.

Trees were tallied by 1/2-dm diameter classes as measured at breast height (1.4 m). All trees of this height and taller were measured in the macroplot. Basal area was calculated by the formula:

$$ba = (\tfrac{1}{2}d)^2 \times \pi,$$

where d equals diameter at breast height (Mueller-Dombois and Ellenberg 1974). Densities of trees less than breast height and shrubs were measured in 2 belt transects, 1 × 25 m, which were located along the central 5 × 25-m section of the macroplot. Average tree ages were estimated by obtaining increment cores from a minimum of 2 trees per diameter class in each plot and counting annual rings. Downed woody fuel accumulations were measured by the planar intersect method (Brown 1974) in two 10-m line transects. This technique provided the following information:

1. Weights per hectare of downed woody material for:
   a. Diameter size classes 0 to 0.6 cm (0 to 0.25 inch)
      0.6 to 2.54 cm (0.25 to 1 inch)
      2.54 to 7.62 cm (1 to 3 inches)
   b. Sound and rotten fuel particles of diameters of 7.62 cm larger.
   c. Forest floor duff.
2. Depth of fuel and forest floor duff.

One-way analysis of variance and Student's *t*-test were used for statistical analyses of differences between grazed and ungrazed stands for all variables. Throughout the paper the term *significant* refers to $P<0.05$.

Results and Discussion

Overstory Structure

The largest number of trees in both grazed and ungrazed stands were in the smaller diameter classes. As diameters increased, total number of trees decreased. Number of ponderosa pine and Douglas-fir in grazed stands were greater than in ungrazed stands in every diameter class up to 4 dm (Fig. 1, 2), but, more significantly, in the .5 to 2-dm classes. There were no large or consistent

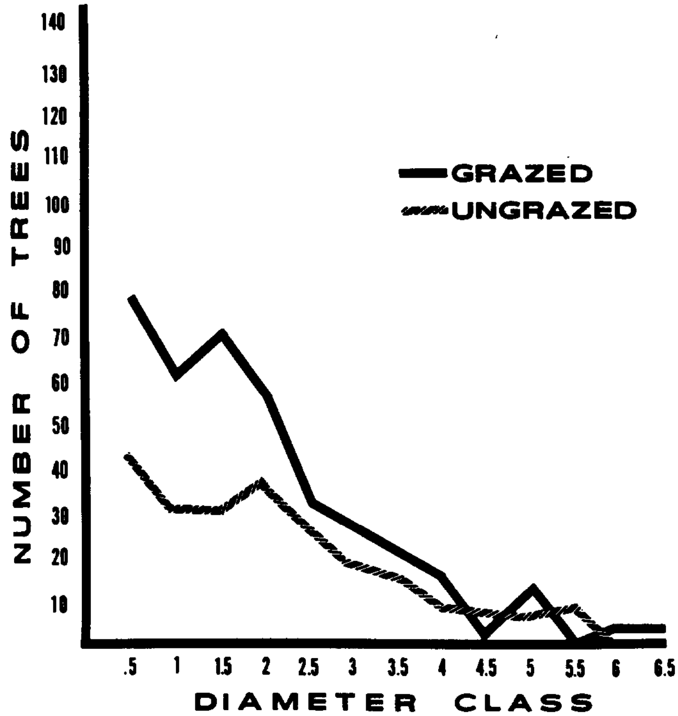

Fig. 1. *Mean number of ponderosa pine trees by .5 decimeter diameter classes for grazed and ungrazed stands.*

differences between the stands in the number of trees in diameter classes larger than 3 dm. In grazed stands there were more Douglas-fir trees than ponderosa pine in nearly every diameter class. In the ungrazed stand, with the exception of the .5-dm diameter class, there was a similar number of each tree species. However, in grazed stands, Douglas-fir were more abundant than ponderosa pine in the smaller size classes.

Number of Douglas-fir seedlings was about the same (1,277.6/-ha) on grazed and ungrazed stands. Number of ponderosa pine seedlings was significantly different, with only 55.6/ha on grazed stands but 555.6/ha on ungrazed stands. Many researchers have

[2]Flat Creek-Hatter Creek Allotment Management Plan. Cooperative plan developed by the University of Idaho, Palouse Ranger District (USFS), and Latah Soil and Water Conservation District. On file at Palouse Range Station, Potlatch, Ida.

found an increased number of seedlings following natural regeneration on moderately grazed sites in freshly cut forested stands (c.f. Adams 1975, Young et al. 1942, Tisdale 1950), but this benefit is apparently reduced for ponderosa pine when succession advances. In grazed stands, ponderosa pine regeneration was reduced as the quantity of shading and duff increased. Douglas-fir is more shade tolerant than ponderosa pine, is climaxed on these sites, and has the greater ability to regenerate in both open areas of ungrazed stands and shaded areas of grazed stands. In the long term, heavy grazing is more beneficial for Douglas-fir regeneration than for ponderosa pine.

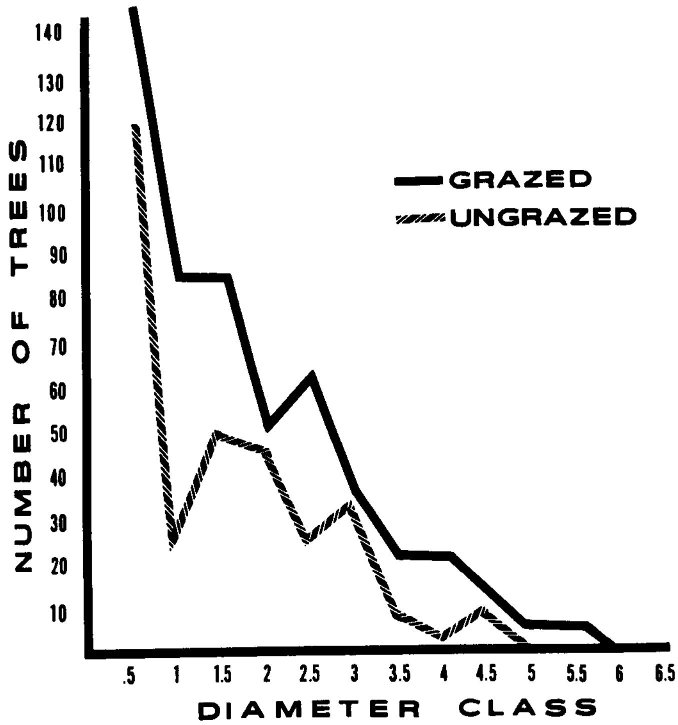

Fig. 2. *Mean number of Douglas-fir by .5 decimeter diameter classes for grazed and ungrazed stands.*

Increase in young tree densities has been attributed to the removal of the competing herbaceous layer by heavy grazing (Pearson 1923, Leopold 1924, Arnold 1950, Cooper 1960, Tisdale 1960, Pearson 1942, and Young et al. 1942). Weaver (1950) reported that overgrazing resulted in development of abnormally dense stands because it resulted in breakup of original sod and preparation of mineral seedbed. Rummell (1951) concluded that heavy grazing was primarily responsible for dense tree reproduction in central Washington.

In the majority of diameter classes, tree growth rates in grazed stands were slightly less than in ungrazed stands (Table 1). Lower growth rates in areas heavily grazed were reported by Adams (1975). Higher tree densities resulting from livestock grazing may have been the cause for decreased tree growth rates in grazed stands. Competition in dense stands reduced the growth and vigor of all trees, resulting in diameter growth reductions (Smith 1962).

Tree diameter classes which had the greatest difference between grazed and ungrazed stands (.5 to 2 dm), ranged in age from 16 to 56 years (Table 1). Thus, most of smaller diameter trees had become established during the past 50 years, a period of heavy grazing. Livestock grazing was probably the principal factor in creating and maintaining conditions that favored increased tree regeneration.

There was a significantly higher mean basal area in grazed stands (37 m^2/ha) than in ungrazed stands (22 m^2/ha) (Fig. 3). This large difference may be attributed to increased number of smaller trees in the grazed stands.

Table 1. Average tree age by diameter class for ponderosa pine and Douglas-fir in grazed and ungrazed stands.

Diameter class (.5 dm)	Age[1] *Pinus ponderosa* Grazed	*Pinus ponderosa* Ungrazed	*Pseudotsuga menziesii*[1] Grazed	*Pseudotsuga menziesii*[1] Ungrazed
.5	20.25	15.67	22.14	22.50
1.0	32.20	26.67	34.86	30.00
1.5	36.50	38.00	41.33	35.60
2.0	42.71	55.75	48.83	32.20[2]
2.5	55.20	51.17	51.17	41.33
3.0	67.67	61.50	59.40	43.00
3.5	64.67	65.20	67.25	39.00
4.0	96.00	91.00*	81.00	112.00*
4.5	123.00*[a]	74.00*[b]	97.75[ab]	86.50[b]
5.0	105.33	119.00	80.00*	—
5.5	—	108.00	96.00	—
6.0	104.00*	—	—	—
6.5	165.00*	98.00*	—	—

[1]Species ages followed by different letters are significantly different at the 0.05 level.
[2]Tree ages followed by different numbers are significantly different at the 0.05 level.

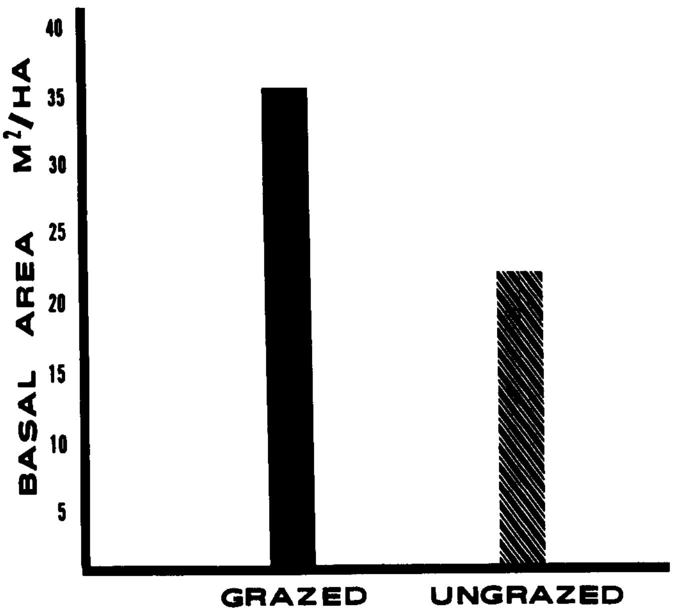

Fig. 3. *Mean basal area for ponderosa pine and Douglas-fir in grazed and ungrazed stands.*

Shrub Layer

Total shrub density did not differ significantly between heavily grazed and ungrazed stands, but individual species density did (Table 2). Of the 12 shrub species sampled, only 3, serviceberry *(Amelanchier alnifolia)*, ninebark, and white spiraea *(Spiraea betulifolia)*, had a greater density in grazed stands. Serviceberry was either very tall and out of reach of livestock and big game, or very small and unutilized. The 9 other species had greater densities in ungrazed stands, but only redstem ceanothus *(Ceanothus sanguineus)*, chokecherry *(Prunus virginiana)*, and yerba buena *(Satureja douglasii)* densities were significantly greater. Redstem ceanothus, apparently suppressed through heavy use by livestock and big game, was nearly absent in grazed stands. Chokecherry and scouler willow *(Salix scouleriana)* occurred in such low densities in all stands that comparisons were not meaningful. Yerba buena, kinnikinnick *(Arctostophylos uva-ursi)*, and creeping Oregon grape *(Berberis repens)*, were probably less resistant to trampling by livestock due to their small size and shallow rhizomes, and were present in lesser amounts in grazed stands. Little wild rose *(Rosa gymnocarpa)* and snowberry also had higher densities in

Table 2. Numbers per hectare, percnt cover, and average percent frequency for major shrub species.

Species	Number of shrubs[1]		Cover • Frequency	
	Grazed	Ungrazed	Grazed	Ungrazed
Amelanchier alnifolia	5622	1755*	0.3 • 2.2	0.3 • 2.0
Arctostaphylos uva-ursi	233	755	+[3] • 0.4	0.2 • 2.0
Berberis repens	1600	1755	0.7 • 4.0	1.1 • 5.8
Ceanothus sanguineus	122	2033*	0.0 • 0.0	2.7 • 5.3*
Holodiscus discolor	522	989	0.6 • 1.3	2.6 • 4.4*
Physocarpus malyaceus	2077	1611	2.3 • 6.9	1.7 • 4.4
Prunus virginiana	0	67*	0.0 • 0.0	0.0 • 0.0
Rosa gymnocarpa	3489	4510	1.2 • 8.2	2.1 • 12.4*
Satureja douglasii	78	700*	+ • 0.4	0.5 • 3.3*
Salix scouleriana	67	253	0.0 • 0.0	0.2 • 0.9
Spiraea betulifolia	7900	5033	5.8 • 42.0	4.7 • 32.0
Symphoricarpos albus	9767	12377	4.6 • 26.0	7.2 • 39.3*
Total for all shrub species	31477	31838	15.8 • —	24.5* • —

[1]Species means followed by an asterisk are significantly different at the 0.05 level.
[2]Numbers represent percent cover (first) and average frequency (second).
[3]Values less than 0.1 are represented by +.

ungrazed stands indicating that livestock grazing retarded their spread, possibly through rhizome damage by trampling.

Total percent cover for all shrubs was significantly lower in grazed stands (15.8%) than in ungrazed stands (24.5%) (Table 2). This reduction in cover suggested that shrub species sustained heavy use by livestock. Because of the unequal size distribution of individual plants, ninebark and white spiraea had higher cover and frequency values in grazed stands. Serviceberry had higher frequency in the grazed stands but equal cover in both grazed and ungrazed stands. All nine of the other individual species had higher cover and frequency in ungrazed stands. Five of these, redstem ceanothus, oceanspray, little wild rose, yerba buena, and snowberry were significantly higher. Krueger and Winward (1974) found similar results with oceanspray and snowberry in northeastern Oregon. They also found that ninebark had lower percent cover in stands grazed by cattle and big game in stands grazed by big game only. Redstem ceanothus occurred frequently with one of the higher cover values in the ungrazed stands, but was not encountered in microplots in grazed stands.

Herbaceous Layer

Production, percent cover, and frequency of grasses indicated that livestock grazing was a substantial influence (Table 3). Production of bluebunch wheatgrass, pinegrass, and Idaho fescue were significantly lower in grazed stands. Bluebunch wheatgrass production in grazed stands was nearly 140 times greater than that in stands grazed by livestock. Pinegrass production in grazed stands was only 28% of that found in ungrazed stands (a reduction of nearly 72%). Idaho fescue was absent in stands grazed by livestock (Evanko and Peterson 1955). Columbia brome *(Bromus vulgaris)* production was slightly less in grazed stands. Kentucky bluegrass *(Poa pratensis)* and elk sedge production increased in grazed stands and was nearly absent in ungrazed stands.

In grazed stands, cover of Columbia brome and Kentucky bluegrass was significantly higher, while cover of bluebunch wheatgrass, pinegrass, and Idaho fescue was lower. Pinegrass had the largest difference, with cover in grazed stands less than one-half the cover in ungrazed stands. Elk sedge cover was the same in grazed and ungrazed stands. In central Washington ponderosa pine stands, Rummell (1951) found that the most striking effect of heavy grazing was reduction of grasses, principally pinegrass, to half or less of the cover found in ungrazed stands. R. and J. Daubenmire (1968) reported that Kentucky bluegrass increased under heavy grazing.

Combined production of all forb species was found to be significantly lower in stands grazed by livestock (340 kg/ha) than in ungrazed stands (469 kg/ha) (Table 3). Bigleaf sandwort *(Arenaria macrophylla)* and mountain sorrel *(Rumex paucifolia)* production was higher in grazed stands. Producton of Piper's anemone *(Anemone piperi)*, raceme pussytoes *(Antennaria racemosa)*, showy aster *(Aster conspicuus)*, pinewoods peavine *(Lathyrus bijugatus)*, western starflower *(Trientalis latifolia)*, American vetch *(Vicia americana)*, and early blue violet *(Viola adunca)* was lower in grazed stands. No meaningful responses to grazing were found for other species.

Total forb cover was not substantially different between the stands (Table 3). However, bigleaf sandwort, heartleaf arnica *(Arnica cordifolia)*, and narrowleaf collomia *(Collomia linearis)*, had significantly higher cover in grazed stands. Raceme pussytoes, showy aster, mountain sweetroot *(Osmorhiza chilensis)*, Gairdner's yampa *(Perideridia gairdneri)*, cinquefoil *(Potentilla gracilis)*, western starflower, and American vetch had significantly lower cover in grazed stands. There were no substantial differences in cover of other species.

Frequency of forb species in grazed and ungrazed stands generally followed the same trends observed in production and cover (Table 3), but some very distinct changes in species occurrence were obvious. In grazed stands, Piper's anemone and western starflower decreased markedly from (22.2% to 12.2% and from 15.6% to 3.1%, respectively) and bigleaf sandwort increased substantially (from 15.8% to 39.1%). Krueger and Winward (1975) found that frequency of forbs generally increased under heavy grazing pressure.

Fuel Accumulation

Livestock grazing did not directly alter the fuel loading. However, grazing did change the density and composition of woody and herbaceous material, which indirectly influenced the fuel accumulation. Total accumulation of downed woody material was found to be greatest in stands grazed by livestock (75,804 kg/ha compared to 53,984 kg/ha) (Fig. 4). Inspection of downed woody material accumulation by size classes revealed that stands used by livestock contained higher weights per area in every category (Fig. 4). The largest differences were found in the 7.62 cm and larger size classes, with sound particles of this size comprising 9,200 kg/ha (5.11 tons/acre) in grazed and only 3,881 kg/ha (2.16 tons/acre) in ungrazed stands. Rotten particles of this size comprised 9,759 kg/ha (5.42 tons/acre) in grazed and 5,729 kg/ha (3.81 tons/acre) in ungrazed stands. In each of the smaller size classes, grazed stands contained nearly double the amount of fuel found in ungrazed stands. Accumulations of duff comprised the highest weights per area of any single category in both grazed and ungrazed stands. Stands grazed by livestock had 52,563 kg/ha (29.2 tons/acre) of duff. Grazing has reduced duff accumulation by compacting litter and increasing the rate of decomposition of western forests (Hattin 1920, Weaver 1951). However, as tree

Table 3. Production in kilograms per hectare, percent cover, and average percent frequency for major herbaceous species.[1]

	Production		Cover frequency[2]			
	Grazed	Ungrazed	Grazed		Ungrazed	
Graminoids:						
Agropyron spicatum	0.17	23.98*	+[3]	0.9	0.5	10.2*
Bromus vulgaris	1.00	2.00	1.3	24.0	0.7	19.3*
Calamagrostis rubescens	47.09	165.48*	0.8	21.3	2.1	34.2*
Carex geyeri	114.26	57.48	2.5	49.6	2.6	44.9
Festuca idahoensis	0.00	10.85*	+	0.0	0.4	8.2*
Poa pratensis	16.95	0.00*	0.9	14.7	0.0	0.0*
Total for all graminoids	188.83	273.47	5.9	—	6.3	—
Forbs:						
Achillea millefolium	50.20	83.10	0.9	15.8	0.7	16.2
Apocynum androsaemifolium	25.30	8.20	0.4	4.7	0.5	5.3
Anemone piperi	1.30	4.00*	0.8	12.2	1.1	22.2
Antennaria racemosa	0.10	0.30*	+	0.2	0.1	1.8*
Arenaria macrophylla	5.20	1.90*	2.9	39.1	0.6	15.8*
Arnica cordifolia	6.90	6.60	2.9	27.8	1.5	26.2*
Aster conspicuus	0.00	4.50*	+	0.7	0.4	4.4*
Collomia linearis	4.20	6.90	0.2	9.8	0.1	4.4*
Collinsia parviflorus	0.00	0.00	0.2	6.9	0.2	8.7
Cryptantha echinella	41.70	34.00	0.1	1.1	+	1.6
Fragaria virginiana	2.00	2.70	4.2	39.8	4.9	50.7
Galium boreale	161.80	196.00	0.4	6.0	0.4	9.8
Goodyera oblongifolia	18.80	34.10	+	0.7	+	0.7
Gypsophila paniculata	0.20	0.30	+	1.6	+	1.1
Lathyrus bijugatus	3.40	7.40*	0.5	12.0	0.6	10.9
Lupinus sericeus	9.00	22.00	0.7	6.4	0.8	8.9
Madia exigua	0.10	2.40	0.2	1.8	+	3.4
Osmorhiza chilensis	0.03	0.12	+	1.6	0.4	6.2*
Perideridia gairdneri	0.30	1.00	+	0.2	0.1	2.9*
Potentilla glandulosa	0.00	28.70	0.3	4.0	0.4	5.8
Potentilla gracilis	3.20	10.00	+	0.2	0.2	1.8*
Rumex acetosella	0.40	0.10	+	0.9	+	0.4
Rumex paucifolia	1.00	0.10*	0.2	2.4	+	1.3
Smilacina stellata	3.20	1.30	0.7	6.0	0.4	2.4
Taraxacum officinale	0.20	7.30	0.3	4.0	0.2	7.1
Thalictrum occidentale	1.30	2.10	0.6	6.2	0.7	8.4
Trientalis latifolia	0.60	1.90*	0.2	3.1	0.5	15.6*
Vicia americana	0.00	1.30*	+	0.2	0.2	5.6*
Viola adunca	0.03	1.40*	0.2	3.1	0.3	8.0
Total for all forbs	340.46	469.72*	17.6	—	17.3	—

densities increased in dry Douglas-fir stands following grazing, the quantity of litter fall increased and the composition of the duff changed. Probably this created a microenvironment that was not conducive to increased litter fall or reduced rate of decomposition. Heavily grazed stands had greater accumulations of duff and downed woody fuel suppression mortality and lower branch drop that followed the canopy closure. Heavy grazing indirectly increased the accumulation of organic debris in the grazed stands of this study.

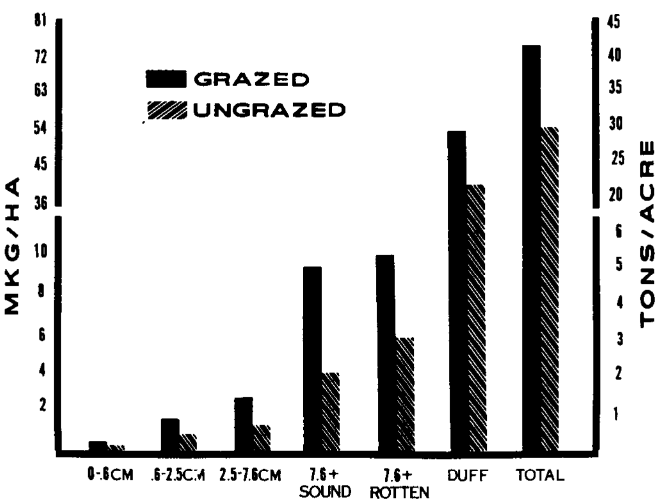

Fig. 4. *Mean fuel loading by size classes for grazed and ungrazed ponderosa pine and Douglas-fir stands.*

In general, in fire-danger ratings, living fuels are burnable fine fuels when dry and are part herbaceous and part nonherbaceous material (Fosberg and Schroeder 1971). Nonherbaceous fine fuels are perennial foliage of shrubs and tree reproduction, and woody stems less than .6 cm in diameter. Herbaceous fine fuels are comprised of vegetation such as grasses, sedges, and forbs. Nonherbaceous fine fuels were not measured in this study because of sampling difficulty. Total live herbaceous fine fuels were found to be significantly lower in grazed (467 kg/ha) than in ungrazed stands (719 kg/ha) (Table 3).

Little research has been done concerning burning characteristics of living fuels, but their importance in reaction intensity and rate-of-spread has been discussed (Richards 1940, Fosberg and Schroeder 1971, Rothermel 1972). Based on fuel arrangement, Rothermel (1972) indicated that herbaceous fuels were considered as flashy and have the highest potential reaction intensity. He also showed that with the addition of wind, herbaceous fuels had the highest rate-of-spread. Richards (1940) reported that plant moisture content was the major factor controlling vegetative influence on fire rate-of-spread. Decreased moisture content occurring during the summer resulted in increased flammability. He also found that the rates at which plants lost moisture when subjected to fire caused different fire behavior. Hatton (1920) directly attributed reductions in the incidence of fire to removal of herbaceous material and increased decomposition through trampling from grazing livestock. Jemison (1934) reported that tree canopy density significantly influenced flammability. Increasing tree canopy density reduced temperature, humidity, wind, and evaporation below the canopy, which resulted in increased moisture holding capacity of understory vegetation and reduced flammability. Thus, as livestock grazing influenced canopy density and reduced fine fuels, it also affected the ability of the forest to sustain a surface fire.

Management Implications

Livestock grazing has altered the composition and quantity of ground cover vegetation. Removal of herbaceous competition combined with exposure of mineral soil has aided in preparing stands for increased tree reproduction. Consequently, regeneration success of both ponderosa pine and Douglas-fir has increased with potentially long-lasting effects.

Douglas-fir habitat types in northern Idaho have typically supported uneven-aged forests with many age and diameter classes represented. The proportion of trees in each diameter class has remained relatively constant over time (until complete crown closure has occurred), with the diameter distribution usually taking the form of a falling exponential curve with the number of trees plotted against diameter. In grazed stands the balance in forest structure shifted so that greater numbers of trees now occur in smaller size classes. Overstocked ponderosa pine and Douglas-fir stands may stagnate, causing reductions in growth rates, and increased susceptibility to damage from insects or disease. Increased stocking levels and basal area have reduced both shrub and herbaceous layers. In the Douglas-fir/snowberry habitat type, understory production decreased as tree canopy cover increased (Froeming 1974). An inverse relationship between overstory canopy or basal area and the density or production of shrubby and herbaceous understories had been reported by researchers working under a wide variety of conditions (Arnold 1950, Tisdale 1950, Pase 1958, Cooper 1960, McConnell and Smith 1965, Hedrick et al. 1968). Also, as stocking levels increased, livestock movement became more difficult. Cattle concentrated in open areas, or along roads or fences, causing further pressure on already overused range. These concentrations may have caused trampling and compaction damage to tree reproduction.

Livestock grazing appeared to have no significant influence on density of shrubs, although it did cause significant reductions in cover and composition. Continuous heavy grazing suppressed the growth of redstem ceanothus, a browse species highly desirable and important to big game species. Thilenius (1960) found that cattle first used palatable forage grasses, then were forced to subsist on browse and forbs for the remainder of the growing season. He also found that browse species comprised the greater part of the food supply of livestock using forested ranges when the areas were overused. Thus, as tree canopy cover increased, the browse component received heavier use from grazing livestock, causing additional shrub species to be suppressed.

Generally, influence of livestock grazing on the herbaceous layer was most pronounced in production. Significant reductions were found in the major palatable grass species and in total forb production.

It appeared that livestock grazing was responsible for retrogression of plant succession within the herbaceous layer. Climax grass species were replaced by species common to seral communities. There were apparent changes in dominance of certain forb species.

In the overstory, grazing advanced succession. Ponderosa pine was the most prevalent seral tree species found in these stands, although there were occasional lodgepole pine *(Pinus contorta)*. Douglas-fir regeneration was most pronounced, and comprised the majority of trees in all of the smaller diameter classes. It appeared to be gaining dominance in the heavily grazed stands.

Modifications in plant succession were not defined as clearly in the shrub layer. Livestock showed preference for the more palatable browse species, which were commonly seral in this habitat type. In climax situations, ninebark was the principal species, with oceanspray, snowberry, and white spiraea also well represented. In stands used by livestock, ninebark had increased, although not significantly, but was not the dominant species. In the grazed stands, oceanspray and snowberry had decreased while white spiraea had increased.

Livestock grazing increased total accumulations of downed woody fuels. While it is possible that incidence of low intensity surface fires was reduced through the increase in forest canopy and removal of the herbaceous layer, this reduction may not be as significant as once thought. As the highly palatable species were selectively removed, they were replaced in lesser amounts by unpalatable and high flammable species.

Douglas-fir forest communities and environmental conditions that influenced them interacted to establish a level of duff accumulation and decomposition rates of woody material. Livestock grazing in these forests increased duff accumulation but apparently did not accelerate decomposition rates. Larger fuels and forest floor duff contributed very little to the rate-of-spread, but once ignited, persisted in the form of smoldering fires. These smoldering fires are difficult to extinguish, providing a source of burning embers for further fire spread. Thus, over long periods of time, the physical accumulation of large amounts of downed woody fuels and duff layers may induce flammability (Bloomberg 1950.).

Increased total tree numbers and unpalatable shrub species, when combined with increased duff and all size classes of dead organic material, created bridges between the ground layers and tree canopies. This manner of fuel distribution is highly conducive to the vertical spread of fire through a forest canopy.

Douglas-fir/ninebark forest stands have historically experienced damage from wildfires (Wellner 1970). In western Montana, extreme fire damage was, generally, confined to northern exposures. Southern exposures experienced frequent, low intensity fires (Arno 1976). Concentrations of flashy or herbaceous fuels and moderate stocking levels permitted surface fires to pass quickly through stands, causing little damage. In the future, if grazing-induced fuel buildups and fuel ladder situations are permitted to continue, the potential destructiveness of crown carrying wildfires will increase.

Several types of forest management practices lend themselves to the mitigation of adverse fuel conditions in these stands. Prescribed understory burning can remove herbaceous fuels, reduce litter and downed woody fuel accumulations, and control excessive tree reproduction. For dense sapling and pole-sized stands, precommercial and commercial thinning can achieve and maintain desired stocking levels. Depending on the residual stand, prescribed burning can be used in conjunction with thinning operations to control fuel levels.

If effects of intensive grazing are allowed to continue over long periods of time, prescribed burning treatments will be difficult to administer. During attempts to carry out prescribed understory burning in grazed and ungrazed Douglas-fir stands, Zimmerman (1979) found that the 2 areas could not be burned under the same fire weather conditions. He found that temperature and moisture conditions suitable for burning quickly drying herbaceous fuels of ungrazed stands created fuel moisture conditions that severely restricted the ignition and spread of fire in the abundant, larger fuels of grazed stands. These stands only burned under dry, wildfire weather conditions.

The influence of excessive livestock grazing on community structure in the Douglas-fir/ninebark habitat type resulted in modifications of plant cover and fuel distribution and composition.

The modifications that resulted in fuel distribution and composition were slightly less favorable to frequent surface fires, highly conducive to vertical spreading of fire, and potentially more capable of major conflagrations. Therefore, continued livestock grazing without fuel management will cause reductions in the frequency of low intensity fires, but will promote conditions that favor the occurrence of infrequent, high intensity fires.

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Economic Evaluation of Fire-based Improvement Systems for Macartney Rose

L. GAROIAN, J.R. CONNER, AND C.J. SCIFRES

Abstract

Integration of prescribed burns into management systems with herbicide and mechanical controls is proposed as an economically efficient means of improving the productivity of Macartney rose infested rangeland. Roller crushing followed by prescribed burns produce the highest rate of return (15%) and the lowest maximum investment. However, because of the great regrowth potential of the brush, this low-intensity system is also associated with the greatest risk. Systems which utilize initial mechanical controls followed by aerial application of 2,4,5-T+ picloram and maintenance treatments of prescribed burning and/or individual-plant treatments with herbicides are less risky but more capital intensive. Internal rates of return for the more intensive treatments range from 11.2 to 11.7%. Fire-based systems increase the rate of return by as much as 13.8% over systems with the same initial treatment but without prescribed burning.

Macartney rose (*Rosa bracteata* Wendl.) occurs on approximately 201,000 ha of highly productive grazing lands in eastcentral Texas and on the Coastal Prairie (Hoffman et al. 1964). This troublesome species occupied less than 17,000 ha in 1948 (Hoffman 1966). Recommended chemical treatment of Macartney rose during the early 1960's and until the mid 1970's was multiple, successive annual applications of 2,4-D [(2,4-dichlorophenoxy)acetic acid], with the rate and time of application dictated by growth form of Macartney rose. However, a generalized treatment schedule usually consisted of 2.2 kg/ha of 2,4-D (amine formulation for spring applications and low volatile ester for fall treatments) broadcast applied the first year followed by 1.1 to 2.2 kg/ha of 2,4-D the next year (Scifres 1980). As many as five successive, annual applications of 2,4-D were used in some cases (Hoffman 1966).

Multiple 2,4-D applications have become increasingly expensive, are not always highly effective, remove desirable forbs from the grassland, and pose repeated potential for spray drift to susceptible crops. Therefore, research was initiated in 1970 to evaluate several herbicides which might improve control, especially with fall applications (Scifres 1975a). Research also investigated the potential for replacement of herbicide application with prescribed burning (Scifres 1975b, Gordon and Scifres 1977) which led to the development of several Integrated Brush Management Systems (IBMS) for improvement of Macartney rose-dominated Coastal Prairie (Scifres 1975b, 1980, 1981).

Prescribed burning, subsequent to an initial treatment to reduce the cover of live brush and/or prepare the fuel, is a component of the more effective Macartney rose management systems (Scifres 1981). Use of prescribed burning has become more widely accepted among producers for range improvement, especially during the past 10 years (Scifres 1980, Wright and Bailey 1982).

Authors are research associate, Department of Agricultural Economics; professor, Department of Agricultural Economics and Range Science; and Thomas M. O'Connor professor, Department of Range Science, Texas Agricultural Experiment Station, Texas A&M University, College Station, 77843.

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Economic considerations are critical to developing a range improvement program to meet specific land management objectives. Therefore, the objective of this research is to quantify the economic performance of previously developed schemes, non-fire and fire based systems, for improvement of Macartney rose-dominated Coastal Prairie.

Procedures

Specific systems evaluated have been applied under both research and operational conditions since 1971. Most of the treatment sequences were originally proposed by Scifres (1975b).

Response curves were developed based on research results (Gordon and Scifres 1977, Hoffman 1966, Hoffman et al. 1968, Scifres 1975b) and verified by interviews with producers having experience with the specific system or treatment. Published data were used to estimate carrying capacities of cattle based on herbage production following treatment (Whitson et al. 1979) for the first 10 years of the planning profiles. These data were verified and changes in weaning percentages and weaning weights obtained by producer interview (P.H. Welder, pers. comm.). Estimates of carrying capacity change for some treatments were also published by other workers (Hoffman 1966). Production responses for the remaining 10 years of the planning periods were projected based on perpetuation of treatment effects established earlier in the profiles.

Assumptions underlying development of the response curves were:

1. All sites infested with Macartney rose will respond, on a relative basis, to the systems selected as will the Blackland site (primarily Victoria clay [fine, montmorillonitic, hyperthermic Ucid Pellustert]) from which the data base was formed.
2. Other management practices (grazing system, parasite control, etc.) are not limitations to production change from brush management, nor will there be synergisms between brush management and livestock management (this assumption presumably resulted in conservative estimates).
3. Planning horizon of 20 years depends on systems equilibrating after 10 years, i.e., allows perpetuation of range improvement by practices applied after year 10.
4. Systems will cause no change in other products, such as wildlife.
5. Systems will not change ratio of breeding males to females.
6. Annual rainfall will follow annual average for past 20 years (94 cm).
7. System selection is constrained by past vegetation management practices such that 2 brush growth types, disturbed and undisturbed, must be considered separately.

Response curves were developed as discussed by Whitson and Scifres (1980) for 2 growth forms, disturbed (control attempted within last 3 years) and undisturbed stands, because of the influence on response of Macartney rose to treatments such as herbicide sprays (Hoffman et al. 1964), and because of the stage of secondary succession normally associated with infestations of the 2 growth forms. Stands of undisturbed Macartney rose may develop canopy covers of 75% or greater with some plants to 5 m tall (Scifres 1975b). Whereas previous disturbance usually allows establishment of perennial native grasses in the proximity of the brush plants, the area beneath undisturbed Macartney rose plants is bare and herbaceous cover is established by secondary succession (Gordon and Scifres 1977).

Economic evaluation of the systems was determined by utilizing multi-year partial budgeting techniques (Whitson and Scifres 1980, 1981). Annual costs and returns in constant 1982 dollars, were calculated for systems based on a 202-ha pasture. Annual costs included specific brush treatments, livestock investment costs and additional variable costs. Returns were additional pounds of beef sold, reduced management costs and livestock disinvestment.

Economic comparisons are based on cash flows, internal rates of return and net present values. Determination of net present values requires that annual costs and returns be discounted to the present. The discount rate reflects time preference for money and risk under the assumption of constant price levels. While the risk associated with each system is unknown, a risk premium is included in the 10% discount rate used in this analysis. This discount rate maintains that a rancher must obtain a 10% rate of return on investment before net present value will be positive.

Difficulties existed with using net present value and internal rate of return as indicators of economic performance (Workman 1981). Differences in treatment lives[1] and cost may have resulted in contradictory selections of treatments. Response curves for fire based systems were developed for a 20-year period. Responses for previously recommended treatments and treatments without fire-based maintenance had treatment lives of less than 20 years. Initial and subsequent maintenance treatments were repeated to extend the project lives to 20 years. Responses for repeated treatment sequences were assumed the same as initial sequence responses. Normalization of initial and followup treatment costs were not attempted. Since selection of treatments was influenced by factors in addition to net present value and internal rate of return, the possibility of contradictory selections was not considered critical.

The systems developed have residual economic benefits beyond the 20-year period generated from maintenance or repetition of treatments. These benefits include increased stocking rates, weaning weights, and calving percentages above initial levels. Economic evaluation suggests that a value be placed on this productive potential. Estimates of productive potential are based on the assumption that maintenance or repetition of treatments will be continued indefinitely. An annual average benefit for treatments from 20 years to infinity is obtained and discounted to year 20. This "salvage value" is included in the analysis of year 20 and discounted to the present. This procedure accounts for the increased productive potential created by continuation of the systems.

Systems Evaluated

Systems and treatments evaluated for undisturbed, dense stands (average 75% canopy cover, 2,000 plants/ha) were:

1. Aerial spray with 2.2 kg/ha 2,4-D ester in fall of year 0 and 1.1 kg/ha 2,4-D amine formulation in years 1 and 2 (Hoffman et al. 1964, 1968; Hoffman 1966; McCully et al. 1959).
2. Rake and stack Macartney rose and burn stacks in year 0 (Scifres 1975).
3. Rake, stack, and burn stacks in year 0; aerially spray with 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] + picloram (4-amino-3,4,5-trichloropicolinic acid) (1:1) at 1.1 kg/ha in year 3; prescribed burning during winters of years 5, 8, 16, and 19; and individually spray with 1.1 kg 2,4,5-T + picloram (1:1) in 172 liters water containing 0.5% (v/v) commercial surfactant in year 12. Costs of individual-plant treatments were calculated as required to reduce (a) light, scattered stands, and (b) moderate stands to less than 125 small (0.3 m tall) plants/ha.
4. Rake, stack, and burn stacks in year 0 followed by aerial spray with 2,4,5-T + picloram at 1.1 kg/ha in year 3.
5. Rake, stack, and burn stacks in year 0; aerially spray with 2,4,5-T + picloram at 1.1 kg/ha in year 3; and prescribed burn during winters of years, 5, 8, 11, 14, and 17 (Scifres 1975b).
6. Compact Macartney rose fuel by roller chopping (crushing) in the fall of the year 0 and prescribed burn in the winters of years 1, 4, 7, 10, 14, and 18 (P.H. Welder, pers. comm.).

Systems and treatments evaluated for disturbed, dense stands (average 50% canopy cover, 1,500 plants/ha, average 0.5 to 1.5 m tall) of Macartney rose were:

1. Aerial application of 2,4,5-T + picloram (1:1) at 1.1 kg/ha in the fall (September-October) of year 0 with no subsequent treatment (Scifres 1975a, 1975b).
2. Aerial spray with 2,4,5-T + picloram in the fall of year 0 followed by prescribed burning using the fire plan for tall-grass prairie (Wright and Bailey 1982) during the winters of years 2, 5, 8, 11, 14, 17, and 20 (Scifres 1975b, Gordon and Scifres 1977).

Economic Responses from Systems

Physical results obtained from adaption of the systems were improved forage quality improved botanical composition of herbage stands and increased forage production. Economic benefits occur from utilization of forage in a cow-calf operation. Benefits include increased stocking rates, calving percentages, weaning weights, and reduced management costs.

Increased forage production was utilized by purchasing livestock. Decreases of forage because of decreased range condition (reinfestation of brush) or deferments resulted in livestock being sold at the purchase price.

Production Parameters for Undisturbed Stands

Pretreatment stocking rates, calving percentages, and weaning weights for undisturbed stands of Macartney rose-infested land were 11.3 ha/animal unit (AU), 65%, and 176.9 kg, respectively. Changes in production parameters for non-fire based systems were cyclic. Initial improvement of production parameters following treatment and later deterioration, because of brush reestablishment, created symmetric responses. Treatments were reinitiated when production parameters had returned to pretreatment levels. Average stocking rates, calving percentages and weaning weights ranged from 6.8 to 8.5 ha/AU, 67 to 68% and 181.4 to 184.3 kg, respectively.

Production parameters for fire-based systems increased and stabilized at these higher levels. Stabilization of systems was characterized by cyclic stocking rates. Cyclic behavior was the result of reestablishment of Macartney rose between prescribed burns. Raking, stacking, burning of stacks, and aerial spray, followed by a succession of prescribed burns, allowed stocking rates to increase to 2.0 ha/AU by year 12.[2] Stocking rates stabilized in 3-year cycles of 2.0 ha/AU, 2.4. ha/AU and 4.2 ha/AU starting in year 12. Calving percentages increased steadily and stabilized at 78% by year 10. Weaning weights increased to 204.1 kg by year 14, and maintained an average of 203.3 kg.

Integrating spraying of individual plants with raking, stacking, burning of stacks, aerial spray, and prescribed burns increase maintained production parameters. Stocking rates increase to 2.0 ha/AU in year 11, remained constant, and sustain 3-year cycles, beginning in year 15 of 2.0 ha/AU, 3.0 ha/AU, and 2.0 ha/AU. Calving percentages are identical to the system without individual-plant treatments, but weaning weights are 5.3 kg greater by year 17.

Roller crushing, followed by prescribed burning, generates lower

[1]Treatment life refers to the number of years a treatment or series of treatments induces production above pretreatment levels.

[2]Fluctuations in stocking rates did occur due to deferments associated with prescribed burns.

sustained production parameters than the other fire-based systems. Stocking rates fluctuate before increasing to 3.2 ha/AU in year 11 and stabilize in 4-year cycles of 4.0 ha/AU, 6.1 ha/AU, 3.2 ha/AU, and 3.2 ha/AU beginning in year 13. Calving percentages and weaning weights gradually increase to maintained levels of 76% and 204.1 kg in years 17 and 18, respectively.

Production Parameters for Disturbed Stands

Initial stocking rates, calving percentages, and weaning weights on pastures with previously disturbed stands were 8.1 ha/AU, 65%, and 183.7 kg, respectively. Aerial application of 2,4,5-T + picloram (1:1) at 1.1 kg/ha without prescribed burning produced long cyclic responses characteristic of non-fire based systems. Stocking rates increased to 3.2 ha/AU in year 3, remained there for another year, and returned to pretreatment level in year 8. Calving percentages increased gradually to 70% in year 4, remained constant for 4 years before declining to 68% in year 8. Weaning weights were 188.2 kg in year 2, increased to 195.0 kg in year 4, and began to decline in year 7. Spraying was repeated in year 8 with the same production responses.

Prescribed burns subsequent to aerial application of 2,4,5-T + picloram enhanced initial treatment. Stocking rates averaged 4.1 ha/AU for the first 8 years, before stabilizing in 3-year cycles of 2.0 ha/AU, 2.0 ha/AU, and 3.6 ha/AU. Calving percentages and weaning weights increased to 78% and 208.6 kg in years 8 and 10, respectively, before stabilizing.

Beef Production

Changes in production parameters are directly related to changes in beef production. Systems used to improve undisturbed stands result in 20-year average increases of 5.4 to 49.2 kg/ha (Table 1). Production levels for non-fire based systems increase beef production by an average of only 9.6 kg/ha/yr.

Fire-based systems with initial treatment by raking, stacking, and burning stacks produced an average 17.3 kg/ha additional beef per year during an 8-year establishment period. Subsequent treatment by aerial spraying and prescribed burning produced an average of 47.4 kg/ha additional beef during the next 6 years, before stabilizing with an average annual increase of 48.4 kg/ha. Followup treatments of aerial spraying, individual plant treatments, and prescribed burning resulted in large increases after establishment. During the prestabilization period, annual beef production increased by 66.6 kg/ha and stabilized at an average 59.6 kg/ha/yr by year 17.

Roller crushing resulted in approximately half the increases obtained from the other fire-based systems. Beef production increased by 9.8 kg/ha/yr during the early adjustment period. Increased beef production averaged 26.6 kg/ha between years 9 and 16 and stabilized at an average 28.7 kg/ha/yr.

The non-fire based system used to control disturbed stands produced an average annual increase of only 13.5 kg/ha/yr over a 20-year period. Continuation of the system would result in increased beef production of 12.8 kg/ha per year. The fire-based system produced 32.1 kg/ha/yr additional beef during the first 9 years. The system stabilized in year 10, with an average increase in beef production of 51.8 kg/ha/yr.

Returns

Increased returns from implementation of a system are the product of additional beef produced and the selling price of beef. The price used in this study, $1.54/kg, is the real average price of beef for the past 20 years. It is assumed that this price will prevail for the future.

Another benefit is reduced management costs of $3.09/ha, based on estimates from Whitson et al. (1979) as the result of labor savings in livestock handling and management following brush control. Labor savings result when stocking rates increase to 10.2 ha/AU in response to reduction of Macartney rose stands.

Costs

Costs associated with the development of a system to control Macartney rose are initial treatment costs, followup treatment costs and livestock investment, indirect deferment, and additional variable costs. Initial treatment costs occur in year 0 and include aerial

Table 1. Additional beef production (kg/ha/year) resulting from the application of selected treatment systems for improvement of Macartney rose-dominated Coastal Prairie.

	Undisturbed stands						Disturbed stands	
Year	Multiple sprays	Rake, stack, burn stacks	Rake, stack burn stacks spray, burning	Rake, stack, burn stacks, spray, burning, ind. spray, burning	Rake, stack burn stacks, spray, burning	Roller chop, burning	Aerial spray	Aerial spray, burning
1	1.7	2.6	2.6	2.6	2.6	0	3.6	3.6
2	3.5	8.7	8.7	8.7	8.7	5.4	11.1	2.7
3	9.7	10.4	10.4	10.4	10.4	7.2	23.9	23.9
4	20.8	9.3	20.3	20.3	20.3	1.2	26.2	50.3
5	30.2	3.8	21.6	10.5	10.5	6.0	18.5	14.2
6	23.1	2.4	21.6	28.9	28.9	19.8	12.7	56.2
7	16.1	1.2	17.0	34.5	34.5	9.8	5.5	58.5
8	9.6	0	9.8	22.6	22.6	28.9	.9	17.0
9	2.7	2.6	5.6	48.7	48.7	21.9	3.6	62.3
10	.3	8.7	3.4	50.8	50.8	17.4	11.1	67.2
11	1.7	10.4	1.2	64.8	40.1	31.7	23.9	29.1
12	3.5	9.3	.1	66.5	66.5	33.8	26.2	63.1
13	9.7	3.8	2.6	66.5	52.0	25.1	18.5	63.1
14	20.8	2.4	8.7	66.5	26.1	13.7	12.7	29.1
15	30.2	1.2	10.4	67.3	66.5	34.6	5.5	63.1
16	23.1	0	20.3	41.8	52.7	34.6	.9	63.1
17	16.1	2.6	21.6	68.2	26.1	26.4	3.6	29.1
18	9.6	8.7	21.6	68.2	66.5	14.7	11.1	63.1
19	2.7	10.4	17.0	42.4	52.7	36.9	23.9	63.1
20	.3	9.3	9.8	68.2	26.1	36.9	26.2	29.1
21 to ∞	11.8	4.8	10.2	59.6	48.4	28.7	12.8	51.8
20-yr avg	11.8	5.4	11.7	42.9	35.7	20.3	13.5	42.5

application of 2,4-D; aerial application of 2,4,5-T + picloram; raking, stacking, and burning of stacks; and roller chopping (Table 2). Roller chopping is the least expensive initial treatment costing $19.77/ha. Application of 2,4-D and 2,4,5-T + picloram cost $35.21/ha and $50.65/ha, respectively. Raking, stacking, and burning the stacks is the most expensive initial treatment, costing $70.42/ha.

Individual-plant sprays are the most costly followup treatments estimated at $55.97/ha for light stands and $101.02/ha for moderate stands. In general, aerial application of herbicides for maintenance of improvement, costs the same as initial treatments. The second aerial application of 2,4-D amine is less expensive than the first treatment because less herbicide is applied. Prescribed burning is the least expensive maintenance procedure available costing $11.12/ha for the initial burns and $2.47/ha for subsequent burns.

Utilization of increased forage production following brush treatment requires investment in livestock. Livestock investment costs are $699.55/cow unit (CU)[3] (Texas Agricultural Experiment Station, 1982). Annual variable cost associated with raising additional livestock is $102.76/CU (Texas Agricultural Experiment Station, 1982). Decreased use of the hypothetical pasture because of deferments results in livestock being sold for the purchase price. Deferments average 4 months for prescribed burning, and 2 months for aerial herbicide application; and raking, stacking, and burning of stacks.

Results and Discussion

Roller chopping of undisturbed Macartney rose, primarily to crush and compact the coarse fuel, followed the subsequent winter by prescribed burning, produced the highest internal rate of return, highest net present value, and required the least maximum invest-

[3]A cow unit as used refers to cow, 0.15 replacement, .05 bull, and 0.2 horses.

Table 2. Initial and maintenance treatment costs associated with selected systems for improvement of Macartney rose-dominated Coastal Prairie.

Initial treatment	Maintenance treatment	Years of maintenance	Costs ($/ha) Initial	Maintenance
	Undisturbed stands			
Aerial spray, 2,4-D ester (2.2 gk/ha)	Aerial spray, 2,4-D amine (1.1 kg/ha)	1 & 2	35.21	25.33
Rake, stack, burn stacks		—	70.42	—
Rake, stack, burn stacks	Aerial spray, 2,4,5-T + picloram (1.1 kg/ha)	3	70.42	50.65
Rake, stack, burn stacks	Aerial spray, 2,4,5-T + picloram (1.1 kg/ha)	3	70.42	50.65
	First burn[1] and subsequent burn	5 & 8	—	13.59
	Individual-plant herbicide treatments	12		
	Light stands			55.97
	Moderate stands			101.02
	First burn and subsequent burn	16 & 19		13.59
Rake, stack, burn stacks	Aerial spray 2,4,5-T + picloram (1.1 kg/ha)	3	70.42	50.65
	First burn	5		11.12
	Subsequent burns	8, 11, 14, 17, 20		2.47
Roller crushing	First burn	1	11.12	
	Subsequent burns	4, 7, 10, 14, 18		2.47
	Disturbed stands			
Aerial spray 2,4,5-T + picloram (1.1 kg/ha)			50.65	
Aerial spray 2,4,5-T + picloram (1.1 kg/ha)	First burn	2	50.65	11.12
	Subsequent burns	5, 8, 11, 14, 17, 20		2.47

[1]Refers to burns that require initial construction of fire lanes.

Table 3. Maximum investment in selected treatment sequences for improvement of Macartney rose-dominated rangeland and expected annual rates of return on the investments, present values of treatments at the end of the planning profiles, years to breakeven on the investments, and 20-year net cash flows on the Coastal Prairie.

Treatment/treatment sequence	Maximum investment ($)/h	Annual rate of return (%)	Present value $/ha (10%)	Breakeven[a] (yr)	20-year net cash flow ($/ha)
		Undisturbed stands			
Multiple aerial spray (2,4-D)	202.85	5.0	-51.96	8 & 18	130.52
Rake, stack, burn stacks	164.29	-30.1	-95.72	—[b]	-132.36
Rake, stack, burn stacks-aerial spray (2,4,5-T + picloram)	210.39	-2.3	-103.51	—[b]	-40.44
Rake, stack, burn stacks-aerial spray-prescribed burn	232.81	11.5	33.89	15	761.34
Rake, stack, burn stacks-aerial spray-prescribed burn-individual-plant treatment (light stand)-prescribed burn	232.81	11.7	44.18	14	923.57
Rake, stack, burn stacks-aerial spray-prescribed burn-individual-plant treatments moderate stand)-prescribed burn	232.81	11.2	29.82	15	878.52
Roller crush fuel-prescribed burn	138.33	15.0	61.33	12	566.88
		Disturbed stands			
Aerial spray (2,4,5-T + picloram)	161.40	6.3	-28.16	6 & 13	104.68
Aerial spray-prescribed burn	292.56	16.1	140.06	10	1,024.62

[a]Based on average price for steer and heifer calves of $1.54/kg and a 10% discount rate.
[b]Did not breakeven.

ment[4] (Table 3). However, there is a relatively high degree of risk associated with this treatment since roller chopping, if not followed promptly by burning, may actually increase the Macartney rose stand density. Canes severed from the parent plant may be pressed into the soil surface, especially if the soil is damp, and take root (Hoffman et al. 1964). Also, roller chopping kills relatively few, if any, of the Macartney rose plants (Scifres 1980). Therefore, the pescribed burns must be applied regularly (at about 3-year intervals) to prevent the Macartney rose infestation from nullifying the positive effects of previous treatments (Gordon and Scifres 1977).

Because of the regrowth potential of Macartney rose, simple top removal by raking and stacking did not generate positive rates of return (Table 3). Forage response to such treatments is short-lived, with production usually not increased for more than 4 or 5 years, depending on rainfall. Herbaceous response to removal of undisturbed Macartney rose requires that secondary succession reinstate the cover on the bare areas beneath the brush canopies. Application of aerial sprays of 2,4,5-T + picloram (1:1) at 1.1 kg/ha increased the life of the raking and stacking. However, response was not adequate to result in a positive annual rate of return, indicating that the additional range improvement did not compensate for the increased investment.

Multiple aerial sprays of 2,4-D resulted in an annual rate of return of 5.0% with a breakeven period of 8 years (Table 3). However, net present value was $-51.95/ha.

In addition to the roller crushing-prescribed burning treatment sequences, the mechanical (rake-stack)-herbicide-burn system resulted in positive net present values. The internal rate of return for the mechanical-herbicide burn system without individual-plant herbicide treatments was 11.5%. Use of individual-plant treatments, an extremely intensive management input, resulted in higher internal rates of returns for light stands and lower for moderate stands, compared to the same system without individual-plant treatments (Table 3).

Investment capital not limiting, intensive manipulation systems, by virtue of maintaining a relatively high level of productivity, are well adapted to Coastal Prairie ecosystems. The more intensive management systems resulted in the greatest 20-year net cash flows ($878.51 to $923.56/ha) but required 14 to 15 years to pay back the investment.

Maximum investment was increased by $22.42/ha (10.7%) when prescribed burning followed the mechanical-herbicide sequence. However, the internal rate of return was increased to 11.5% when prescribed burning was employed, compared to -2.3% without burning, and the present value was increased from $-103.51 to $33.89/ha. The 20-year net cash flow was increased from $-40.44 to $761.34/ha, a 20-fold improvement, attributable to use of prescribed fire.

Prescribed burning following herbicide application to disturbed Macartney rose stands increased the internal rate of return from 6.3 to 16.1%, and the present value of treatment from $-28.16 to $140.07/ha. Although maximum investment was increased from $161.40 to $292.56/ha, the 20-year net cash flow was increased from $104.07 to $1,024.62/ha. These changes are attributable to prescribed burns.

[4]Refers to the maximum amount invested, including costs of additional livestock, at any given time in the planning profile.

Management Implications

These analyses indicate that selection of an appropriate sequence of treatments which includes prescribed burning may result in positive economic effects whereas the standard multiple herbicide applications or mechanical-herbicide treatments may result in negative rates of return, present values, and/or 20-year net cash flows. Prescribed burning at 3 to 5-year intervals increases the effective life of range improvement with a relatively small increase in investment.

However, as each additional treatment is incorporated into the improvement systems, management must become progressively more intensive to maintain level of improvement. Moreover, because of rapid regrowth potential of Macartney rose, the prescribed burns must be applied in a timely fashion. Otherwise, a preparatory treatment, mechanical or herbicide, may have to be employed to reduce the brush cover so that burning may be applied most effectively.

These analyses did not consider Macartney rose removal in a pattern to improve or maintain wildlife habitat. All treatment sequences described are amenable to patterned application, and habitat requirements of wildlife such as white-tailed deer *(Odecoilius virginiana)* should be considered in the development of improvement systems (Whitson et al. 1977).

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Edaphic and Microclimate Factors Affecting Tobosagrass Regrowth after Fire

LEON F. NEUENSCHWANDER AND HENRY A. WRIGHT

Abstract

The plant-air layer and soil surface structure affect regrowth succession following burning in the tobosagrass *(Hilaria mutica)*-mesquite *(Prosopis glandulosa)* community in West Texas by altering the microenvironment. Data are presented for the plant-air layer and the soil surface structure as they are related to the recovery of the tobosagrass and the successional response of the annuals. Changes in plant-air layer and the soil surface structure alter the microenvironment and affect plant growth and species composition. A conceptual model is developed illustrating vegetational development as affected by the plant-air layer and the soil surface structure.

In the last decade, many research papers have been written about the response of tobosagrass *(Hilaria mutica)* following burning. The tobosagrass-mesquite *(Prosopis glandulosa)* community in the southern-mixed prairie of West Texas is a simple community dominated largely by tobosagrass. The literature on tobosagrass, reviewed by Neuenschwander et al. (1975), indicates that production, forage quality, and utilization are increased by removing excessive litter. Spring burning is the most inexpensive method of removing the litter tobosagrass. At the same time, fire top kills and, under proper fire weather conditions, inflicts mortality on mesquite. Tobosagrass and mesquite populations following spring burns have been studied for as long as 6 years (Wright 1972, 1974; Wright et al. 1976). The community structure and vegetational development have been reported by Neuenschwander et al. (1978), while the effect of burning on the soils of that area has been studied by Whigham (1976), Sharrow and Wright (1977), and Ueckert et al. (1978).

Data from these studies and additional data on microclimate and surface soil structure will be used to formulate a conceptual model for vegetational development and to demonstrate that the plant-air layer and the surface soil structure affect the vegetational development following fire in the tobosagrass-mesquite community.

The primary objective of this report is to demonstrate the importance of the microenvironment created by the plant-air layer and soil surface plates on the regrowth of tobosagrass and on the succession of annuals. The secondary objective is to provide data from previous studies in the tobosagrass-mesquite communities to support a unifying theory on the regrowth and vegetational development in the mesquite-tobosagrass community.

Attempts to frame a single theory of succession have identified some intriguing properties of communities, but no universal pattern or unifying theory has been developed (Horn 1974, 1975, 1976; Connell and Slatyer 1977). Keever (1950) studied causes of succession and found that life cycle strategies of pioneer plants are very important. If soil remains unaltered (Coile 1940), light (Oosting and Kramer 1946) and soil water relations (Crafton and Wells 1934, Olson 1958) are important. Since tobosagrass resprouts from rhizomes following fire, critical factors for plant growth and development are also important. In reviews of successional patterns, Drury and Nisbet (1971, 1973) point out that much of the empirical evidence for successional patterns of biomass and organic development of the soil is inferred. With the possible exception of Olson's (1958) sand dune paper, basic data directed to determine successional mechanisms following fire have not been reported.

Authors are associate professor of forest resources, University of Idaho, Moscow 83843 and Horn professor of range and wildlife management, Texas Tech University, Lubbock 79409.

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Methods

This study was conducted on the southwestern edge of the Rolling Plains on the Spade Ranch, 22.5 km south of Colorado City, Mitchell County, Texas. The area is transitional between the humid climate of central Texas and semiarid climate of the western region of Texas (Soutiere 1971). The macroclimate averages 50.3 cm precipitation per year with a high daily maximum average summer temperature of 36°C during July. Winds are predominantly from the southwest. The average annual potential evaporation is about 254 cm. High evaporation and transpiration rates in conjunction with runoff during heavy summer thunderstorms provide a more xeric condition than the average precipitation might indicate.

Study areas were restricted to the Stamford soil series. The Stamford series consists of nearly level to gently sloping areas (1 to 3% slopes) of deep and well-drained calcareous clays. Both Stamford and Dalby clays were present in undifferentiated units (Stoner et al. 1969). Except for one control, study areas were aerially sprayed with 2,4,5-trichlorophynoxyacetic acid (2,4,5-T) in 1966. The herbaceous vegetation had recovered from the herbicide by 1969 (Neuenschwander 1976). Beginning in 1969, 220 hectares (500 acres) to 1,012 hectares (2,500 acres) were burned each year through 1975. Techniques and conditions of the burns in the sprayed tobosagrass community were given by Britton and Wright (1971).

The entire area was lightly grazed year long (about 2 cows/ha), with a four-pasture deferred rotation system. Based on small enclosures in tobosagrasslands, grazing was insignificant and removed less than 15% of the unburned forage (Heirman and Wright 1973, Wright 1972). In this study, burned plots were protected from grazing because cattle concentrated in recently burned areas and consumed up to 85% of the yield in recently burned areas (Wright 1972).

Seven treatments were selected for this study. The first 6 were sprayed with 2,4,5-T in 1966. Five of these sprayed treatments were then burned at intervals providing a sequence of 1-, 2-, 3-, 4- and 6-year-old burns, respectively. Treatment 6 constituted a spray, but not burned treatment, and treatment 7 served as an untreated control. Twenty-five quadrats (25×25 cm^2) were located in each of 2 homogenous tobosagrass stands (minimium 25×25m^2) within each of the 7 treatments.

On these treatment areas, Ueckert et al. (1978) studied the effect of burning on infiltration and Sharrow and Wright studied nitrogen dynamics (1977).

Soil surface plates (soil crust) are polygonal plates that form in the Stamford soil. The thickness of these surface plates was measured. Fifty samples were collected in each treatment from between the canopies of tobosagrass on 3 dates. Surface plates were also measured between and within the root crown of tobosagrass in each treatment.

Soil temperature was measured on 7 dates with thermometers placed between canopies of tobosagrass on the freshly burned and the sprayed control. On 3 of these dates, 20 thermometers were placed between and within the canopies of tobosagrass.

Soil moisture was measured with a calibrated relative soil moisture meter (Edmund Sci. Co. No. 80, 159). Soil moisture was measured on resistance scale from 1 to 12 scale and converted to a percent soil moisture by gravimetric calibration. Fifty samples were used in a curvilinear regression of the relative scale to percent soil moisture and to test the reliability of the instrument. This method was selected because of the rapidity in which samples could be collected in the field on the Stamford clay soils.

Three replications of 25 soil moisture samples were taken at a 5-to 10-cm depth between the canopies of tobosagrass in the treatments during the June and July season. Samples were collected 2 to 3 days after a 2.5- to 5.0-cm rain with the soil in a drying phase. This procedure was selected to reduce variation and isolate treatment differences. Samples were collected in 2 consecutive years, 1974 and 1975.

Duplicate samples for the analysis of percent organic carbon were taken at a 0- to 2.5 cm depth and replicated 6 times on the different aged burns and the sprayed control. Percent organic carbon was obtained through the Walkley and Black (1934) method.

Bacteria colonies were counted in 1974 and 1975. Data were taken by standard plating and culturing techniques and replicated 6 times on different age burns and the control (Frobisher 1968). Samples were randomly collected from the surface plates at a 0- to 2.5-cm depth. Samples were taken in the unburned plot and burned plots of the first, third, and fifth growing seasons after the burn.

Data were analyzed using a completely random design, and the difference between means was determined by Duncan's multiple range test (Cochran and Cox 1957). Both a paired *t*-test and grouped *t*-test were used for the appropriate data. Sample sizes were adequate to detect differences at the 5% level of significance.

Results and Discussion

In vegetational development where climax species recover following fire, factors affecting successional processes must include resprouting, plant reestablishment, and factors affecting vegetational regrowth. The most important factors are water, air, and soil around individual plants. We examined soil temperature, soil moisture, soil surface structure, soil organic carbon, surface litter, and canopy cover. Biomass (Neuenschwander et al. 1978), soil nitrogen data (Sharrow and Wright 1977), and soil water relationships (Ueckert et al. 1978) were extracted from previous studies. Based on biomass, the burned tobosagrass community reaches equilibrium with the control within 6 years after the fire (Neuenschwander et al. 1978).

The plant-air layer is the microenvironment created by the canopy structure of the plant. Because of the growth form of tobosagrass, the plant-air layer includes the current year's growth, litter in the canopy, and litter on the soil surface (Fig. 1). Total plant cover, as defined here, is composed of litter held in the canopy, litter on the soil surface, and the current year's growth of tobosagrass. Thus, cover is a quantitative expression of the plant-air layer. Burning reduced the canopy cover of tobosagrass from 74.0% before the fire to 0% immediately after the fire. By the middle of the first growing season, the canopy cover of tobosagrass was restored to 16.3%. Canopy cover increased $Y = 0.7 + \log_{10}X$ after burning (Fig. 2); where Y is the percent canopy cover and X is the growing season after the burn ($X \leq 6$). Canopy cover reached equilibrium by the fifth growing season after the burn. Recovery time of canopy coverages was similar to that of biomass (Neuenschwander et al. 1978).

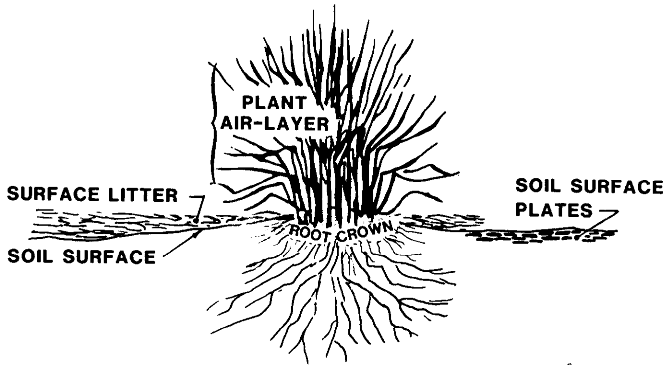

Fig. 1. *An illustration of the plant-air layer and soil surface plates found with tobosagrass on a Stamford clay.*

Fire alters soil temperature, moisture, surface structure, and organic carbon, but physical and chemical properties of the soil

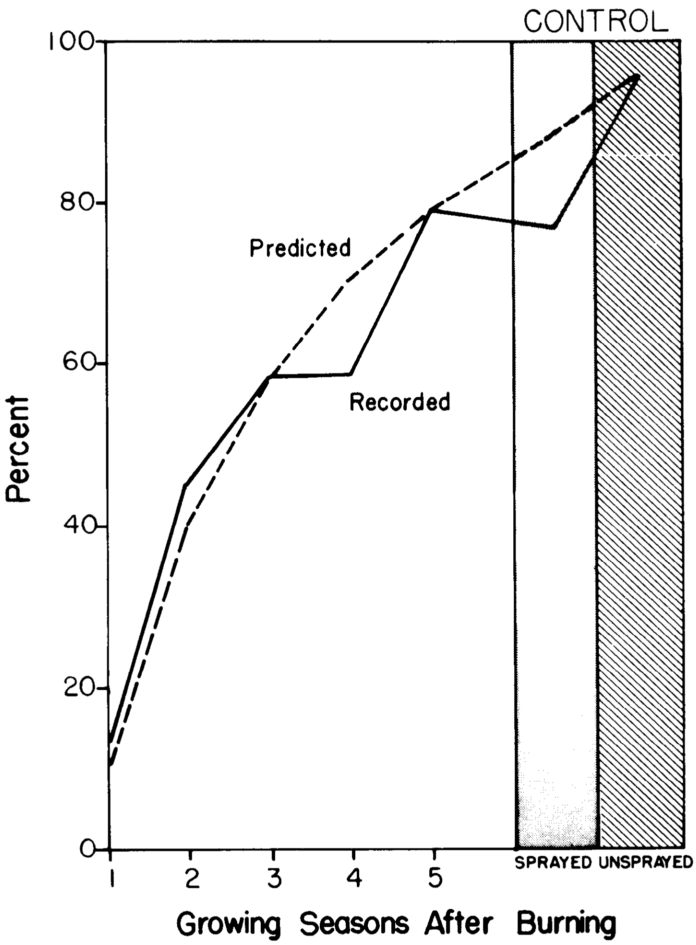

Fig. 2. *Average percent grouped cover for all species for the growing seasons after the burn and for two unburned controls (the sprayed control and the unsprayed control). The dashed line was drawn from predicted points ($Y = 0.7 \times \log_{10}X$, where X was the growing season after the burn).*

below 5 cm do not change significantly (Whigham 1976). The return of these soil properties to preburned conditions is important in the reestablishment of vegetation.

Microclimate

Sharrow (1973) found a yearly average soil temperature of 6.7°C higher on recently burned than on unburned plots at a 2.5 cm depth. Refining his technique, he sampled at a depth of 7.5 cm between April and July and found an average temperature difference between burned and unburned plots of 3.9°C.

In this study, soil temperature samples were stratified based on canopy of tobosagrass. Thermometers were placed within and between the canopies of tobosagrass (Table 1). Soil surface temperature varied significantly between burned and unburned areas by dates, but this variation was primarily between the canopies of tobosagrass and not within the canopies. Soil temperature means were not different within the canopy and root-crown of tobosagrass throughout the sere, but they were different between the canopies. This implied that the surface temperature reached equilibrium when the canopy cover reached equilibrium, or about 5 years after the burn in the tobosagrass community.

Table 1. Soil temperature means taken at a soil depth of 2.5 cm between and within canopies of tobosagrass on unburned and on one- and two-year-old burns.

Plots	Soil temperature (°C)	
	Between canopies	Within canopies
Unburned	33[a1]	30[a*2]
Growing season after burn		
1	43[c]	31[a*]
2	39[b]	30[a*]

[1]Column means followed by the same letter were not significantly different ($P<0.05$).
[2]*Row means were significantly different ($P<0.05$).

Soil moisture was measured between the canopies (Table 2) and within the root crown of tobosagrass. A statistical difference in soil moisture was evident between the canopies of tobosagrass, but not within root crowns. This implied that surface soil moisture also reached equilibrium at the same time as biomass and canopy cover.

Table 2. Soil moisture (%) means taken between the root crowns for unburned and burned plots by the number of growing seasons after the burn at a soil depth of 2.5 cm[1].

Plots	Soil moisture (%)	
	1974	1975
Unburned	26[bc2]	20[d]
Growing season after burn		
1	22[a]	18[a]
2	24[b]	15[a]
3	25[bc]	18[b]
4	26[cd]	19[bc]
5	28[d]	20[bcd]
6	28[d]	18[abc]

[1]Data were averages from 25 readings taken after 1.5 inches rain in 1974 and 1975 on two and three dates, respectively.
[2]Means in columns followed by the same letter were not significantly different ($P<0.01$).

Soil moisture differences in the burned and unburned areas were present at different depths during the growing season. The soil surface was dry (7%) between tobosagrass canopies, but not within root crowns (12%). Between canopies of tobosagrass, soil moisture increased rapidly with depth. During the growing season, soil moisture at 2.5 cm was 18.0% between canopies, and it was 21.5% within the root crowns.

Sharrow (1973) studied soil moisture at 2.5 cm in burned and unburned tobosagrass plots. His work indicated that the unburned plots had a yearly average of 4.8% more soil moisture than the burned plots. He compared clipped to unclipped tobosagrass plots, and found that litter reduced soil water loss by 2% in the plot without active roots and about 6% in the plot with active roots. He suggested that about 2% was evaporational loss and 4% was transpirational loss.

Higher soil temperatures on burned areas created higher evaporation from the surface, but, at the same time, when sufficient soil moisture was present at root depth available moisture to the plant root system increased. When conditions were very dry, tobosagrass assumed dormancy (Herbel 1963, Nkemdirim and Haley 1973).

Infiltration

Ueckert et al. (1978) studied infiltration. Initially, differences were observed in simulated rainfall infiltration rates among the different ages of burns. However, these differences seemed to be related to site differences rather than to the effects of fire (Whigham 1976). Analyses of co-variance using bulk density, non-capillary porosity, capillary porosity, silt, sand, and antecedent soil moisture as co-variables revealed no significant differences in total 40-minute infiltration between treatments as determined by the modified Purdue sprinkling infiltrometer. Similarly, no differences in infiltration were found for any of the 5-minute intervals during the 40-minute period. However, the double-ring infiltrometer revealed significant differences in infiltration rates among treatments (Whigham 1976). Infiltration was lowest on recently burned areas and increased with lapse of time following burning. Infiltration rates on burned areas approached that of unburned areas after 3 to 5 years (Ueckert et al. 1978) (Table 3).

Table 3. Means of infiltration rates (adjusted by covariance) on control and on different age burns, modified from Whigham (1976).

Plots	Infiltration (Purdue) (in/40 min)	Infiltration (Rings) (mm/hr)
Unburned	2.1[a1]	130[de]
Growing season after burn		
1	1.1[a]	79[abc]
2	2.0[a]	63[abc]
3	1.2[a]	82[abc]
4	1.4[a]	91[bcd]
6	2.1[a]	149[e]

[1]Means within a column followed by the same letter are not significantly different ($P<0.10$).

Tobosagrass-Soil Interactions

Current year's growth of tobosagrass increased about 3 times after burning in a normal rainfall year than in stands not burned for at least 4 years (Neuenschwander 1976, Sharrow 1975, Wright 1972). The yield decreased after the first growing season according to $Y = 3125 - 604\,X + 24\,X^2$ where Y is the predicted yield (kg/ha) and X is the growing season after the burn (Fig. 1). About 80% of the growth during the first growing season was attributed to litter removal (Sharrow 1973). Fertilization as a result of the combustion process was thought to be important (Wright 1972), but ash alone had little affect on plant growth (Sharrow 1975). However, Sharrow (1975) found available nitrogen to increase after burning (Table 4). The increase was attributed to an increase in microflora activity.

Bacterial colonies were counted for 2 successive years, 1974 and 1975 (Fig. 3). Bacterial growth increased tenfold after the burn. Populations on burned areas decreased exponentially after the first growing season until equilibrium with the unburned area was reached. This growth, when moisture was sufficient, was primarily attributed to higher soil temperatures and increased organic carbon levels following burning.

Initially, organic carbon increased by 47% at the soil surface

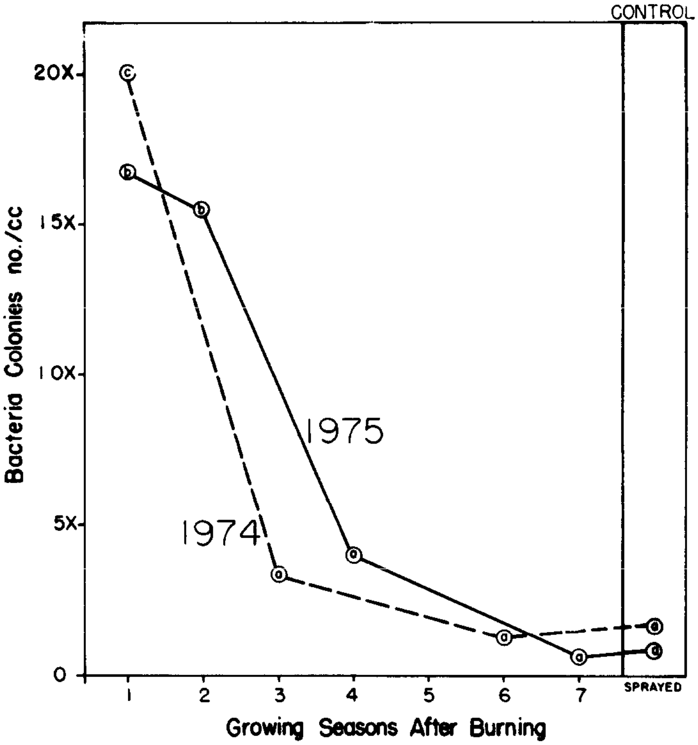

Fig. 3. *Bacteria colonies per cc taken in two successive years responded similarly through seven growing seasons after control burning. Different years required 1 × 10⁶ (1975) and 3 × 10³ (1974) dilution factors. Means for the same year with the same letter are not statistically different (P≤0.01).*

Table 4. Nitrogen (kg/ha) content of the upper 5 cm of soil taken during wet (1973) and dry (1974) years for four and five growing seasons after the burn, respectively, and for the sprayed control (1966). Data were adapted from Sharrow (1975).

Growing season	Wet	Dry
1	802^{b1}	1036^{ab}
2	857^{b}	1112^{abc}
3	527^{a}	916^{a}
4	1185^{c}	934^{a}
5	—	1334^{bc}
unburned	1237^{c}	1174^{bc}

¹Means in a column with the same letter are not statistically ($P<0.05$) different.

after burning (Fig. 4). Organic carbon levels were 2.6% in the control and 3.4% in the fresh burn. Apparently, soil organic carbon decreased as the ash disappeared for 3 growing seasons after the fire. (Perhaps soil organic carbon levels increased thereafter as a result of decayed litter and new roots.) Soil organic carbon reached equilibrium about the sixth growing season after burning.

The initial increase of soil organic carbon was attributed to the addition by fire of charred organic material to the soil surface. Burning added about 1,000 to 1,100 kg/ha of ash and charred material to the soil surface. Bacteria then had a nutrient-rich soil with temperatures about 5.5°C above normal for active growth. Rapid growth of the bacteria lowered the soil organic matter, which was not replaced for several years.

After fire, tobosagrass grew erectly and very little litter reached the soil surface before the third growing season. The soil-litter interface was gradually reestablished over the next 3 years, resulting in the incorporation of organic matter into the soil. Soil organic carbon returned to a comparable level with the unburned area in

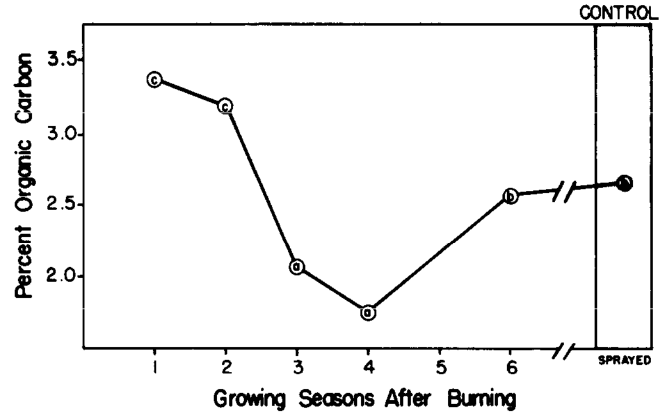

Fig. 4. *Percent organic carbon for seven growing seasons after burning. A pre-burned tobosagrass community contained 2.3% O.C. and a post-burned community contained 2.7% percent O.C.*

about 6 years. A 2.6% level of soil organic carbon appeared to be a steady state indicator of equilibrium in tobosagrass communities.

The microflora activity decreased as the canopy cover increased, and the soil temperatures and moistures returned to steady-state conditions. Stimulation of soil microflora was only a temporary effect of the fire. The higher populations of bacteria disappeared after the first couple of growing seasons.

Soil-Surface Plates

Soil-surface plates (soil crust) formed 4 to 6 months after burning the heavy clay soil between root crowns of tobosagrass plants. The surface plates were not well developed within the root crown (Fig. 5) or beneath the canopy of tobosagrass in the unburned area.

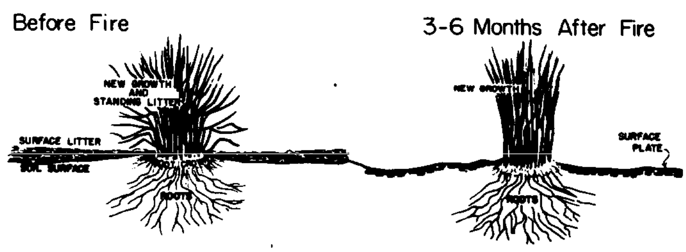

Fig. 5. *Tobosagrass before burning was compared with tobosagrass 3 to 6 months after burning. Standing litter and surface litter were removed. The new growth was vertical in the burned plots and the surface plant had formed.*

We have not resolved, in a quantitative manner, the mechanism by which the surface plates were formed. We believe that these surface plates were formed as follows:

1. The fire removed most of the standing and surface litter and replaced them with ash. The remaining surface organic debris and ash disappear by the end of the first growing season. We found some ash in cracks and in a horizontal layer about 1.8 cm beneath the soil surface.
2. The head load increased on the exposed soil. This baked the heavy clay soil and oxidized organic matter in the very top of the plates. Biological decomposition was accelerated with adequate soil moisture.
3. Thunderstorm rain and hail broke down the existing surface soil structure and compacted the soil platy micro-structure. Wetting and drying of the soil appear to be important in producing a platy micro-structure of the soil. Whigham (1976) found a reduction in surface aggregates in a Stamford soil after burning.
4. Repeat step two. Organic matter was reduced by both chemical and biological oxidation. A distinct soil surface-interface

between the above- and below-ground biotic functions was formed. It was relatively impervious.

Surface plates increased in thickness for 3 years on the same soil, then began to decrease (Table 5) until they reached preburn conditions by the sixth growing season.

Table 5. Soil surface plate thickness (cm) by growing season after burning was compared to unburned areas.

	Burned					Unburned
Growing seasons:	1	2	3	5	5	control
Surface plate	2.0^{ab1}	—	2.4^{b}	2.1^{ab}	1.3^{a}	1.3^{ab}

[1]Row means followed by the same letter were not statistically different ($P<0.01$).

Surface plates may cause a redistribution of soil moisture and of heat load (Fig. 5). Horizontal surface water redistribution has been reported previously by Perry (1970) and Slatyer (1961). Noy-Meir (1973) reported both horizontal and vertical water redistribution anisotropically throughout the soil profile in arid regions. Root crown areas were higher in organic matter and were shaded more by the vertical canopy than areas between plants. Also, the basal cover of tobosagrass was reduced by 12% by burning. Surface plates do not form in the burned-out root crowns; therefore, root crowns offer an entrance for water runoff that would normally be lost due to the presence of the relatively impervious surface plates. Surface runoff may be channeled into the root crowns where it enters the soil system. By virtue of root crown entrance, the following seemingly contradictory data were compatible: (1) a relatively impervious surface plate was formed, and (2) the total infiltration rate was about the same in the Purdue sprinkling method but not in the double ring method. The Purdue microplots were .24 m^2, and there were many tobosagrass plants within each plot. However, the double ring areas were small (.10 m^2) and contained fewer plants within the area.

The relatively impervious surface plates also probably reduced the evaporation from the soil surface. Thus, the surface plate may have contained a part of the soil moisture allocated to evaporation and retained it within the soil system.

Probably surface plates were important in the thermal properties of the soil. The heavy clay soil expanded and contracted with wetting and drying. An air space may have occurred below the soil crust. There was a zone of separation which created an air space between the surface plates and the soil below the plates, but the thickness of the air space was not constant (≤ 3 mm). It fluctuated with moisture content and a great deal of natural variation existed with similar moisture conditions.

The importance of the air space was thermal insulation. When the space was saturated with moisture, the surface heat load was readily transferred into the soil due to the high heat conductivity of water. The air space under dry conditions acted as a barrier to vertical heat movement due to the insulation effect of the low heat capacity of the dry soil. During the growing season, the net result below the surface plate was warmer, moist conditions after summer rains and cooler, dry conditions during summer drought. The warmer and moister conditions, with the increased availability of organic matter, induced rapid biological decomposition of organic debris by the microflora immediately after burning.

Vegetational Development

In the tobosagrass-mesquite community, the physical factors are not severely distorted by fire. The first stage in vegetational development is bare ground immediately after the plant-air layer is removed by the fire, and the plant-air layer is thus destroyed. By the middle of the first growing season, the community is dominated by tobosagrass, which resprouts from extensive rhizomes and basal root crowns. Annuals are rare in the first growing season except for a legume *(Hoffmannsigia glauca)*. After the fire, the interface between the organic horizons (O_1 and O_2) and the mineral soil (A_1) becomes an abrupt boundary between plant-air and soil-surface environments.

Vegetational development proceeds, at the interface on the soil surface, as the plant-air layer redevelops [$Y = 0.7 + \log_{10} S$, where Y is the percent canopy cover, X is the growing season after the burn, and $X \leq 6$]. Surface soil moisture and temperature relationships are regulated by the plant-air layer. The successional pattern of increased annuals, which are xeric species in this community, during the second, third, and fourth growing season is described by Neuenschwander et al. (1978). Annuals are confined to areas between the canopies of tobosagrass. Annuals extend their distribution from the higher dry sites into the more mesic lower sites as the soil surface plates form. Also, annuals remain for a longer time because of the presence of surface plates. Their density and diversity are correlated with the formation and development of the soil surface plate. As plates increased in thickness, diversity and density of annuals increased. As surface plates decreased, annual plant diversity and density decreased. Thus, successional patterns of annuals correspond to development of the soil surface plate. The surface plates are an expression of the interface between the soil and the plant-air layer. Soil surface plates modify the soil-surface environment in that it alters hydro-thermal properties in the clay soil.

Vegetational development proceeds as organic debris is deposited on the soil surface. Continual incorporation of organic material from the litter into the soil occurs at the interface between the plant-air/soil-surface. This boundary becomes more continuous as a result of organic matter incorporation at the interface and leaching. The plant-air layer forms the environment for the soil-litter organisms. Their successional patterns follow litter accumulation (Engelmann 1961, Blake 1925). The microfauna and flora with the mesofauna reach their maximum successional development as the plant-air layer and soil-surface reach equilibrium in their vertical structure. At the same time, soil moisture and temperature become less extreme as the microenvironment becomes more mesic and the interface boundary becomes less discrete. Producers and decomposers with corresponding trophic levels react to the changing environment. Competition favors species that are adapted to this more mesic environment. Consequently, xeric species are replaced by mesic species.

Both pre-burned and post-burned stages are dominated by tobosagrass. However, freshly burned areas are dominated by green tobosagrass and the post-burn areas, after the fifth growing season, are overshadowed by the litter of tobosagrass. The climax stand contains few other herbaceous plants and an impoverished annual flora with a diminished productivity of tobosagrass due to the buildup of litter (Neuenschwander et al. 1978).

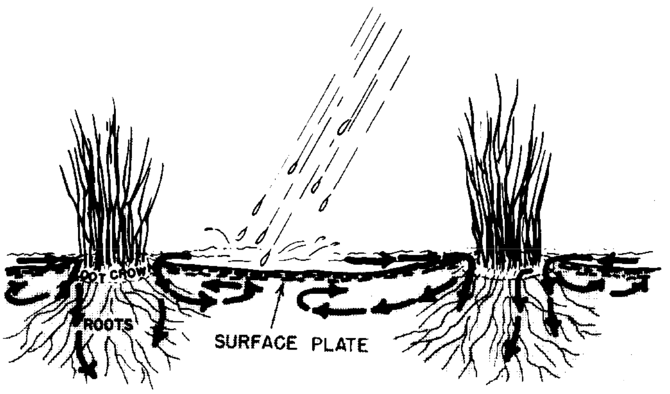

Fig. 6. *The pathway of water in a burned tobosagrass community where surface plates were formed.*

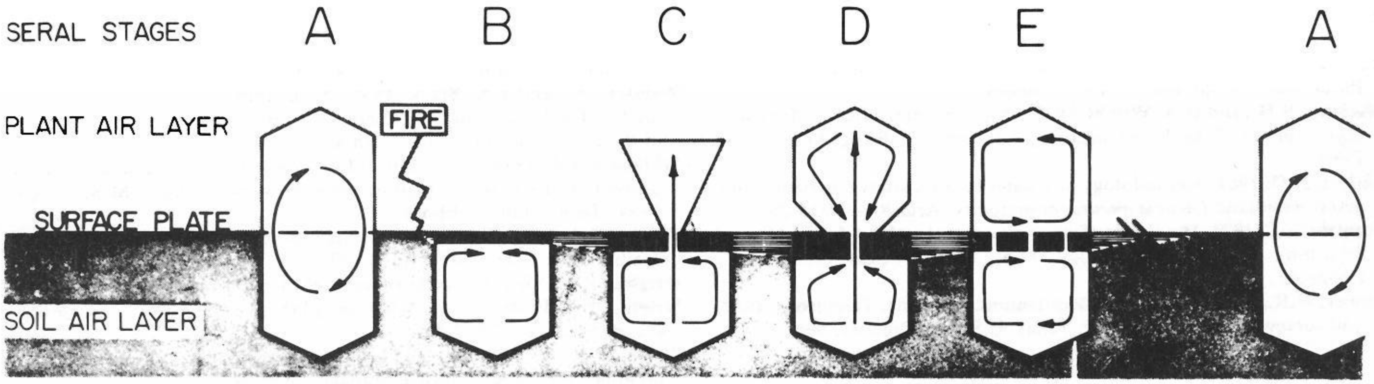

Fig. 7. *Model for the plant-air/soil-surface interface hypothesis for vegetational development following burning in the tobosagrass-mesquite communities. Five seral stages, A through E, are symbolized by the polygons for the plant-air and soil-surface layers separated by the surface plate. The arrows represent transport of organic debris and minerals. State "A" is the climax "B" is freshly burned, and "C" the burn in the first growing seasons. Stage "D" occurs during the second and third growing season and represents the point before litter in the canopy is returned to the soil surface. It is the seral stage of annual invasion. In state "E," the plant-air layer has been restored, but the soil-surface has not. Bio-transport is restricted by the soil surface plate.*

The Model

The model for plant-air layer/soil-surface interface for regrowth and vegetational development following fire in the tobosagrass-mesquite community is conceptualized by Figure 7. The arrows in the seral stages B through E indicate an interrupted or restricted flow of organic material; consequently, energy and mineral flow. In climax stand "A," "OMIS" (organic matter incorporating system) is viewed as relatively continuous within the plant-air/soil-surface environments. When environments are united through a diffuse surface plate, the interface is not well defined. The burn occurs before "B." Inflow of organic and inorganic debris probably occurs by physical rather than biological processes. The net flow of energy is upward, and the interface is abrupt. As the surface plate thickens, it restricts vertical flow of organic material. The process is restricted until the surface plate is removed and the plant-air/soil-surface environments are relatively continuous.

The plant-air and soil-surface layers are functional during all the seral stages of secondary succession. Since the climate and soil remain the same following burning in the tobosagrassland, the successional process is completed when both the plant-air and soil-surface environment have returned to the original condition. At that point, "OMIS" is relatively continuous, and the interface is not an abrupt boundary. Thus, the community is in a steady state with the climate of the area.

"OMIS" unites the plant-air layer/soil-surface. Without transport of organic debris and minerals, regrowth of tobosagrass and succession of annuals cannot proceed. It provides the mechanism for habitat modification through soil enrichment and for a more mesic environment. "OMIS" may be the driving force in vegetational development as it provides the gradient for competitive replacement of species and the energetic properties for growth and development during the seral process in the tobosagrass-mesquite community.

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Acceptable Block Beef from Steers Grazing Range and Crop Forages

C. WAYNE COOK, DAVID A. CRAMER, AND LARRY RITTENHOUSE

Abstract

Steers from 3 frame sizes were raised from birth to slaughter under different feed regimens including raised on the range to 18 months of age, raised on the range along with complementary forages to 18 months of age, and raised on the range to 18 months of age with subsequent concentrate feeding for 66 days. Quality grade, marbling, rib-eye area, fat thickness, and intramuscular fat were significantly higher for grain fed animals than for the grazing animals. There were no significant differences in overall palatability traits for grazing steers and grain fed steers. Small-frame steers gained less per day but had higher finish at comparable ages and period of treatment than large-frame steers. Acceptable primal cuts can be produced from grazing alone but the quality grade is higher for grain-fed animals. It was concluded that future beef production may use far more range and forage because of higher grain prices and an increasing demand for leaner meat by the consumer.

The costs of grains for domestic livestock feeding and the price for beef at the marketplace will determine the future production systems that are profitable. As a result of relative-cost inputs, such systems will no doubt include larger quantities of pasturage and forages and less grain. These systems include finishing animals on grazed range and/or forages, supplementing on grazed forages with grain, or growing animals on grazed forages followed by finishing in the drylots. This latter alternative can be accomplished by feeding shorter periods of time on high grain rations or feeding a longer time on high roughage rations.

Such changes in finishing practices are causing packers and merchandizers to question the quality and acceptance of beef produced under these new forage systems. As a result, research has not had an opportunity to investigate all of the ramifications of forage finished carcasses. Which breeds or biological types of cattle are best suited to such feeding regimens are still unknown. What factors influence consumer acceptance of such meats are still somewhat vague. Also of importance is that current research may reveal new tenderization methods along with longer chilling treatments that will enhance the palatability traits of lower grades of beef.

In addition to changes in beef production systems being dictated by fluctuating grain prices, the consumer appears to be seeking a leaner piece of beef than was formerly found in the marketplace. As a result, purveyors and retailers are attempting to select beef with a minimum fleshiness or finish that is acceptable to consumers. Too little fat may reduce eating quality of beef but too much fat is expensive to produce and reduces the percent of saleable meat because of trimming. A covering of subcutaneous fat appears to extend the chilling period with an insulating action which makes the meat more tender and flavorful. Bowling et al. (1981) suggests that if this is indeed the case, time in the feedlot could be greatly reduced by using alternative chilling methods which would lower production costs as well as the amount of fat on the carcass.

All of these situations favor increased slaughter of pasture-finished cattle, cattle fed on high roughage rations or on high grain rations for only short periods. The alternative systems will differ by region because of environment and the resultant availability of forages for grazing and feeding.

This study summarizes animal responses, carcass characteristics, and taste panel evaluations of beef produced under various feeding regimens including grazed range, grazed range and complementary forages and short feedlot finishing.

Prospectus

First it should be pointed out that about 50% of the land area in the United States is rangeland, which produces an annual renewable forage resource that comes about without high expenditures of fossil fuels or cultural energy. For this reason alone, these lands should receive full use under sustained high levels of production because they represent a valuable food source at reasonable prices.

In addition to the immense area of rangeland in the United States, much of our crop residues could be more effectively used by livestock. Also, most of our low producing croplands could grow complementary forages to supplement rangelands.

Authors are with the Departments of Range Science and Animal Science, Colorado State University, Fort Collins 80523.

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Many forage finishing systems are fashioned from total grazing of range, permanent pastures, or from grazing annual forages such as sorghum, wheat, rye, millet, etc. A combination of selected forages can furnish highly nutritious intake for the animal from birth to slaughter (Bohman et al. 1981, Bowling et al. 1978, Burris et al. 1976, Craig et al. 1959, Dolezal et al. 1981, Harrison et al. 1978, Huffman and Griffey 1975, Shinn et al. 1976, Shupp et al. 1979, Wanderstock and Miller 1948, Williams et al. 1979).

Some pasture finishing systems suggest adding high energy supplements to the grazed forage, especially during the final finishing period (Bidner et al. 1981, Bowling et al. 1978, Burris et al. 1976, Clanton 1977, Coleman et al. 1976, Dougherty et al. 1980, Hunt et al. 1953, Turner and Raleigh 1977, Wanderstock and Miller 1948).

Forage finishing systems also include those practices which use drylot feeding or solely roughages such as silage and chopped hay from various feed sources (Bowling et al. 1977, Cross and Dinius 1978, Harrison et al. 1978, Nelson and Landblom 1978, Oltjen et al. 1971, Wheeling et al. 1975, Young and Kauffman 1978).

Shorter grain feeding periods will occur normally when animals are grown on forages prior to being fed in drylots and when conventional feeding periods are merely shortened because of the need to reduce fleshiness and costs of producing acceptable block beef.

Several studies have shown that beef from cattle finished on all forage rations was of acceptable palatability (Bidner 1975, Bowling et al. 1977, Cross and Dinius 1978, Huffman and Griffey 1975, Nelson and Landblom 1978, Oltjen et al. 1971, Schupp et al. 1979, Wheeling et al. 1975, Young and Kauffman 1978). When carcasses exceed 500 lb and are of similar age and finish, taste panel evaluations could not distinguish between forage- and grain-fed systems (Bidner 1975, Harrison et al. 1978, Huffman and Griffey 1975, Schupp et al. 1979, Young and Kauffman 1978).

Grazing trials that have provided high nutritional forage throughout the growth period of animals show that young steers of Angus, Hereford, or Hereford-Angus crosses can be finished to good quality grades that score desirable by professional taste panels (Bidner et al. 1981, Craig et al. 1959, Harrison et al. 1978, Huffman and Griffey 1975, Schupp et al. 1979).

Procedure

The research was carried out over a 4-year period on 3 sets of steers in the sandhill range type at the Eastern Colorado Research Center and at the Meats Laboratory on the University campus at Fort Collins, Colo. From a total of 11 feeding regimens studied by Cook et al. (1980, 1981), 3 were chosen for presentation of the topic to be discussed. However, all of the animals (220) in all 11 treatments were analyzed among frame sizes for presentations herein. The 3 treatments to be discussed were: (1) control group which consisted of animals grazed on native range year-long from birth to slaughter at 18 months of age, (2) animals that grazed native range except during spring when they grazed crested wheatgrass and during the winter and late summer when they grazed forage sorghums, and (3) animals from the native range group that were fed a concentrate ration for 66 days in drylot following the grazing season. Small amounts of supplement were added during winter grazing to correct suspected deficiences of forages especially protein and phosphorus. The supplement was 20% total protein and was fed at 2.75 lb day.

Animals in treatments 1 and 2 were slaughtered directly off range and forage sorghums in the fall at the time of frost when animals were about 18 months of age. Animals from the feed lot treatment were slaughtered after the 66-day feeding period following grazing on the range to 18 months of age.

Three frame sizes were used in the overall experiment and are referred to as small (3), medium (4), and large (5) because of the 3 rather normal biological types present among the breeds in the study. The biological types of cattle consisted of Hereford, Hereford × Angus, and Exotic × British cows which were bred to Hereford, Angus, or Simmental bulls. The 3 frame sizes are approximately equivalent to the Missouri frame scores 3, 4, and 5 presented by Massey (1979). These were based primarily upon breed, hip height, girth length, and birth and weaning weights adjusted for age and randomly assigned to treatments.

Carcasses were analyzed for cutability, chemical composition, quality, marbling, backfat thickness, palatability traits, yield, and quantity of trimmed primal cuts.

A professionally trained sensory panel evaluated the rib eye steaks for tenderness, juiciness, flavor, and overall satisfaction on an 8-point hedonic scale (8 = very satisfactory, >4.5 = acceptable, 1 = very unsatisfactory). Warner-Bratzler shear force values were made on 1.3 cm core from these steaks after they had cooled to 25°C. Because of a rather complicated experimental design, the number of animals in the various subclasses varied somehwat because of an effort to use offspring of equal age class distribution in the study. Data were analyzed by least squares analysis for disproportionate subclass numbers (Harvey 1975).

Results and Discussion

Animal weights at slaughter were 408, 429, and 537 kg (916, 962, and 1,203 lb) respectively for treatments one, two and three.

Table 1. Average daily gains while grazing range and forages and while being ration-fed, along with cold carcass weights for the three treatments and frame sizes.

		Forage and/or range grazing							Feedlot rations	
			Post weaning							
	No. animals	Preweaning (kg/da)	Winter[d] (kg/day)	Spring[e] (kg/day)	Summer (kg/day)	Late summer[f] (kg/day)	Cold carcass (Wt. kg)	F teedlot (kg/day)	Cold carcass[g] (Wt. kg)
Treatment									
1	43	.89	.28[ab]	1.04	.89	.64[ab]	213[a]	—	—
2	36	.90	.35b	.99	1.00	.73[b]	—	—	
3	19	.94	.24[a]	1.02	1.04	.56[a]	—	2.03	311
Frame									
3	44	.76[a]	.26[a]	.99[a]	.85[a]	.71	202[a]	2.02[a]	255[a]
4	115	.88[ab]	.29[ab]	.99[a]	.96[ab]	.67	217[b]	1.17[ab]	267[a]
5	61	1.02[b]	.33[b]	1.08[b]	1.05[b]	.74	246[c]	2.20[b]	297[b]

[a,b,c]Indicates that means among treatments and among frame sizes in the same column are significantly different ($P<.05$) when superscript letters are different.
[d]Animals in treatments 1 and 3 grazed range and animals in treatment 2 grazed sorghum.
[e]Animals in treatments 1 and 3 grazed range and animals in treatment 2 grazed crested wheatgrass.
[f]Animals in treatments 1 and 3 grazed range and animals in treatment 2 grazed sorghums.
[g]Number of animals were 22, 61, and 33 for frame size 3, and 4 and 5 respectively.

Treatment one, which was the range only group, had carcasses grading 50% Standard, 47% Good, and 3% Choice. Carcasses in treatment two, which was the group that received range and complementary grazing from forages, graded 30% Standard, 67% Good, and 3% Choice. Carcasses from treatment three, which were from the group that was fed for 66 days, graded 31% Standard, 53% Good, and 16% Choice. Most of the Standard grade in all treatments were high Standard and most of the Choice grade were low Choice.

Generally, animals that grazed sorghum during winter and late summer (Treatment 2) gained more than animals that grazed range (Treatments 1 and 3) during comparable periods (Table 1).

Carcass Characteristics

The carcass characteristics are shown in Table 2. Quality grades and marbling scores were not significantly different between the 2 grazing treatments, but animals fed an additional 66 days were significantly higher in both respects. This would be expected since grain-fed animals had more intramuscular fat, which was displayed in higher marbling scores and higher quality grades.

Dressing percentages were highest for the grain fed animals and lowest for the range animals. Rib eye area and quantity of trimmed primal cuts were significantly higher for the animals retained in the feed lot as compared to the 2 groups grazed on forages. This would be expected because of the marked differences in body size between the comparisons. Yield grade was lower (higher cutability) for the animals raised on the range compared to treatments two and three because of the leaner qualities for the grazed animals.

Palatability Evaluations

In the present study there was no significant difference (P<.05) between the 2 groups that grazed forage for either amount of marbling, backfat thickness, or percent longissimus muscle fat, but the group fed 66 days on concentrates were significantly higher in all 3 cases. The amount of marbling was 2.41, 2.52, and 2.92, respectively, for the 3 treatments. The average backfat thickness was 0.36, 0.43, and 0.79 cm (0.16, 0.18, and 0.32 inches) and the average percent muscle fat was 2.4, 2.4, and 4.3, respectively, for range, range-forage, and 66-day fed animals (Table 2). This might imply that neither of the forage fed groups actually produced acceptable meat, but taste panel evaluations showed otherwise (Table 3). There were no significant differences (P<.05) in palatability traits (tenderness, flavor, juiciness) among the 3 treatment groups. All differences in organoleptic scores among treatments were small and all average scores were above 4.5, which is the mid-point of the scoring range and is considered acceptable from the viewpoint of palatability traits. Only juiciness and overall acceptability scores were below 5 but even in these cases they all round off to 5. If the carcasses below high Standard are eliminated, the taste panel scores for all palatability traits for all treatments are increased somewhat.

It is thus shown that average carcasses from all 3 treatments met palatability standards based upon professional taste panel scores to meet evaluations for acceptable meat. It is shown, however, in Table 3 that organoleptic traits (tenderness, flavor, and juiciness) are higher for the grain fed animals than for the animals raised and finished on grazed range and complementary forages. This means that grain-fed animals are more palatable, but the average rating for meats from forage fed animals were still acceptable for block beef. Eight. percent of the carcasses in standard grade were rated desirable (>4.5) with about 70% of the carcasses being a high Standard. Likewise, about 84% of the carcasses in Good grade were rated desirable (>4.5) with about equal distribution of carcasses in low, medium, and high Good. Approximately 88% of the carcasses in Choice grade were scored desirable (>4.5) with 77% of them in the low Choice category.

Lower quality grades tend to have lower palatability scores and likewise lower probability of furnishing carcasses that score acceptable for block beef. Production costs, however, are being lost because under conventional methods it is impossible to precisely differentiate between the 80% of the carcasses in high Standard and Good grades that are acceptable from those that are unacceptable from the standpoint of palatability traits. This results in large numbers of acceptable carcasses being placed in low quality grades generally used for manufactured meats rather than block meat.

Lower Thresholds for Block Meat Evaluation

It is realized that lower thresholds are established for the sake of presenting a high probability of the meat meeting desirable palatability traits, but it neglects the option of including a high percentage of the meat that may be lower quality grade yet acceptable as primal cuts. These carcasses might feasibly be an economy grade for many people. In any case, such meat deserves more than being used for manufactured products. Indications are that consumers will purchase such meats if given the opportunity and will return for more because of lower price, leaner meat characteristics, and suitability to individual tastes (Schupp et al. 1979).

Amount of backfat thickness and percent lipid (percent fat in the longissimus muscle) have been suggested as lower thresholds for identifying acceptable beef from unacceptable beef by Tatum et al. (1982) and Campion et al. (1975) respectively. Tatum et al. (1982) suggested as the lower limit a backfat thickness of 0.76 cm (0.3 inch) and Campion et al. (1975) suggested 2.9% intramuscular fat as the lower limit for segregating desirable from undesirable beef in young animals less than 30 months of age.

In recent study by Cramer et al. (1984), it was shown that if backfat thickness of 0.76 cm (0.3 inch) were accepted as the lower threshold of desirability, only 13% of the total carcasses in Choice grade would be rejected, but in the Good grade 53% would be

Table 2. Means for carcass characteristics by treatment and frame size.

Item	Number of carcasses	USDA[d] quality grade	Marbling[e] amount	Dressing percent	USDA[f] yield grade	Rib eye area (cm²)	Adjusted fat[g] thickness (cm)	Trimmed primals (kg)	Intra-muscle fat (%)
Treatment									
1	43	6.67[a]	2.41[a]	54.0[a]	1.80[a]	63.2[a]	0.36[a]	144[a]	2.42[a]
2	36	7.14[b]	2.52[a]	56.4[b]	1.96[b]	65.8[a]	0.43[a]	125[b]	2.44[a]
3	19	7.47[b]	2.92[b]	58.6[c]	2.06[b]	85.2[b]	0.79[b]	160[c]	4.35[b]
Frame[h]									
3	44	7.82[a]	2.84[a]	56.6	2.48[a]	67.7[a]	0.84[a]	132[a]	3.36
4	115	7.75[a]	2.88[a]	57.3	2.27[a]	71.6[a]	0.74[a]	134[a]	3.30
5	61	7.08[b]	2.66[b]	57.2	1.93[b]	80.6[b]	0.58[b]	155[b]	3.24

[a,b,c]Means within a main effect and in the same column bearing different superscript letters are significantly different (P<.05).
[d]10 = low choice; 7 = low good, 4 = low standard.
[e]4 = small; 3 = slight; 2 = traces.
[f]Carcass with Yield Grade 1 would have >52.3% trimmed retail cuts and Yield Grade 5 would have <45.4% trimmed retail cuts.
[g]Fat measurement taken over the *longissimus* muscle at the 12th rib, then adjusted for unusual fat deposition over the carcass.
[h]Modified Missouri frame score for 220 animals included in 11 treatments studied by Cook et al. (1980, 1981).

Table 3. Means for taste panel evaluation and Warner-Bratzler shear force values on ribs steaks by treatment and frame size.

Item	Number of animals	Tenderness[c]	Flavor[c]	Juiciness[c]	Overall[c] acceptability	W-B shear (kg)
Treatment						
1	43	5.19	5.08	4.78	4.92	7.00
2	36	5.26	5.13	4.88	4.95	6.87
3	19	5.22	5.31	4.97	5.10	6.43
Frame[d]						
3	44	5.20[d]	5.17	4.96	4.99	6.29[a]
4	115	5.22[a]	5.28	4.79	5.05	6.57[a]
5	61	4.88[b]	5.21	4.80	4.85	7.14[b]

[a,b]Means within a main effect and in the same column bearing different superscript letters are significantly different ($P<.05$).
[c]Based on an eight point hedonimic scale 8=extremely tender, desirable, juicy or acceptable; 5=slightly tender, desirable, juicy or acceptable, 1=extremely tough, undesirable, dry or unacceptable). Scores of 4.5 or above are considered desirable or acceptable meat for primal cuts.
[d]Modified Missouri frame score for 220 animals included in 11 treatments studied by Cook et al. (1980, 1981).

rejected. If 2.9% intramuscular fat is used as the lower threshold of acceptability, 16% would be rejected from Choice grade, but in Good grade 41% would be rejected. Under conventional methods of chilling, the study by Cramer et al. (1984) indicates that both thresholds for backfat thickness and percent intramuscular fat were perhaps too high to include most of the acceptable meat in both Good and high Standard grades.

The present study shows that both range and range along with complementary forages can produce acceptable meat. It may grade lower and it may score lower in taste panel evaluations, but it is indeed acceptable and would be purchased by consumers at an advantageous price even though the probability of receiving an unacceptable steak is somewhat higher (about 10%) compared to grain fed steaks of Choice grade. Huffman and Griffey (1975) state that "anyone who says pasture beef must be poor in quality is simply misinformed. Meat from cattle finished on high quality winter grazing can be equal to that from comparable cattle getting a 90-day feedlot finishing period after grazing."

Breidenstein et al. (1968) and Henrickson and Moore (1965) found that the degree of marbling in the muscle beyond, perhaps, a trace was of little importance in young beef animals. Data in the present study would tend to agree that young animals 18 to 24 months of age place a high percentage of carcasses in desirable meat categories with only a trace of intramuscular fat.

Frame Size and Animal Response

In the present study large-frame animals gained slightly more than small-frame animals (Table 1), but small-frame animals had higher finish at comparable ages and period of feeding. In other studies large-frame animals also made substantially higher daily gains but not always with higher quality meat grades (Koch et al. 1976, 1977; Prior et al. 1976, 1977; Smith et al. 1980). In another study Laster et al. (1976) found that small-frame cattle reached puberty at an earlier age than large-frame cattle. Koch et al. (1976), Smith et al. (1977) and Prior et al. (1977) found that small-frame cattle fattened faster and reached a particular quality grade sooner than large-frame cattle.

Animals in treatments one and two that were finished on range and range along with complementary forages, respectively, had 42, 47, and 11% in Standard, Good, and Choice grades for the small-frame animals and 58, 42, and 0% in Standard, Good, and Choice grades, respectively, for large-frame animals. Thus the smaller frame animals tended to finish more rapidly on forages and have higher quality grades than larger-frame animals.

Steers that were fed for an additional 66 days also had a larger number of the small-frame animals grading Good and Choice than the large-frame animals. The average for all 220 animals in all treatments in the original study (Cook et al. 1980, 1981) showed that animals in the small-frame sizes graded 0.74 of a point higher than larger-frame animals. Steers in frame sizes 3 and 4 graded average Good to high Good compared to an average low Good for the frame-size 5 steers. Bohman et al. (1981) stated that British breeds (Hereford and Angus) fatten earlier at lighter weights with limited grain and hence have a greater probability of producing acceptable beef on pasture and roughage than the bigger exotic breeds.

Although not presented in tabular form in this paper, small-frame cattle (frame-size 3) in addition to having greater backfat thickness and more intramuscular fat, also had more separable fat and less separable lean and bone than large-frame steers at the same age. This would be expected since the small-frame animals generally had higher finish indexes than the large-frame animals at any comparable age or time on the trials.

Tenderness and shear force measurements were affected by frame size (Table 3). Rib steaks from frame-sizes 3 and 4 steers were slightly more tender ($P<.05$) and required less shear force ($P<.05$) compared to steaks from frame-size 5.

Summary and Conclusions

From 1976 to 1981, 3 annual sets of steer calves were raised from birth to slaughter. Three treatments were involved, namely: (1) raised entirely on range to 18 months of age; (2) raised on range and complementary forages to 18 months of age; and (3) raised on range to 18 months of age and fed subsequently for 66 days. Animals in the study were of crosses with Hereford, Angus, and exotic breeds; thus steers that were slaughtered were of the general frame sizes (small, medium, and large).

Carcass characteristics and organoleptic traits were measured and compared by treatments and frame sizes. Quality grade, marbling score, rib eye area, fat thickness, and percent intramuscular lipid were significantly higher for the animals receiving grain at the end of the grazing period than for the 2 grazing groups.

There were no significant differences in palatability traits (tenderness, flavor, and juiciness) among the grazing cattle and those that were finished on grain for 66 days. About 80% of the carcasses in each of the 3 treatments were scored acceptable by the taste panel. Neither backfat thickness of 0.76 cm (0.3 inch) or percent intramuscular fat at 2.9% appeared adequate as a lower threshold to identify unacceptable carcasses within any of the 3 treatments because they caused a high number of acceptable carcasses to be used in manufactured meats at a loss to the producers.

Small-frame animals gained less per day but had higher finish at comparable ages and period on treatments than large-frame animals. Carcasss of small-frame animals had significantly more intramuscular fat, more separable fat, and less separable lean than large-frame animals. Tenderness and shear force measurements were significantly more favorable for small-frame animals than large-frame animals when measured over all forage and concentrate feeding trials.

An economy grade of beef featuring pasture and range finished animals for moderate income people at prices commensurate with lowered costs of production should receive consideration by the beef industry. Choice grade beef with a probability of 1 out of 10 steaks being slightly unacceptable compared to a Good grade or high Standard grade meat at a probability of 2 out of 10 steaks being slightly unacceptable should have a financial advantage to both the consumer and the producer.

It was concluded that the use of small-frame cattle could enhance the use of more pasture and forages because they mature more rapidly and finish at a younger age than large-frame cattle. This allows grazing to contribute more to finishing beef animals either through finishing directly on pasturage, or through forages along with shorter drylot feeding periods.

It was further concluded that acceptable beef could be produced directly from range if calves were kept on a growing diet of nutritious forages with minimum supplement until they were 18 months of age. Steers raised by grazing on the range and complementary forages such as crested wheatgrass and forage sorghums without grain can produce acceptable beef of a higher quality grade than steers grazing only native range. Animals fed 66 days following grazing produced palatable beef comparable to animals that had only native range along with the complementary forages.

It is apparent that future beef production will rely more on range and forages to produce block beef because of the anticipated higher prices for grain and the trend for consumers to purchase leaner meat.

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Early Weaning and Part-year Confinement of Cattle on Arid Rangelands of the Southwest

C.H. HERBEL, J.D. WALLACE, M.D. FINKNER, AND C.C. YARBROUGH

Abstract

This study compared part-year confinement of cows with yearlong placement on rangeland and weaning calves in late May with regular weaning in mid-October. Weaning rates tended to be higher with part-year confinement than with yearlong placement on rangeland (86% vs. 72%) and with early weaning in May than with regular weaning in October (86% vs. 72%). There were significant year effects in weaning weights with the lowest weights in drought years. The production per cow exposed tended to be higher with part-year confinement than with yearlong placement on rangeland (134 kg vs. 110 kg), and with regular weaning than with early weaning of calves (156 kg vs. 88 kg). Part-year confinement of cows and early weaning of calves are useful tools for the range manager in droughty years.

Production of livestock accounts for about 75% of the total agricultural income in the arid and semiarid regions of the Southwest. Much of this production is on rangelands. Because of frequent droughts, livestock production is particularly perplexing.

Every additional estrous cycle needed to get the beef cow rebred after parturition results in an economic loss. This loss is due to low weaning weights and eventually to cows left unbred at the end of the breeding season. Breeding performance is strongly affected by the cow's nutrition. Nutritional levels, before and after calving, influence pregnancy rate for next year's calf crop (Wiltbank et al. 1965). After parturition, the cow must provide milk for the growing calf as well as prepare for reproduction. This shift in feed requirements boosts dry matter and energy needs by about 40% and protein needs by about 120% (National Academy of Sciences 1976). Thomas and Durham (1964) suggested confinement of cows may relieve range plants during stress situations, such as drought, while satisfactory livestock production is maintained. Research in Texas indicated that conception rate was higher for cows in drylot than on rangeland (Marion et al. 1971). Confinement may improve livestock production when range forage is of low quality, or quantity, or both. In the Southwest, droughty periods in spring may be an ideal time to confine cows to drylot to rest range forage and maintain livestock production.

Suckling calves reduce reproductive activity of the dam. Several workers have suggested that suckling can be a major factor causing long postpartum intervals, particularly in young beef cows (Short et al. 1972, Laster et al. 1973, Bellows et al. 1974). Lusby et al. (1981) found early-weaned calves on concentrate feeds had about the same weight at seven months as calves remaining with their dams on native range in Oklahoma.

The primary purpose of this study was to compare performance of beef cows under 2 management systems: (1) conventional, yearlong on arid rangeland; and (2) part-year confinement in drylot, the remainder of the year on rangeland. A secondary objective was to compare cow performance with early weaning of calves and weaning at the usual time in both systems.

Experimental Procedures

This research was conducted on the Jornada Experimental Range 40 km north of Las Cruces, N. Mex. The climate is arid, 230 mm annual precipitation, 55% of which occurs in summer. The springs are often droughty and windy. The precipitation is highly variable spatially, and from time to time. The vegetation is dominated by black grama *(Bouteloua eriopoda)*, tobosa *(Hilaria mutica)*, mesa dropseed *(Sporobolus flexuosus)*, and honey mesquite *(Prosopis glandulosa)*.

Heifer calves born during the spring of 1973, 1974, and 1975 were placed in a lot about April 1 each year as yearlings and fed alfalfa hay free-choice and corn grain at the rate of 0.9 kg/head/-day. Bulls were placed with these yearling heifers about May 1, and were removed after a 65-day breeding season. Without liberal feeding of alfalfa hay and some concentrates, the heifers would not have been heavy enough to satisfactorily breed when they were yearlings. Similar heifers on rangeland only, normally weigh 200 to 227 kg, which is less than the weights found necessary for yearlings to breed satisfactorily. A total of 117 heifers of Hereford (H), Santa Gertrudis (SG), H × SG, and SG × H breeds were alloted to the treatments by breeds. All the animals were returned to rangeland when the bulls were removed.

After breeding, the yearling heifers were divided into 4 treatments: (1) range-regular weaning (47 head), (2) range-early weaning (17 head), (3) part-year confinement-regular weaning (34 head), and (4) part-year confinement-early weaning (19 head). The group on range was treated as cows are customarily treated on arid rangelands of the Southwest, i.e., yearlong grazing with a minimum of supplemental feed. The amount of supplemental feed given to range cattle is variable depending on forage conditions. In this study, each range cow received the following amounts of cottonseed meal pellets: 1977, 39.0 kg; 1978, 45.2 kg; 1979, 24.1 kg; 1980, 60.3 kg; and 1981, 45.1 kg. The group in part-year confinement was fed and handled the same as the yearlings during each spring. The breeding season was the same for each group and similar to that used for the yearlings. All calves were born on rangeland under similar conditions. Regular weaning was in mid-October when the calves were about 225 days of age. Early weaning was in late May when the calves were about 75 days of age. Additionally, we recorded sire, sex, and weaning weight of calves, and weight and pregnancy results from rectal palpation of cows in mid-October. We did not study calf performance following weaning from cows. All weights of heifer calves were adjusted by adding 5% of the weight to make them more comparable to steer calf weights (U.S. Department of Agriculture 1965). This study was terminated after calves were weaned in 1981. Because of normal culling procedures and death losses, 92 cows remained in the experiment until termination.

The basic experimental design was a split-plot in randomized complete blocks with 3 replications. All heifers born in 1973 were designated as Replication I and were treated as cohorts throughout the entire experiment. Similarly, heifers born in 1974 and 1975

Authors are supervisory range scientist, Jornada Experimental Range, ARS, USDA, Las Cruces, N. Mex. 88003; animal nutritionist and statistician (head), Agr. Exp. Sta., New Mexico State Univ., Las Cruces 88003; supervisory range technician, Jornada Experimental Range, ARS,USDA, Las Cruces, N. Mex. 88003.

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were designated as Replication II and Replication III, respectively. Therefore in the experimental design advantage was taken of the variability among the 3 cohort groups. Main plots consisted of the 2 environments (range vs. part-year confinement) and sub-plots were defined as the 2 weaning ages (225 vs. 75 days). Each year calving data from all cows within each sub-plot were averaged and this average was designated as the experimental unit for analysis.

In longitudinal research the effects of years and the effects of ages are confounded. These effects can be estimated, however, by grouping the data in 2 different ways for analyses. In order to estimate and compare year effects in conjunction with different environments and weaning ages, data for the last 5 years of each replication (1977–1981) were analyzed (ANOVA #1). This allowed age groups (months) to be somewhat confounded with replications as follows:

Year	Rep. I	Rep. II	Rep. III
1977	54	42	30
1978	66	54	42
1979	78	66	54
1980	90	78	66
1981	102	90	78

Considering the ages of cows in mid-October, these effects were estimated and compared by analyzing data for 5 age groups (ANOVA #2). In this case the years were confounded with replications as follows:

Age	Rep. I	Rep. II	Rep. III
30	1975	1976	1977
42	1976	1977	1978
54	1977	1978	1979
66	1978	1979	1980
78	1979	1980	1981

Dependent variables analyzed included conception rate, weaning rate (the number of calves weaned per cow exposed), weaning weight (225 or 75 days) adjusted for sex, and production per cow exposed adjusted for sex. The separation of means, when appropriate, were by the least significant difference (LSD) method. The LSD was applied only after a significant F-test ($p<.05$) from the analyses of variance.

Results

There were essentially no differences among treatments in birth date of calves. The averages for year-cow age-treatment ranged from February 23-April 10.

Pregnancy rates of cows in mid-October were significantly higher [p=.036 (ANOVA #1), .042 (ANOVA #2)] for the part-year confinement group (92%) than for the range group (74%). Pregnancy rate in October tended to be higher for cows weaning calves in late May (88%) as compared with cows weaning calves in mid-October (80%). The conception rate was only 44% of the range group in 1978 while the lowest in the part-year confinement group was 86% in 1977 (Fig. 1). Conception rates were much more

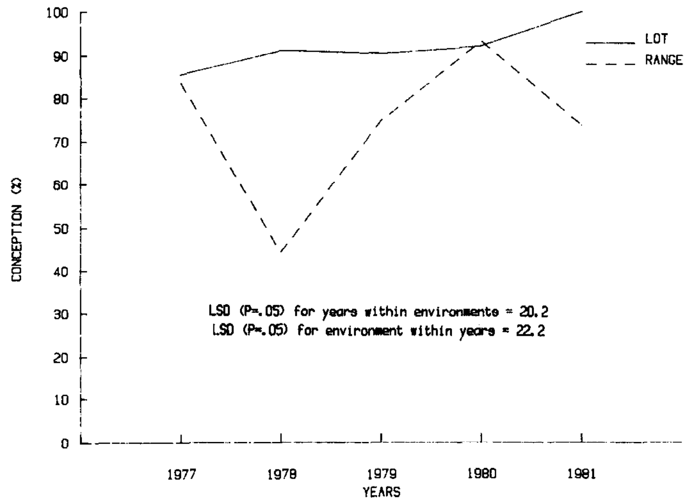

Fig. 1. *Conception rates for the cows in part-year confinement and on rangeland yearlong, 1977-81.*

Table 1. Average production per cow exposed under two environmental regimes and two weaning schedules.

Year	Cow age in October Month	Avg. production per cow exposed[1] Regular weaning: Range year long	Regular weaning: Range/confinement	Early weaning: Range yearlong	Early weaning: Range/confinement
			——Kg——		
1975	30	74	138	68	65
1976	30	177	184	45	64
	42	114	125	62	91
1977	30	91	117	94	74
	42	107	200	71	73
	54	151	206	68	107
1978	42	144	109	89	48
	54	157	192	99	83
	66	145	166	85	116
1979	54	99	125	16	73
	66	82	224	29	88
	78	168	141	44	109
1980	66	92	147	101	100
	78	181	144	90	113
	90	134	180	78	118
1981	78	259	211	83	122
	90	160	252	110	94
	102	160	137	111	134
Average (1975-81)		142	170	78	97
Average (1977-81)		139	166	75	93

[1]These figures have been adjusted to reduce sex effects by adding 5% to all heifer calf weights.

consistent for the cows in part-year confinement. Weaning rate tended to be lower in the range group [72%, ANOVA #1 and #2] than in the part-year confinement group [86% (#1), 85% (#2)] [p=.132 (#1), .115 (#2)]. It also was lower in the cows with calves weaned at the regular time [72% (#1), 71% (#2)] compared with cows with calves weaned early [86% (#1), 87% (#2)] (p=.051 (#1), .032 (#2)]. Weaning rate was significantly greater in 1978 (82%), 1980 (83%), and 1981 (90%) than in 1979 (62%).

Overall, there were no significant differences in adjusted weaning weights between calves from cows in part-year confinement or when the cows were on the range yearlong. The combined weaning weights over all treatments were significantly lower in 1978 than in 1979 and 1981 (p=.001). Of the calves weaned in mid-October from cows in part-year confinement, weights were significantly higher in 1977, 1979, and 1981 than in 1980 (Fig. 2). The average daily gain

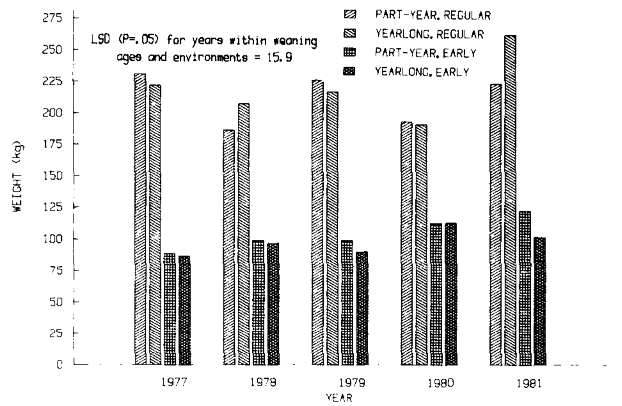

Fig. 2. *Adjusted weaning weights during 1977-81 for calves weaned in mid-October and in late May from cows in part-year confinement and on rangeland yearlong.*

(ADG) for 1977-81 of the calves weaned in October from cows in part-year confinement when we assumed a birth weight of 34 kg, was 0.80, 0.69, 0.84, 0.71, and 0.83 kg, respectively. From cows on range yearlong, mid-October weaning weights were significantly higher (p<.05) in 1981 than the other years and higher in 1977-79 than in 1980 (Fig. 2). The ADG for 1977-81 of the calves weaned in October from cows on range yearlong was 0.81, 0.75, 0.84, 0.71, and 1.06 kg, respectively. The weight of calves weaned in late May from cows in part-year confinement was significantly greater in 1980 and 1981 than 1977, and greater in 1981 than 1977-79. The ADG for this group of calves for 1977-81 was 0.70, 0.78, 0.79, 0.92, and 0.92 kg, respectively. The early weaners from cows kept on range yearlong had a significantly higher weaning weight in 1980 than in 1977 or 1979 (Fig. 2). These calves had an ADG for 1977-81 of 0.70, 0.71, 0.71, 0.83 and 0.75 kg, respectively.

The production per cow exposed to a bull [(calves weaned × weaning weight)/no. cows] tended to be higher in the part-year confinement group (134 kg) than in the range group (110 kg) [p=.123 (#1), .110 (#2)]. It was also significantly higher when calves were weaned at the regular time in October [156 kg (#1), 149 kg (#2)] than in late May [88 kg (#1), 79 kg (#2)]. Production per cow was significantly higher in 1981 than 1977-79 (Table 1).

Combining cow weights for the 2 weaning times resulted in very small differences in cow weights within ages and within years for the cows on the range yearlong compared to those with part-year confinement. Early weaning resulted in heavier cow weights, particularly in cows when they weaned their first calf (414 kg vs. 380 kg). The average cow weights at calf weaning in October for 1977-81 were: 447, 430, 497, 449, and 507 kg, respectively.

About 79% of the cows survived until the end of the experiment. Unavoidable death losses were 7% and culling accounted for 14% of the cows not finishing the experiment. No difference in losses was found among treatments. Only data from cows completing the experiment were included in the analyses.

The cows consumed 11.8 kg alfalfa hay and 0.9 kg corn grain per head per day while they were confined. At $77.00/t for alfalfa hay and $220.00/t for corn, it cost $1.11/day or $105.45 to feed the cows in confinement for 95 days. Additionally, the feed costs for bulls for 65 days was $4.51/cow, for a total of $109.96/cow. Cows on the range were given an average 0.45 kg/day of a high protein feed (cottonseed meal pellets) for 95 days. At $220.00/t, feed costs for cows and bulls would be $9.93/cow. Therefore, at these prices, the feed costs per cow unit were $100.03 greater for cows in part-year confinement than for those on the range yearlong. When calf prices are $1.54/kg, calves from cows in confinement must weigh an additional 65 kg to pay for the feed ($100.03 ÷ $1.54/kg = 64.95 kg or 65 kg). Table 2 shows the additional production per cow needed to offset feed costs with varying feed costs and calf prices when the cow is kept in confinement for part of the year. In

Table 2. Additional production per cow required to offset feed costs at varying calf selling prices for cows in confinement as compared to those on range.

Additional[1]	Calf selling price (dollars/kg)				
feed costs	1.30	1.60	1.90	2.20	2.50
Dollars			Kg		
50	38	31	26	23	20
75	58	47	39	34	30
100	77	62	53	45	40
125	96	78	66	57	50
150	115	94	79	68	60

[1] Feed costs for cows and bulls in confinement minus feed costs for cows and bulls on rangeland for that same period.

addition to the feed costs, more labor was required for the cattle in part-year confinement but vehicle costs were higher for the cattle on range yearlong. For purposes of this economic analyses, these costs were considered to offset one another. Part-year confinement resulted in production of 65 kg/cow or more in 1977 for the cows 42 months of age, in 1979 for the cows 66 months old, and in 1981 for the cows 90 months old (Table 1). Thus, the same group of cows on rangeland yearlong were adversely affected by conditions in some years although they were in the same group as other cows on rangeland yearlong and cows in part year confinement while they were on the range.

Discussions and Conclusions

During this study the major differences were among years instead of cow ages. The years 1978 and 1980 were droughty, resulting in a reduction of forage quantity and quality. This reduction was partially compensated in 1980 by the liberal use of supplemental feed. In 1979 there was a significant reduction in number of calves per cow exposed because of the low conception of cows in the range group in 1978. The weaning weights were also lower in 1978 and 1980 for calves weaned in mid-October. Cow weights at calf weaning were also reduced in 1978 and 1980.

Part-year confinement of cows following calving is a useful tool in droughty periods. As calf prices increase and/or feed costs decrease, part-year confinement of range cows is a more viable option. In this study, conception and weaning rates were higher, and production tended to be higher, from cows in confinement part of the year. Early weaning of calves will also improve conception and weaning rates of cows in dry years. The management of calves weaned early may present a problem to a producer unaccustomed to handling young calves weaned from their dams. The performance of range cows and calves will be improved with nutritional assistance during stress periods in the Southwest.

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Horses and Cattle Grazing on the Wyoming Red Desert, III

G.E. PLUMB, L.J. KRYSL, M.E. HUBBERT, M.A. SMITH, AND J.W. WAGGONER

Abstract

Vegetative cover losses due to trampling near watering sites in the summer and winter are compared for horses grazed alone, cattle grazed alone and horses and cattle grazed in combination. There were significant differences ($p<.05$) found in the rates of total cover loss as a function of distance to water in both the summer and winter. Grasses sustained heavy trampling losses in all treatments in both seasons. Forbs sustained heavy losses in all treatments during summer. Shrub losses were moderate to low in all treatments during both seasons. Total cover loss was similar in all summer and winter treatments.

Water sources of cattle *(Bos taurus)* and horses *(Equus caballus)* on open range in the Red Desert of Wyoming have surrounding areas with heavy grazing or trampling use. Loss of forage due to trampling has long been recognized as a problem by livestock producers. Thomas (1960) suggested heavy trampling effects may be equal to, if not more important than, excessive grazing in reducing forage production. Several studies have examined the effects of trampling on rangeland vegetation (Packer 1953, Pegua 1970, Bryant et al. 1972, Laycock and Harniss 1974). None of these studies have investigated trampling losses by horses, or horses and cattle grazing in combination. The objective of this study was to determine rate of cover loss due to trampling near a water source for horses alone, cattle alone, and horses and cattle in combination under heavy grazing regimes.

Authors, at the time of the study, were research aides III, research associate, Division of Animal Science, University of Wyoming; assistant professor, Division of Range Management, University of Wyoming; associate professor, Division of Animal Science, University of Wyoming, Laramie, 82071.

Mr. Plumb is currently a graduate assistant, Department of Range and Wildlife Management, Box 4169, Texas Tech University, Lubbock, Texas 79409.

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Study Area and Methods

The study was conducted in the Red Desert of Wyoming approximately 93 km northeast of Rock Springs, Wyo., in Sweetwater County. A semiarid climatic pattern prevails over the area. Three distinct vegetation types; sagebrush-grass, saltbrush, and greasewood-rabbit brush, cover most of the area. For a more complete description of the study area see Krysl et al. (1984).

The study sites were located on traditional summer or winter ranges of cattle and feral horses. Pastures were selected to be as similar as possible although some differences did ocur in species composition. Animal numbers and stocking rates for the summer study by treatment were: horses grazed alone, 12 horses and 1 colt (2.8 AU/ha); cattle grazed alone, 13 cattle and 8 calves (2.4 AU/ha); horses and cattle grazing in combination, 11 horses, 2 colts, 13 cattle and 8 calves (2.5 AU/ha). Animal numbers and stocking rates for the winter study by treatment were; horses grazed alone, 14 horses and 2 colts (3.3 AU/ha); cattle grazed alone, 12 cattle (2.3 AU/ha); horses and cattle grazed in combination, 12 cattle, 14 horses and 1 colt (2.8 AU/ha). Detailed information on grazing treatments is found in Krysl et al. (1984).

One, 1,300-liter, 2m × .7m × .6m, water trough was used as the water source in each treatment. Each trough was located in an area visually determined to be as vegetatively homogeneous as possible. Ice in each trough was broken and or removed once a day when necessary. For the purposes of this study, trampling loss refers to that portion of the forage which, through the trampling action of horses or cattle, has been removed or damaged so that it will not be available for consumption (Quinn and Hervey 1970). Heavy trampling losses are considered greater than 60%, moderate losses are 59-30%, and light losses less than 30%.

Trampling losses were determined using an adapted form of the line interception method (Canfield 1941). Five, 61-m line transects radiated out from a post behind each trough. Transects were permanent and vegetative cover increments were measured to the nearest estimated .6 cm.

In most trampling studies the effects of grazing and trampling are confounded because the effects of grazing are not easily separated from the effects of trampling (Reynolds and Packer 1962). However, the removal of vegetation in the 61-m area around each water source of this study was considered to be an effect of trampling only. It was observed that in both summer and winter cattle and horses generally went directly to water when they arrived within 100-150 m of the water source. Quinn and Hervey (1970) also observed that steers failed to stop and graze when travelling to water.

Vegetation was divided into three classes: forbs, grasses, and shrubs. The initial measurement and following measurements were designated by T_0, T_1, T_2, and T_3, respectively. Measurement T_0 was completed before the water trough was placed in each treatment. Subsequent measurements were made at 10- to 14-day intervals. During the winter study, T_2 was not obtained due to snow cover.

Total cover loss by treatment and plant type was determined from the difference in total centimeters of cover between T_0 and T_3. Total cover loss as a function of distance from water was determined by dividing the transects into 15-m increments and comparing each increment from T_0 to T_3. An approximate variance was calculated for each T_3/T_0 ratio (Cochran 1975). A standard *t*-test was conducted comparing the variance of two selected ratios. Significance is reported at $p<.05$. Observations of inter- and intra-specific interactions between horses and cattle around the water source were made throughout the study.

Results and Discussion

There were significant differences ($p<.05$) in the amount of total cover loss due to trampling related to distance from water in all treatments for both the summer and winter periods (Table 1). For both summer and winter studies, heavy trampling by cattle grazed alone occurred within the 0–15 m increment. Losses within the 16–61 m increment were moderate and similar over the entire distance for both study periods. We believe the different levels of trampling losses are due to the behavior of cattle around the water source. Cattle generally travelled to water 3 or 4 times a day during summer and only 1 or 2 times each day during winter. After watering during summer, cattle usually bedded close to water for several hours. During winter they usually stayed close to water but remained standing. No grazing was observed during these periods. Sneva et al. (1973) indicated cattle with easy access to water generally drank twice a day and stayed close to water 2–3 hours following drinking.

Table 1. Percent total cover loss in 15 m increments, T_0-T_3, summer and winter study periods.

Grazing treatment		Distance from water source			
		0–15 m	16–30 m	31–45 m	46–61 m
Cattle alone	S[1]	74_a[2]	32_b	26_b	31_b
	W	63_a	44_b	47_b	44_b
Horses alone	S	54_a	60_a	50_a	44_a
	W	57_a	39_b	27_b	21_b
Horses & Cattle together	S	60_a	76_a	34_b	7_c
	W	65_a	70_a	35_b	37_b

[1] S = summer, W = winter
[2] Values with unlike subscripts in rows are significantly different ($p<.05$).

The heaviest trampling losses within the 0–15 m increments were a result of cattle remaining close to the water source following drinking. Packer (1953) and Quinn and Hervey (1970) reported increased use of an area resulted in greater vegetation loss due to trampling. Moderate losses within the 16–61-m area are concluded to be a result of failure of cattle to stop when proceeding to and leaving water.

During summer in the treatment containing only horses, trampling losses were moderate and similar over the entire 61-m distance. However, during winter significantly greater losses occurred in the first 15-m increment with moderate to low losses within the 16–61-m increment. During summer horses came to water 5–7 times daily, remained briefly, and left as group immediately upon finishing drinking. It should be noted that not all horses drank each time they came to water, but all did come to water as a group. During summer the 61-m area around the trough received little use when total amount of time per day spent at the trough is considered. Less use could account for the lower rate of trampling losses.

During winter horses came to water 3 or 4 times a day as a group. The water source was sometimes iced over and the herd would remain close to the water source while one or two horses attempted to break the ice by hoof action. As would be expected, an increased amount of time spent in the 0–15 m increment, in an attempt to get water, increased trampling losses. Moderate to low vegetation loss in the 16–61 m increment was thought to be a result of horses proceeding to and leaving water without stopping.

The summer and winter treatments of horses and cattle grazed together showed very similar trends although actual amounts of loss differed. The increment of heavy trampling was twice as large as found for cattle during both study periods. Moderate losses occurred in the 31–61 m increment during both study periods except in summer in the 45–61 m increment, losses were very low.

The increase in area of heaviest trampling indicates possible effects of a horse-cattle interaction in close proximity to the water source. Horses coming to water occasionally encountered cattle at the trough. When this occurred several dominant horses would make threatening movements such as biting and kicking, similar to those described by Eibl-Eibesfeldt (1975), which prompted the cattle to disperse from the trough. When the horses had finished watering and left the area the cattle usually re-established themselves closer to the trough. When cattle and feral horses concentrate on the same water source in a free-roaming situation, aggressive behavior of horses towards cattle has been observed (Miller 1980).

This interaction between horses and cattle may cause heavier use of the entire 0–30 m increment and thus result in heavy trampling. Moderate to low losses due to trampling were sustained in the 31-61 m increment and were a result of animals failing to stop when travelling to and from water.

All treatments sustained increased total trampling losses over all increments and plant classes from T_0 to T_3. Total vegetative cover losses were moderate and very similar in all treatments during both study periods with one exception. Total cover loss was lower during winter where horses were grazed alone (Table 2).

Table 2. Percent load loss in 0–61 m increment, T_0–T_3, for summer and winter study periods.

Grazing treatment	Summer	Winter
Cattle alone	46_a[1]	48_a
Horses alone	46_a	32_b
Horses & Cattle together	43_a	45_a

[1] Values with unlike subscripts in columns are significantly different ($p<.05$).

It is generally accepted that horses consume snow to supplement their water requirements. This activity was observed for both horses and cattle. Snow consumption likely accounts for fewer trips made each day to water by both horses and cattle during winter. Since the water source was used less in winter, lower rates of total trampling losses caused by horses over the entire 0–61 m increment could be expected. Total trampling losses caused by horses and cattle grazed in common were the same ($p<.05$) from summer to winter. Since total trampling losses from horses grazed alone dropped, the main trampling effect in the winter treatment where horses and cattle grazed together appears to be due mainly to cattle.

Although some differences in vegetal composition occurred between treatments in both seasons, mean values of initial percent cover by forage classes were calculated to give perspective to resulting cover losses (Table 3). Trampling losses of forbs during summer were very heavy (Table 3). Forbs were not a major diet component for horses; however, they made up 9% of the cattle diet during summer (Krysl 1984). By mid June to early July forbs were drying out and were extremely susceptible to trampling damage in all three stocking treatments. Forbs were rare during winter and were not measured.

Table 3. Initial percent cover and percent loss by plant class in 0–61 m increment, T_0–T_3, for summer and winter study periods.

			Grazing treatment		
Forage	Season	Initial cover	Cattle alone	Horse alone	Horse & Cattle together
Forb	S[1]	20	92_a	91_a	95_a
Grass	S	17	80_a	91_a	89_a
	W	13	70_a	85_a	61_a
Shrub	S	63	0_a	17_b	31_c
	W	87	42_a	18_a	42_a

[1] S = summer, W= winter
[2] Values with unlike subscripts in rows are significantly different ($p<.05$).

Grasses sustained heavy trampling losses in all treatments during both summer and winter (Table 3). Dominant grass species were mature by mid June to early July. Quinn and Hervey (1970) found needleandthread more likely to be trampled in July when seedheads were in various stages of maturity. Losses of grasses were generally lower during winter than during summer. Since animals came to water less during winter than summer, trampling damage decreased as expected.

Trampling losses of shrubs were the lowest of the various plant classes and different between treatments in the summer. Winter losses were similar for cattle grazed alone and in combination with horses, and lower for horses grazed alone (Table 3). The minimal loss of shrubs during summer when cattle grazed alone was thought to be due to avoidance of shrubs by cattle. By early winter some species of shrubs had lost all foliage. During winter, cattle grazed alone trampled shrubs with greater frequency than that observed during summer resulting in moderate trampling losses. Snow cover may have resulted in increased trampling of low shrubs. Horses grazed alone during summer and winter caused light losses of shrubs due to trampling. The horses avoided medium to large shrubs but when excited sometimes caused damage.

During summer, when horses and cattle grazed in common, moderate shrub loss was sustained but losses during winter were slightly higher. The increase in shrub losses during summer under common use, as compared to either horses or cattle grazed alone, were thought to be due to interaction between horses and cattle in the watering area. Both cattle and horses tended to damage shrubs when excited. During winter, when horses and cattle grazed in common, moderate shrub loss was sustained and losses were the same as where cattle grazed alone. This indicates the main trampling effect under common grazing was due to cattle.

Conclusions

Water sources on the open range in the Red Desert are sparse and much larger in size than those used in this study. Heavy concentrations of feral horses at water holes are common throughout summer months. Miller (1980) indicated that it is common to find 50 to 100 cattle at a single water hole in the Red Desert during summer. Since grasses and forbs sustain the heaviest trampling damage, ranchers might expect to lose a valuable portion of forage production adjacent to water sources. If horses and cattle use the same water sources a large area of heavy trampling of forage should be expected. Under such conditions, cattle and horses will have to travel further from water for feed. Squires (1978) stated that liveweight gain, and food and water intake were drastically affected when animals walked long distances for either grazing or water. According to Stephens et al. (1980), heavy trampling in sagebrush-grass types encourages microhabitat conditions favorable for succession of sagebrush rather than perennial grasses. Although precise amounts of trampling damage cannot be predicted under open range conditions, results similar to these might be expected to be found on a larger scale. Effects of winter trampling under free roaming conditions may be different because water sources are often frozen and thus not used for extended periods of time.

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Comparison of Grazed and Protected Mountain Steppe Rangeland in Ulukişla, Turkey

TUNCAY TÜKEL

Abstract

A typical steppe range having a semiarid climate at an altitude of about 1,350 m was studied to determine the yield potential of an area protected from grazing for a 30-year period representing about 36,690 ha rangeland. This study area has a class VII capability and was compared with a public grazing area on the immediate vicinity. Total ground cover, composition, and dry forage yields were significantly decreased on the continuously grazed public ranges. Two grasses *(Festuca ovina* and *Poa bulbosa* var. *vivipara),* one shrub *(Salvia criptantha)* and a forb species *(Asphodeline isthmocarpa)* were the main plants causing the difference in the ground cover. The grazed and ungrazed ranges did not differ significantly in infiltration rate. However, the southerly aspect of the protected range had a higher infiltration rate than the other aspects.

Very little has been done to determine the production potential and to describe the truly protected mountain steppe range vegetation in Turkey. Most of the steppe rangelands in Turkey are either under very heavy and uncontrolled grazing pressure for a long time or under cultivation for growing cereal crops.

Although there have been several notable studies on Turkish rangelands (Uslu 1959, Çetik 1965, Alinoglu 1969, Erkun 1971 and 1972, Özmen 1977 and Tosun et al. 1977), they were primarily conducted on overgrazed public rangelands repre-senting only the current grazed status, not the true potential that can be expected from the ranges. Most of these studies are unavailable to the interested American readers. Two articles however have been published in the *Journal of Range Management* concerning the general grazing potential of Turkey (Cornelius 1962, and Pringle and Cornelius 1968).

The main purpose of this study was to determine the floristic composition and the potential production capabilities of a typical steppe range protected from grazing for 30 years, compared to a nearby continuously and heavy grazed public range located in Ulukişla, Turkey.

Study Area

This study was conducted on the rolling hills of Ulukişla, a county of Nigde Province of Turkey. The study area has a semiarid climate at an elevation of about 1,350 m. Average annual precipitation is 362 mm. Of this total, 39% occurs during the growing season of March, April, and May; precipitation in winter is usually in the form of snow and accounts for 34% of the total. A small amount of all precipitation (64 mm on the average) makes possible regrowth of vegetation following summer dormancy. Most rainfall in the spring comes from high intensity thunderstorms. Annual precipitation is highly variable and drought is common, especially during the summer season in July, August, and September. The frost-free period is approximately 175 days, depending on the rainfall distribution.

There has not been a detailed geological survey of the study area; however, a general purpose geological map of Turkey places this area into the tertiary period with parent materials composed of Andezite, Spilite, and Porphyrite (Anonymous 1961). The study area is classified as class VII having shallow rocky soils highly eroded with steep slopes. The class of soils represents a total of 36,690 ha rangelands in the region.

Soils in the upper profiles of the protected rangelands investigated were usually sandy-clay-loams or clay-loams, and loams in the lower portion of the profiles. An exception was the Northwest aspect, which was low throughout the profile. The soils of the grazed lands, however, were mostly clay and clay-loam types. Soil color varied from dark brown, dark grayish brown, brown to reddish brown in the upper but were olive-gray in the lower layer indicating a complex type of parent material with andezite and serpantine.

Methods

Four different aspects in both the protected and the grazed areas were selected to represent the soil moisture gradient in the study area. At each location, 8 permanent 20-m long transect lines were established. Vegetative cover, composition and frequency data were obtained by using a loop with a 2-cm radius. Measurements were taken at 20-cm intervals to provide 100 loop readings on each transect line. Forage yields were obtained by cutting the plants at ground level in randomly thrown O.1-m^2 quadrats; 20 quadrats were clipped at each location. Crude protein content of the dried forage was determined by the micro-kjeldahl method utilizing standard laboratory procedures as developed by (Kaçar 1972). Vegetative data were analyzed by multiple discriminant analysis procedures explained by (Öztük et al. 1978). Soil infiltration rate was measured by a double ring infiltrometer, 25 cm tall with an inner radius of 10 cm and the outer of 16 cm. Disappearance of the water column in the inner ring was recorded every 5 minutes over a 45-minute period, replicated 4 times at each location.

Vegetative cover, composition, frequency, and the yield data were obtained at the beginning of grazing period in 1980, and at the end of the grazing seasons both in 1979 and 1980.

Results and Discussion

Vegetative Cover, Frequency and Botanical Composition

Total ground cover, frequency, and plant community composition of the grazed and ungrazed ranges are shown in Table 1. Two shrub species, *Salvia criptantha* and *Thymus squarrosus,* dominated the continuously grazed ranges, and 2 grasses, *Festuca ovina* and *Poa bulbosa* var. *vivipara,* dominated the protected rangelands. These results revealed that the good quality forage grasses were replaced by the less palatable shrub species in the continuously grazed ranges. These results also indicate that the secondary succession is still taking place in the rangelands protected since 1949. It may be expected that 3 other grass species, namely *Koeleria cristata, Stipa lagacea* and *Bromus tomentellus* would also be increasing under protection in the future. These findings support the more or less similar results of the other research workers (Bakir 1970a and 1970b, Johnston et al. 1971, Erkun 1972, Uluocak 1974, Lanford and Buel 1979, and Özmen 1977).

Author is a faculty member, College of Agriculture, University of Çukurova, Adana, Turkey.

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Table 1. Vegetative cover, frequency and botanical composition of the grazed and ungrazed rangelands.

Plant species	Total ground cover(%)		Frequency (%)		Botanical composition (%)	
	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
Festuca ovina	+	7.4	3.0	43.2	1.7	23.0
Poa bulbosa var. *vivipara*	0.6	4.8	5.1	32.6	3.5	15.3
Thymus squarrosus	2.4	4.3	16.7	26.1	14.0	14.1
Poa bulbosa	+	2.2	3.4	20.0	1.53	7.0
Stipa lagacea	0.6	1.7	6.2	13.75	3.5	5.3
Bromus tomentellus	+	1.6	3.6	15.1	2.0	5.3
Anthemis cretica	0.6	1.4	5.4	12.4	2.9	4.7
Salvia criptantha	5.9	1.0	34.3	10.4	28.2	3.4
Koeleria cristata	+	0.9	2.5	7.3	1.8	2.8
Artemisia fragrans	+	0.9	1.5	7.0	1.0	2.7
Onobrychis oxydonta	+	0.5	0.7	4.3	+	1.2
Xeranthermum squarrosum	0.8	+	7.6	+	+	1.2
Alyssum condensatum	0.6	+	6.0	1.6	3.0	0.6
Ventenata macra	0.5	+	4.4	1.1	3.2	+
Bromus squarrosus	0.5	+	4.6	4.0	2.3	1.4

+ indicates the values less than 0.5%.

Forage Yield

The forage yields of the grazed rangelands were significantly less than that of the ungrazed ranges in both early and late summer seasons. Dried forage in the grazed areas in early season was about half-that in the ungrazed areas. In the late summer, this production difference was not as large as in the early summer season. These lesser yields of dried forage on the grazed rangelands result from heavy and continuous past grazing of the public lands, confirming the findings of Schmutz et al. (1967) and Brown and Schuster (1969).

The most interesting fact concerning the dried forage yields of the investigated rangelands was that the yield differences in the grazed areas for both early and late summers (53.5 kg/da and 52.7 kg/da, respectively) were negligible. This lack of difference was, of course, another indication of the heavy and uncontrolled grazing indiscriminately taking place in the common grazing lands of Ulukişla in both seasons. This heavy grazing would not allow the more palatable grasses to be regrown during the grazing period. Whereas dried forage yield differences was appreciable in the ungrazed areas for both seasons (109.6 kg/da and 83.2 kg/da, respectively). This difference may be explained on the basis that annual grass species such as *Poa bulbosa* and *Poa bulbosa* var. *vivipara* have good growth in the early summer but mature and die later in the season.

Key Plants

Four species, *Poa bulbosa* var. *vivipara Festuca ovina, Bromus tomentellus* and *Poa bulbosa* consistently decrease under grazing. Two species, *Salvia criptantha* and *Asphodeline isthmocarpa* increase under heavy and uncontrolled grazing. Therefore, a practical suggestion for range managers is that the overpopulations of *Salvia criptantha* and *Asphodeline isthmocarpa* indicate that resting such rangelands is necessary to allow palatable grasses such as *Festuca ovina, Poa bulbosa* var. *vivipara, Bromus tomentellus* and *Poa bulbosa* to increase.

Crude Protein

Crude protein percentages of the forage on both grazed and protected ranges were higher in the early summer than in the late summer (Fig. 1). However, crude protein of the grazed ranges in both early and late summer, although not statistically tested, was slightly more than that of the protected ranges. This was probably because the heavily grazed range had more fresh regrowth and less dry matter than the protected ranges. Thus, protected ranges, due to greater total production will have more crude protein than the grazed areas. This result supports the findings of Demarchi (1973).

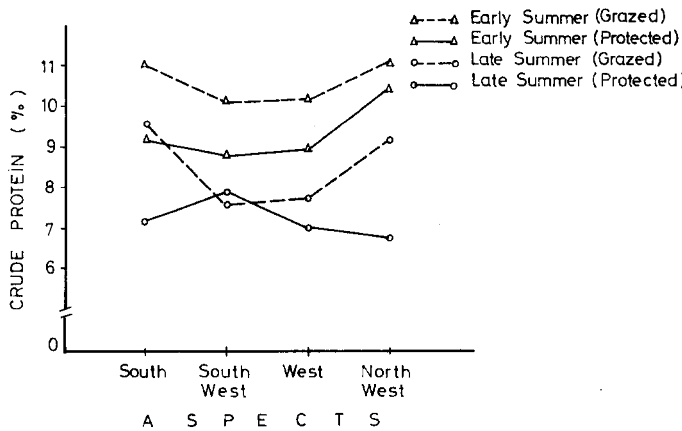

Fig. 1. *Crude protein percentages of the grazed and protected ranges during two different grazing periods and on our different aspects.*

Infiltration Rate

Infiltration rates of the grazed and protected ranges are shown in Table 2. Some interesting relations were found between the ranges and among different aspects. Although the mean infiltration rate of the grazed ranges (22.1) cm/hr was slightly higher than that of the protected ranges (20.5 cm/hr), the difference was not statistically significant. These results are contradictory to Brown and Schuster (1969). Infiltration sampling, was during the summer period when soils of the grazed ranges were very dry with more soil cracking than on the protected ranges.

Table 2. Infiltration rates (cm/hr) on different aspects of grazed and protected ranges at the end of 45 minutes.

Aspects	Protected ranges	Grazed ranges
South	33.6 a*	27.6 a
Southwest	14.7 b	21.9 a
West	17.4 b	19.20 a
Northwest	16.2 b	19.5 a
X	20.5	22.1

*Means having the same letter are not statistically significant ($p \leq 0.05$)

There was a significant difference between the infiltration rates of aspects in the protected area. The highest rate, 33.6 cm/hr, was observed in the south-facing aspect. Although similar differences occurred on the grazed range, they were not significant statistically. This finding suggest that heavy grazing on public ranges was nullifing the aridity differences between northerly and southerly aspects.

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Effects of Soil Disturbance on Plant Succession and Levels of Mycorrhizal Fungi in a Sagebrush-Grassland Community

T.B. DOERR, E.F. REDENTE, AND F.B. REEVES

Abstract

A 5-year study was conducted to determine the effects of soil disturbance on plant succession and the relationship between plant succession and mycorrhizal inoculum potential (MIP) in a big sagebrush-grassland vegetation type. Disturbed plots, consisting of 4 levels of soil disturbance, were established in 1976, 1977, and 1979 to evaluate environmental fluctuations. Perennial grass canopy cover and aboveground biomass production were positively correlated with MIP and negatively correlated with disturbance treatments. Annual forb canopy cover (primarily nonmycorrhizal species) and aboveground biomass were negatively correlated with MIP and positively correlated with level of soil disturbance. Weather fluctuations had a greater effect on annual plants than perennial plants after the perennial species were established. MIP values appeared to be a general indicator of the type and rate of plant succession that will evolve following soil disturbance.

Above- and belowground ecology of plant communities are interacting segments of the successional process. Though not generally realized, belowground biomass in grasslands may constitute 85% of the entire community (Clark 1975). An important component of the belowground ecosystem is vesicular-arbuscular mycorrhizal (VAM) fungi which form symbiotic relationships with plant roots. Mycorrhizae improve water absorption capacity (Safir et al. 1972, Menge et al. 1978) and assist plants in mineral nutrition (Mosse 1973, Lambert et al. 1979). Both may be particularly important for plant survival in the semiarid West where precipitation is low and minerals, especially phosphate, have been considered limiting for plant growth (Williams and Aldon 1976). Mycorrhizal fungi have been reported to increase the survival of seedlings (Aldon 1975) and increase the growth of mature plants (Gerdemann 1975, Aldon 1978).

Few studies have examined the influence exerted by mycorrhizae on plant growth on disturbed and mined lands. Daft and Nicholson (1974) found that established plants were mycorrhizal on coal wastes in Scotland. Daft and Hacskaylo (1976) concluded that plant infection by mycorrhizal fungi was important in revegetating Pennsylvania coal spoil because of increased growth and survival of infected plants. Aldon (1978) found that fourwing saltbush *(Atriplex canescens)* growth and survival were greater for infected plants compared to uninfected plants on coal spoil in New Mexico. Similarly, Lindsey et al. (1977) found on coal spoil in New Mexico that Douglas rabbitbrush *(Chrysothamnus nauseosus)* survival and production were greater when plants were mycorrhizal. The amount of mycorrhizal infectivity on disturbed soils

Authors are research associate and assistant professor, Department of Range Science; and professor, Department of Botany and Plant Pathology, Colorado State University, Fort Collins 80523. T.B. Doerr is presently biologist with Waterways Exp. Station in Vicksburg, MS. 39180.

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(Reeves et al. 1979, Miller 1979) and eroded soils (Powell 1980) was significantly reduced compared to that on similar undisturbed soils. Reeves et al. (1979), Miller (1979), and Janos (1980) also found that the predominant species revegetating the disturbed soils were nonmycorrhizal species. Reeves et al. (1979) suggested that the recovery of disturbed areas to high seral or climax stages may be slowed by the lack of VAM fungi to infect seedlings and provide greater plant vigor and survival.

Approximately 35.5 million hectares of land are encompassed in coal-producing counties in the western United States (McMartin et al. 1981). Much of this land may be disturbed as the need for energy increases. Succession and the factors controlling or modifying succession will ultimately determine the success of reclamation practices on disturbed sites. Therefore, it is important to understand how factors such as VAM fungi affect secondary plant succession. The objectives of this study were to examine the effects of 4 levels of soil disturbance and weather fluctuations on mycorrhizal fungi and secondary plant succession and to determine the relationship between population levels of VAM fungi and plant succession.

Site Description

Study sites were established in a sagebrush-grassland range located in the Piceance Basin 65 km northwest of Rifle, Colo., at an elevation of 2,200 m. Important species included big sagebrush *(Artemisia tridentata),* wheatgrasses (*Agropyron* spp.), Indian ricegrass *(Oryzopsis hymenoides),* prairie junegrass *(Koeleria cristata),* bluegrasses (*Poa* spp.), needle-and-thread grass *(Stipa comata),* cheatgrass *(Bromus tectorum),* and Russian thistle *(Salsola iberica).* Soils were loam to clay loam with the combined A and B horizons being 13–25 cm deep. The pH was 8.0, electrical conductivity (1:1 extract) was 0.3 mmhos/cm, organic matter was 1.7%, nitrate-nitrogen was 5 ppm (water extract), and phosphorus was 2.3 ppm (ammonium bicarbonate extract). Annual precipitation was 25–31 cm, with 50% falling in the form of snow.

Methods

Disturbance treatment plots (6 × 8 m) were established in the fall of 1976, 1977, and 1979 to determine the effects of weather fluctuations on natural revegetation and succession. The design was a randomized block design with 2 replicates of each treatment established annually. Four levels of soil disturbance were created as treatments:

Treatment 1: Vegetation was mechanically removed and the topsoil was left in place.

Treatment 2: Vegetation was mechanically removed and the soil was scarified to a depth of 30 cm.

Treatment 3: Vegetation was mechanically removed and 1 m of soil (A, B, and C horizons) was removed, mixed together and returned to the excavated area.

Treatment 4: Vegetation was mechanially removed. The top 1 m of soil was removed and stored. A second meter of soil was removed and stored. The first meter of soil was placed in the excavated area, and the second meter of soil was placed over the first meter of soil.

Vegetation was sampled annually in July using ten 0.25-m² permanent quadrats randomly placed in each treatment plot. Density, aboveground biomass, and percent canopy cover were recorded by species.

Potential seed reserves were estimated by removing 5 soil samples (15×15×3 cm) from each plot in the summer of 1981. Soil was placed in containers 5 cm deep in a greenhouse and watered to field capacity. Number and species of emergent plants were recorded daily for 28 days and tabulated.

The mycorrhizal infectivity of the soil was measured as percent infections (mycorrhizal inoculum potential or MIP) in corn bioassay plants as described by Moorman and Reeves (1979) and Schwab and Reeves (1981). Three samples from the upper 15 cm of soil were removed in 1978, 1979, and 1980 from each plot and composited; a bioassay was run on each soil to determine MIP. The bioassay plants were grown in soil samples for 21 days. For each treatment the roots of 5 plants were washed and cut into 10-cm pieces. One hundred root pieces (<2 mm in length) were randomly selected, fixed in 'FAA', stained using procedures described by Phillips and Hayman (1970), mounted on slides, and examined with a compound microscope. The percent infection was calculated as the number of infected segments per 100 samples.

Mycorrhizal data were examined using a one-way analysis of variance with mean separation tests. Vegetation was analyzed using multiple regression with treatment, MIP, and weather data as variables. Sheffe's multiple range test was used to separate vegetation means. In addition, Pearson's corelation was used to determine the relationship between MIP and vegetation.

Results and Discussion

Effect of Treatment on MIP

Mean MIP values generally decreased with increasing disturbance (Table 1). However, because of the variation between replicate plots, differences were not significant ($P<0.05$) between

Table 1. Mean MIP values on disturbance plots established in 1976, 1977, and 1979 and sampled in 1978, 1979, and 1980.

Year of plot disturbance	Sample date		
	Nov 1978	Jul 1979	Jun 1980
1976 Plots			
Treatment 1	23.0[a1]	55.0[a]	66.5[a]
Treatment 2	24.0[a]	44.5[b]	52.5[a]
Treatment 3	4.0[a]	13.0[c]	11.0[b]
Treatment 4	3.5[a]	11.5[c]	20.0[b]
1977 Plots			
Treatment 1	9.5[a]	49.5[a]	39.0[a]
Treatment 2	1.0[a]	21.0[b]	7.5[b]
Treatment 3	9.5[a]	16.5[b]	2.5[b]
Treatment 4	6.5[a]	10.0[b]	5.0[b]
1979 Plots			
Treatment 1	—[2]	33.5[b]	48.5[a]
Treatment 2	—	59.0[a]	49.5[a]
Treatment 3	—	29.0[b]	18.0[b]
Treatment 4	—	3.8[c]	1.0[b]

[1]Means with different letters within column and year of plot disturbance are significantly different ($P<0.10$).
[2]Plots were not established until 1979.

treatments until the third year following disturbance. Treatments 1 and 2 (least soil disturbance) exhibited greater and more rapid MIP recovery after soil disturbance than Treatments 3 and 4 (greatest soil disturbance) on plots disturbed in 1976 (Table 1). Recovery of MIP was rapid only in Treatment 1 in plots disturbed in 1977; for Treatments 2, 3, and 4, mean MIP values remained less than 10% the third year following disturbance.

Effect of treatment on vegetation

The level of soil disturbance affected the rate and type of plant succession following disturbance. Recovery of grasses was most rapid in Treatment 1 (Fig. 1); canopy cover values equivalent to grass canopy cover values on undisturbed areas were present by the second year following disturbance. The fourth year following disturbance, grass canopy cover on Treatment 2 was similar to cover on undisturbed areas, while grass cover on Treatments 3 and 4 was significantly less than cover values found on undisturbed areas throughout the study.

There was a negative correlation between grass production and cover, and intensity of soil disturbance ($r^2 = 0.79$ for biomass and $r^2 = 0.70$ for cover). The general reduction of grasses as soil disturbance increased can be attributed to differences in MIP, soil fertility, soil water holding capacity, and the presence of seed and rhizomes. Treatment 1 plots had the least disturbance and the highest MIP values. The perennial grasses composing 90% of the grass production on disturbed plots were mycorrhizal species dominated by western wheatgrass *(Agropyron smithii)*, slender wheatgrass *(A. trachycaulum)*, Indian ricegrass, and needle-and-thread grass. In general, it appears that typically mycorrhizal species,

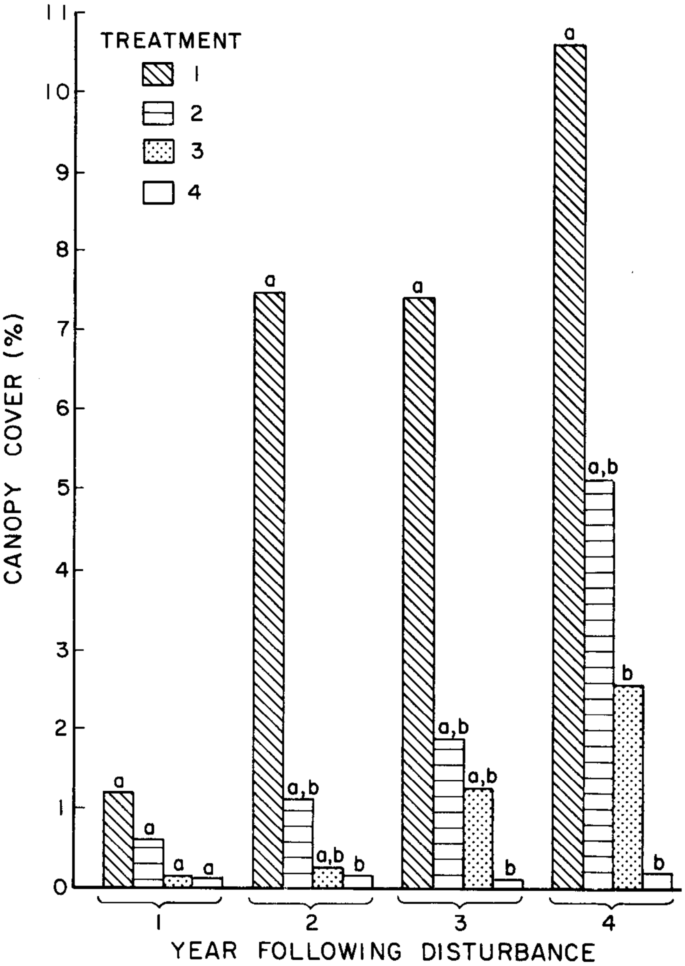

Fig. 1. *Mean canopy cover of grasses on disturbance treatments for each successive year following disturbance. Means with different letters within years are significantly different* ($P<0.10$). *Treatment numbers (1–4) represent increasing severity of soil disturbance, with Treatment 1 being the least severe and Treatment 4 being the most severe.*

when infected, establish more rapidly because of higher survival rates and have greater production than noninfected mycorrhizal plants (Aldon 1975, Powell 1980). The higher MIP values and therefore the higher potential infection in the least disturbed plots (Treatments 1 and 2) enabled species to have greater production (800 kg/ha) compared to production (110 kg/ha) on highly disturbed, low MIP plots (Treatments 3 and 4) in 1980. Soil structure was not changed greatly in Treatment 1 plots compared to Treatment 2, 3, and 4 plots. Soil disturbance will alter the structure of soil, and the breakdown of aggregates by compaction tends to reduce pore space resulting in reduced aeration. Although compaction initially increases micropore space, it may inhibit root penetration (McCormack 1974, Brady 1974). Soil bulk density measurements on nearby research areas with disturbances similar to Treatments 2 and 3 showed that bulk density increased with increasing disturbance when compared to undisturbed soil bulk density. This indicates that aeration and root penetration may have decreased in the moderately and highly disturbed plots (Treatments 2, 3, and 4). Seed and rhizome sources were highest in Treatment 1 plots (13.8 emergent plants/sample) at least in Treatment 4 plots (0.3 emergent plants/sample); seed sources in Treatment 2 and 3 plots were immediate (4 emergent plants/sample) due to the mixing of the top new centimeters of topsoil with underlying subsoil.

Forb canopy cover generally increased as disturbance increased (Fig. 2). Russian thistle, a nonmycorrhizal species, was the dominant forb on the disturbed plots, composing 80% of the forb

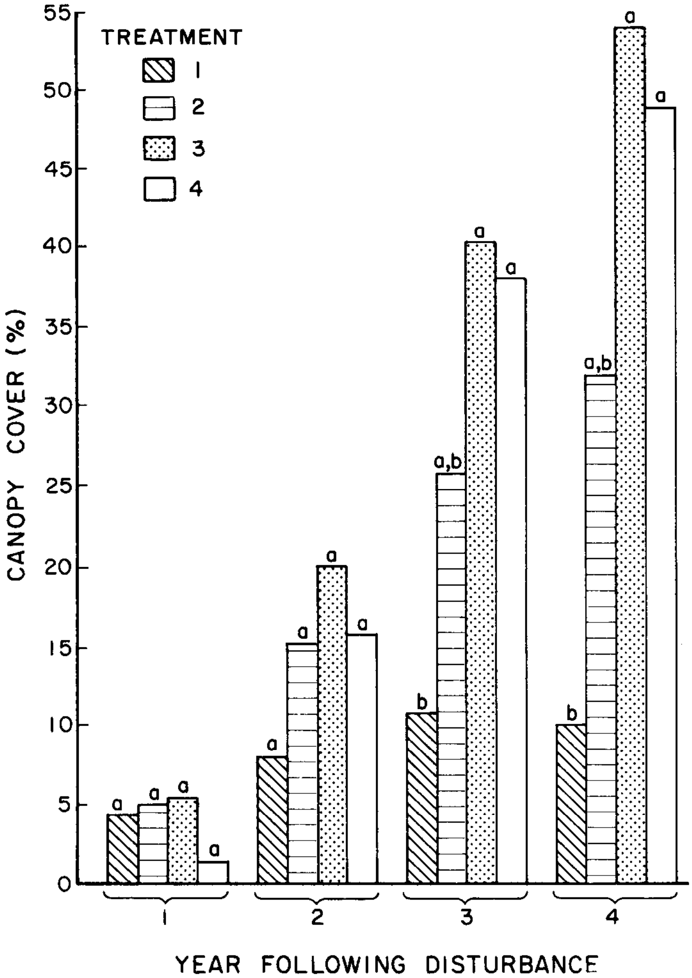

Fig. 2. *Mean canopy cover of forbs on disturbance treatments for each successive year following disturbance. Means with different letters within years are significantly different* ($P<0.10$). *Treatment numbers (1–4) represent increasing severity of soil disturbance, with Treatment 1 being the least severe and Treatment 4 being the most severe.*

community. The nonmycorrhizal nature of Russian thistle (Reeves et al. 1979) appears to offer a competitive advantage, when compared to grasses, for establishment on the highly disturbed, low MIP plots (Treatments 3 and 4). Russian thistle seed source was greater on Treatment 3 and 4 plots (95 emergent plants/sample) compared to Treatment 1 and 2 plots (40 emergent plants/sample) in 1981, but this represents establishment of the species in previous years. Phlox *(Phlox longifolia)* and scarlet globemallow *(Sphaeralcea coccinea)* were also present in the disturbed plots. Both species are perennial and mycorrhizal, and scarlet globemallow is rhizomatous (Reeves et al. 1979). Both species were less productive as disturbance increased (280 kg/ha to 26 kg/ha) on Treatments 1 and 4 plots, respectively. The lower production was attributed to a lowering of MIP, seed and rhizome sources, and competition with Russian thistle.

Establishment of shrubs was poor on all treatment plots 4 years after disturbance. Biomass and cover of big sagebrush, broom snakeweed *(Gutierrezia sarothrae)*, and Douglas rabbitbrush combined on all treatment plots averaged 116 kg/ha and 2.3%, respectively, which was still far below the levels found in surrounding native vegetation (280 kg/ha and 14.1%). Densities of shrubs in 1980 were no greater than 2 plants/m^2 compared with 4 plants/m^2 in the native vegetation.

MIP-Vegetation Relationships

Generally, biomass and cover of grasses were positively correlated with MIP. The correlation was generally greater than 0.90 ($P<0.05$) each sampling year. The exceptions were in 1980 on 1976 disturbance plots and in 1978 on 1977 disturbed plots when the correlations were 0.60. In 1980 on 1976 disturbed plots, the MIP values of Treatment 3 were below Treatment 4 values (Table 1) while the biomass and cover of grasses were significantly greater in Treatment 3 plots compared to Treatment 4 plots indicating that other factors, particularly microhabitat, can modify the effect of MIP on succession. The large variation of MIP values in 1978 on 1977 disturbed plots may have been caused by insufficient time for mycorrhizae in Treatments 1 and 2 to increase. MIP values on Treatments 1 and 2 in 1979 (Table 1) support these results. Grass production on 1977 plots increased in Treatments 1 and 2 from 80 kg/ha in 1978 to 220 kg/ha in 1980; this response correlates with the recovery of MIP and suggests 2–3 years are sufficient time for grasses to respond in the least disturbed treatments.

There was a poor negative correlation between forb biomass and cover and MIP. Correlations ranged from 0.08 to 0.90. These correlations often were confounded by annual weather fluctuations and competition with grasses.

The high correlations between MIP and grass production found in this study indicate that natural succession of mycorrhizal plants in semiarid environments is highly related to MIP. Similarly, the work of Lindsey et al. (1977), Aldon (1975), and Powell (1980) illustrated the increase in establishment and vegetation production of mycorrhizal species on disturbed lands. Another indication of the importance of MIP in succession is the mycorrhizal status of plants dominating the disturbed plots. Nonmycorrhizal Russian thistle was the dominant plant on low MIP plots while mycorrhizal grasses were the dominant species on high MIP plots. Reeves et al. (1979), Miller (1979), and Janos (1980) reported a similar relationship and suggested that if mycorrhizae are not present, the nonmycorrhizal species will establish first on disturbed sites. Reeves et al. (1979) also noted that on new volcanic islands, e.g., Surtsey (Lindroth et al. 1973) and Long Island (Ball and Glucksman 1975), pioneer plants were from typically nonmycorrhizal families. Since most higher plants are mycorrhizal (Slankis 1974), the high percentage of nonmycorrhizal species found to be successful invaders in disturbed sites with low MIP values supports the idea that mycorrhizal species are dependent on sufficient MIP levels to establish successfully on disturbed areas.

As anticipated, weather fluctuations affected etablishment and production of perennial grasses the first 2 years after disturbance. High levels of precipitation increased grass biomass while low amounts of precipitation were generally correlated with low grass biomass. However, grass production was virtually identical the third year after disturbance regardless of the year of disturbance. Grass densities remained relatively constant through time while biomass increased. This indicates that seedlings, which are more susceptible to moisture stress than mature perennials, composed a higher percentage of grass production the first year after disturbance, but by the third year established plants provided most of the grass production. Therefore, the effect of precipitation on grass production was minimized by the third year following disturbance. However, if drought conditions persisted for several consecutive years, then the effect of precipitation on perennial species would be more pronounced.

Forb biomass was also affected by annual weather fluctuations throughout the study. Forb production in 1979 was high (1500 kg/ha) with high summer (June, July and August) precipitation (4.4 cm) and low (1200 kg/ha) in 1980 when summer precipitation was low (3.8 cm). Most forbs were annuals and must establish from seed each year. Since Russian thistle and other forb seedlings have relatively shallow root systems, they are most susceptible to drought stress compared with established perennial plants with well-developed, lateral root systems (Piemeisel 1938). Therefore, precipitation is always important for establishment and subsequent production of annual species each year.

Conclusions

No single factor consistently affects succession the same way or at the same rate. The intensity of disturbance affected the establishment rate and species that were successful. Mycorrhizal grasses and perennial forbs were more successful on least disturbed plots while nonmycorrhizal annuals were more successful on highly disturbed plots. If perennial grasses are desired, then disturbance should be minimized, topsoil should not be mixed with subsoil, and topsoil should be used as the upper most growing medium.

Annual weather fluctuations affected vegetation production as expected. Dry years (<23 cm precipitation) appeared to retard perennial grass establishment and annual forb production but did not significantly affect previously established perennial grass production.

Levels of MIP appeared to be an indicator of the type and rate of plant succession that will evolve after soil disturbance. However, modifying factors including water holding capacity, the presence of seed and rhizomes, and other environmental factors make MIP only a general indicator and not a precise predictor. Parkinson (1978) suggested that a knowledge of belowground systems, and mycorrhizal relationships in particular, is as important as aboveground information in understanding the mechanisms of plant recovery following disturbance. This study supports the importance of examining mycorrhizae-plant relationships in successional studies as suggested by Reeves et al. (1979), Miller (1979), Janos (1980), and Powell (1980).

Stochastic processes on highly disturbed soils with low MIP values will be particularly important in determining succession. The fortuitous association of a viable seed with viable propagules of VAM fungi is a function of disturbance. When the population of viable VAM fungi is reduced to a point where the chances of infection of a seedling are very low, then the chances of seedling survival are reduced. Since these fungi are obligate symbionts, the viable population is expected to decrease with time on soils without mycorrhizal hosts further reducing the chances of a seedling to become mycorrhizal.

The net effect of such reductions in MIP or mycorrhizal infectivity of a soil will prolong the time necessary for recovery to a stable community wherein most species are mycorrhizal. These results emphasize the importance of preserving the necessary and beneficial microbiological components in soils if successful reclamation practices are to be developed. Further, these results may have profound significance for microbiological changes that occur in topsoil stored for long periods of time before being used for reclamation.

The importance of MIP in determining the short-term rate and direction of succession supports the use of mycorrhizal inocula in improved reclamation of disturbed lands (Khan 1981). However, long-term effects of mycorrhizae on native plant succession needs to be addressed to determine the long-term benefits of mycorrhizae on community stability.

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Repellent Effects on Distribution of Steers on Native Range

D.M. ENGLE AND J.G. SCHIMMEL

Abstract

Range livestock production and uniform use of ranges are often limited by poor distribution of livestock over the range. A repellent was applied to preferred grazing areas (subirrigated range sites) of a mixed prairie range in northcentral South Dakota. Cow chips were used as a measure of occupation of yearling steers on sites where the repellent was applied. Comparison sites did not receive a repellent application. There was no significant difference in chip numbers between the 2 treatments. However, there was a nonsignificant short-term decline in cow chips deposited on repellent-sprayed subirrigated sites. Steers appeared to be marginally displaced from the sprayed subirrigated sites to adjacent unsprayed silty range sites.

Proper use of a range, although dependent upon many factors, is often complicated by poor distribution of livestock. Animals naturally congregate at preferred locations. Cattle prefer accessible areas such as valley bottoms, low saddles between drainages, level benches, mesas and areas adjacent to water sources. Drainageways often receive additional run-in moisture from surrounding slopes. The additional moisture results in a continuous supply of palatable, regrowth forage during the growing season which attracts cattle and leads to overutilization. The same areas are sometimes critical habitat areas for wildlife or critical management areas for other uses. Areas which are steep, rough, or are distant from water are least preferred by cattle and are usually underused or unused (Mueggler 1965; Cook 1966). Overgrazing of a range is commonly a result of nonuniform distribution in which the preferred use areas are overused and nonpreferred areas are underused. By obtaining more uniform use of an entire range, range condition may be improved on the preferred areas. Uniformity of use allows increased stocking rates without attendant overuse of any area on the range.

Salting, an inexpensive method to improve distribution of use in underused areas, may not be effective in reducing utilization near water (Martin and Ward 1973). Water developments can be used effectively to control utilization, but usually require construction of additional watering facilities, controlling access to water sources, or hauling water. Drift fences or cross fences effectively control access to preferred areas. Fences and water developments are usually permanent and costly range improvements. Roads and trails have been found to be effective in improving access and use of inaccessible areas (Workman and Hooper 1968), but do not appear to reduce use on preferred areas (Roath and Krueger 1982). Generally, management practices to improve uniformity of grazing use have been designed to prevent access to preferred areas (e.g. fences) or to attract animals to nonpreferred areas (e.g. water, salt or trails). To our knowledge, no studies have been conducted on practices or methods used to repel livestock from preferred use areas. This study was designed to test the effectiveness of a repellent to deter steer occupation of preferred areas.

Authors were assistant professor and instructor, Department of Animal and Range Sciences, South Dakota State University, Brookings 57007. Currently Engle is associate professor, Agronomy Department, Oklahoma State University, Stillwater 74078, and Schimmel is Extension livestock specialist, South Dakota State University, West River Agricultural Research and Extension Center, Rapid Center, S. Dak.
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Methods and Materials

The study was conducted in 1982 on the Samuel H. Ordway Memorial Prairie in northcentral South Dakota, about 10 km west of Leola. The area is mesic mixed prairie in the glaciated pothole region of the Northern Great Plains. Topography of the area is gently undulating to undulating with slopes of less than 6%. Drainage patterns on these glacial till plains are not well developed so that the landscape is characterized by dry uplands interrupted by mesic, often ponded depressions (potholes). These depressions are a minor portion of the land area. The average annual precipitation at Leola is approximately 50 cm with a single peak of 10.5 cm in June. Precipitation during the study period was slightly above the average in May and July and 33 and 80% below average in June and August, respectively. Vegetation is dominated by a mixture of mid and tall grasses. Big bluestem *(Andropogon gerardii)*, a warm-season grass, and Kentucky bluegrass *(Poa pratensis)* are the dominant species of depressions. Green needlegrass *(Stipa viridula)* and Kentucky bluegrass, both cool-season species, dominate the upland sites. In most years the depressions provide additional run-in water for forage growth, which results in continuous, season-long, heavy grazing pressure on these sites. Cool-season species on upland sites usually mature early in the grazing season as soil water is depleted. Grazing pressure is concentrated on vegetation in depressions because of continuous forage growth throughout the summer.

The 162-ha study pasture was grazed with yearling steers at approximately 1.7 AUM's/ha from May 28 to August 28. Steers weighed an average of 330 kg at the beginning and 358 kg at the end of the study period.

In mid-June 13 potholes in the study pasture contained ponded water. Treatments were randomly assigned to these potholes. On July 20, a commercially available deer and elk repellent with an active ingredient of putrescent whole egg solids was applied in a liquid spray at about 140 l/ha to a narrow band of vegetation encircling 6 potholes. The mid-season treatment date was selected since it was believed that substantial grazing pressure on subirrigated range sites would not normally occur until late July. The treated vegetation was dominated by big bluestem, characteristic dominant of the subirrigated range site. Seven other potholes were selected for comparison and were not treated with the repellent.

Distribution of yearling steers were measured by bi-weekly cow chip counts on 2 belt transects (3m × 30m) located at each pothole. To avoid double counting, newly deposited cow chips were identified by spray paint at each enumeration date. One transect was located along the edge of the pothole in the big bluestem dominated vegetation (subirrigated range site) and the other was located 25m upslope in green needlegrass-Kentucky bluegrass dominated vegetation (silty range site). Cow chip counts have been suggested as an indicator of relative time spent on various areas of a range (Julander 1955, Mueggler 1965, Cook 1966).

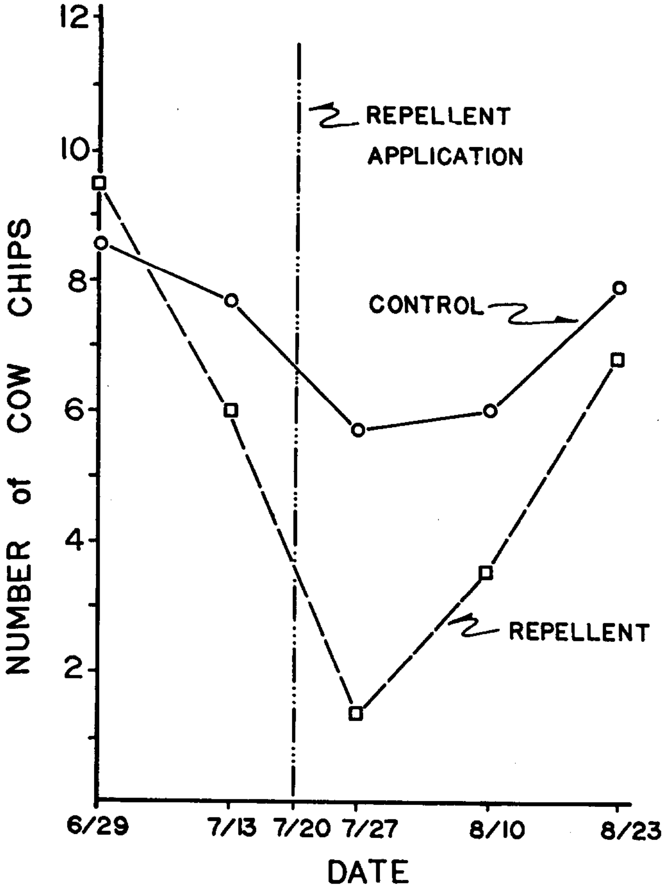

Fig. 1. *Least squares means of cow chip numbers on subirrigated range sites.*

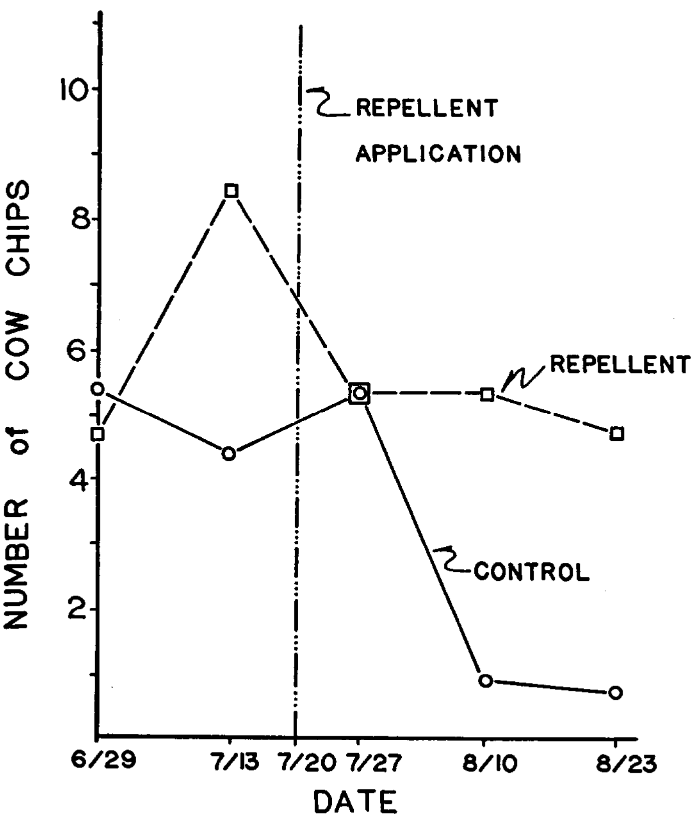

Fig. 2. *Least squares means of cow chip numbers on silty range sites.*

Analysis of variance was performed on cow chip data by the General Linear Model procedure in the Statistical Analysis System (Barr et al. 1979). Data from 5 cow chip counts were analyzed as split plots over time. Tukey's *w*-procedure was used to compute range values for mean separations (Steele and Torrie 1960). The 2 hypotheses tested in this analysis were: (1) The repellent was effective in controlling the grazing distribution of yearling steers, and (2) the repellent was equally effective in repelling yearling steers from repellent sprayed subirrigated sites and adjacent silty range sites.

Results and Discussion

The least squares means of the number of cow chips counted by dates were: 7.04 on June 29; 6.66 on July 13; 4.47 on July 27; 3.92 on August 10; and 5.02 on August 23. Less than 1.0% of the variation in cow chip numbers was accounted for by treatment. Steers deposited significantly more ($P<.05$) fecal groups on the subirrigated than the silty sites (6.30 and 4.54, respectively) over the entire study period.

The effect of the repellent on occupation of yearling steers as estimated by cow chips is shown in Figures 1 and 2 for subirrigated and silty range sites, respectively. The repellent did not significantly affect the number of cow chips counted on any date on either site. Although not statistically significant there was an indication that the repellent was responsible for a short-term decline in cow chips deposited on the subirrigated site. Later in the growing season (8/10 and 8/23), the number of cow chips deposited on the repellent silty range sites adjacent to repellent treated subirrigated sites stayed at a high level whereas there was a decrease in the cow chips deposited on the control silty sites. Also, the mean number of cow chips counted for all sampling dates was significantly higher on silty range sites adjacent to repellent treated subirrigated range sites than on control silty range sites. This indicates a marginal displacment of the steers from the repellent-treated subirrigated site.

Cattle possibly develop preferred areas early in the grazing season. At the time of the repellent application (July 20), precipitation was below the monthly average and forage on silty sites had ceased active growth. Steers were probably attracted by lush, actively growing vegetation on the subirrigated sites by early June. To protect conifer seedlings from deer and elk browsing the repellent manufacturer's label instructions suggest application at the onset of browsing. In this study the repellent was applied after steer grazing preferences were probably fixed. An earlier application of the repellent may have increased its effectiveness.

Further studies with repellents to manipulate distribution of livestock on rangelands are warranted. In cases where management alternatives prohibit the application of conventional distribution techniques, repellents may offer a viable method of obtaining selective nonuse of rangelands.

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Stream Water Quality as Influenced by Beaver within Grazing Systems in Wyoming

QUENTIN D. SKINNER, JOHN E. SPECK, JR., MICHAEL SMITH, AND JOHN C. ADAMS

Abstract

Stream water flowing from watersheds subjected to continuous and deferred rotation grazing by livestock was sampled to enumerate bacteria for detecting differences between grazing treatments and streams. Fecal coliforms, fecal streptococci, total counts at 20° C, and bacteria capable of fluorescing under long wave radiation were selected as indicators of pollution. The study was conducted two summers, 1979 and 1980, on mountain rangeland near Laramie, Wyo. Bacteria counts for different indicator groups varied in their ability to detect change between grazing treatments as well as between streams. Fluorescing bacteria and total counts were of little value in explaining nonpoint source pollution whereas fecal coliform and streptococci were. Variation in counts of fecal coliform and streptococci could not be fully accounted for by differences in grazing management but is partially explained by beaver damming of stream flow. Given that beaver impoundment of selected stream reaches is equal, variation in nonpoint pollution may be caused by differences in grazing treatments.

Recently the role of livestock grazing in causing nonpoint pollution to stream flow has received attention (Stephenson and Street 1978, Doran and Linn 1979, Jawson et al. 1982). To help differentiate best management practices for grazing livestock on native rangeland, bacterial indicators of pollution must be determined.

Many researchers have observed elevated fecal coliform and fecal streptococci counts in streams draining grazed rangeland (Morrison and Fair 1966, Kunkle and Meiman 1967, Stevenson and Street 1978, Doran and Linn 1979, Jawson et al. 1982). Declining counts of these bacteria were observed in the streams in pastures after the removal of livestock (Kunkle and Meiman 1967, Skinner et al. 1974b, Milne 1976, Skovlin et al. 1977, Duff 1978, Doran and Linn 1979). Variations in fecal coliforms in streams have been partially explained by rainfall runoff (Doran and Linn 1979, Jawson et al. 1982) deferred grazing management, animal density, access to streams, as well as physical, hydrologic and biological characteristics of drainage basins (Stephenson and Street 1978). In contrast Buckhouse and Gifford (1976) were unable to detect any significant changes in bacterial contamination associated with cattle grazing on watersheds using rainfall simulation to create overland flow. Milne (1976) and Stephenson and Street (1978) have found that livestock being fed on irrigated pastures during winter have a significant effect on bacterial contamination of adjacent streams. Milne (1976) reported, however, that this high contamination was short lived and quickly declined with the cessation of grazing. Bacterial concentrations have been shown by many to vary with stream flow (Morrison and Fair 1966; Kunkle and Meiman 1967; Skinner et al. 1972, 1974b; Stevenson and Street 1978; Jawson 1982).

Indicator bacteria have been found to be more numerous in sediments than overlying water (Hendricks 1971, VanDonsel and Geldrich 1971, Matson et al. 1978). Disruption of sediment has been found to increase fecal coliforms in the overlying water (Grimes 1975). Stephenson and Street (1978) inferred and Stephenson and Rychert (1982) confirmed settling of organisms in sediment could explain higher counts in streams at times when livestock were not present. These studies suggest that it is important to sample both sediment and overlying water to obtain an accurate evaluation of water quality in pastured lands. In addition to sedimentation, increased numbers of indicator bacteria may result from release of cells growing in algae mats (McFeters et al. 1977). They stated that stream aspect, shade, depth, and temperature were important for sustaining algae growth which allowed growth of trapped indictor bacteria.

Johnson et al. (1978) reported that suspended solids in a stream typical of those draining the front range of Colorado were higher in a nongrazed pasture than in an adjoining downstream grazed pasture. Removal of beaver dams in the nongrazed pasture was thought to be the probable cause of the increased suspended solids in the stream. Foote (1937) found little effect of beaver upon the numbers of the coli-aerogens group of bacteria in water above and below beaver ponds. However, he stated that under certain circumstances beaver could excrete large numbers of these organisms.

The purpose of the present study was to monitor change in bacterial counts within streams flowing through 2 different large pasture grazing systems. Beaver activity was prevalent on streams flowing through the study region. Their possible role in explaining differences found in bacteria counts between grazing systems and streams was investigated. Null hypotheses tested include (1) there were no differences in bacterial counts between grazing systems and (2) and there were no differences in bacteria counts between streams studied.

Study Area

This study was conducted in the Pole Mountain District of the Medicine Bow National Forest, located in the southern extension of the Laramie Mountains of southeastern Wyoming. This area is located between Laramie, Wyo., 18 km to the west, and Cheyenne, Wyo., 46 km to the east. Elevation of the study area is between 2,608m (west) and 2,250m (east). The climate of this region is semiarid. Average annual air temperature is 3.3 to 4.4°C and the frost-free period is approximately 60 days. Average precipitation is approximately 430mm.

The streams in the Pole Mountain District flow in a west to east direction. During the recorded years 1933-1969, peak flow occurred 29% of the time in April, 44% in May, and 26% in June for stream G (Fig. 1) a representative stream of the region (USGS 1964). Low flow occurs in September and remains constant through winter months. Annual runoff for this stream is about 2.96 million m^3 (USGS 1964).

Upland soils of the Pole Mountain District are granite derived. Soils along streams are cumulic cryaquolls, Silas Venable Association (Soil Conservation Service, unpublished soil survey, 1981). Vegetation can generally be described as a ponderosa pine *(Pinus*

Authors are associate professor, former graduate student, and assistant professor Division of Range Management; and associate professor, Division of Microbiology and Veterinary Medicine, College of Agriculture, University of Wyoming, Box 3354, Laramie 82071.

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ponderosa savanna (Daubenmire 1943). Cattle are grazed under 2 management systems: continuous season-long and deferred-rotation, from June 1 until October 15. The only continuous system, the Lodgepole allotment, has a gross area of 4,815 ha, 3,481 of which are open and usable for grazing (Johnson 1958). The grazing rate of this allotment is 1.34 ha per animal unit month (AUM).

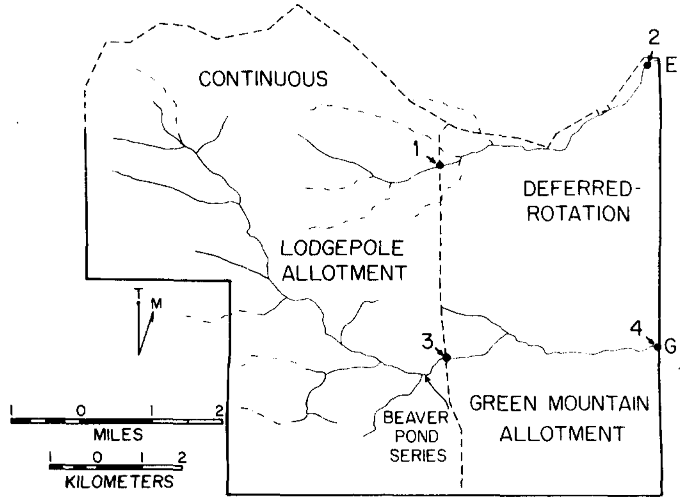

Fig. 1. *Water sampling sites in the Lodgepole (continuous) and Green Mountain (deferred-rotation) allotments of the Pole Mountain District.*

The deferred-rotation allotments used in this study encompass 3,785 ha, 3,633 of which are open and usable for grazing (Johnson 1958). This four-pasture system completes a rotation in the sequence of use every 4 years. Each pasture is grazed only once during the grazing season, and over 4 years each is grazed at a different time of the grazing season. The stocking rate is 1.58 ha per AUM.

Methods

Bacteria and sampling sites: fecal coliforms, fecal streptococci, the aerobic plate count on modified Henrici's agar at 20°C and flourescent bacteria were monitored. Samples for bacterial analysis were collected every other week from June 1 to October 15, 1979 (grazing season) and May 1 to June 1, 1980 (spring runoff), June 1 to October 15, 1980 (grazing season) from 4 sites located on 2 streams flowing through 2 grazing systems (Fig. 1). This sampling scheme was initiated to follow the decline of spring snowmelt runoff and base flow during summer and fall months. In addition, 1 sample was collected every other day for 10 days from August 10 to 20, 1979 and 1980 (intensive periods). This was done to improve the estimate of bacterial concentrations in streams during low flow conditions.

Basin parameters: total stream, main stream and perennial stream lengths and drainage basin area were calculated for 2 streams. Calculations were made using a map wheel and planimeter from topographic maps (USGS - 15 minute series). Stream flow data from Call (1966) and McDowell (1975) provided yearly flow patterns and relative discharge of respective streams.

Effect of beaver on bacterial numbers: fecal coliforms and fecal streptococci were monitored to evaluate the entrapment of bacteria in beaver ponds. A 3-pond series located on stream G, just above site 4 within the continuous grazing system, was selected for collecting water samples just above and below each pond. Sediment cores were collected at 5 points within each pond. Each pond above as well as below was sampled once. Water and sediment samples were compared for difference in the number of organisms above, below, and in ponds.

Number of ponds, impoundment differential, and percent sediment deposition were measured for streams G and E. A measuring rod was placed at the edge of the dams in the lowest point in the stream channel and vertical distance to a point horizontal to the dam's highest point was recorded. A second measurement in the same manner on the upstream edge of the dam to record distance from top of accumulated sediments to top of dam was made. The upstream measurement was then divided by the downstream measurement. This quotient (impoundment differential) represents the potential of ponds for trapping additional sediment. The quotient, subtracted from 1 and multiplied by 100, represents sediment accumulation in ponds and is referred to as percent sediment deposited.

Bacterial sampling and processing: water samples were grab samples collected aseptically from streams in sterile 1-liter plastic bottles. Sediment samples were obtained by pushing a sterile kimkap test tube closure (16mm) into the sediment. Collections were made at sites in a consistent sequence between 1 and 4 p.m. and were packed in ice and processed within 5 hours of collection.

Total counts of aerobic heterotrophs were made by the spread plate method on a modified Henrici's medium (Stark and McCoy 1938). The plates were incubated for 7 days at 20°C to allow for maximum growth to occur (Skinner et al. 1974a). The plates were then placed under long wave ultraviolet light, and colonies capable of fluorescing were recorded (Skinner et al. 1974b, McTernan et al. 1974). Fecal coliforms and fecal streptococci were enumerated by membrane filtration (Standard Methods 1976) using 0.7 micrometer (Millipore-HC) gridded filters. The medium used for fecal coliform was MFC-broth while KF agar was used for fecal streptococci.

Statistical analysis: The analyses of collected data were carried out utilizing an analysis of variance (ANOV) with a completely randomized design. A least squares procedure was applied to data with unequal sample sizes within treatments. Tests were evaluated at the 1%, 5%, and 10% confidence level for significant differences.

Results and Discussion

Grazing Systems

Fluorescent bacteria: Counts of these organisms in stream E and G ranged from 0.1 to 56/ml (Table 1). Collins (1963) and Silvey and Roach (1964) found these bacteria in significant numbers in surface waters. Rovira and Sands (1971) found that fluorescent pseudomonads were unevenly distributed in soils, were associated with particulate organic matter, and may be carried by water. Johnstone (1970) implied that these organisms might be useful indicators for monitoring eutrophication between stream reaches. We found no significant differences or distinct trend in counts between grazing treatments. This suggests that fluorescent bacteria were not influenced by different grazing management systems and livestock in this study.

Aerobic Bacteria: Total counts of aerobic bacteria between grazing treatments from stream E and G were not significantly different except during spring runoff 1980 in stream E (Table 1). There was no difference between total counts for streams except during the 1979 grazing season. Because concentrations of bacteria were generally not different between grazing systems, this bacteriological test does not appear useful for evaluating effect of livestock grazing management practices on water quality.

Fecal Coliforms: During the 1979 grazing season and the period of runoff in the spring of 1980 no significant differences between grazing treatments occurred for streams E and G. Higher concentrations of these organisms were observed in the deferred rotation treatment during the intensive sampling period in 1980. These high counts may have been caused by recreational activity of humans. This statement is supported by the location of sites E2 and G4 below recreation facilities. During this sampling period in August, recreational activity on the flood plain was observed during sampling. Recreational activity was not observed during the intensive sampling period of 1979. Varness et al. (1978) suggested that changes in fecal coliform counts obtained in a stream system in

Table 1. Bacteria concentrations sampled from streams flowing through continuous and deferred-rotation grazing systems.

Bacteria sampled	Stream E		Stream G		Streams E and G[a]	
	Grazing systems[a]		Grazing systems[a]		E	G
Sampling period	Continuous (Site 1)	Deferred (Site 2)	Continuous (Site 3)	Deferred (Site 4)	(Sites 1&2)	(Sites 3&4)
Fecal coliforms/100ml						
Grazing season 1979	140.0	162.0	30.0	37.0	150.0**	34.0
Intensive period 1979	230.0	180.0	141.0	139.0	200.0	140.0
Spring runoff 1980	44.0	21.0	9.0	12.0	25.0*	8.0
Grazing season 1980	250.0	148.0	31.0	65.0	200.0*	48.0
Intensive period 1980	46.0	370.0***	27.0	70.0*	200.0*	48.0
Fecal streptococci/100ml						
Grazing season 1979	140.0***	75.0	47.0	87.0	110.0**	67.0
Intensive period 1979	20.0	18.0	67.0	27.0	193.0	472.0
Spring runoff 1980	1,100.0**	400.0	540.0	1,000.0***	664.0	666.0
Grazing season 1980	1,700.0***	500.0	235.0	1,180.0**	1,100.0	700.0
Intensive period 1980	800.0***	178.0	130.0	1,000.0***	500.0	582.0
Fecal coliform Fecal streptococci ratio						
Grazing season 1979	1.0	2.0	0.8	0.5	1.0	0.5
Intensive period 1979	1.0	1.0	0.3	0.5	1.0	0.3
Spring runoff 1980	0.1	0.1	0.1	0.1	0.04	0.01
Grazing season 1980	0.4	0.7	0.3	0.1	0.2	0.07
Intensive period 1980	0.1	2.0	0.2	0.1	0.4	0.08
Aerobic bacteria/ml						
grazing season 1979	14,300.0	11,300.0	33,500.0	26,000.0	12,800.0	30,000.0**
Intensive period 1979	20,000.0	15,500.0	52,880.0	25,700.0	18,000.0	39,000.0
Spring runoff 1980	27,200.0***	14,500.0	25,300.0	20,000.0	24,000.0	26,000.0
Grazing season 1980	35,600.0	11,220.0	20,000.0	31,700.0	23,400.0	25,800.0
Intensive period 1980	25,200.0	21,100.0	24,200.0	47,000.0	23,200.0	35,600.0
Fluoresent Bacteria/ml						
Grazing season 1979	56.0	33.0	22.0	15.0	45.0**	19.0
Intensive period 1979	12.0	10.0	13.0	17.0	11.0	15.0
Spring runoff 1980	30.0	35.0	26.0	29.0	38.0	34.0
Grazing season 1980	3.0	1.0	0.1	0.1	0.3	0.1
Intensive period 1980	0.1	0.1	0.1	0.1	0.1	0.1

[a]Means identified by ***(α=.01), **(α=.05), or *(α=.10) were significantly larger than comparable mean for grazing system or stream.

Washington were related to direct user pressure of streams and adjacent areas.

Fecal Streptococci: Significantly higher concentrations of these organisms were observed in water flowing from the continuous treatment for stream E. In contrast stream G had higher concentrations in water flowing from the deferred rotation grazing treatment.

Fecal streptococci may indicate contributions of fecal pollution to streams by warm-blooded animals (Geldrich and Kenner 1969, Geldrich 1970, Geldrich 1976). However, *Streptococus bovis,* a predominant species in the microflora of cattle feces, implicates livestock as the contaminating source (Doran and Linn 1979). *Streptococcus bovis* was not enumerated in this study. Contribution of these organisms to streams E and G by livestock is implied by the stream's presence in grazing systems. Doran and Linn (1979) found that fecal coliform/fecal streptococci ratios below 0.05 were indicative of wildlife sources, and ratios above 0.1 were indicative of wildlife sources, and ratios above 0.1 were characteristic of grazing cattle. The range of fecal coliform/fecal streptococci ratios (0.04 to 2) found in this study indicates that the source of the streptococci in streams E and G was wildlife and livestock.

Because opposite results were obtained between grazing systems for streams E and G, we assumed there may differences in streams. These differences may possibly be explained by some drainage basin characteristic.

Streams

Overall stream E had higher fecal coliform and fecal streptococci counts during the 2 grazing seasons than did stream G (Table 1). Assuming even distribution of animals per unit stream length or basin area one would expect higher concentrations of bacteria in flow with increased potential for receiving overland runoff to channels. The total length and basin area of stream E was approximately ½ that of stream G (Table 2) but yet had significantly

Table 2. Drainage basin characteristics for stream E and G.

Stream	Total stream length (km) (All tributaries)	Main stream length (km) (No tributaries)	Perennial stream length (km) (No tributaries)	Drainage Basin (ha)	Representative* Stream flow (m^3/sec) August 15th
E	23.2	9.7	9.7	2857	0.001
G	40.2	16.4	33.6	5609	0.021

*From Call 1966 and McDowell 1975

higher fecal coliform concentrations in the water during the grazing season. Perennial stream length of stream E is approximately 1/3 that of stream G. If animal distribution is concentrated within stream side habitats then one would expect the longer perennial stream length to carry more organisms. This was not the case here.

Differences in amount of flow between streams could be related to higher fecal coliform and streptococci counts in stream E. Stream G with more flowing water would enhance the chance for dilution of organisms and with increased depth be cooler. Less flow in stream E could be conducive to concentration of nutrients, increased water temperature, and growth of algae. These factors could in turn promote additional reproduction of trapped indicator organisms (McFeters et al. 1977). Higher fluorescent counts in 1979 (Table 1) may suggest nutrient increase in stream E (Johnstone 1970). Periodic increase in flow would increase counts downstream through flushing of algae and sediments (McFeters et al. 1977, Stephenson and Rychert 1982).

The higher fecal streptococci counts found in water flowing through the continuous grazing Stream E and deferred rotation grazing system of Stream G were not fully explained by estimated differences in amount of flow between the 2 streams. The rate of flow through a watershed should be independent of present grazing treatment during any segment of the water year. Beaver activity however in either drainage basin could manipulate flow patterns within any stream reach. The presence of beaver and their activity was not the same on both streams and thus might have affected the observed bacterial numbers within the streams.

Beaver

In 1980 the beaver ponds were surveyed on stream E and G (Table 3). Stream E had a total of 16 ponds at 4.03 ponds per km of stream compared to 192 ponds at 30.35 per km of stream on G. The presence of beaver ponds could cause entrapment of organisms by reducing the velocity of stream flow thereby causing bacteria to settle from stream water to bottom sediment. Stream G had the highest number of beaver ponds and also had significantly lower fecal coliform and streptococci concentrations (Table 1). It appears that entrapment of organisms may be greater on G resulting in lower fecal bacteria counts in water while total bacterial counts increase with water impoundment. Possibly, growth and multiplication of some members of the bacteria were enhanced by environmental conditions in beaver ponds.

Bacterial counts responded between grazing systems on the same stream in a similar manner. On stream G the continuous system had 41.08 ponds per km of stream, compared to 12.31 ponds per km in the deferred system. Numbers of fecal streptococci were higher for the deferred system (Table 1). On stream E there were 1/3 as many beaver ponds on the continuous as on the deferred system. Higher numbers of fecal streptococci were recorded for the continuous treatment (Table 1). Even though the deferred system had more ponds, the number of ponds per km was similar at 2.94 in the continuous allotment and 4.61 in the deferred allotment. Number of beaver ponds alone may cause differences in bacterial counts in stream flow but does not help explain if one grazing treatment contributes more nonpoint source pollution than does another.

Beaver ponds may be active or abandoned. Newly built and active ponds normally have a greater capacity to store water because less sediment has been trapped. Flood waters behind new dams may dissipate channel flow, thereby reducing stream flow velocity within ponds. Abandoned or older dams are likely to be partially filled with sediment. In this case stream flow would be directed towards a channel within the pond and flow velocity would likely increase, resulting in more scouring of sediments and less deposition of organisms than in newer ponds.

A difference existed in the efficiency of trapping sediment by beaver ponds between grazing systems for stream G (Table 3). The continuous system had a greater average potential for sediment deposition with a differential of 0.71 or 29% of the pond's capacity was filled with sediment. In the deferred treatment 45% of the ponds' capacity was filled with sediment. The continuous grazing system with the highest impoundment by beaver dams had the highest potential value for trapping sediment. Bacterial counts were lower with the higher impoundment differential. In stream E the impoundment differential and percent sediment deposited behind beaver dams between grazing treatments was similar between grazing systems (Table 3). Fecal streptococci counts however were not. Counts were significantly higher for this indicator group in the continuous system (Table 1). This seemed to indicate that on stream E with approximately equal water impoundment, bacterial counts were responding to differences in grazing systems. On stream G it appeared that water impoundment may have masked the effect of grazing systems and their contribution to nonpoint source pollution of streams.

Fecal coliforms of water and sediment samples taken from a series of 3 beaver ponds were 13 times more numerous in the sediment samples than they were in water samples (Table 4). There

Table 4. Bacterial counts of water and sediment samples taken in a beaver pond series on the Middle Fork of Crow Creek in the Green Mountain (deferred-rotation) allotment in 1980.

Beaver Pond	Indicator group	Water counts[a] Above	Water counts[a] Below	Sediment Counts[b]
1	Fecal coliforms	32	19	476
	Fecal streptococci	245	375	797
	FC/FS ratios	0.13	0.05	0.60
2	Fecal coliforms	24	31	235
	Fecal streptococci	355	345	456
	FC/FS	0.07	0.09	0.52
3	Fecal coliforms	24	20	324
	Fecal streptococci	280	400	2811
	FC/FS ratios	0.09	0.05	0.12
$\bar{X}$	Fecal coliforms	27	23	345
	Fecal streptococci	293	373	1355
	FC/FS ratios	0.09	0.06	0.25

[a]Count per 100 ml of water.
[b]Count per 100 grams of sediment.

Table 3. Beaver impoundment on the main channels of the streams in the continuous and deferred-rotation system—1980.

Streams	Grazing treatments[b]	Number of ponds	Number of ponds per (km) of stream	Impoundment[a] differential	Percent sediment[a] deposited
E	C	4	2.94	0.82	18
	D-R	12	4.61	0.88	12
	C plus D-R	16	4.03	—	—
G	C	163	41.08	0.71	29
	D	29	12.31	0.55	45
	C plus D-R	192	30.35	—	—

[a]Average of all ponds in streams or grazing systems
[b]=Continuous, D-R = Deferred Rotation

were 3 times as many fecal streptococci in the sediment samples.

Water samples collected above and below ponds suggested settling of fecal coliforms occurred (Table 4). These organisms were more numerous in the influents to ponds 1 and 3 than they were in the effluents. In pond 2 fecal streptococci were also less numerous in the effluent. Beaver might be a point source of pollution by contributing bacteria to stream flow as a result of excretion and by stirring sediments. This might explain the higher number of fecal coliforms in the effluent of pond 2 and the fecal streptococci being more numerous in the water below ponds 1 and 3.

This work extends that of Stephenson and Rychert (1982) and Jawson et al. (1982) to other grazing systems. It follows the findings of Stephenson and Rychert (1982) that water samples alone may be insufficient to assess the impact of grazing upon bacterial water quality and that sediments also need to be sampled. It suggests that beaver ponds may have an influence upon the numbers of bacteria in water. In addition it indicates that bacterial numbers determined for different stream within the same grazing system may not be similar and that results from one stream with a grazing system should not be considered to be representative of other streams flowing through similar systems. Various bacterial populations can be useful as indicators of grazing and other user impacts on rangeland. To be useful significant change must be observed and correlated to a specific user or watershed condition.

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Water Stress of Tallgrass Prairie Plants in Central Oklahoma

D.R. HAKE, J. POWELL, J.K. MCPHERSON, P.L. CLAYPOOL AND G.L. DUNN

Abstract

The predawn xylem water potentials of *Andropogon gerardi, Schizachyrium scoparium, Panicum oligosanthes, Sporobolus asper, Ambrosia psilostachya, Psoralea tenuiflora* and *Solanum eleagnifolium* were determined by the pressure equilibration chamber method during the 1980 growing season in a Central Oklahoma tallgrass prairie. Water potentials declined rapidly after June indicating high levels of water stress in all species. The decline in plant water potential for *Schizachyrium scoparium,* and to a lesser extent, *Panicum oligosanthes,* was much greater than that for the other 5 species. *Andropogon gerardi* apparently avoids dehydration by having a deep root system, whereas *Schizachyrium scoparium* survives in spite of a high degree of dehydration. Aboveground live biomasses declined sharply at about the same time plant water potential values decreased sharply. Results indicate plant water potential data are useful for interpreting range plant growth responses and predicting adaptability of species to harsh growing conditions.

The soil water supply in Central Oklahoma grasslands, as in the majority of all rangelands, is often inadequate for optimum plant growth throughout much of the growing season. When transpiration exceeds water absorption a decline in plant water potential results, inducing water stress (Kramer 1969, Slatyer 1967). Hsiao et al. (1976) stated that cell metabolism is markedly affected by the removal of only 10 to 15% of the water held in plant tissues at full turgor. In an extensive literature review, Hsiao (1973) noted that cell growth, wall synthesis, and protein synthesis were the cell functions initially inhibited by water stress. Under prolonged stress, cell division was also affected. Kramer (1969) stated that the degree of plant water stress is probably best expressed in terms of water potential, because this appears to be the most closely related to physiological and biochemical processes controlling growth.

Leaves or shoots often show mid-day depressions in water potentials on sunny days when atmospheric water demand are high (Hsiao et al. 1976). If adequate soil moisture is available, internal gradients produced the previous day are usually diminished at night. At that time atmospheric demand for water is low and stomatal closure prohibits transpiration allowing leaf, shoot, and soil water potentials to reach an equilibrium (Ritchie and Hinckley 1975). If soil water availability is low, plants do not regain the early morning equilibrium with soil water potentials. When this occurs, daily water stress begins to form long-term stress patterns (Brown 1977, Slatyer 1967), causing unfavorable physiological and morphological effects on the vegetation (Hsiao 1973, Hsiao et al. 1976, Boyer 1976). Ritchie and Hinckley (1975) stated that, if transpiration is sufficiently retarded, overnight equilibrium tends to be established in soils with high soil water potentials. Thus predawn xylem water potentials are closely related to the effective soil moisture. They further asserted, as soils dry, predawn xylem water potentials become less indicative of soil moisture, but do indicate the level of water stress at which the plant begins the day and therefore remain useful as estimates of effective soil moisture.

Although the direct dependence of plant growth on plant water status is generally accepted, very few studies concerning tallgrass prairie plant species and plant water stress appear in the literature. Consequently, the main objective of this study was to determine levels and conditions of water stress in tallgrass prairie plant species during a dry growing season.

Study Area

The study was conducted on an excellent condition, tallgrass prairie in Canadian County, Okla. (elevation 600 m). Annual precipitation (Fig. 1) averages 750 mm with nearly 80% occurring during the 208-day growing season from early April to early November (NOAA 1980). Monthly precipitation is lowest in winter and highest in spring. The highest monthly average maximum temperature of 34° C occurs in August and the lowest monthly average minimum temperature of -3° C occurs in January. Mean monthly wind velocities vary from 18 km/hr in July to 24 km/hr in March. Monthly relative humidity at 0600 hours is approximately 80% throughout the year. Precipitation data were collected at the study site; all other weather date were collected at El Reno, Okla., by the National Weather Service.

The study area was on a 3% northwest-facing slope. Soils were transitional between a claypan prairie (Renfrow series) and a loamy prairie (Milan series) range site (Nance and Gray 1977). The predominant soil, Renfrow, is a member of the fine, mixed, thermic family of Vertic Argiustolls, except that the surface 0–34 cm had a loam texture. The secondary soil, Milan, is a member of the fine loamy, mixed, thermic family of Udic Paleustolls, with a 0–15 cm A1 horizon and a 15–30 cm B1 horizon of loam texture. Both soil types are deep and well drained with slow permeability which developed from either shale or clayey and loamy sedmentary parent materials. The vegetation on these soils is dominated by *Andropogon gerardi, Schizachyrium scoparium, Panicum virgatum,* and *Sorghastrum nutans* when the range is in excellent condition (USDA 1976). Common increaser and invader species include *Bouteloua curtipendula, B. gracilis, Buchloe dactyloides,* annual *Bromus* spp., *Ambrosia psilostachya,* and *Achillea lanulosa.* A detailed description of the site was given by Dunn and Powell (1979).

The study area has a rather long and varied history of grazing, but it was never plowed. For about 30 years prior to the study the area was part of a pasture grazed moderately (0.25 animal unit/ha) by a cow/calf beef herd. In the fall of 1977 the area was mowed, but the hay not removed. The area was not grazed since 1978.

Methods

A pressure equilibration chamber (Scholander et al. 1965, Rit-

Authors at the time of study were graduate research assistant, professor of range science, associate professor of botany, professor of statistics, and graduate research assistant, Oklahoma State University, Stillwater, 74078. Presently J. Powell is professor of range management, Department of Range Management, University of Wyoming, Laramie, and G.L. Dunn is vice president, research and development, Technical Drilling Services, Oklahoma City, Okla., D.R. Hake is a land management technician, state of Oklahoma Commissioners of the Land Office, Oklahoma City, OK.

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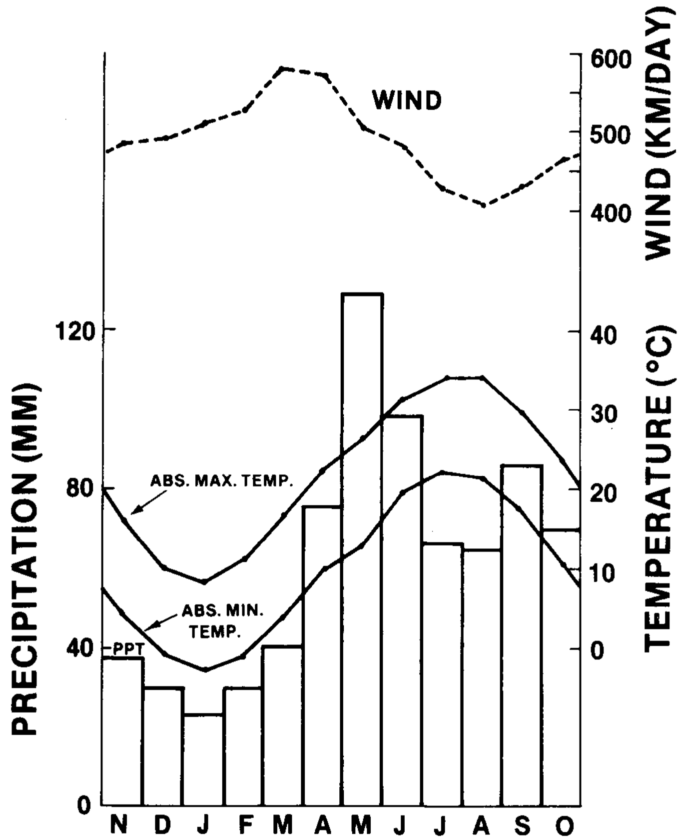

Fig. 1. *Long-term average monthly precipitation (mm), absolute maximum and minimum temperatures (C) and wind (km/day) for study area, in Canadian County, Oklahoma.*

chie and Hinckley 1975) was used to determine the predawn water potentials (Ψ) of 4 grasses and 3 forbs. Grasses sampled were *Andropogon gerardi* (ANGE, big bluestem), *Schizachyrium scoparium* (SCSC, little bluestem), *Sporobolus asper* (SPAS, tall dropseed) and *Panicum oligosanthes* (PAOL, Scribner's panicum). The forbs sampled were *Ambrosia psilostachya* (AMPS, western ragweed), *Psoralea tenuiflora* (PSTE, slimflower scurfpea) and *Solanum eleaginfolium* (SOEL, silverleaf nightshade). Experimental plants were randomly selected from a 20 m × 20 m study area. Sampling began about 2 hours before sunrise and ended just before sunrise. A grass blade or a forb stem was cut from the sample plant and sealed in a pressure chamber with the cut surface of the excised blade or stem protruding through a stopper located on the top. Pressure in the chamber was increased at a constant rate of approximately 0.7 bars/sec until xylem sap appeared at the cut end. The balancing pressure was then read and recorded. This procedure was replicated 3 times on individual plants of each species every sampling.

The vegetation in an area adjacent to the study area was sampled throughout the 1980 growing season to coincide as closely as possible to pressure chamber sampling days. Aboveground, live biomass (ALB) and composition of the vegetation were determined using a combination of the double sampling (Wilm et al. 1944) and weight-estimate (Pechanec and Pickford 1937) methods.

The soil water content was determined in an adjacent area of similar soils and physical features using a neutron probe and access tubes (Stone et al. 1955). The area where the access tubes were located was part of another ongoing study and was subjected to moderate grazing. Soil water values presented indicate probable soil water status and movement in the study area.

Data were analyzed with an analysis of variance for a completely randomized design. Regression equations were developed for interpretation of data. Water potential models were developed for each species for the sampling period. An aboveground, live biomass model was also developed for the 1980 growing season. Water potential and ALB (kg/ha) values were used as dependent variables. Independent variables for both models were days, which for calculation purposes were based upon a modified Julian year beginning 1 November. Unless otherwise stated, all differences were significant at the 0.05 level of probability.

Results and Discussion

Weather conditions in the summer of 1980 were hot and dry (Fig. 2). After an unusually wet spring, only 120 mm of rainfall

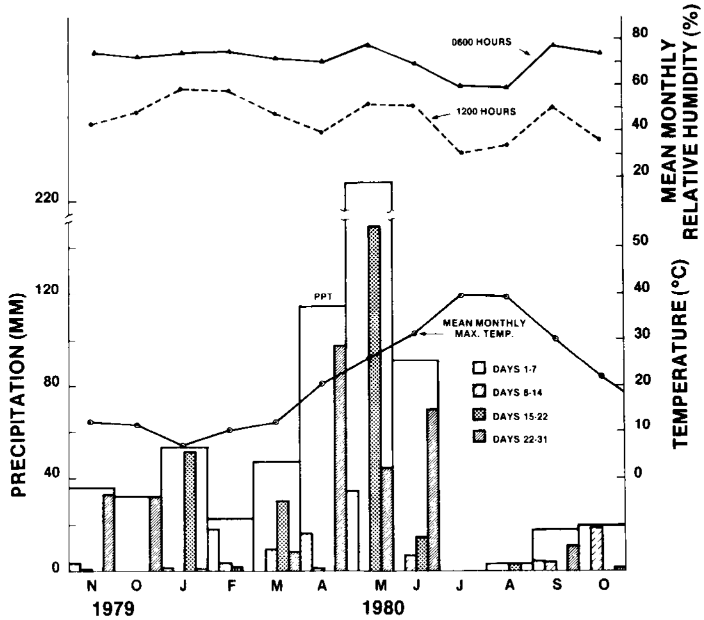

Fig. 2. *Monthly precipitation (mm), weekly precipitation (mm, inside average monthly precipitation bars), mean monthly maximum temperature (C) and 0600- and 1200-hour relative humidity values (%) in Canadian County, Oklahoma, 1980.*

were recorded for the June-through-September period. Most (91 mm) of this rainfall occurred in late June. Average monthly temperatures were 33, 39, 38, and 31° C during June, July, August and September, respectively. The relative humidity at 0600 hours ranged from 59% in August to 77% in September.

Schizachyrium scoparium had the lowest mean water potential, –48 bars, recorded 13 August (Fig. 3). The highest daily mean value recorded for the grasses, –1.0 bar, occurred 24 June in *Andropogon gerardi.* Water potentials for forbs decreased gradually, with pressures ranging from –1.2 bars to –12.0 bars. Significant differences ($P<.05$) among species occurred on 6 of 10 sampling days, but on only 2 of the first 6 sampling days. *Sporobolus asper* Ψ was greater than that of other species on 4 June, but differences were small. On 9 July, *Panicum oligosanthes* had the lowest Ψ value, –10.0 bars. Pressures on 23 July were not significantly different although all species had significantly lower pressures than previously recorded, indicating probable reduction of available soil water. After 23 July, large differences in mean Ψ occurred, with Ψ for SCSC and PAOL being lower than those for the other species. *Psoralea tenuiflora* plants began to die and abscise from their root crowns in late July. Dunn (1977) noted that reaching a critical Ψ value may cause abcission in the majority of plants in a PSTE population. The lowest Ψ for this plant, –11.5 bars, occurred 6 August. No PSTE plants were found after 13 August.

In a summary of permanent wilting points of plants as quoted from studies in the literature, permanent wilting points in leaves ranged from –13 to –45 bars, with values of –19, –17.7, –17.7, and –34 bars for tomato, smooth brome, intermediate wheatgrass, and

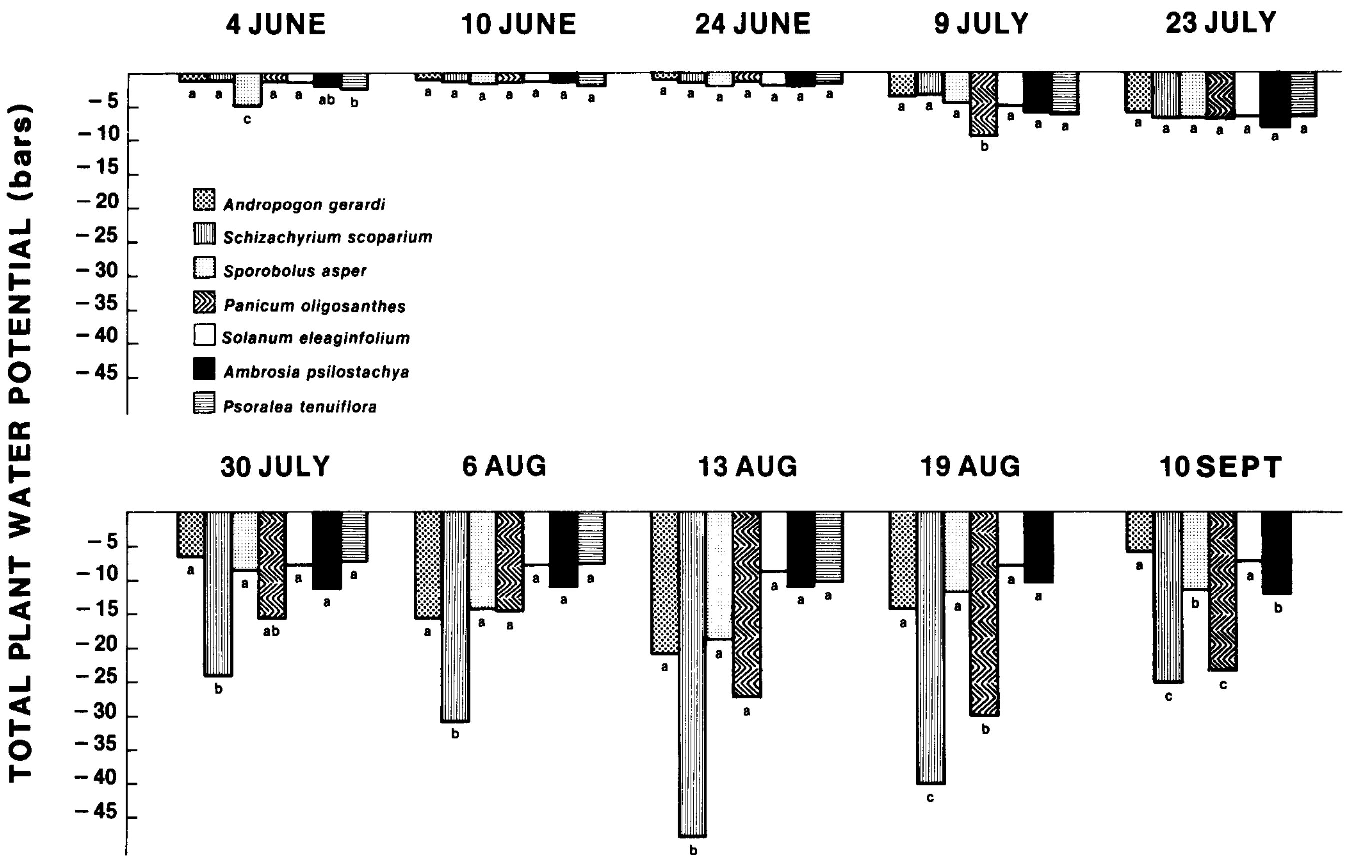

Fig. 3. *Tallgrass prairie plants species' mean water potentials 4 June to 10 September, 1980, Canadian County, Oklahoma. All values with the same lower case letter are not significantly different at the 0.05 level.*

cotton, respectively (Brown 1977). Brown also indicates that protoplast collapse was observed at -36.7 bars in smooth brome and -37.8 bars for intermediate wheatgrass as measured under controlled environmental conditions.

All species had decreasing seasonal Ψ trends (Fig. 4). Fluctuations early in the season seem to coincide with late June precipitation events. Only SCSC and PAOL had rapid decline in predicted Ψ values; these occurred in mid to late August. All other species' Ψ followed a gradual decline until 10 September when species sampled had increased Ψ values. This increase late in the season may have been due to light rain showers occurring several days before and on the evening before the sampling day, possibly allowing the dehydrated plant cells to regain water. It is also possible the mid-season measurements did not represent an equilibrium condition with soil water potentials. All plants became dormant late in the season, and Ψ values increased slightly, possibly due to reduced water loss and passive absorption by tissue (Brown 1977, Kramer 1969). Decreased photosynthetic activity, stomatal closure, changes in solute potential and absorption of atmospheric moisture are other factors which may have also contributed to increased Ψ (Boyer 1976, Hsiao et al. 1976, Slatyr 1967).

Soil water monitored with a neutron probe at 15-cm increments to a 122-cm depth indicated total soil water for the profile ranged from 38 cm in late May to 19 cm in mid-September (Fig. 4). The upper 45 cm (37% of profile depth) of the profile held 40 to 45% of the total soil water until early June (Fig. 5). In June, 91 mm of rain (91 mm of rain; 0 mm runoff) entered the soil. However, during June, evaportranspiration losses caused a large reduction in soil water in the upper 45 cm of the profile. As soil water levels in the upper profile decreased, mean pressure potentials became less uniform indicating different levels of stress beginning among plant species.

Vegetation growth began in early April and reached peak production in early June. An aboveground biomass (kg/ha) model developed from vegetation samples estimated the peak ALB to be approximately 3,100 kg/ha (Fig. 6). Low summer precipitation combined with record high temperatures induced rapid depletion of soil water and slowed vegetation growth after late June. Growth patterns on grasslands dominated by warm season plants are greatly influenced by the spring and summer rainfall events (Sims and Singh 1978). Peak ALB periods in the tallgrass prairie can vary from June through August (Conant and Risser 1974, Dunn 1981, Powell et al. 1978, Sims and Singh 1978).

In a comparison of net primary production of North American grasslands, Sims and Singh (1971) found a significant inverse curvilinear relationship between the amount of belowground plant material and depth (decreasing biomass with increasing depth) on several grazed and ungrazed grasslands. The majority of grassland root biomass is located in the upper 30 cm of the soil profile (Dahlman and Kucera 1965, Sims and Singh 1978, Weaver 1968).

Root studies in a true prairie region near Lincoln, Nebr., by Weaver (1958) determined that ANGE roots varied from 0.5 to 3 mm in diameter and were found at depths greater than 2 m. SCSC roots varied from 0.1 to 0.8 mm in diameter and usually grew to a maximum depth of 1.5 m, with a possible lateral spread of 0.5 m. During a midseason drought period in southwest Kansas, maximum root depth attained by grasses, including SCSC, on shallow soils was only 1.5 m (Tomanek and Albertson 1957). Many forb roots in both studies were measured at depths below 1.8 m ;*Ambrosia psilostachya* roots and the tap roots of PSTE reach depths of 1.5 to 1.8 m and 2.2 to 4.3 m, respectively (Dunn 1977, Weaver 1958). Due to the high root biomass content in the upper layers of the soil, transpiration is high and soil water is rapidly depleted when not recharged during the growing season. Deep root penetration and high root densities are important for maximum

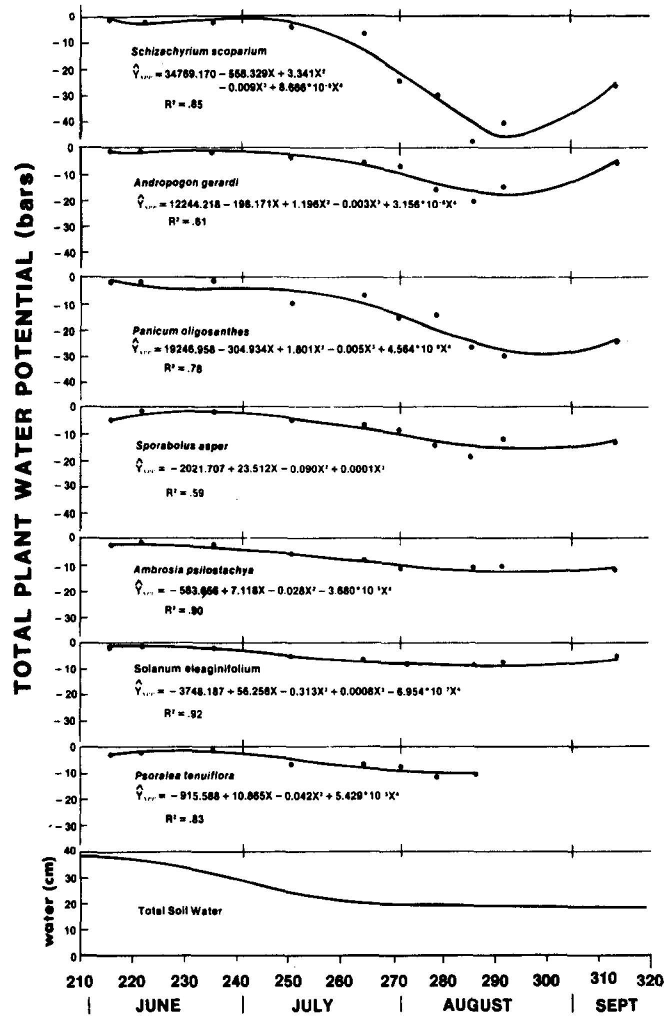

Fig. 4. *Water potential (bars) models for 7 tallgrass prairie plant species and total soil water 0–122 cm depth), June–September, 1980, Canadian County, Oklahoma.*

water uptake (Kramer 1969, Ritchie and Jordan 1972).

Both SCSC and PAOL have shallow root systems. Thus as the upper soil dries, water availability decreases causing higher degrees of stress. *Andropogon gerardi* and SPAS have relatively deep root

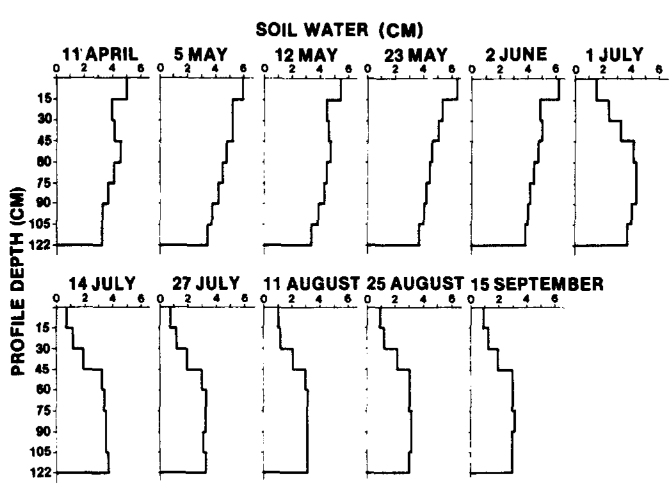

Fig. 5. *Soil water content (cm) at 15-cm increments of a vertic argiustoll prairie soil profile between 11 April and 15 September 1980, Canadian County Oklahoma.*

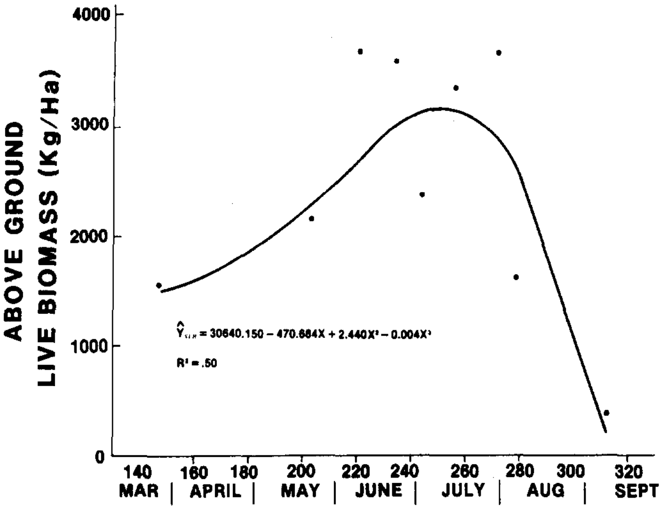

Fig. 6. *Model of tallgrass prairie aboveground live biomass (kg/ha), March–September, 1980, Canadian County, Oklahoma.*

systems which help these and other deep-rooted plants (Cook 1943) maintain lower levels of water stress during dry periods. The forbs sampled are all deep-rooted and showed only moderate levels of stress.

Rooting patterns are only one of several factors which affect water stress resistance capabilities in plants. Brown (1977) stated that plant drought resistance results from either (1) an ability to tolerate or endure stress because the protoplasm can sustain dehydration, or (2) structural and physiological adaptions that result in avoidance or postponement of the lethal effects of drought.

Low Ψ values may not be uncommon for SCSC or other shallow-rooted prairie plants due to drought tolerance adaptations (Levitt 1980). This drought tolerance may be due to structural adjustments such as smaller cell size (Cutler et al. 1977) or other adaptations to prevent mechanical injury and development of disiccation resistant protoplasm (Brown 1977). However, further study of these factors in SCSC and other tallgrass prairie species is needed to determine their role in plant survival and their relationships with plant water stress and growth.

Conclusions

Plant water stress expressed in terms of water potential appears to be closely related to the physiological and biochemical processes controlling growth. In our Central Oklahoma study, 7 tallgrass species were sampled to determine Ψ through a dry, hot growing season. Water potentials declined rapidly after June due to increasing temperatures and decreased soil water, causing increased levels to water stress in all species sampled. The decline in Ψ for SCSC, and to a lesser extent, PAOL, was much greater than that for the other 5 species. Data analyses indicated that ANGE was less affected by soil water depletion in the upper soil profile than was SCSC. Aboveground live biomass declined sharply at about the same time plant water potential values decreased sharply. Water potential levels in these species indicate differing water relationships with their environment. Understanding these relationships may be important for determining appropriate plants for seeding different range sites, estimating optimum herbage production and grazing periods during a growing season and for other management decisions. The effect of stress on total herbage yield on grazed and ungrazed grasslands is still poorly defined. Continued investigation of this subject is greatly needed.

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Economic Evaluation of Chemical Mesquite Control Using 2,4,5-T

D.E. ETHRIDGE, B.E. DAHL, AND R.E. SOSEBEE

Abstract

Honey mesquite *(Prosopis glandulosa* var. *glandulosa)* represents the most severe brush problem in the Texas Rolling Plains. Substantial research has been conducted on control methods, but economic analysis has been limited. The purpose of this study was to develop an evaluation model and evaluate the economic feasibility of 2,4,5-T (2,4,5-trichlorophenoxy acetic acid) for honey mesquite control in the Rolling Plains. The model is used to estimate the net present value of added grass production from treatment with 2,4,5-T over the life of the treatment; the central part of the model is the estimated herbage yield response function. The gross value of treatment with 2,4,5-T was estimated using different combinations of livestock price, top kill, canopy cover, and discount rate. Of the situations analyzed, gross value of mesquite control varied from a low of $22/ha to over $73/ha. These returns compare to current treatment costs of $22-25/ha.

Infestation with honey mesquite *(Prosopis glandulosa* var. *glandulosa)* constitutes the single most severe deterrent to range production in the Texas Rolling Plains. Almost 4.8 million hectares of the 5.6 million hectares of native rangeland in the Texas Rolling Plains are infested with mesquite (Whitson and Scifres 1980). Osborn and Witowski (1974) estimated that mesquite decreased economic activity in Texas by $429 million to $832 million in 1967 dollars; adjusting to 1981 dollars with the Gross National Product implicit price deflator, the cost becomes $1.05 billion to $2.04 billion.

The decision to invest in mesquite control, or any other form of brush control measure, is complex. A major factor contributing to this complexity is that results of a control measure extend over a period of time, the length of which may vary. Some factors may be unknown or not well understood, and others may be known or understood but beyond the decision maker's control. Another major factor is the uncertainty associated with important economic variables, such as livestock prices and production costs, through time.

A substantial amount of research has been conducted on both mechanical and chemical control of mesquite; however, economic research on the various methods has been limited. Several studies have evaluated costs with little or no emphasis on benefits. Boykin (1960) estimated the costs of root plowing and reseeding in the Rio Grande Plains. Wiedemann and Cross (1975) considered costs of grubbing small trees. Freeman et al. (1980) estimated costs of harvesting mesquite in the Texas Rolling Plains using mechanical methods. In a study evaluating costs and revenues, Freeman et al. (1978) studied the effects of cattle prices and levels of mesquite control on ranch organization and income in the Texas Rolling Plains. In the linear programming analysis, they assumed that forage production would increase by 31% in each year from year 2 through year 7 after treatment from spraying mesquite with 2,4,5-T (2,4,5-trichlorophenoxy acetic acid); lower response rates were also assumed to test for sensitivity. Workman et al. (1965) conducted a study of costs and returns from spraying in which they attempted to determine the longevity of chemical treatment in a survey by asking ranchers to estimate the life of treatment. Sharp and Boykin (1967) evaluated returns from mesquite control using a dynamic programming model in which they assumed a distribution of added forage production over a 10-year planning horizon. Whitson and Scifres (1981) conducted an extensive economic study of different methods of controlling mesquite in several regions of Texas. Their study provided recommendations for control on a regional basis; it was not addressed to specific situations or to the most efficient method of control in most instances. Among procedural problems they recognized was that long-term response data were lacking because of cost, personnel changes, and short-term research goals. Consequently, they assumed a 20-year production response for each region in their study.

The general objective of this study was to develop a procedure for evaluating the economic feasibility of honey mesquite control on rangeland with which decision makers can consider (1) variations in effectiveness of control in terms of longevity and (2) variations in economic variables affecting returns from the control technique through time. The specific objective was to evaluate the economic feasibility of 2,4,5-T for control of honey mesquite in the Texas Rolling Plains.

Analytical Framework

Purchasing mesquite control is fundamentally different from purchasing production inputs, such as supplemental feed, which are used in a single production period. Mesquite control by chemical or mechanical means constitutes a capital investment. The major expenditure occurs at a point in time and the effects of the control extend for some period of time into the future, usually several production periods. Since the treatment is expected to last for several years, there is more uncertainty and more production risk than with the one-period production input. Sources of risk are of two types: (1) biological variation, of which the impact of weather is an example, and (2) economic uncertainty, arising mostly from variations in product (livestock) prices.

The effectiveness of mesquite control treatments over time, in conjunction with certain economic variables, largely determines the feasibility of treatment. A treatment which reduces mesquite and its impact on rangeland and productivity for 10 years is more likely to be economically feasible than a treatment which diminishes the mesquite infestation for fewer years. Although the time pattern of control is an important element of economic feasibility (Whitson and Scifres 1980, Freeman et al. 1978), little empirical analysis exists on the longevity of treatments on control of mesquite; little data have existed with which to establish longevity.

The conceptual model developed for this analysis consists of

Authors are associate professor, Department of Agricultural Economics and professors, Department of Range and Wildlife Management, respectively, Texas Tech University, Lubbock, Texas 79409.

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several generalized relationships. The basic relationship on which the other relationships depend is a herbage yield response function which relates grass production resulting from treatment of mesquite with the herbicide to time and other variables.

$$MP_G = f(X_1, X_2, \ldots, t) \quad (1)$$

where MP_G = additional grass production per unit of land associated with the mesquite control treatment,
t = time, and
X_i = other explanatory variables.

It is expected that MP_G declines over time because mesquite reestablishes after the initial damage from treatment and consequently decreases the added grass production as reinfestation occurs.

Added grass production is not directly marketable, but it may be converted to a product which is marketed—livestock. This relationship can be expressed as:

$$MP_L = k(MP_G) = g(X_1, X_2, \ldots, t) \quad (2)$$

where MP_L = additional livestock production per unit of land associated with the mesquite control treatment, and

k = units of livestock produced per unit of grass; a conversion factor for converting grass to meat.

Equations (1) and (2) are biological relationships. No purely economic factors have been introduced. Equation (2) is transformed into an economic relationship as follows:

$$VMP = MP_l(P_L) = j(X_1, X_2, \ldots, t) \quad (3)$$

where VMP = value of the additional production per unit of land, and
P_L = price (net) of the livestock produced.

The ranch manager cannot affect the price of the livestock, thus price is determined outside his influence. However, price may not remain constant over time. The VMP is the additional revenue from the mesquite control treatment, and there is VMP each year during which the treatment has an impact on grass (and livestock) production. If it is assumed that all costs of treatment occur at the time of treatment, the stream of additional returns must be discounted in order to place them on an equivalent basis with the costs (Whitson and Scifres 1980). Thus,

$$PV_{VMP} = \Sigma[VMP_t/(1 + r)^t] \quad (4)$$

where PV_{VMP} = present value of the added revenue from mesquite control treatment,
VMP_t = added revenue from treatment in year t, and
r = discount rate, i.e, the price of the capital used for the treatment.

Equation (4) shows that the longer the life of the treatment (t) and the lower the discount rate (r), the greater the present value of the revenue generated from mesquite control.

For the manager, the decision criterion is: If PV_{VMP} is greater than or equal to the cost of treatment, the treatment is economically feasible. Otherwise, the added costs exceed the added revenues. This is a modification of the marginal analysis principle explained by Whitson and Kay (1978) and numerous other authors. To make reliable estimates of the appropriate costs and returns, several things must be known: (1) the nature of the MP_G and/or the MP_L relationship, (2) the price of livestock, and (3) the cost of mesquite control treatment. Item (3) is relatively easy to determine with a small margin of error. Item (2) is extremely difficult to forecast, especially with a high degree of precision and over a long period. There are, however, ways to use alternate assumptions regarding livestock prices to facilitate analysis and decisions. Item (1) requires identification of factors which affect productivity of the treatment and quantification of impacts of those factors.

Methods and Procedures

The source of data for this analysis was a 6-year plot study at 7 locations in the Rolling Plains treated with 0.55 kg 2,4,5-T/ha. The sites were located in Kent, Lynn, and Tom Green counties. Details of treatments are reported in Dahl et al. (1978) and grass response data were from those experiments.

The first question relating to equation (1) in the previous section was: What are the variables which affect the grass response from treatment with 2,4,5-T (i.e., what are the X_i's which impact on MP_G?). The experimental results clearly indicated that initial mesquite infestation (measured as canopy cover or number of trees /ha) and top kill (the percentage of trees unsprouted at the end of the first year) were explanatory variables. The study also implied that soil type might be an explanatory variable. It was hypothesized that climatic factors (rainfall and temperature) also affect additional grass production and that location may also have an impact. It was further assumed that the relationship between MP_G and each of the independent variables except time was linear and relationship to time was hypothesized to be in semi-log form. The mathematical model formulated was:

$$MP_G = B_o + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6\ln t + B_7D_1 + B_8D_2 + B_9D_3 + B_{10}D_4 \quad (5)$$

where MP_G = added grass production from treatment (kg/ha),
X_1 = mesquite canopy cover prior to treatment (%),
X_2 = top kill measured as percent of trees unsprouted at the end of the first year,
X_3 = rainfall during the Sept.–Mar. period prior to the growing season (cm),
X_4 = rainfall during the April–Aug. growing season (cm),
X_5 = number of days during the year with the high temperature >37.8°C,
$\ln t$ = natural logarithm of year following treatment (1 = year of treatment),
D_1 = location dummy variable; D_1 = 1 if site in Tom Green County, O otherwise,
D_2 = location dummy variable; D_2 = 1 if site in Lynn County, O otherwise,
(If D_1 and D_2 are both O, site is in Kent County.)
D_3 = soil type dummy variable; D_3 = 1 for Redland, O otherwise, and
D_4 = soil type dummy variable; D_4 = 1 for valley soil, O otherwise.
(If D_3 and D_4 are both O, soil is hardland.)

Data on rainfall and temperature were obtained from secondary sources (U.S. Dep. Commerce). For the Kent County site, climatological data for Jayton was used. For the Lynn County site, averages of observations for Post and Tahoka were used and for the Tom Green County site, averages of Water Valley and San Angelo Airport observations were used. Ordinary least squares was used to estimate parameters of equation (5).

Once the MP_G relationship was established, conversion to MP_L was accomplished as follows. It was estimated that for the Rolling Plains areas in the study 9,525.5 kg of grass were required annually to support one animal unit (AU); this allowed for trampling and restoring vigor. It was assumed that the livestock enterprise would consist of a cow-calf operation and that one animal unit consists of a 453.6-kg cow, one 181.4-kg calf, a 5% of a 725.8-kg bull, and 14% of a 294.8-kg replacement heifer (Kennedy 1970). A calving rate of 90% and marketing of calves at 181.4 kg was assumed. Thus, under these conditions, one AU produced 137.9 kg; .76 = .90 calving rate minus .14 heifer replacement.

Therefore,

9525.5 kg grass = 137.9 kg calf and
1 kg grass = .0145 kg calf.

The value of the calves (P_L) was determined in terms of net value rather than gross value; i.e., if additional animal units are placed on the land, there are additional costs associated with grazing those livestock. The value of livestock marketed was calculated as:

$$P_L = P_c - VC_c \quad (6)$$

where P_c = market price of 181.4 kg calves in dollars/kg, and
VC_c = variable cost of producing 181.4 kg calves in dollars/kg

Variable costs consist of supplemental feed and minerals, veterinarian costs, fuel, lubrication, and repair costs on equipment, marketing cost, depreciation, taxes, and insurance on livestock, interest on operating capital, and interest on investment in the cows, bulls, and replacement heifers. Variable costs in this case excluded land costs and overhead costs and the value of cull cows, a function of cow prices, was subtracted to make calf costs a net cost estimate. Cost estimates were derived from enterprise budgets by the Texas Agricultural Extension Service (1982). The VC_c was estimated to be $.55/kg. The market price for calves, P_c, was obtained from Texas Department of Agriculture (1982).

Results and Interpretation

Estimation of equation (5) yielded the following relationship:

$$MP_G = 11.48 + 19.15\,X_1 + 23.72\,X_2 - 15.56\,X_3 - 13.50\,X_4 - 31.14\,X_5 - 625.6 \ln t \quad (7)$$

(.01) (.00) (.05) (.12) (.12) (.04)

Numbers in parentheses below the estimated regression parameters represent the probability of an equal or greater *t*-value associated with the parameter (the significance level). The *F*-statistic for the model was 4.89 and R^2 was .607. The location and soil type dummy variables were insignificant; i.e., with the data used, location, and soil type had no significant effect on the added grass production from treatment of mesquite with 2,4,5-T. Canopy cover, top kill, pre-season rainfall, and time were highly significant explanatory variables; growing season rainfall and temperature were less significant. Negative signs for coefficients at X_3 and X_4 indicate that treatment of mesquite with 2,4,5-T adds less to grass production in high rainfall years than in low rainfall years, as expected. When there is sufficient soil moisture for both the mesquite and the grass, damaging the mesquite does not benefit the grass to the same extent as when mesquite and grass are more competitive for soil moisture.

To facilitate interpretation, several variables in equation (7) were fixed at some value(s) to produce a grass yield function with added grass yield as a function of time. If all independent variables

Table 1. Descriptive statistics for variables in the MP_G relationship.

	Variable	Mean	Standard deviation
MP_G	(added grass produced); kg/ha	358.40	376.1
X_1	(initial % canopy cover)	25.85	14.98
X_2	(% top kill)	74.88	14.33
X_3	(pre-season rainfall); cm	25.10	12.28
X_4	(growing season rainfall); cm	34.29	13.68
X_5	(number of days with high temperature >37.8°C)	9.08	3.57
ln t	(logarithm of year)	1.103	.39

except time are held constant at their mean values (Table 1), then equation (6) becomes

$$MP_G = 1048.6 - 625.6 \ln t \quad (8)$$

shown graphically (Fig. 1). This relationship indicates that with normal (average) temperature and rainfall conditions, a 26% initial canopy cover, and a 75% top kill, treatment with 2,4,5-T would produce 1,049 kg more grass per hectare the first year after treatment, 615 kg the second year, 361 kg the third, 181 kg the fourth, and 42 kg the fifth year. After year five, the effect of the treatment is negligible.

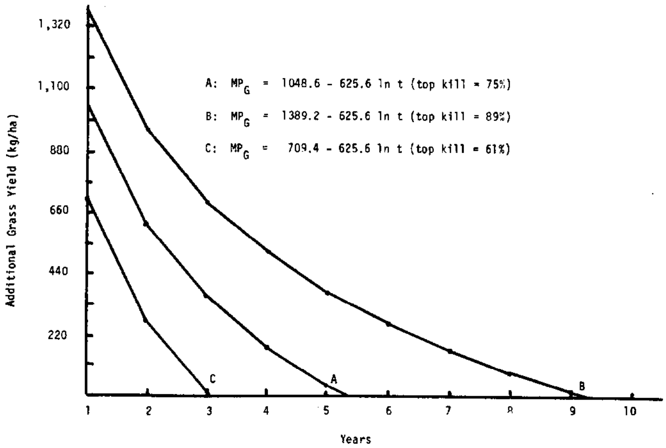

Fig. 2. *Estimated grass yield functions with independent variables at mean values and top kill varying one standard deviation.*

As climate, initial infestation, or top kill change, the MP_G relationship changes. For example, with normal weather patterns and average top kill but a more dense (sparse) infestation of mesquite, the MP_G relationship increases (decreases). With all conditions the same except the initial canopy cover increased one standard deviation from the mean, from 25.85% to 40.83%, the grass production relationship became

$$MP_G = 1336.9 - 625.6 \ln t \quad (9)$$

also shown (Fig. 1). If the initial canopy cover is one standard deviation below the mean, the MP_G relation is the lowest curve (Fig. 1). The heavier the infestation of mesquite when treated with 2,4,5-T, the greater the grass production from the treatment and the longer the life of the treatment.

If we assume normal climate conditions and average canopy cover but let the top kill vary, the results are illustrated (Fig. 2.). As

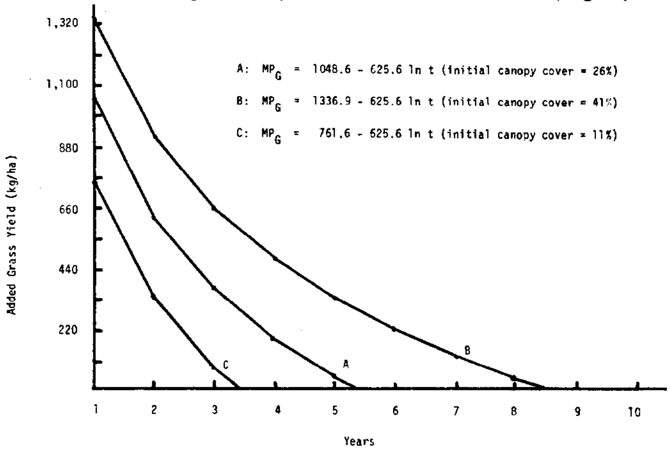

Fig. 1. *Estimated grass yield functions with independent variables at mean values and canopy cover varying one standard deviation.*

the top kill increases one standard deviation from its mean, from 74.88% to 89.12%, the relationship shifts from that of equation (7) to

$$MP_G = 1389.2 - 625.6 \ln t \quad (10)$$

The greater the top kill the greater the added production per year and the longer the life of the treatment. This demonstrates the effect of proper application methods, spraying under good environmental conditions, and other management practices which affect top kill.

To convert the added grass production to added beef production, the factor of 1 kg of grass = .0145 kg of marketable calf was used. To convert to dollar values, the estimated added cost of producing the marketable calf of $.5467/kg was used. The price of beef is subject to variation from numerous sources, but for purposes of this analysis, the price quotations for the San Angelo market for medium frame #1 feeders, 136.1–181.4 kg and 181.4–226.8 kg reported on June 12, 1982, were used (Texas Dep. Agr.). Based on those prices, a calf price of $1.62/kg was assumed. Thus, P_L = $1.62 – .5467 = $1.073, or an additional kg of marketable beef produces $1.073 income above added costs. Each added kg of grass produced thus has a value of (.0145) ($1.073) = $.01556.

If average conditions hold and the above production cost and market price conditions hold, derivation of the present value of mesquite treatment with 2,4,5-T are shown (Table 2). A discount rate of 10% was assumed over the 5-year life of the treatment. Under these conditions, the treatment would produce a present value of additional income of $29.85/ha. If the treatment cost is less than $29.85/ha, investment in the treatment is economically feasible because the expected additional revenue from treatment exceeds the expected additional costs. If it cost more than $29.85/ha to treat, the treatment is not economically feasible. Cost of treatment with 2,4,5-T in the Texas Rolling Plains is about $22/ha.

Table 2. Calculation of value of added grass production.

Year	Additional grass production[1]	Value of additional grass production[2]	Discounted value of additional grass production[3]
	kg/ha	—$/ha—	
1	1048.8	16.63	15.12
2	615.0	9.76	8.06
3	361.4	5.73	4.30
4	181.4	2.87	1.95
5	41.8	.67	.42
	2246.4	35.66	29.85

[1]Conditions: 26% initial canopy cover, 75% top kill, 25.1 cm pre-season rainfall, 34.3 cm growing season rainfall, 9 days/year with high temperature >37.8°C.
[2]Assumes 9,526 kg grass produces 137.9 kg of calf for market, variable calf production cost of $.55/kg, and calf market price of $1.62/kg.
[3]Assumes 10% discount rate.

As any changes in the physical conditions occur, the economic feasibility may change. Consider a greater-than-average initial mesquite infestation. If all conditions are the same as above except the infestation is increased to 40.83% canopy cover (one standard deviation above the mean), the PV_{VMP} increases from $29.85 to $52.90/ha. Thus, the manager could invest up to $52.90/ha for treatment under these conditions. This increase in value results from greater additional grass production and a longer life of return from the treatment. Since rangeland is a dynamically changing resource and mesquite infestation tends to increase over time, treatment which is not feasible under a set of conditions at one point in time may be feasible under the same set of conditions at a later time.

Consider also the effect of a greater-than-average top kill on the economic returns. Factors such as spraying under more advantageous soil moisture, atmospheric temperature, etc., conditions may affect top kill and are under control of the ranch manager. If all conditions are average except for top kill, which is at 89.12% (one standard deviation above the mean), then PV_{VMP} increases from $29.85/ha to 54.85/ha.

As with changes in the physical conditions, changes in economic condition likewise affect the economic feasibility. Economic factors which affect beef prices, costs of producing beef, and discount rates may have a substantial effect on the returns from and feasibility of mesquite control (Table 3). The data indicate that the value of mesquite control with 2,4,5-T in the Texas Rolling Plains increases as beef prices increase, decrease as discount rates increase, increase as the initial canopy cover increases, and increase as the percentage top kill increases. The price of cull cows, included in the calculation of VC_c, was assumed to be constant in this analysis. To the extent the cow prices vary directly with calf prices, the discounted values (Table 3) are under-estimated at higher calf prices.

Table 3. Discounted present values of additional grass production ($/ha) under alternative situations.[1]

Calf price	Average conditions[2]		Heavy intial canopy cover[3]		High top kill[4]	
	Discount rate:		Discount rate:		Discount rate:	
($/kg)	10%	15%	10%	15%	10%	15%
1.43	24.54	22.26	46.34	35.44	45.02	38.18
1.54	27.63	25.08	46.55	38.83	50.33	42.72
1.65	30.69	27.89	51.69	44.23	56.31	47.74
1.76	33.78	30.64	56.86	48.73	61.50	52.21
1.87	36.82	33.43	61.97	53.08	67.06	56.88
1.98	39.91	36.25	67.21	57.55	73.19	61.70

[1]Conditions: 25.1 cm pre-season rainfall, 34.3 cm growing season rainfall, 9 days/year with high temperature >37.8°C, $.55/kg calf production cost.
[2]26% initial canopy cover, 75% top kill.
[3]41% initial canopy cover, 75% top kill.
[4]26% initial canopy cover, 89% top kill.

Implications

The economic feasibility of controlling mesquite with 2,4,5-T in the Rolling Plains of Texas depends on many variables; some are environmental, some are economic and some may be influenced or manipulated by managers. Among the environmental variables which affect added grass and beef production, and therefore, economic feasibility associated with mesquite control are initial canopy cover, degree of top kill achieved with treatment, pre-season and growing season rainfall, and number of high temperature summer days. Of these variables, ranch management may manipulate initial canopy cover by choosing the time to engage in spraying and influence top kill by choosing conditions at the time of spraying which promote high top kill. Among the economic variables which affect economic feasibility are livestock prices, costs of production, and discount rates. While an individual ranch manager is quite limited on the degree to which he may influence these variables, some impact on them through livestock production management, financial management, and marketing strategies may occur. This analysis shows the relative magnitudes of effects from the various factors on the economic returns from treatment of mesquite with 2,4,5-T. To determine economic feasibility, the discounted added returns from treatment must be compared to the added costs of treatment. Economic feasibility may, therefore, vary with time, among ranches, and among pastures within ranches. The MP_G relationship estimated in this study is believed to be generally reliable for the Rolling Plains region. The appropriate values of the variables within the relationship, the appropriate factor to convert to marketable product, and the appropriate values for the economic variables will vary from one situation to another. The analytical framework, along with the MP_G relationships, should be applicable to individual decision situations.

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Control of Aspen Regrowth by Grazing with Cattle

R.D. FITZGERALD AND A.W. BAILEY

Abstract

Aspen *(Populus tremuloides)* forest occupies potentially useful grazing land in the aspen parkland of western Canada, and is expanding. The replacement of forest with grassland involves the removal of trees and the control of suckers which invariably emerge following overstory removal. The control of aspen suckers by heavy browsing with cattle may be a useful technique especially in the presence of logs and stumps.

In order to evaluate the effectiveness of browsing by cattle, aspen forest was burned and seeded to forages, after which the regrowth was heavily grazed by cattle either after emergence of suckers (early) or just prior to leaf fall (late). Grazing treatments were conducted over two growing seasons.

A single heavy late grazing practically eliminated aspen regeneration, and two quite different plant communities resulted from the two grazing regimes. After the first year, the plant biomass in early-grazed plots consisted of 29% aspen and 28% grass (mainly sown species), while late-grazed plots had only 2.5% aspen and 18% grass, with a higher proportion of shrubs, especially snowberry. Trends established after the first year were still evident after the second year. The results indicated that heavy browsing by cattle in August may be an effective technique for control of aspen suckers following initial top kill.

The aspen parkland of Western Canada covers an area of about 14.5 million ha, and in its native state, consists of groves of aspen *(Populus tremuloides)* alternating with fescue grasslands, predominantly rough fescue *(Festuca hallii)* (Looman and Best 1979). Aspen also occurs extensively in the warmer climes of the Boreal Forest (Rowe 1972). Since the forage yield within the forest groves may be less than 10% of adjacent grasslands (Bailey and Wroe 1974), the removal of trees and their replacement with productive forage species should increase the carrying capacity for beef cattle, especially since the aspen groves usually occupy the more moist, and hence, potentially more productive sites in depressions and around sloughs.

The removal of the aspen tree overstory by mechanical means, herbicides, or fire, almost invariabily stimulates vigorous suckering from shallow lateral roots (Schier 1976). Hence, in addition to the initial removal of trees, the replacement of aspen forest with grassland involves the elimination or suppression of suckering aspen and understory shrubs and the establishment of productive forage species.

Substantial suppression of aspen suckering has been associated with heavy browsing by elk (Gruell and Loope 1974), and by sheep and to a lesser extent by cattle (Smith et al. 1972). Hence, heavy grazing by sheep or cattle may be an effective low cost control measure, especially where logs and stumps inhibit mechanical operations. Canada Agriculture recommends that control operations be conducted in spring to coincide with the time of lowest root carbohydrate levels (Friesen et al. 1965), but cattle on open range appear to browse aspen more readily as the season advances (Smith et al. 1972).

Timing may be critical to the effectiveness of the use of cattle as a regrowth control measure. Hence, we investigated the timing of heavy grazing by cattle to control aspen suckers which emerged after the overstory was burned and forage seeds were broadcast into the burned forest. Complete defoliation by cattle following emergence of suckers, when root carbohydrates would be minimal (Schier and Zasada 1973), was compared with defoliation just prior to leaf fall, when carbohydrate levels would be relatively high, but when little time remains for shoot development or carbohydrate replenishment before the dormant season.

Methods

Experimental Site

The experiment was conducted on the University of Alberta Ranch at Kinsella, in the aspen parkland of Alberta. Average annual precipitation recorded at the University's Meteorological Station is 432 mm of which 75% or 323 mm falls in the growing season from April to September inclusive. Growing season precipitation in 1979 and 1980 was 259 mm and 503 mm respectively. The normal frost-free period is 100-120 days from late May to early September (Wonders 1969). Average maximum and minimum

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Authors are research agronomist, Department of Agriculture New South Wales, Agricultural Research and Advisory Station, Glen Innes, N.S.W. Australia, and formerly, graduate student, Department of Plant Science, University of Alberta, Edmonton, Alta., Canada, T6H2P5; and professor, Range Management, Department of Plant Science, University of Alberta, Edmonton, Alberta, Canada, T6H2P5.

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temperatures (1962-1980 inclusive) range from –14.0° and –21.0°C in January respectively to 21.9° and 12.5°C in July. Generally, the glacial moraine topography is strongly undulating with numerous lakes and sloughs. The experiment was located on the slopes surrounding 2 adjacent sloughs, the soils of which were described by Scheffler (1976) as Dark Gray, Black and Dark Brown Chernozems and Humic Gleysols following nomenclature of Canada Soil Survey Committee (1978). Generally, the soils of the area are classified as unsorted glacial loams, having an average 7-10 cm of black or brown topsoil (Wyatt et al. 1944).

Experimental Design

Mature aspen forest was burned in May 1972, and the 7-year-old regrowth burned again on May 15, 1979. Prior to burning in 1979, trees were about 3-4 m high, with an average trunk diameter at breast height of 2.0 ± 0.3 cm. Aspen density was estimated at 23,100 ± 8,300 ha^{-1}. Practically all top growth within the experimental area was killed by the 1979 fire.

Three days after the 1979 fire, the burned forest was sown to a mixture of seed of 2.8 kg ha^{-1} of 'Drylander' alfalfa *(Medicago sativa)* inoculated with rhizobium, and 7.0 kg ha^{-1} each of 'Magna' bromegrass *(Bromus inermis)* 'Key' orchard grass *(Dactylis glome rata)* and 'Boreal' creeping red fescue *(Festuca rubra)*. The seed was broadcast and forage seedlings were established successfully. The effects of subsequent grazing treatments on initial seedling survival and growth have been reported elsewhere (FitzGerald and Bailey 1981).

The area was subdivided into 6 paddocks of an average 0.5 ha each, to provide 3 completely randomised replications of each of 2 grazing treatments. Each paddock consisted of approximately 70% regenerating aspen forest and 30% native grassland. Three of the paddocks were heavily grazed with cattle from July 5 to 17 1979 (12 days), soon after emergence of suckers of regenerating forest species. The remaining 3 paddocks were heavily grazed from August 22 to September 1 1979 (10 days); i.e. just prior to the breakdown of leaf chlorophyll in late summer, and approximately coinciding with the expected time of maximum root carbohydrate concentration. The plots were subjected to the grazing treatments again in 1980 when early grazing took place from May 31 to June 13 (13 days) and late grazing from August 15 to 23 (8 days).

The objective of the grazing treatments was to completely remove all accessible and edible plant material. Grazing was considered to be a substitute for mechanical removal. Hence, it was conducted over a short time interval to prevent any grazing of subsequent regrowth. In 1979, complete removal of edible vegetation within about 10 days required 8 animals ha^{-1} for early grazing, and 25 animals ha^{-1} for late grazing, when there was more material to be removed. In 1980 the early treatment was grazed with 8 animals ha^{-1}, and the late treatment with 27 animals ha^{-1}. Grazing achieved complete or near complete defoliation of all species except snowberry *(Symphoricarpos occidentalis)* in both treatments.

Measurements

Fixed quadrats (1 m^2) were established at random within the aspen community, 10 per paddock, 30 per grazing treatment. Density of individual woody species was determined from counts of all species within these fixed quadrats. In order to facilitate counting, density estimates were conducted during grazing periods when some foliage had been removed. Thus, density in the early grazed treatment was determined in May/June in 1979 and 1980, while in the late-grazed treatment it was determined in August in those years. In 1981 it was determined in July in both treatments. This difference in the timing of density counts in 1979 and 1980 prevented a comparison being made between grazing treatments, but allowed an analysis of density changes over time.

Estimates of the yield of the components of the regenerating forest were made in both May and August in 1980, and in July 1981. Unlike the density counts, sampling took place in both treatments on each sampling occasion. Quadrats (1 m × 0.5 m) were placed at predetermined distances (about 2 m) and directions from the above-mentioned fixed quadrats. All material within these 0.5 m^2 quadrats (10 per paddock, 30 per treatment) was clipped, sorted into species, dried in a forced draught oven at *ca.* 100°C for 24 hours, and weighed. Estimates (paddock means) were subjected to analyses of variance. Effects of grazing season treatments on species yield were analysed separately for each year because seasonal sampling time varied.

Results

The yield of aspen was profoundly influenced by the timing of grazing (Table 1). It was much lower in late-grazed paddocks than in early grazed paddocks. On the other hand, the yield of rose (*Rosa* spp.) was lower in early grazed paddocks in August 1980, although by July 1981 the difference was no longer significant.

Table 1. Yield (kg ha^{-1}) of the components of regenerating aspen forest under early or late grazing, in May 1980, August 1980, and July 1981.

Date		Grazing season	Species/category: Aspen	Rose	Snowberry	Grass[1]	Other
May	1980	Early	615	210	417	381	366
			*			*	
		Late	70	466	631	175	360
	SE[2]		278	276	501	100	181
August	1980	Early	953	224	524	1117	402
			**	**			
		Late	56	605	1364	791	1009
	SE		230	167	1073	273	757
July	1981	Early	1640	435	792	1191	715
			*				
		Late	136	865	1394	1031	698
	SE		805	785	770	209	123

[1]Includes sown grasses, alfalfa and volunteer grasses.
[2]SE = Standard error
*Difference between early and late grazing significant ($P<0.05$).
**Difference between early and late grazing significant ($P<0.01$).

"Grass" consisted mainly of sown grasses, but included a small proportion of alfalfa and volunteer grass species especially Kentucky bluegrass *(Poa pratensis)*. Grass contribution was greater in early grazed than late-grazed paddocks in early 1980, but not thereafter.

The high mortality of aspen plants under late grazing was confirmed by the plant density counts (Table 2). Aspen plant density declined dramatically from 1979 to 1980 in late-grazed paddocks, though not in early grazed paddocks. Increases in densities of rose, raspberry (*Rubus strigosus*) and snowberry were apparent by 1981,

Table 2. Density (plants M^{-2}) of the major woody plants in regenerating aspen forest grazed early or late, and measured at grazing in 1979 and 1980, and in July 1981.

Species	Grazing season	Year: 1979	1980	1981	SE[1]
Aspen	Early	18.3[2]	20.3	12.9	5.6
	Late	12.6a	1.3b	0.9b	1.2
Rose	Early	9.4b	14.6ab	23.4a	5.3
	Late	18.0ab	14.4b	26.0a	3.3
Raspberry	Early	13.1	11.2	19.0	5.0
	Late	17.7ab	14.9b	26.1a	3.6
Snowberry	Early	21.6b	28.2ab	36.1a	5.3
	Late	31.2b	23.1b	46.9a	5.7

[1]SE = Standard error
[2]Means within rows followed by the same letter, or without following letters are not significantly different ($P<0.05$).

particularly under late grazing.

Discussion

Two quite different plant communities developed under the 2 grazing treatments. With early grazing, the major species within the old forest were grasses and aspen suckers, the latter appearing in clumps, mostly at the base of old burnt trees. Snowberry was also a significant component. With late grazing, the major species were snowberry, rose and grasses, with little or no aspen. This dramatic effect of late grazing on aspen regeneration was established after only 1 period of heavy grazing (Tables 1 and 2).

Hence a substantial degree of control over plant succession in a regenerating aspen forest was demonstrated. It was possible, by changing the season of defoliation, to radically and consistently alter the type of plant community which developed after burning.

The suppression of growth of rose by early grazing (Table 1) is consistent with previous studies on time of clipping of range shrubs. Willard and McKell (1978) found the same relative effects of June 1 and September 1 clippings on little rabbitbush *(Chrysothamnus visidiflorus)* and a palatable species of snowberry, *(Symphoricarpos vaccinioides)* in Utah. Wright (1970) observed a similar depression in regrowth of 2 species of *Artemisia* from clipping in June or July relative to August or September. Clearly the timing of defoliation is critical for plant succession in a regenerating forest, and effects different species in different ways.

The reason for the suppression of aspen suckering by late grazing is not clear. Since root carbohydrates are lowest in spring (Schier and Zasada 1973), a decline in the vigour of regrowth would seem to be most likely from defoliation in spring. This is the experience with many partially defoliated shrubs (Wright 1970, Trlica et al. 1977, Willard and McKell 1978). It did not occur in this experiment. It seems unlikely that late-grazed aspen plants suffered carbohydrate exhaustion after 1 defoliation, when plants grazed early (when carbohydrate levels would have been low) resuckered vigorously.

Suckers released by spring logging and emerging in mid-summer may not be thoroughly "hardened off" by fall and, consequently, may be winter-killed (Zehngraff 1946). Again alfalfa is rendered susceptible to winter-killing if cut in the fall (McKenzie and McLean 1980). If aspen suckers were released by the defoliation in August before conditions became too cold for growth, then probably they were killed by cold. Temperatures which were low enough to kill very young shoots might also prevent the formation of new primordia. In this way, existing viable primordia may have been eliminated, leaving no primordia to produce suckers the following spring.

The existing defoliated stems also perished after late grazing, though not after early grazing (Table 2). Late August defoliation may have prevented the development of dormancy characteristics in these stems. Abscisic acid (ABA) is synthesised in chloroplasts in the leaves (Zeevaart 1977) in response to shortening day length (Wareing and Saunders 1971) and transported out of the leaves to the stem and apex (Phillips et al. 1980), where it has been associated with the development of bud scales and other characteristics of winter dormancy in woody plants. Total removal of leaves of aspen in August would remove the source of ABA, perhaps preventing the normal development of dormancy. Plants left in a non-dormant state would freeze in the winter. Obviously, there is room for further investigation into the effect of late-season defoliation.

The study indicates 2 conflicting needs under range conditions. Aspen control requires late season defoliation, while the initial establishment of grasses is enhanced by early defoliation (Table 1). A third factor requiring consideration is the presence of snowberry and its tendency to expand in the absence of aspen (Tables 1 and 2). A development program may involve some combination of early and late grazing conjunction with a strategy, as yet undefined, for control of snowberry.

Cattle grazed aspen quite readily in August in the presence of ample alternative forages, but early in the season they tended to avoid it until the herbaceous species had been consumed. If cattle are to be used for early season defoliation, some method of concentrating them on regenerating shrubs, such as temporary electric fencing, may be necessary. Alternatively, other methods of achieving complete rapid defoliation of aspen suckers may be more practical and equally effective if timed correctly.

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Control of Leafy Spurge in Pastures Using Dicamba and 2,4-D

PAUL N.P. CHOW

Abstract

In the greenhouse, dicamba amine (dimethylamine of 3,6-dichloro-*o*-anisic acid) at 1.1 and 2.2 kg/ha (a.i.) controlled young seedlings of leafy spurge (*Euphorbia escula* L.) and prevented shoot formation 66 days after herbicide application. The 2,4-D amine (dimethylamine of 2,4-dichlorophenoxyacetic acid) did not effectively control the growth of leafy spurge at 0.6 and 1.1 kg/ha, but gave good control at 2.2 kg/ha. In a separate test, dicamba at 2.2 kg/ha controlled growth of shoots and roots of 100-day-old stands of leafy spurge more effectively than 2,4-D at the same rate. Dicamba killed mother stands and prevented the production of new shoots, whereas 2,4-D suppressed root growth of mother stands but induced more new shoot growth than found in untreated check plants. In a 5-year (1977-1981) field study (Brandon, Manitoba) of naturally established leafy spurge in a 'Carlton' smooth brome (*Bromus inermis* Leyss.) pasture, dicamba at 2.2 kg/ha, applied each year from 1977 to 1979, controlled leafy spurge satisfactorily and resulted in increased smooth brome yield. The 2,4-D at 2.2 kg/ha controlled the weed satisfactorily in 1977 and 1979, but not in 1978 and 1981. The mixture of 2,4-D (2.2 kg/ha) and dicamba (1.1 kg/ha) improved weed control and increased smooth brome yield. The smooth brome yield was inversely proportional to leafy spurge control. Under field conditions from 1978 to 1979, ^{14}C-dicamba in the plant translocated to the lower part of stems and accumulated in roots of established leafy spurge more readily than did ^{14}C-2,4-D, measured at 7, 47 and 350 days after herbicide application. It was concluded tht dicamba applied each year gave better spurge control than 2,4-D and resulted in a large yield increase of smooth brome due to killing young seedlings and mother stands. This prevented the spread of root system and seed multiplication of leafy spurge on pasture.

Leafy spurge (*Euphorbia escula* L.) is an aggressive, persistent dicotyledonous perennial weed having the ability to tolerate a variety of habitats and to survive under unfavorable conditions. The vigorous spreading root system, which is an efficient storage organ for growth, often branches below the soil surface to produce erect clumps. It is propagated sexually from seeds and asexually from root buds. Seeds may remain viable in the soil for 8 to 13 years (Sellect et al. 1962). Seeds in the soil were unharmed by picloram (4-amino-3,5,6-trichloropicolinic acid) (Bowes and Thomas 1978). This weed is now widespread, threatening millions of hectares of pasture and rangeland in the prairie region of western Canada and the north central United States (Richardson 1968, Vore and Alley 1980). Studies in Canada indicated that leafy spurge was widely distributed in various soil zones of Saskatchewan and it was declared a noxious weed (Selleck et al. 1962). In the United States a 3-year (1975-1978) survey revealed that leafy spurge was found in 26 states since its introduction about 100 years ago (Dunn 1979). It was first discovered in North Dakota in 1909, increased to 40,000 hectares by 1973, and had infested an area of over 240,000 hectares by 1981 (Messersmith and Lym 1981). A similar situation was found in Wyoming (Vore and Alley 1980). Wyoming has developed a control program provided through the 1978 Leafy Spurge Control Act. An extensive leafy spurge awareness program has been conducted in Montana since 1980 (Barreto and Fay 1981).

In addition to its spreading characteristics, leafy spurge exhibits allelopathic properties (Steenhagen and Zimdahl 1979). Leaf and stem extracts inhibit germination of a number of plant species (Richardson 1968, Selleck et al. 1962). If eaten by cattle, it causes scours and weakness, often resulting in death (Muenscher 1940). Prostrate spurge (*Euphorbia supina* Raf.), a related species to leafy spurge, was found to be very inhibitory to several strains of nitrogen-fixing and nitrifying bacteria and to several associated seed plants (Rice 1969).

Mechanical control of leafy spurge with deep plough plowing is very expensive and not practical in pastures. Chemical control is feasible with herbicides that leave a residue in the soil for a reasonably long period. For controlling deep-rooted species such as leafy spurge, herbicides should have high mobility in the plant down to the roots. Dicamba (3,6-dichloro-*o*-anisic acid) is considered to be a very mobile herbicide (Ashton and Crafts 1973). It is readily translocated in phloem and xylem, and exuded to the soil by the roots of treated Canada thistle (*Cirsium arvense* L.) (Chang and Vanden Born 1968). Translocation of foliar-applied ^{14}C-2,4-D (2,4-dichlorophenoxy acetic acid) into the shoots, roots, and root buds in greenhouse-grown seedlings was significantly increased both by shoot removal and by increasing the nitrogen supply (Hunter and McIntyre 1974). Low economic returns from pasture production tend to favor use of low-cost herbicides such as 2,4-D for suppressing leafy spurge growth. Trumpet-creeper [*Campsis radicans* (L.) Seem.], another deep-rooted woody perennial pasture weed, is controlled more effectively by dicamba than by 2,4-D (Thompson et al. 1973).

Despite the importance of leafy spurge, there is little research reported on its control This lack of information may be due to the lack of uniform stands on pasture under natural infestation for experimental evaluation and to the need for a relatively long period (several years) for evaluation of control methods. The objectives of the investigation reported here were (1) to measure the effect of dicamba and 2,4-D on growth of leafy spurge in the greenhouse; and (2) to compare the effectiveness of the 2 herbicides for the control of established leafy spurge on smooth brome pasture. The translocation and accumulation of ^{14}C-dicamba and ^{14}C-2,4-D in leafy spurge in microplots under natural pasture conditions were also compared.

Materials and Methods

Greenhouse Investigation

Under natural infestation conditions in the field, young seedlings grown from seeds and clumps from root buds in established mother stands are found simultaneously. It is necessary to measure

The author is research scientist in weed/herbicide physiology, Agriculture Canada Research Station, Brandon, Manitoba, R7A 5Z7, Canada.

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Table 1. Effect of dicamba amine and 2,4-D amine on growth of leafy spurge seedlings, evaluated in two cuttings in the greenhouse.

Treatment		1st cutting[1], 21 days after application		2nd cutting[1], 66 days after application	
Herbicide	Rate (kg/ha)	Visual rating (0–9[2])	Fresh weight (g/pot)	Shoots (no./pot)	Fresh weight (g/pot)
Untreated check	0	0 d	2.4 a	6.3 a	4.1 a
Dicamba	0.6	3.1 c	1.4 b	1.5 bc	0.5 bc
Dicamba	1.1	3.6 b	0.8 c	0 c	0 c
Dicamba	2.2	8.9 a	0.4 d	0 c	0 c
2,4-D	0.6	2.9 c	1.0 c	4.3 b	1.6 b
2,4-D	1.1	3.3 bc	0.8 cd	3.5 b	1.0 b
2,4-D	2.2	8.8 a	0.4 d	0 c	0 c

[1]Means within column followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.
[2]Visual rating, 0–9, 9 = complete kill.

the responses of both young seedlings and old stands to herbicides. Therefore, 2 types of greenhouse pot experiments were conducted.

Effect of Herbicides on Young Seedlings

Leafy spurge was seeded in pots containing 1,500 g Pipestone clay loam (a gleyed carbonated Rego Balck Chernozem) with 5.6% organic matter and a pH of 7.5. After emergence, seedlings were thinned to 3 plants per pot. Water was added periodically to the surface of the soil as required for seedling growth. A photo-period of 16-hour was provided by flourescent lamps at 322 $\mu E \bullet m^{-2} \bullet s^{-1}$. Temperatures ranged from 16 to 23°C during the day and 12 to 18°C at night. The pots were arranged in a randomized complete block with 4 replicates. At 28 days of growth, seedlings were treated with 3 rates (0.6, 1.1, and 2.2 kg/ha a.i.) of dicamba amine or 2,4-D amine. Visual rating (0–9, 9 = 100% kill) of weed control and fresh top weight (referred to as the first cutting) were recorded 21 days after herbicide application. After harvesting, the pots were watered and exposed to the lights under the same environmental conditions as described previously. Regrowth (including number of tillers and fresh weight) of shoots of leafy spurge (referred to as the second cutting) was measured 66 days after application (45 days after the first cutting).

Effect of Herbicides on the Growth of Shoots and Roots in Established Stands.

Three root stocks, 7.5 cm in length with 4 buds, were planted in pots (22 cm diameter and 20 cm in depth) containing 4.5 kg Pipestone clay loam. Plants were grown in the greenhouse for 100 days, after which both dicamba amine or 2,4-D amine at 2.2 kg/ha (a.i.) were applied. Untreated plants were used as a check. Seventy-one days after treatment, roots were washed and the plants having mother stands and new shoots were separated out and measured or weighed. Five replicates in a randomized complete block were used and the pots were rearranged on the bench weekly.

Field Experiments

Leafy Spurge Control and Smooth Brome Yield

Heavy natural infestations of leafy spurge on smooth brome pasture [a Miniota sandy loam (Orthich Black Chernozem, level lacustrine and flacio-fluvial sand deposit) with organic matter 3.4%] were chosen for the experiment. The population of leafy spurge was 35 plants/per m² and plant height averaged 40 cm. For rigid selection of uniform stands, 3 replicates (3 × 9 m) were arranged in a randomized complete block for the 5-year (1977 to 1981) evaluation period. Herbicides (rates listed in Table 3) were applied 1977 to 1979 in early July when leafy spurge was in the early bloom stage with vigorous vegetative growth. Herbicides were applied in 130 litres/ha of water at 310 kPa of pressure. Visual ratings of weed control were made each year 6 to 8 weeks after herbicide application. Smooth brome yield was estimated from 3 m² areas clipped at different sites in each plot in 1979 and 1981. Ground coverage by leafy spurge and smooth brome in each plot in 1981, 2 years after application of the herbicides, was also visually scored by 2 persons and averaged estimates were presented.

Measurement of Labelled Herbicide Movement in Established Leafy Spurge

In microplots (0.5 by 0.5 m) in established stands 2 plants of similar size and height (40 cm on average) were selected for each treatment in 3 replicates. In late July, plants with 7 to 8 yellow leaves within 7.5 cm of the top were dipped into diluted ^{14}C-labelled herbicide solutions [^{14}C-dicamba (8.3 μCi) alone or in mixture with 0.24 kg/ha 2,4-D, and ^{14}C-2,4-D (7.9 μCi) alone or in mixture with 0.24 kg/ha dicamba] containing 0.25% Tween 20 (polyoxyethylene 20 sorbitan monolaurate) surfactant for 0.5 min. This application procedure for radioactive solutions in the field is similar to that used by Jacobsohn and Andersen (1968). The treated and untreated plants were tagged with identification labels. On assigned dates (7, 47, and 350 days after application), the plants were dug out, roots were washed, and tops and roots separated. Unabsorbed labelled herbicides on the tops of plants were washed with 95% ethanol for 1 min. The plant tissues were dried at 50°C for 24 hours and ground to pass through a 420 μ sieve. Three 100 mg samples were extracted with 95% ethanol. The extracts, 1.0 ml in 3 replicates, were bleached with 0.5% benzoyl peroxide in the vial (Chow 1977). Radioactivity in the bleached extracts was counted in the scintillation toluene solution containing Triton x-100 [octoxynol, *a*,(*p*-1,1,3, 3-tetramethyl butylphenyl)-*w*-hydroxypoly(oxyethylene)] at 2:1 (v/v) by using a standard procedure.

Table 2. Effect of dicamba amine and 2,4-D amine on growth of 100-day-old stands of leafy spurge, measured 71 days after application in the greenhouse.

Treatment				Dry weight[1]	
Herbicide	Rate (kg/ha)	Alive mother stand[1] (no./pot)	New shoots produced[1] (no./pot)	Shoots[2] (g/pot)	Roots (g/pot)
Untreated check	0	1.0 a	0.2 b	12.1 a	10.1 a
Dicamba	2.2	0.0 b	0.0 b	3.4 b	1.2 c
2,4-D	2.2	0.9 a	8.6 a	11.4 a	3.7 b

[1]Means within column followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.
[2]Included mother stands and new shoot produced.

Results and Discussion

Greenhouse Investigation

Effect of Herbicides on the Growth of young seedlings of leafy spurge

Dicamba at 3 rates (0.6, 1.1 and 2.2 kg/ha) gave good control of young leafy spurge seedlings at a significant level compared to untreated check plants, as measured 21 days after herbicide application in the first cutting (Table 1). However, only the 1.1 and 2.2 kg/ha rates killed the plants, as measured at 66 days in the second cutting. Only the 2.2 kg/ha rate of 2,4-D controlled leafy spurge seedlings and killed the plants. At these higher rates, the herbicides were probably toxic to buds and roots, which did not produce new shoots below the soil surface.

Effect of Herbicides on the Growth of Shoots and Roots of Established Stands

The application of dicamba at 2.2 kg/ha killed all shoots including 100-day-old mother stands, and reduced shoot and root weight significantly in comparison with untreated plants (Table 2). The 2.2 kg/ha rate of 2,4-D suppressed root growth but did not reduce mother stand numbers and shoot weights. These results on shoots were different from the previous experiment, probably because the leafy spurge plants were older, larger, and growing more vigorously, which may lead to resistance to the 2,4-D effect. The suppression of root growth by 2,4-D appeared linked to the stimulation of new shoots produced under the soil surface resulting in 8.6 new shoots per pot vs. 0.2 shoots for the untreated plants. Apical dominance associated with auxin in stem, tubers (Michener 1942), and roots (Thimann 1936) are common in the plant kingdom. If 2,4-D at this rate injures, but does not kill, the apex of the roots, it would be expected that the release of auxin effect on apex-dominance would produce new shoots from the buds on the root system or stem under the soil surface.

Field Experiment

Leafy Spurge Control and Smooth Brome Yield

Visual ratings on weed control from 1977 to 1979 when the herbicides were applied showed that dicamba at 2.2 kg/ha consistently gave the best control (Table 3). Even in 1981, 2 years after the last application, dicamba still gave 84% control. The 2.2 kg/ha treatment of 2,4-D obtained 83 and 82% leafy spurge control in 1977 and 1979, respectively, but only 62% control in 1978. Two years after application, the control with 2,4-D was reduced to 16%. Fresh weight production of leafy spurge also differed significantly, with herbicide treatment with 2,4-D treated plants out-weighing dicamba treated plants by 14 times in 1979 and 22 times in 1981. The mixture of dicamba (1.1 kg/ha) and 2,4-D (2.2 kg/ha) improved weed control over 2,4-D (2.2 kg/ha) applied alone. The highest yield of smooth brome in 1979 and 1981 resulted from successful control of leafy spurge with dicamba (2.2 kg/ha). Smooth brome and leafy spurge production was much lower in 1981 than in 1979. Reduction in vegetative growth may be related to a number of factors, one of which may be the availability of soil moisture (Morrow 1979) because of continuously dry conditions from spring and summer in 1980 and low snowfall in the following winter. the growth competition between these 2 species appears to be strong. This was reflected in the inversely proportional ground coverage between the crop and the weed (Fig. 1). This also

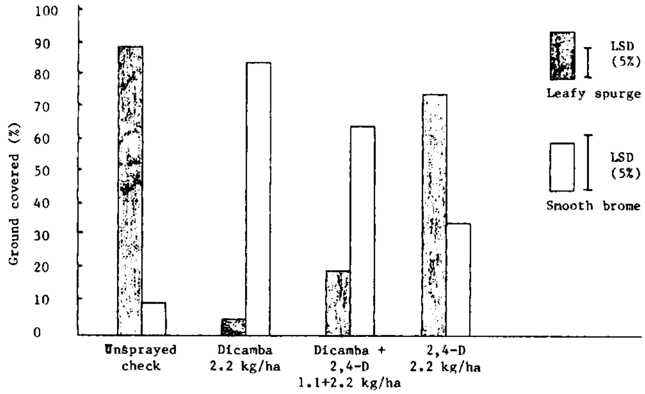

Fig. 1. *The relationship of ground coverage in plots between leafy spurge and smooth brome, visually estimated in 1981.*

indicated that maximum yield of smooth brome requires successful control of leafy spurge.

Movement of ^{14}*C-dicamba and* ^{14}*C-2,4-D in Leafy Spurge*

The movement of ^{14}C-dicamba from the top to the lower part of stems or to the roots was faster than was ^{14}C-2,4-D movement (Table 4) as found in several other species (Chang and Vanden Born 1968, Thompson et al. 1973). Seven days after application and thereafter, ^{14}C-dicamba alone or in a mixture with 2,4-D moved faster and accumulated faster in roots than ^{14}C-2,4-D alone or in mixture with dicamba probably because of free mobility of ^{14}C-dicamba (Ashton and Crafts 1973). At 350 days after application, approximately half (47 to 48%) of the ^{14}C-dicamba had moved to the roots. In contrast, about 36 to 38% of ^{14}C-2,4-D had moved to the roots and 62% remained in the stem. These findings may provide a partial explanation of differential activity of the herbicides against leafy spurge.

Conclusion

Results of this investigation indicated that leafy spurge in smooth brome pasture must effectively be controlled to obtain

Table 3. Leafy spurge control with dicamba and 2,4-D and smooth brome yield in the field.

	Treatment			Leafy spurge control and date of evaluation[1]						Smooth brome fresh weight yield[1,2]	
	Date and rate (kg/ha)			Visual rating (%)				Fresh weight (kg/ha)		(kg/ha)	
	1977	1978	1979	1977		1979	1981	1979	1981	1979	1981
Herbicide	7-8	7-6	7-11	8-16	9-5	8-7	7-3	7-10	7-3	7-10	7-3
Unsprayed check	0	0	0	0 d	0 c	0 c	0 b	1033 a	867 a	1330 c (100)	87 d (100)
Dicamba	2.2	2.2	2.2	81 c	84 a	82 b	84 a	34 c	32 c	2591 a (195)	858 a (986)
2,4-D + dicamba	2.2 1.1	2.2 1.1	2.2 1.1	88 a	80 a	85 a	71 a	363 b	158 b	2170 ab (163)	617 b (709)
2,4-D	2.2	2.2	2.2	83 b	62 b	82 b	16 b	479 b	710 a	1725 bc (130)	328 c (377)

[1]Means within column followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.
[2]In each column values in parentheses represent yield in % of the unsprayed check.

Table 4. Distribution of ¹⁴C-dicamba and ¹⁴C-2,4-D in the lower part of stem or roots of leafy spurge in the field.

Treatment			Days after application		
			7	47	350
Herbicide	Labelled (μCi)	Nonlabelled (kg/ha)	Lower part of stem[1] (%)	Roots (%)	Roots (%)
^{14}C-dicamba	8.3	0	8.1 ± 0.2	21.5 ± 1.4	46.8 ± 0.1
^{14}C-dicamba	8.3	0			
+ 2,4-D	0	0.24	6.3 ± 0.2	34.0 ± 0.7	48.2 ± 0.4
^{14}C-2,4-D	7.9	0	2.8 ± 0.3	10.1 ± 0.1	37.9 ± 0.3
^{14}C-2,4-D	7.9	0			
+ dicamba	0	0.24	2.0 ± 0.6	2.0 ± 0.2	35.5 ± 0.3

[1]After cutting the treated tops, each stem was separated into lower and upper parts of equal length (average 15 cm). Radioactivity in the roots was not measured on the 7th day.

high yield of the crop. Dicamba at 2.2 kg/ha applied in 3 consecutive years gave better leafy spurge control with 2,4-D at equal rate and resulted in larger brome yield increases. Greenhouse experiments demonstrated that dicamba (2.2 kg/ha) not only controlled young seedlings but also killed mother stands and inhibited new shoot production. This implied that in the field dicamba exerted herbicidal action to prevent the spread of leafy spurge, young seedlings and mother stands, and eventually reduced seed production.

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Influence of Range Seeding on Rodent Populations in the Interior of British Columbia

THOMAS P. SULLIVAN AND DRUSCILLA S. SULLIVAN

Abstract

This study was designed to determine the influence of range seeding on rodent populations inhabiting cutover lodgepole pine forest land in the interior of British Columbia, Canada. Both deer mice and voles were strongly attracted to an area seeded with grass mixture in the early spring, even though overwinter mortality had dramatically reduced the average density to ≤2 animals/ha. Five rodents as well as several seed-eating birds appeared on this seeded area while no animals were recorded on a nearby control. Subsequent seeding experiments in the summer also produced significant increases (2 to 2.2 times) in rodent populations. Success of range seeding in B.C. can be quite variable, possibly due to seed predation by mice and voles. Consequently, both the quality and quantity of seed remaining for germination and forage production may be radically altered.

Grass seeding of cutover forest land is designed to improve range conditions for cattle grazing in many parts of western Canada and the United States. These seedings are successful in some areas but do not produce the expected growth of forage in other localities. There are probably several factors responsible for this inconsistency, but one potential problem is rodent predation on the grass seed.

Seed predation by the deer mouse *(Peromyscus maniculatus)* has contributed to the failure of several range seeding projects (Howard 1950, Casebeer 1954, Johnson 1961, Nord 1965, Nelson et al. 1970). Everett et al. (1978) have reviewed the range seed preferences of deer mice. Voles of the genus *Microtus* spp. also harvest large quantities of grass seed (Batzli and Pitelka 1970, Marshall and Jain 1970, Borchert and Jain 1978). These microtines usually inhabit grassland areas but may also occur on interior logged sites (Radvanyi 1973, Sullivan and Sullivan 1982).

Little quantitative information is available on the response of rodent populations to range seedings. To determine the influence of range seeding on deer mice and voles and devise suitable control methodology for reduction of seed predation, a preliminary assessment of rodent populations is required. This study was designed to monitor rodent populations before and after grass seeding of cutover lodgepole pine *(Pinus contorta)* forest lands.

Methods

Study Areas

This study was located at 2 areas in the south-central interior of British Columbia, Canada. The Okanagan study area was 30 km northwest of Summerland adjacent to the Okanagan Valley in the Kamloops Forest Region. The forest type corresponds to the Interior Douglas fir *(Pseudotsuga menziesii)* biogeoclimatic zone (Krajina 1969) and the dominant lodgepole pine was logged in 1978. Groundcover included slash with pinegrass *(Calamogrostis rubescens)* and lupine (*Lupinus* spp.).

The Chilcotin study area was 53 km west of Williams Lake in the Cariboo Forest Region. This area is classified as the Douglas fir-pinegrass subzone (northern phase) (Annas and Coupe 1979) of the Interior Douglas fir biogeoclimatic zone. The forest was logged in 1977 and burnt in the spring of 1978. Ground-cover included burnt slash, pinegrass, and a variety of early successional herbs.

All experimental sites were on relatively flat terrain with little discernible aspect. Both clearcut blocks were approximately 10 ha in area.

Rodent Populations

Two 1-ha matrix grids 1 control (A) and 1 experimental (B)) were established at the Okanagan, and 3 identical grids 1 control (A) and 2 experimental (B and C)) at the Chilcotin study area. Grids were centrally located on each study area and were separated from each other by at least 200 m to minimize recapture of animals moving between sampling areas. All grids had 49 trap stations (7 × 7) located at 15.2-m intervals. Grids were trapped at 3-week intervals from August 1979 to August 1980 in the Chilcotin and May to September 1980 in the Okanagan. One Longworth live-trap was located within a 2-m radius of each station. Traps were baited with peanut butter, Purina Lab Chow® or whole oats, and cotton was supplied as bedding. Traps were set on day 1, checked on days 2 and 3, and then locked open between trapping periods.

All rodents captured were ear-tagged with serial-numbered fingerling fish tags. Population densities were determined by number of individuals caught (for low sample sizes) or by the enumeration technique of minimum number of animals known to be alive (MNA) (Hilborn et al. 1976) at each 3-week interval. If x number of animals captured at time t are not caught at t+1 but are recaptured at t+2, then these x animals are alive but not censused at t+1 and so should be included in the density estimate for that time.

Grass Seeding

The grass seed mixture used in this study was composed of 26% 'hay' orchard grass *(Dactylis glomerata)*, 10% climax timothy *(Phleum pratense)*, 15% bromegrass (*Bromus* spp.), 15% intermediate wheatgrass *(Agropyron intermedium)*, 10% perennial ryegrass *(Lolium perenne)*, 12% white clover *(Trifolium repens)*, and 12% alsike clover *(Trifolium hybridum)*. In experiment 1 in the Chilcotin, this mixture was uniformly distributed over a 4-ha block which included the centrally located 1-ha area of grid B. Cyclone seeders were used to disperse seed onto snow (depth of 30 to 45 cm) on March 28, 1980, at a seeding rate of 5 kg/ha. This spring period was typical for range seedings on the interior of B.C., which vary from just before snowfall to late spring before snowmelt. This seed was distributed approximately 1 month prior to the first possible post-seeding trapping period (late April 1980).

Experiment 2 in the Chilcotin commenced on June 18, 1980' when 10 kg of grass seed was manually distributed over the 1-ha

Authors are research scientist and research associate, Applied Mammal Research Institute, 23523 47th Avenue, R.R. #7, Langley, B.C., Canada. V3A 4R1.
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area of grid C. Experiment 3 in the Okanagan replicated this summer seeding with 10 kg of grass seed manually dispersed over the 1-ha area of grid B on June 28, 1980.

Results and Discussion

Experiment 1–Spring Seeding

The effect of spring grass seeding on rodent populations at the Chilcotin study area is illustrated in Figure 1. The first trapping period in 1980 occurred 4 weeks after seeding and 5 new animals: 3 deer mice *(Peromyscus maniculatus)* and 2 heather voles *(Phenacomys intermedius)* were captured on the seeded area (grid B). No rodents were captured on control grid A. The 3 deer mice captured on grid B were all tagged animals which had emigrated from grid A, a distance of approximately 350 m. These deer mice were presumably attracted to the seeded area because of the artificial food supply. Their average home range size was 0.06 ha prior to seeding, and this range expanded to 1.7 ha after seeding.

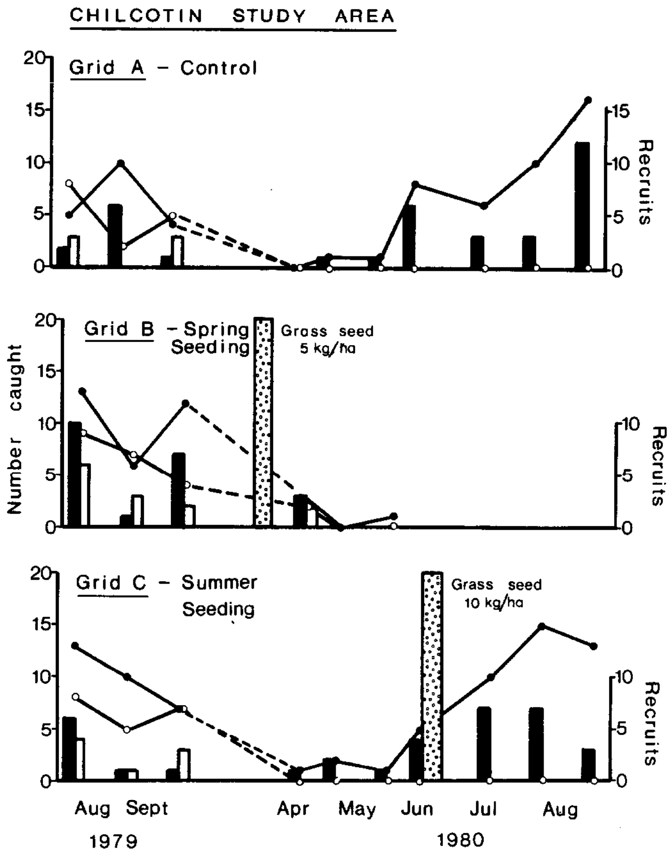

Fig. 1. *Population densities of* Peromyscus maniculatus *(closed circles) and the voles* Phenacomys intermedius *and* Microtus pennsylvanicus *(open circles) at the Chilcotin study area during the fall of 1979 and spring and summer of 1980. Histograms indicate number of deer mice (shaded) and new voles (unshaded) recruited into populations. Grass seed mixture was applied to grid B on March 28, 1980 and to grid C on June 18, 1980.*

In general, the populations of deer mice and voles *(Microtus pennsylvanicus* and *P. intermedius)* on both grids declined dramatically over the winter of 1979-1980 to an average density ≤2 animals/ha. This is consistent with that reported by Sullivan and Sullivan (1982) for rodent populations on interior cutover forest land in British Columbia. No meadow voles *(M. pennsylvanicus)* were captured in 1980, which represented a low year in the 3–4 year cyclic fluctuation in abundance of this microtine.

Small sample size precluded statistical analysis of this rodent response to grass seeding. However, the capture of 5 animals on the seeded grid compared with a total of only 2 other mice captured 1 deer mouse on grid C and 1 heather vole on a fourth grid) strongly suggests that the grass seed attracted rodents. It is very likely that the majority of mice on the clearcut block (10-ha area) were concentrated on the seeded area during the 4- week period after seeding.

Several white-crowned sparrows *(Zonotrichia leucophrys)* and dark-eyed juncos *(Junco oreganus)* were observed in grid B during the first trapping period in late April. These seed-eating birds were consuming the grass seed as has been documented for granivorous birds in other range seeding projects (Goebel and Berry 1976). Thus, both rodents and seed-eating birds congregated on the seeded area. They presumably had a serious impact on the quantity and perhaps quality of grass seed remaining for germination and forage production.

Experiment 2–Chilcotin Summer Seeding

If the rodent populations are influenced by range seeding during the winter and spring, then application of a large amount (10 kg/ha) of grass seed should provide a significant response. To rigorously analyze this predicted response, a summer seeding experiment was conducted at the Chilcotin study area. This time period allowed for assessment of the number of rodents immediately before and after seeding. The results of this experiment are illustrated in Figure 1. While the control population declined from 8 deer mice to 6 during the first post-seeding trapping period, the grid C population doubled in density (from 5 to 10). This increase was followed by another burst of recruitment up to a density of 15 deer mice per ha on the seeded area. The response was not statistically significant ($p = 0.20$; chi-square) but may be biologically significant in terms of deer mice appearing on the area to utilize the seed as a food source.

Experiment 3–Okanagan Summer Seeding

This summer seeding (10 kg/ha) experiment was replicated at the Okanagan study area where the rodent community was dominated by the long-tailed vole *(M. longicaudus)* and the meadow vole. Deer mice were present but at considerably lower densities than the voles. The results of grass seeding are illustrated in Figure 2. Prior to seeding, the grid B vole population declined from 31 to 12 animals/ha. This drop was not related to trapability since the enumeration technique of minimum number alive was employed for the populations. The control population of voles was increasing at this time before stabilizing at 28 to 34 animals/ha. Recruitment of new animals was generally consistent throughout the summer. Application of grass seed to grid B resulted in more than a doubling of vole numbers (from 12 to 27). Of these new voles, 92% were adults colonizing the seeded area. Five new deer mice also appeared on the area even though only 1 deer mouse was captured in the 4 trapping periods prior to seeding.

The dramatic increase in voles on the seeded area was statistically significantly ($p = 0.02$; chi-square) when compared with the control population. This result is not surprising since *Microtus* spp. readily harvest various species of grass seed (Batzli and Pitelka 1970, Marshall and Jain 1970, Borchert and Jain 1978).

Conclusions

We conclude that range seeding of cutover forest land may strongly influence rodent populations. Both voles and deer mice respond positively by their attraction to seeded areas. Since range seed is readily consumed by rodents, the quality (species) and quantity of seed remaining for germination and forage production may be radically altered. Deer mouse and vole preference for certain grass and forb seed species has been documented (Borchert and Jain 1978, Everett et al. 1978).

Our studies were conducted in the southern and central interior of British Columbia where range seeding and cattle production are concentrated. In general, the success of range seeding projects can be quite variable. Factors which affect seeding success include weather, soil, and related site components, as well as predation by rodents. Additional replication in our experimental design would

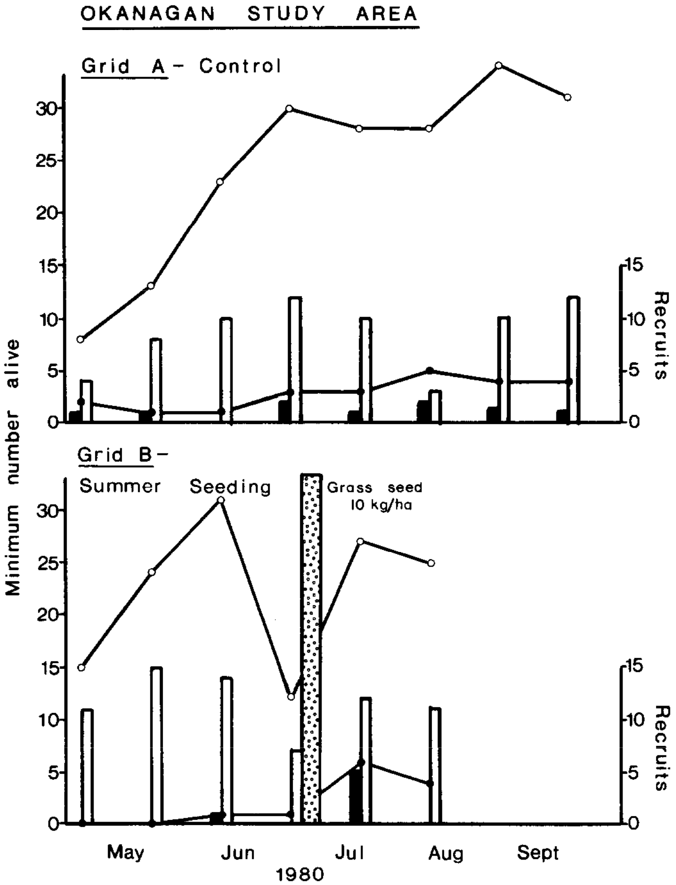

Fig. 2. *Population densities of* Peromyscus maniculatus *(closed circles) and the voles* Microtus pennsylvanicus *and* M. longicaudus *(open circles) at the Okanagan study area during the spring and summer of 1980. Histograms indicate number of new deer mice (shaded) and now voles (unshaded) recruited into populations. Grass seed mixture was applied to grid B on June 28, 1980.*

have provided a more rigorous analysis of the rodent response. However, since mice and voles are attracted to seeded areas and presumably consume seed, we advocate further study of seed species preference and forage production in areas with rodent populations.

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Viewpoint: Trinomials Are in Poor Taste

ALAN A. BEETLE

In botanical literature three Latin names in a sequence without designation of subspecies, variety, or form are considered trinomials. These trinomials have no official standing in taxonomy. According to the 1978 International Code of Botanical Nomenclature adopted by the 12th International Botanical Congress Article 35, "A new name or combination published on or after Jan. 1, 1953, without a clear indication of the rank of the taxon concerned is not validly published." Article 24 says: "The name of an intraspecific taxon is a combination of the name of a species and an infraspecific epithet connected by a term denoting its rank."

Trinomials have appeared frequently in the *Journal of Range Management*. Part of the confusion may arise because trinomials are acceptable in Zoological literature. However, when used in botanical literature they are not Latin names, nor are they common names. They are never used in any of the botanical magazines covering other subjects than taxonomy.

The fact is that while range managers may use trinomials, they are in poor taste and the *Journal of Range Management* would attain a more scholarly recognition if it did not use them. Most authors would be quite receptive to the editorial change if they understood this.

Author is Professor Emeritus, University of Wyoming, Laramie.

Costs and Returns of Angora Goat Enterprises with and without Coyote Predation

JERRY H. SCRIVNER AND J. RICHARD CONNER

Abstract

During 1980, 101 ranchers in 3 counties (Bosque, Hamilton, and Coryell) in Texas, were interviewed regarding livestock losses and expenses resulting from methods used to reduce predation. Using data from the survey and other primary and secondary sources, 2 cost/return budgets were developed for nanny (female), wether (castrated males), and nanny/wether goat operations typical to the study area. First, budgets representing the 3 types of operations in the absence of predation were developed. Then, using an average of the predation rates and levels of prevention practices revealed by the survey, budgets were developed to represent the 3 types of operations with predation. Predation reduced gross revenues for nanny, nanny/wether, and wether goat operations by 22.2%, 14.3%, and 13.5%, respectively, when predation was a problem. Fewer saleable goats and pounds of mohair were the major reasons for this decrease in revenues. Also, when predation was a problem, operational costs were increased by 32.8%, 17.7%, and 16.4% for nanny, nanny/wether, and wether goat operations, respectively. Factors which accounted for the majority of this increase included extra feed, travel expenses, and labor primarily associated with predator control efforts and penning, kidding, and extra surveillance of goats because of the presence of predators. The results illustrate the importance of costs due to attempts to reduce predation. These costs may equal or exceed the value of animals killed by predators; however, without these added costs predation losses likely would be greater.

Predation, primarily by coyotes *(Canis latrans)*, has long been a problem to the livestock industry (Delorenzo and Howard 1976, Klebenow and McAdoo 1976, Nesse et al. 1976, Nass 1977). Such losses often result in a substantial reduction in cash returns to ranchers (Nesse et al. 1976, Taylor et al. 1978, Texas Crop and Livestock Reporting Service 1979, Wade and Connolly 1980). For the sheep industry, the U.S. Fish and Wildlife Service (1978) estimated predation losses at $19-38 million in 1977 for U.S. sheep producers in the 17 western states. Meanwhile, consumers lost $4 million in benefits because of reduced quantities and higher prices for lambs available.

In Texas, the number of sheep has declined from 10.8 million in 1943 to 2.4 million in 1980. The number of goats has declined from 4.1 million in 1965 to 1.4 million in 1980. A significant factor contributing to the decline of the Texas sheep and goat industry is predation (Kensing 1978, 1980). The Texas Crop and Livestock Reporting Service (1979) estimated that in 1978 predators accounted for 58% of all sheep and lamb losses and 72% of all goat and kid losses in Texas. About $13 million or 62% of the total market value of sheep, lamb, goat, and kid losses was due to predators.

Most researchers determine the cost of predation to ranchers by calculating 1 or 2 cost factors, such as the value of livestock killed by predators and/or direct costs associated with predator control such as traps or fees paid professional trappers (Nesse et al. 1976, Texas Crop and Livestock Reporting Service 1979). Other costs, however, should be considered. These include expenses associated with management to protect livestock from predators such as night-time penning of livestock, shed-lambing or kidding[1], and the use of guard dogs and scare devices (such as propane and acetylene exploders). Costs associated with one or more of these techniques include additional transportation, feed, labor, and equipment over the amount which would be used in the absence of predation.

The financial impact of depredation on the typical production firm can be examined with enterprise budgets (Gee 1978). By evaluating livestock costs and returns for operations with and without predation, the effect of specific levels of predation on representative livestock operations easily can be seen. Furthermore, enterprise budgets can be used to illustrate the financial effects of changes in loss rates and/or control methods on the economic viability of a livestock operation.

Studies which use enterprise budgets to evaluate the cost of predation to Angora goat ranchers are lacking, although Wade and Connolly (1980) have addressed some of the economics involved. The objective of this study was to develop enterprise budgets of typical Angora goat operations with current levels of predation and control methods. These budgets then are compared to budgets for the same operations with no predation and predator control and budgets which reflect current control levels but reduced levels of predation.

Methods

The study area included Bosque, Hamilton, and Coryell counties in Texas. The 3 adjacent counties are in the Grand Prairie land resource area (Rechenthin and Smith 1967). The soils, mostly fine textured, are derived from limestone and marls. The original vegetation consisted of primarily tall and mid-grass prairie but honey mesquite *(Prosopis glandulosa)*, juniper (*Juniperus* spp.), elm (*Ulmus* spp.), and oak (*Quercus* spp.), now have thickened to dense stands on many acres.

These 3 counties are just outside the northeastern edge of the Edwards Plateau. In such counties the annual coyote abundance survey (Roughton 1976) has continually recorded high coyote densities and they reportedly have high goat losses to predators (Pearson and Caroline 1981). These counties were selected for study because of the high probability of finding ranchers with predation problems. During 1968-1981, the number of Angora goats decreased 85%, 81%, and 65% for Bosque, Coryell, and Hamilton counties, respectively, while the statewide decrease was 67% (Texas Crop and Livestock Reporting Service 1968-1981).

In 1981, ranchers in the study area were questioned regarding their costs due to predation for the 1980 calender year. Ranch operations were classified according to herd size and herd composition. Nanny (N) operations consisted of more than 10 nannies with ≤10 male goats; wether (W) operations had more than 10 wethers with ≤10 nannies; and nanny/wether (N/W) operations had >10 nannies and 10 wethers. The number and percent of

Authors are graduate research assistant, Department of Wildlife and Fisheries Sciences and professor, Departments of Agricultural Economics and Range Science, Texas A&M University, College Station 77843. Approved by the Director, Texas Agricultural Experiment Station as TA-18221.

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[1]Shed-lambing and kidding is used for protection from inclement weather, disease, and nutritional deficiencies. We only consider this management alternative as a cost due to predation when the technique would not be used if predators were not a problem.

ranchers questioned in each category for the 3 counties are listed in Table 1.

Table 1. Number and percent of ranchers personally interviewed in Bosque, Hamilton, and Coryell counties. Ranch operations were classified as nanny, nanny/wether, and wether.

	Nanny		Nanny/Wether		Wether	
	Number	Percent	Number	Percent	Number	Percent
Bosque	4	18	12	18	5	36
Hamilton	7	32	31	48	2	14
Coryell	11	50	22	34	7	50
Total	22	100	65	100	14	100

Ranchers were questioned regarding costs resulting from livestock losses to predators and management techniques used to reduce losses. Cost factors included: (1) the number and percent of kids and adults killed by predators and the number and percent of adults dying from causes other than predation, (2) the amount and types of predator control equipment owned by the rancher as well as hours and mileage used for predator control, (3) dollars spent supporting a full or part-time trapper, (4) the value of feed and the number of kilometers driven and hours spent penning, kidding, and checking goats above which would have been used if predators were not a problem, (5) dollars spent on scare devices, and (6) the number of livestock guarding dogs.

The price/head of goats and pounds of mohair for investment requirements and production revenue were determined by examining March and April market reports for a 5-year period (Texas Sheep and Goat Raisers Association 1978-1982). Each price then was adjusted to 1982 dollars by using a production price index for each year (U.S. Department of Agriculture 1979-1980, 1980-1982). A mean price/item then was calculated using the 5 adjusted values. Prices for other investment requirements and fixed and variable inputs were determined using information provided by the Texas Agricultural Extension Service (1982) and appropriate businesses in the study region.

Table 2 describes a typical management activities for calender for Angora goats in Bosque, Hamilton, and Coryell counties. This management scheme provided a framework on which the goat budgets were built. Revenue and input allocation were based on a production year beginning in October. Obviously for W operations, many of these activities do not occur. During unspecified time periods the primary activity involves observing livestock. Throughout production year, miscellaneous activities also occur, such as repairing fences and water systems and feeding salt and minerals.

Expected costs and returns based on this production system were used to develop a budget for each of the 3 types of operations in the absence of predation. In these budgets, the only survey data used included the expected percent kid crop in the absence of predation and the percent of adult animals dying to causes other than predation. On the average, ranchers with N and N/W operations expected a 73% kid crop (n=15) in the absence of predation. This is similar to kid crop figures once reported by ranchers in areas where formerly predators were not a problem or where grazing by goats has traditionally been at moderate intensities (Bassett 1983 and Shelton 1983). The percent of adult goats dying to causes other than predation was 6.58% (N), 3.23% (N/W), and 1.13% (W). Using survey results, a second budget then was generated for each operation by adjusting cost/return factors to reflect average changes resulting from predation. For each budget, costs resulting from livestock losses to predators and techniques used to reduce predation were averaged based on total number of adults and then converted to cost/animal unit (AU). The average herd size was 113 for N operations; 141 nannies and 170 wethers for N/W operations; and 221 for W operations. Obviously, the total number of goats and animal units fluctuates throughout the year because of kidding, death losses, and sales. However, to be consistent, all AU costs were calculated on the basis of the total number on hand at the beginning of each production year, which is assumed to be constant over years with and without predation.

Results and Discussion

Tables 3, 4, and 5 list the costs and returns/AU for N, N/W, and W operations, respectively, when coyote predation was and was not a problem. For all 3 budgets, investment requirements increased when predation was a problem due to the cost of purchasing a livestock guarding dog. There was an average of 0.32 (N), 0.36 (N/W), and 0.36 (W) guard dogs for the 3 operations. Most dogs purchased were Komondork and Great Pyrenees. Green et al. (1980) reported the average value of such dogs to be $500.00; thus, investment requirements increased $5-10.00/AU for each budget.

An average of 3.52% (N), 4.18% (N/W), and 12.21% (W) of the adult goats were estimated to be killed by predators. Coyotes prefer young Angora kids to adults (Guthery and Beasom 1977), therefore the greater percent of adults killed for W operations was possibly because of the absence of kids in these operations. Thus, because of predation losses, total losses increased from 6.58% (N), 3.23% (N/W), and 1.13% (W) to 10.10% (N), 7.41% (N/W), and 13.34% (W). There was an average of 22.61% (N) and 20.32% (N/W) kids reported killed. The kid crop, therefore, decreased from an expected 73% for the N and N/W operations to 50.4% and 52.7%, respectively. Because of these losses, fewer pounds of adult and kid mohair and fewer kids and salvage adult goats were available to be marketed. As a result production revenues decreased 22.5% (N), 14.4% (N/W), and 13.5% (W).

When predators are a problem, ranchers often use feed to lure goats from pasture to pen, as supplemental feed for grazing time lost due to penning or shed-kidding, and to attract goats so they can be inspected for wounds caused by predators. Costs and returns resulting from the possibility of stocking more goats/ha because of increased uses of supplemental feed with increased

Table 2. A typical management activities calendar for Angora goats in Bosque, Hamilton, and Coryell counties, Texas.

	Months											
Activity	O	N	D	J	F	M	A	M	J	J	S	S
Billies are with nanny flock.	X	X	X[1]									
Goats are supplementally fed.		X	X	X	X	X						
Nannies, wethers, and yearlings are penned, sheared, and drenched and sprayed for parasites.					X							
Culls and yearlings are sold.					X							
Kidding season.						X	X[1]					
Kids are penned, drenched, and marked for identification; kid billies are castrated.									X			
Nannies and wethers are penned, sheared, drenched and sprayed. Kids are sheared and sprayed.										X		

[1]Activity ends the middle of the month.

predation were considered negligible and were not considered in this analysis. For the N, N/W, and W operations, ranchers spent an average of $19.14/AU, $9.62/AU, and $13.93/AU[2], respectively, for extra feed used during penning, kidding, and checking goats. Whereas predators resulted in fewer goats to feed (thereby reducing feed costs), the net effect was a cost increase because of the feed used in management techniques designed to reduce predation. Other operating costs such as veterinary medicine, shearing, and sales commission decreased slightly as a result of predation.

Miscellaneous costs increased for two reasons. First, for the N, N/W, and W operations, ranchers spent an average of $3.01/AU, $2.12/AU, and $2.97/AU, respectively, supporting a full or part-time trapper. When ranchers paid trapper fees, it generally was because they participated in the federal-state cooperative Animal Damage Control program. Rancher fees usually were based on number of goats owned or number of acres in the operation. The second reason for a miscellaneous cost increase was because of guard dogs. Green et al. (1980) estimated the average cost/year to maintain a livestock guarding dog to be $275. This cost includes feed, veterinary fees and drugs, and miscellaneous items. For each of the 3 operations the cost/AU was estimated to be $4.67 (N), $1.91 (N/W), and $2.69 (W).

Transportation costs accounted for a significant portion of the increase in operating inputs. Annually, ranchers drove an average of 2,234.86 (N), 2,287.84 (N/W), and 2,872.55 (W) km valued at $16.96/AU, $6.31/AU, and $11.15/AU, respectively, for personal efforts made controlling predators (such as setting traps, snares,

[2]We cannot explain why feed costs were higher for W operations than for N/W operations. One would expect costs to be greater for N/W operations because of higher nutritional requirements of nannies.

Table 3. Annual costs and returns per animal unit of Angora goats in the absence and presence of predators for a nanny operation.

	Absence of Predators		With Predators	
Investment Requirements	Number head	Value/AU	Number head	Value/AU
Yearling doe	1.03	$ 60.49	1.03	$ 60.49
Does	5.15	376.16	5.15	376.16
Bucks	0.10	18.26	0.10	18.26
Horse	0.02	20.00	0.02	20.00
Guard dog	0.00	0.00	0.02	10.00
Total		$474.91		$484.91
Production	Number	Returns/AU	Number	Returns/AU
Adult mohair	107.12 kg	$224.97	105.16 kg	$220.85
Kid mohair	29.01 kg	98.96	19.86 kg	67.76
Kids	2.56 head	150.35	1.38 head	81.05
Does	0.69 head	22.08	0.51 head	16.32
Total		$496.36		$385.98
Operating inputs	Units	Costs/AU	Units	Costs/AU
Supplement	504.86 kg	$ 24.50	890.67 kg	$ 43.23
Salt & mineral	132.28 kg	10.80	132.28 kg	10.80
Sales commission	3.25 head	3.25	3.09 head	3.09
Vet. medicine		3.92		3.54
Shearing		23.84		20.73
Misc. expense		10.00		17.68
Equip., fuel, & lube		3.29		20.25
Equip. repairs		0.41		2.52
Total		$ 80.01		$121.84
Capital investment	Dollars invested	Costs/AU	Dollars invested	Costs/AU
Equipment	$188.14	$ 28.22	$188.85	$ 28.33
Livestock	474.91	71.24	484.91	72.74
Total		$ 99.46		$101.07
Ownership costs (Depreciation, taxes, and insurance)				
		Costs/AU		Costs/AU
Equipment	$ 26.88			$ 26.98
Livestock		5.55		6.31
Total		$ 32.43		$ 33.29
Labor costs				
	Hours Labor	Costs/AU	Hours Labor	Costs/AU
Equipment	1.40	$ 5.60	3.87	$ 13.76
Livestock	8.00	32.00	19.23	78.64
Total		$ 37.60		$ 92.40
Land costs	Hectares	Costs/AU	Hectares	Costs/AU
Pasture rent	6.07	$ 52.50	6.07	$ 52.50
Total		$ 52.50		$ 52.50
Residual Returns		$194.36		$-15.12

and M-44s) and penning, kidding, and checking goats. Equipment repair costs increased proportionately.

For all 3 operations there was a slight increase in capital investment and ownership costs when predators were a problem. This was because of costs associated with predator control equipment owned by ranchers and purchase of guard dogs, respectively. In contrast, operator labor costs increased an average of 258.00 (N), 405.71 (N/W), and 211.36 (W) hours valued at $54.82/AU, $31.31/AU, and $22.95/AU, respectively. When predators are a problem, extra labor accounted for the single greatest increase in production costs. This was because of rancher's personal efforts in controlling predators and penning, kidding, and checking goats. In all, production costs increased 32.8% (N), 17.7% (N/W), and 16.4% (W) as a result of efforts made to reduce predation.

While N operations have the potential for greatest profits, net returns for this type of operation decline most when predators are a problem ($194.36 to $-15.12). Economically, W operations were the least affected by predation. One obvious problem with such an operation, however, is that residual returns are negative even in the absence of predation. While the potential for monetary profit appears marginal for such operations, ranchers may also measure profit using other standards, such as benefits accrued from the use

Table 4. Annual costs and returns per animal unit of Angora goats in the absence and presence of predators for a nanny/wether operation.

	Absence of Predators		With Predators	
Investment requirements				
	Number head Number head	Value/AU	Number head Number head	Value/AU
Yearling doe	0.46	$ 27.02	0.46	$ 27.02
Yearling wether	0.69	40.52	0.69	40.52
Does	2.32	169.45	2.32	169.45
Wethers	2.81	228.51	2.81	228.51
Bucks	0.05	9.13	0.05	9.13
Horse	0.02	20.00	0.02	20.00
Guard dog	0.00	0.00	0.01	5.00
Total		$494.63		$499.63
Production	Number	Returns/AU	Number	Returns/AU
Adult mohair	125.31 kg	$263.17	122.56 kg	$257.42
Kid mohair	13.07 kg	44.59	9.44 kg	32.19
Kid goats	0.66 head	38.76	0.19 head	11.16
Does	0.39 head	12.48	0.29 head	9.28
Wethers	0.33 head	10.90	0.21 head	6.93
Total		$369.90		$316.98
Operating inputs	Units	Costs/AU	Units	Costs/AU
Supplement	447.54 kg	$ 21.72	639.34 kg	$ 31.03
Salt & mineral	132.28 kg	10.80	132.28 kg	10.80
Sales commission	1.38 head	1.38	0.69 head	0.69
Vet. medicine		3.46		3.25
Shearing		19.12		17.59
Misc. expense		10.00		14.03
Equip., fuel & lube		2.84		9.15
Equipment repair		0.36		1.16
Total		$ 69.68		$ 87.70
Capital investment	Dollars invested	Costs/AU	Dollars invested	Costs/AU
Equipment	$188.14	$ 28.22	$188.66	$ 28.30
Livestock	494.63	74.19	499.63	74.94
Total		$102.41		$103.24
Ownership costs (Depreciation, taxes, and insurance)				
		Costs/AU		Costs/AU
Equipment		$ 26.88		$ 26.95
Livestock		3.61		4.26
Total		$ 30.49		$ 31.21
Labor costs	Hours labor	Costs/AU	Hours labor	Costs/AU
Equipment	1.21	$ 4.84	2.38	$ 9.52
Livestock	6.90	27.60	13.56	54.24
Total		$ 32.44		$ 63.76
Land costs	Hectares	Costs/AU	Hectares	Costs/AU
Pasture rent	6.07	$ 52.50	6.07	$ 52.50
Total		$ 52.50		$ 52.50
Residual Returns		$ 82.38		$-21.43

of goats for brush control. Numerous ranchers responded that as long as the goats "kept the brush down" the animals paid their own way, implying that ranchers thought biological brush control saved money which could otherwise be spent on chemical or mechanical means. Our budgets describe "average" operations. Costs and returns for specific range operations will vary according to management strategies based on individual preferences and circumstances. Also, while we have tried to eliminate some of the variability in goat and mohair prices by indexing and averaging prices over a 5-year period, residual returns for each type of operation will change as commodity and resource prices change.

Budgets are perhaps more accurately viewed in a relative sense. It is clear that the potential for profit is greater for N operations than for W operations. The relative potential for profit without predation and associated monetary losses with predation are consistent with views often expressed by W goat ranchers. Generally these individuals said they would rather have all or some nannies in preference to wethers, but the fear of losing all the kids to predators and the expectation that grown wethers are less vulnerable to predators influenced their decision as to operation type.

N/W operations were somewhat intermediate to N and W operations with respect to net returns in the absence of predation. When predators are a problem, net returns were slightly less than for the N operations but were most like the W operation with regards to the difference in residual returns with and without coyote predation.

In general, current revenue losses and costs associated with techniques used to reduce predation resulted in negative net financial returns for all operations. Clearly, this can be only a short run situation. First, if the firm continues to sustain such losses, and if benefits derived from brush control are not sufficient to off-set these losses, then the firm will go out of business. This provides some evidence for the view that herd liquidations are often the

Table 5. Annual costs and returns per animal unit of Angora goats in the absence and presence of predators for a wether operation.

	Absence of Predators		With Predators	
Investment requirements				
	Number head	Value/AU	Number head	Value/AU
Wethers	6.00	$487.92	6.00	$487.92
Horse	0.02	20.00	0.02	20.00
Guard dog	0.00	0.00	0.01	5.00
Total		$507.92		$512.92
Production	Number	Returns/AU	Number	Returns/AU
Adult mohair	131.53 kg	$276.23	123.49 kg	$259.28
Wethers	0.83 head	27.41	0.10 head	3.30
Total		$303.64		$262.58
Operating inputs	Units	Costs/AU	Units	Costs/AU
Supplement	376.99 kg	$ 18.30	641.55 kg	$ 31.14
Salt & mineral	132.28 kg	10.80	132.28 kg	10.80
Yearling replacement	0.90 head	52.86	0.90 head	52.86
Sales commission	0.83 head	0.83	0.10 head	0.10
Vet. medicine		2.88		2.64
Shearing		14.34		13.44
Misc. expense		10.00		15.66
Equip., fuel, & lube		2.47		13.62
Equip. repair		0.31		1.71
Total		$112.79		$141.97
Capital investment	Dollars invested	Costs/AU	Dollars invested	Costs/AU
Equipment	$188.14	$ 28.22	$188.76	$ 28.31
Livestock	507.92	76.19	512.92	76.94
Total		$104.41		$105.25
Ownership costs (Depreciation, taxes, and insurance)				
		Costs/AU		Costs/AU
Equipment		$ 26.88		$ 26.97
Livestock		1.67		2.12
Total		$ 28.55		$ 29.09
Labor costs	Hours Labor	Costs/AU	Hours Labor	Costs/AU
Equipment	1.05	$ 4.20	1.91	$ 7.64
Livestock	6.00	24.00	10.88	43.52
Total		$ 28.20		$ 51.16
Land costs	Hectares	Costs/AU	Hectares	Costs/AU
Pasture rent	6.07	$ 52.50	6.07	$ 52.50
Total		$ 52.50		$ 52.50
Residual returns		$-22.81		$-117.39

result of predator problems (Kensing 1978, 1980). Alternatively, the current level of predator control may eventually (within a year or two) result in lower levels of predation. This possibility is based on the assumption that the rate (or %) of predation is at least partially a function of the level and/or type of predator control. If current level and/or types of control resulted in no predation, the net return for the N operation would be $95.26/AU[3]. If predator control reduced current predation losses by 1/2, net returns would be $40.07/AU[4]. The other types of operations would be affected similarily. One significant point that emerges from this reasoning is the need to understand which techniques used to reduce predation are the most cost effective. Obviously, eliminating expenses on relatively inefficient control practices would reduce total costs, therefore, increasing net returns. Unfortunately, data regarding cost effectiveness for most techniques which reduce predation are lacking, probably because of difficulties in obtaining reliable data (Connolly 1982). Yet another possible means of increasing returns may be found in new or modifications of existing, production technologies and management practices. That is, since the presence of predators requires increased production costs, producers may be able to develop ways to allocate the additional operational costs so as to increase production output relative to output using existing technologies. While the use of more efficient technologies is a viable alternative in the long; in the short term such practical technologies are unlikely to emerge.

The use of enterprise budgets clearly illustrated the effect of predation on representative livestock operations. Not only can predation result in important economic losses resulting from livestock killed, but these results demonstrate the importance of costs associated with attempts to reduce predation. Such costs may equal or exceed the value of animals killed by predators; however, without these added costs predation losses likely would be greater. Also, studies which estimate the cost of predation by only determining the value of animals killed may greatly underestimate the actual total cost of predation. These results further demonstrate the need for more information on the relative cost effectiveness of various types of predation control strategies.

[3]The difference betwen revenues without predation and production costs with predation.

[4]One-half the difference between revenues without predation and revenues with predation added to revenues with predation; this sum minus production costs with predation.

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Comparative Diets of Rambouillet, Barbado, and Karakul Sheep and Spanish and Angora Goats

L.E. WARREN, D.N. UECKERT, AND J.M SHELTON

Abstract

Diets of Rambouillet, Karakul, and Barbado sheep *(Ovis aries)* and Spanish and Angora goats *(Capra hircus)* grazing in 3 plant communities in western Texas were determined by microhistological analysis of fecal samples. Grasses were commonly the major foods of all sheep breeds as well as Angora goats. Forbs were major diet items of all breeds of sheep and goats when they were readily available. Spanish goats, and to a lesser extent Angora goats, relied heavily on browse. Barbado sheep consumed more browse than did Rambouillet or Karakul sheep. Diets of Rambouillet and Karakul sheep overlapped considerably, whereas diets of Rambouillet sheep and Spanish goats were quite dissimilar. Barbado sheep appeared to occupy a food niche intermediate between that of the goats and the other sheep breeds. Spanish and Angora goats exhibited the strongest tendency and Karakul sheep exhibited the least tendency to selectively graze. Neither Barbado nor Karakul sheep consumed sufficient amounts of undesirable shrubs to be considered valuable for brush suppression.

Rangeland forage utilization and total meat and fiber production could potentially be enhanced by identifying breeds of sheep or goats with the physical capabilities and diet versatility to better adapt to the currently available forage resource. Goats are generally more efficient at suppressing brush than cattle or sheep since they tend to select a wider variety of plants (Merrill and Taylor 1976). They also have the ability to shift their diet from herbaceous broad-leaved plants to shrubs (Scifres 1980). Goats are hardy and adapted to feed over rugged terrain, and can be combined with sheep and cattle to utilize vegetation which otherwise would be used very little (Campbell et al. 1962). Goats utilize a broader spectrum of plants than sheep, generally exhibit a greater tendency to browse, and therefore more efficiently utilize brush-infested rangeland (Maher 1945; Wilson et al. 1975). However, Malechek and Leinweber (1972) reported that grasses were readily selected by Angora goats during summer and fall on the Edwards Plateau of Texas, even though browse was abundant.

Merrill (1975) reported that Spanish goats completely consumed new growth of vasey shin oak *(Quercus pungens* var. *vaseyana)*, hackberry *(Celtis reticulata)* and lime pricklyash *(Zanthoxylum fagara)*, while Angora goats utilized only about 30% of the shin oak and 80% of the hackberry and lime pricklyash. The goat's ability to utilize a diverse variety of vegetation is attributed to their dexterity, narrow mouth, mobile upper lips, prehensil tongue, and propensity to stretch upward on the hind legs and employ the agile front legs to utilize browse species (Maher 1945, Staples et al. 1942).

Sheep usually rely on grasses as their major diet component while forbs are selected opportunistically (Ellis et al. 1977, Bryant et al. 1979, MacCracken and Hansen 1981). Van Dyne and Heady (1965) indicated that a single plant species may frequently compose 50% or more of a sheep's dietary sample.

Differences in diets of sheep and cattle have been attributed to differences in their ability to be selective (Dudzinski and Arnold 1973). Van Dyne (1968) stated that sheep spend more time selecting a higher quality diet compared to cattle. Studies by Meyer et al. (1957), Arnold (1960), and Wilson (1976) indicated that grazing sheep select a diet of higher nutritional value than the average for available forage. When the availability of green herbage is high, the difference in digestibility between the diet selected by sheep and that of all available herbage is the result of selection for the more digestible fractions, such as preference for leaves over stems (Arnold 1960) and new growth over mature herbage (Hamilton et al. 1973).

Karakul and Barbado sheep are not common on West Texas rangeland, and their diet preferences and utility for suppressing undesirable range plants are not known. Intensive studies are needed to determine the food habits of these exotic breeds in relation to that of sheep and goat breeds currently used. If differences do exist, such information could increase the efficiency of plant resource utilization and brush management, and benefit the economics of the range livestock industry. Therefore, the purpose of this study was to determine if significant interspecific and intraspecific variation in seasonal diets of Rambouillet, Karakul, and Barbado sheep, and Spanish and Angora goats occurred in selected range plant communities in western Texas.

Methods

Study Areas

The sheep and goats grazed in common on 3 selected range types: a common curlymesquitegrass-threeawn-liveoak *(Hilaria belangeri-Aristida* spp.-*Quercus fusiformis)* community, a mixed grass-honey mesquite *(Prosopis glandulosa* var. *glandulosa)* community, and a creosotebush-tarbush *(Larrea tridentata-Flourensia cernua)* community.

The common curlymesquitegrass-threeawn-liveoak community was in an 81-ha pasture on the Frances Hill Ranch, 47 km southeast of Sonora in Edwards County. The Low Stony Hill range site consisted of gently sloping to rolling hills, with slopes of 1 to 20%. Soils were very shallow, moderately permeable, calcareous, stony clays of the Tarrant series resting on fractured limestone (Polocek 1980). The pasture was lightly grazed by cattle prior to and during the study. The climate in Edwards County is semiarid with average rainfall of about 41 cm. Major grasses on the common curleymesquitegrass-threeawn-liveoak community were common curlymesquitegrass and threeawn. Major browse species were liveoak, algerita *(Berberis trifoliolata)*, juniper *(Juniperus* spp.), lotebush *(Condalia obtusifolia)*, Texas persimmon *(Diosypros texana)*, and elbowbush *(Forestiera pubescens)*.

The mixed grass-honey mesquite community was in a 24-ha pasture 3.7 km north of San Angelo in Tom Green County. The climate is semiarid with average annual rainfall of about 46 cm. The Angelo clay loam soils were on nearly level to gently sloping terrain (Weidenfeld and Flores 1976). The Clay Loam range site

Authors are research associate and professors, respectively, Texas Agricultural Experiment Station, 7887 N. Hwy. 87, San Angelo, Texas 76901
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supported a wide variety of browse species and had been lightly grazed by sheep and goats prior to this study. Major grasses on the mixed grass-mesquite community were tobosagrass *(Hilaria mutica)*, sideoats grama *(Bouteloua curtipendula)*, and threeawns. Other important grasses were buffalograss *(Buchloe dactyloides)*, sand dropseed *(Sporobolus cryptandrus)*, and common curlymesquitegrass. Major forbs were huisache daisy *(Amblyolepis setigera)*, plantain (*Plantago* sp.), pepperweed *(Lepidium densiflorum)*, Nuttall milkvetch *(Astragalus nuttallianus)*, and bladderpod *(Lesquerella gracilis)*. Major shrubs were honey mesquite, littleleaf sumac *(Rhus microphylla)*, algerita, lotebush and catclaw acacia *(Acacia greggii)*.

The creosotebush-tarbush community was in a 28-ha pasture on the Phillip Robbins Ranch, 13.7 km southeast of Fort Stockton in Pecos County. The climate is arid to semiarid with an average annual precipitation of about 31 cm. Soils on the Limestone Hill and Mountain Range site were of the Ector series, which are very shallow to shallow, well drained, loamy soils on slopes of 1 to 35% (Rives 1980). The major grasses were burrograss *(Scleropogon brevifolius)*, threeawns, and tobosagrass. Major forbs were grassland croton *(Croton dioicus)*, prickleaf dogweed *(Dyssodia acerosa)*, and lanceleaf sage *(Salvia reflexa)*. Creosotebush and tarbush were the most common shrubs.

Diet Analyses

Botanical composition of sheep and goat diets was determined by analysis of fecal material using the microhistological technique as described by Sparks and Malechek (1968). Extensive research indicates that certain plants fragment differently when undergoing the digestive process, thus creating biases when feces is used to estimate diets (Anthony and Smith 1974, Westoby et al. 1976, Vavra et al. 1978, Holechek et al. 1982). Even though we assume biases exist, several methods have been developed to correct such distortions (Vavra et al. 1978, Holechek et al. 1982). Dietary trends and relative importance of forage plants are accurate when using feces to estimate diets (Vavra et al. 1978). In the authors' opinion, the microscopic examination of fecal material was adequate for accomplishing the objective of this study.

Yearling female Rambouillet, Karakul, and Barbado sheep and Spanish and Angora goats were allowed to graze for 7 to 14 days on each study area prior to collection of fecal samples. Fecal samples, consisting of about 5 gm, were collected daily by rectal-phalangeal extraction from 5 to 10 animals of each breed during each 5-day collection period. Each sample consisted of a composite of 5 individual fecal samples from each animal of the 5 different breeds. Fecal samples were collected during a single season at the Pecos and Edwards County locations and 2 seasons at the Tom Green County location. Mean diets for each breed of sheep and goat were calculated for each collection period along with 2 standard errors (SE) of these means. Means with non-overlapping confidence intervals were considered significantly different.

Similarity of diets was calculated using Kulczyniski's similarity index (Oosting 1956). The formula,

$$\frac{2 \sum_{i=1}^{s} w_i (100)}{\sum_{i=1}^{s} a_i + b_i}$$

was used to estimate dietary overlap among the 5 sheep and goat breeds, where a_i represents the mean percentage of food item i in the diet of breed X, b_i represents the mean percentage of food item i in the diet of breed Y, with w_i represents a_i if $a_i < b_i$ and b_i if $b_i < a_i$.

Herbage Availability

Herbage availability was determined during most fecal collection periods by harvesting individual species of grasses and forbs in each of 75 randomly located, 0.25-m^2 quadrats and browse in each of 75, 1-m^2 quadrats. Samples were dried at 60° C for 48 h then weighed. Mean standing crops (±2SE) were calculated in kg/ha for all species. Sampling was inadequate to estimate availability of rare or occasional plant species that occurred in sheep and goat diets.

Spearman's rank correlation (RHO) was used to determine whether availability of plant species significantly correlated with animal diets. The rank correlation was assumed to estimate degree of concordance (RHO = + value) or discordance (RHO = – value) of the animal diets with available food resources (Snedecor and Cochran 1973). Rank order correlations were calculated for each fecal collection period.

Results and Discussion

Animal Diets

Common Curlymesquitegrass-Threeawn-Liveoak Community

Dry grasses, mostly threeawns and common curlymesquitegrass, accounted for 99% of the available herbage during the dry autumn 1979 and winter 1980 on the Edwards County study area (Table 1). No forbs were recorded and algerita was the only browse species that occurred in the sampled quadrats.

Table 1. Mean (±2SE) standing crop of herbage (kg/ha) in a common curlymesquite-threeawn-liveoak community in Edwards County, Texas.

Forage species	February 1980
Grasses	(kg/ha)
Hilaria belangeri	242±68
Aristida spp.	184±60
Bouteloua curtipendula	36±36
Panicum obtusum	55±56
Bothriochloa saccharoides	13±16
Total grasses	530
Forbs	0
Browse	
Berberis trifoliolata	6±13
Total browse	6

Rambouillet and Karakul sheep, along with Angora goats consumed significantly more grass and grasslike plants compared to Spanish goats and Barbado sheep during November 1979, whereas Barbado sheep and Spanish goats consumed significantly more browse (Table 2). The sheep breeds consumed significantly more sedge (*Carex* spp.) than the goat breeds during November, while the goats consumed significantly more Texas wintergrass *(Stipa leucotricha)*. Spanish goat diets included significantly more oak than those of Angora goats or Rambouillet and Karakul sheep, and significantly more Texas persimmon than any of the other breeds in November (Table 2).

Angora goats, as well as all sheep breeds consumed significantly more grass and grasslike plants compared to the Spanish goats in February 1980 (Table 2). All sheep breeds consumed more sedge than the goat breeds, and Angora goats relied more heavily on sedge than Spanish goats. Texas wintergrass, threeawns, and common curlymesquitegrass were significantly less important in diets of Spanish goats compared to the other breeds. Spanish goats consumed significantly more browse than all other breeds during February 1980 (Table 2). Oak was more important in Spanish goat diets than in diets of all other breeds and Angora goats consumed significantly more oak than the sheep breeds. Barbado sheep consumed significantly more browse than the other sheep breeds. Juniper was an important food of all breeds during February 1980.

Forbs, which were rare on the study area, were a minor constituent of the diets for all breeds in the common curlymesquitegrass-threeawn-liveoak community during the winter of 1979-80.

Mixed Grass-Honey Mesquite Community

Forage conditions were below normal due to lack of rainfall and above-average temperatures in the mixed grass-honey mesquite community during the spring-summer season of 1980. Grasses made up about 90% and 84% respectively, of total available her-

Table 2. Mean (±2SE) diet composition (%) of five different breeds of sheep and goats grazing in a common curlymesquitegrass-threeawn-liveoak community in Edwards County, Texas.

Food items	November 1979					February 1980				
	Sheep breeds			Goat breeds		Sheep breeds			Goat breeds	
	Rambouillet	Karakul	Barbado	Spanish	Angora	Rambouillet	Karakul	Barbado	Spanish	Angora
Grasses and grasslike plants										
Carex spp.	33±6.4	27±7.7	24±1.4	9±6.5	10± 4.3	21±3.8	24±6.7	25±3.0	1± 1.4	8±3.8
Stipa leucotricha	—	—	—	10±3.7	27±10.2	20±2.4	19±2.9	18±1.6	8± 1.9	25±6.8
Aristida spp.	5±1.9	9±5.3	2±1.4	7±1.9	8± 1.1	18±3.1	27±2.8	16±1.8	6± 1.4	20±3.3
Panicum spp.	15±4.6	11±3.0	3±1.9	2±1.2	5± 3.7	9±5.2	8±1.3	2±1.8	1± 0.9	4±2.1
Bouteloua spp.	8±2.3	13±4.4	7±1.5	2±1.4	5± 2.2	3±1.8	1±0.9	<1±0.6	—	<1±0.2
Bothriochloa saccharoides	4±2.8	1±0.6	4±1.2	3±2.1	5± 3.0	2±1.3	2±1.0	4±1.2	<1± 0.3	2±0.7
Hilaria belangeri	<1±0.3	<1±0.2	—	3±1.8	2± 1.4	8±3.5	5±1.1	9±1.9	<1± 0.2	7±1.9
Buchloe dactyloides	<1±0.3	1±1.2	<1±0.2	—	<1± 0.2	<1±0.3	—	<1±0.3	—	<1±0.4
Hilaria mutica	<1±0.2	<1±0.2	—	—	—	1±0.5	<1±0.4	—	<1± 0.1	—
Nolina texana	—	<1±0.2	—	—	—	—	<1±0.3	—	—	—
Tridens spp.	—	—	—	<1±0.2	—	—	—	—	—	—
Unknown grasses	—	—	—	—	—	<1±0.9	<1±1.7	3± 1.3	—	1±1.1
Total grasses	65±3.4	63±2.8	40±3.0	36±8.3	62±2.9	82±2.4	87± 2.9	77±2.6	17± 1.1	67±2.7
Forbs										
Croton spp.	2±0.8	2±1.5	3±1.6	<1±0.2	—	—	—	—	<1± 0.6	—
Verbena spp.	—	—	<1±0.2	—	—	—	—	—	—	—
Yucca spp.	—	<1±0.2	—	—	—	—	—	—	—	—
Unknown forbs	—	—	—	<1±0.2	<1± 0.3	1±1.1	1±0.5	2±1.4	1± 0.5	1±0.8
Total forbs	2±0.8	2±1.0	3±1.2	1±0.2	<1± 0.3	1±1.1	1±0.5	2±1.4	1± 0.1	1±0.8
Browse										
Quercus spp.	24±5.3	30± 4.5	38±7.9	50±6.0	27±4.5	6±1.7	3±1.7	6±0.8	74± 5.5	20±6.5
Condalia obtusifolia	4±3.6	2±2.3	4±4.6	2±1.1	6± 4.5	—	—	—	—	—
Juniperus spp.	<1±0.0	<1±0.8	<1±0.3	3±1.0	1± 0.5	6±2.6	5±2.2	8±2.3	8± 7.1	9±2.5
Acacia greggii	—	<1±0.2	10±8.6	1±1.7	4± 2.9	—	—	—	—	—
Rhus microphylla	—	—	—	—	—	3±1.9	3±3.6	7±3.8	—	<1±0.3
Prosopis glandulosa	1±0.6	<1±0.8	3±1.7	1±0.9	<1±0.1	2±1.6	1±1.1	<1±0.8	—	<1±0.4
Diospyros texana	—	<1±0.2	<1±0.2	6±2.6	—	—	—	—	—	—
Zanthoxylum fagara	3±4.3	1±1.1	1±2.3	—	—	—	—	—	—	—
Forestiera pubescens	<1±0.9	<1±0.4	—	—	—	<1±0.2	—	—	—	—
Total browse	33±5.2	35±3.2	57±4.6	63±6.7	38± 4.3	17±1.2	12±1.2	21±1.6	82±22.1	29±4.1
Succulents										
Opuntia spp.	—	—	—	—	—	—	—	—	—	3±2.8

bage of the spring and summer seasons (Table 3). Browse, mainly honey mesquite, contributed about 3% and 13%, respectively. to available herbage during the two seasons.

Rambouillet and Karakul sheep diets contained significantly more grass than those of Barbado sheep or the goat breeds during April 1980 (Table 4). Barbado sheep consumed more grass than the goat breeds and Angora goats consumed significantly more grass than Spanish goats. Grama grasses (*Bouteloua* spp.) were more important in sheep diets than in goat diets, whereas Ozarkgrass (*Limnodea arkansana)* was more important in goat diets. Karakul sheep consumed significantly more tobosagrass than did Barbado sheep and the goat breeds. Forbs were more important in diets of the sheep breeds compared to Angora and Spanish goats, and Karakul sheep diets contained significantly less forbs than those of Rambouillet or Barbado sheep (Table 4). Spanish and Angora goats relied more heavily on browse in April 1980 than did the sheep breeds, and Barbado sheep consumed significantly more browse than did the other sheep breeds. Littleleaf sumac was the major browse plant consumed by all breeds. Honey mesquite was present in trace amounts in diets of Karakul sheep and Angora goats.

During August 1980, Spanish goats also consumed significantly less grass and more browse than the other breeds (Table 4). Grasses contributed about half the diets of the sheep breeds and Angora goats, but only one-fourth the diets of Spanish goats. Major grasses in diets of all breeds included grama grasses, sand drop-

Table 3. Mean (±2SE) standing crop of herbage (kg/ha) in a mixed grass-mesquite community in Tom Green County, Texas.

Forage species	April 1980 (kg/ha)	August 1980 (kg/ha)
Grasses		
Hilaria mutica	750±236	488±280
Aristida spp.	207±116	125±64
Bouteloua curtipendula	65±64	181±100
Buchloe dactyloides	67±68	84±56
Hilaria belangeri	23±24	41±40
Sporobolus cryptandrus	—	59±72
Stipa leucotricha	47±40	5±8
Limnodea arkansana	51±20	—
Leptochloa dubia	39±40	—
Tridens spp.	—	28±76
Bothriochloa saccharoides	—	26±52
Muhlenbergia spp.	6±8	—
Chloris cucullata	—	4±8
Total grasses	1,255	1,041
Forbs		
Miscellaneous forbs	77	—
Total forbs	77	—
Browse		
Prosopis glandulosa	38±51	164±33
Condalia obtusifolia	1±2	16±6
Berberis trifoliolata	4±8	10±4
Rhus microphylla	—	8±3
Acacia greggii	5±14	4±6
Ephedra spp.	2±2	—
Total browse	50	202

Table 4. Mean (±2SE) diet composition (%) of five different breeds of sheep and goats grazing in a mixed grass-mesquite community in Tom Green County, Texas.

	April 1980					August 1980				
	Sheep breeds			Goat breeds		Sheep breeds			Goat breeds	
Food items	Rambouillet	Karakul	Barbado	Spanish	Angora	Rambouillet	Karakul	Barbado	Spanish	Angora
Grasses and grasslike plants										
Bouteloua spp.	46±3.7	46±2.8	36±3.2	9±2.6	12± 5.5	36±10.2	36±3.4	31±2.6	12± 3.8	24± 7.8
Stipa leucotricha	—	<1±0.7	<1±0.5	2±0.9	1± 1.0	—	<1±0.2	<1±0.3	<1± 0.2	<1± 0.3
Sporobolus cryptandrus	2±0.9	2±1.2	3±1.2	<1±0.8	2± 1.2	2±1.0	4±1.8	2±1.2	6± 0.9	13± 2.9
Aristida spp.	2±2.8	2±1.9	<1±0.3	<1±0.5	<1± 0.5	3±2.4	1±0.9	2±2.0	1± 1.5	3± 1.7
Hilaria belangeri	2±1.0	6±5.3	4±2.0	2±1.6	3± 1.7	6±1.5	6±2.4	4±1.2	3± 1.0	6± 1.6
Limnodea arkansana	3±2.2	4±0.6	2±0.9	7±1.3	9± 0.9	—	—	—	—	—
Buchloe dactyloides	6±3.2	6±1.9	2±1.2	<1±0.4	<1± 0.3	<1±0.7	2±0.8	2±0.8	<1± 0.2	<1± 0.4
Hilaria mutica	6±4.5	7±1.8	2±0.8	<1±0.5	<1± 0.3	1±2.5	2±2.1	2±1.1	<1± 0.4	<1± 0.2
Bothriochloa saccharoides	—	—	—	—	—	<1±0.3	<1±0.2	<1±0.3	<1± 0.3	<1± 1.0
Panicum spp.	3±2.0	2±1.3	—	—	—	<1±0.3	<1±0.2	<1±0.5	1± 0.4	<1± 0.9
Bromus unioloides	1±2.0	1±1.1	<1±0.7	1±0.6	2± 1.7	—	—	—	—	—
Phalaris canariensis	<1±0.2	—	—	<1±0.4	2± 0.7	—	—	—	—	—
Unknown grasses	2±1.4	<1±0.6	2±1.4	<1±0.4	<1± 0.6	<1±0.6	—	<1±0.2	<1± 0.2	<1± 0.3
Total grasses	73±3.5	77±3.5	52±3.4	24±0.9	32± 2.1	49±3.5	52±3.3	45±2.6	25± 1.1	50± 2.3
Forbs										
Sphaeralcea spp.	10±3.0	3±1.3	12±3.1	6±1.7	4± 2.6	13±6.4	16±6.9	19±6.4	4± 1.1	3± 2.7
Plantago rhodosperma	<1±0.2	<1±0.4	1±0.5	—	<1± 0.8	—	<1±0.2	—	—	—
Abutilon incanum	6±2.4	7±1.0	10±4.5	1±1.1	3± 2.7	7±1.2	<1±1.1	1±1.1	1± 1.5	3± 1.6
Verbena bipinnatifida	<1±0.6	—	—	—	—	—	—	—	—	—
Unknown forbs	4±1.0	4±0.6	5±2.4	1±0.6	2± 1.3	3±1.1	3±0.8	3±0.8	2± 0.6	3± 1.3
Total forbs	20±1.6	15±1.2	28±2.4	8±1.4	9± 1.1	23±3.4	19±3.3	23±4.7	7± 0.9	9± 0.7
Browse										
Rhus microphylla	7±3.1	8±3.8	20±2.5	68±7.4	59±11.2	24±5.2	26±4.3	30±2.8	60± 5.4	39± 6.0
Prosopis glandulosa	—	<1±0.3	—	—	<1± 0.2	4±1.6	3±2.9	2±1.5	<1± 0.2	—
Condalia obtusifolia	—	—	—	—	—	—	—	—	2± 0.8	—
Acacia greggii	—	—	—	—	—	—	—	<1±1.2	6± 1.0	2± 1.6
Celtis reticulata	—	—	—	—	—	—	<1±0.4	—	—	—
Total browse	7±3.1	8±3.1	20±2.5	68±7.4	59±20.3	28±7.2	29±6.3	32±8.9	68±11.5	41±12.5
Succulents										
Opuntia spp.	—	—	—	—	—	—	—	—	2± 0.8	1± 1.3

seed, and common curlymesquitegrass. Forbs, primarily globemallows (*Sphaeralcea* spp.), were significantly more important in sheep diets compared to goat diets. Littleleaf sumac continued to be the major browse of all breeds. Honey mesquite was more important in diets of sheep, compared to goats. Spanish goats consumed significantly more catclaw acacia and lotebush than did Angora goats or the sheep breeds. Pricklypear (*Opuntia* spp.) occurred in trace amounts in diets of Spanish and Angora goats (Table 4).

Forage conditions were excellent after seasonal rains in the late winter-spring 1981 in the mixed grass-honey mesquite community. Grasses, primarily tobasagrass, contributed about 78% of the total herbage during the early spring 1981 (Table 5). Forb production, mainly huisachedaisy and plaintain, increased to contribute about 66% of total herbage by April 1981.

Diets of all sheep and goat breeds were most varied during the late-winter and spring of 1981 in the mixed grass-mesquite community (Table 6). During February 1981, grasses were the staple food of all breeds. Grasses made up about 80% of the diets of the sheep breeds and Angora goats, but Spanish goats consumed significantly less grass (68%). Texas wintergrass was more important in diets of Barbado sheep and the goat breeds than in those of Rambouillet or Karakul sheep. Rambouillet and Karakul sheep tended to rely more heavily on threeawns, common curlymesquitegrass, buffalograss, and silver bluestem *(Bothriochloa saccharoides).* Forbs, primarily bladderpods contributed 11 to 14% of the diets of the sheep and goats. Browse, primarily Morman tea (*Ephedra* spp.), honey mesquite, and littleleaf sumac, was important in the diets of all sheep and goat breeds, but Spanish goats consumed significantly more browse than the other breeds (Table 6).

During April 1981, grasses continued to be the staple food of all breeds, but forbs increased considerably in dietary importance (Table 6). Karakul and Barbado sheep consumed significantly more grass than all other breeds, while Rambouillet sheep consumed more grass than did the goat breeds. All sheep and goat breeds opportunistically utilized a variety of forbs. Forbs were more important in Rambouillet sheep diets compared to diets of all other breeds; Karakul and Barbado sheep ate significantly more forbs than did the goat breeds. Browse, primarily littleleaf sumac and lotebush, were major foods of Spanish and Angora goats. The goat breeds consumed significantly more browse compared to the sheep breeds, while Karakul sheep tended to consume less browse than did Rambouillet or Barbado sheep (Table 6).

Creosotebush-Tarbush Community

About 10 cm of rain fell the week prior to collection of diet samples in late-summer 1980 in the creosotebush-tarbush community. Grasses, primarily burrograss, contributed 65% of available herbage, while forbs and browse contributed 9% and 26%, respectively (Table 7).

A variety of grasses comprised the major diet component of all sheep and goat breeds during September 1980 in the creosotebush-tarbush community (Table 8). Grasses were significantly more important in sheep diets than in goat diets, and also more important in diets of Angora goats compared to Spanish goats. Spanish

Table 5. Mean (±2SE) standing crop of herbage (kg/ha) in a mixed grass-mesquite community in Tom Green, Texas.

Forage species	February 1981 (kg/ha)	April 1981 (kg/ha)
Grasses		
Hilaria mutica	878±340	749±283
Aristida spp.	146±132	16±11
Buchloe dactyloides	31±56	54±29
Bouteloua curtipendula	60±76	17±32
Stipa leucotricha	19±24	36±59
Limnodea arkansana	—	52±30
Hilaria belangeri	37±44	1±1
Bromus unioloides	6±12	22±37
Tridens spp.	—	6±10
Muhlenbergia spp.	2±4	2±15
Total grasses	1,195	956
Forbs		
Amblyolepis setigera	194±17	851±54
Plantago rhodosperma	55±6	258±27
Astragalus nuttallianus	10±2	171±16
Lepidium densiflorum	—	158±22
Lesquerella gracilis	—	134±22
Oenothera spp.	—	63±14
Nama hispidum	—	43±11
Ammoselinum popei	—	40±9
Lappula redowskii	—	39±11
Linim lewisii	—	35±7
Verbena bipinnatifida	—	22±14
Evax prolifera	—	21±4
Miscellaneous forbs	61±7	207±1
Total forbs	320	2,041
Browse		
Prosopis glandulosa	—	68±16
Ephedra spp.	12±5	3±1
Berberis trifoliolata	5±5	4±2
Rhus microphylla	—	8±3
Condalia obtusifolia	—	7±3
Lycium texanum	—	1±0.3
Total browse	17	91

goats tended to rely more heavily on forbs, primarily spreading sida *(Sida filicaulis)*, than did the other breeds. Browse was significantly more important in goat diets compared to sheep diets, and Barbado sheep consumed significantly more browse than did the other sheep breeds. Littleaf sumac was the major browse plant of both goat breeds and Barbado sheep. Tarbush was not eaten by any of the breeds of sheep or goats, and creosotebush was only present in trace amounts in Barbado sheep diets (Table 8).

Forbs increased considerably in importance in the diets of all breeds during November 1980 in the creosotebush-tarbush community (Table 8). Rambouillet sheep ate significantly more forbs than the other breeds, while Karakul sheep ate more forbs than Barbado sheep or the goats. Forbs were least important in diets of Spanish goats. Grasses were significantly more important in diets of Barbado sheep and Angora goats compared to the other breeds, while they were least important in diets of Rambouillet sheep. Spanish goats consumed significantly more browse than all other breeds, while Angora goats and Barbado sheep consumed more browse than did Rambouillet and Karakul sheep. Littleleaf sumac, wolfberry *(Lycium texanum)*, redberry juniper *(Juniperus pinchotii)*, and javelinabrush *(Microrhamnus ericoides)* were the major browse plants in goat and sheep diets. Tarbush occurred in trace amounts in Barbado sheep diets, whereas creosotebush was not present in diets of any of the breeds (Table 8).

Dietary Overlap

Dietary similarity indices computed over sampling periods within plant communities indicated that diets of Rambouillet and Karakul sheep overlapped considerably, while the diets of Rambouillet sheep and Spanish goats were the least similar (Table 9). Diets of Barbado sheep and Angora goats overlapped to the same degree as diets of Angora and Spanish goats. Diets of Angora goats and Barbado sheep overlapped more in the mixed grass-mesquite community than in the other 2 communities. Barbado sheep generally utilized more browse than Rambouillet or Karakul sheep, thereby occupying a food niche intermediate between those of Rambouillet and Karakul sheep and Spanish and Angora goats. The relatively low dietary overlap between Spanish and Angora goats in the common curlymesquitegrass-threeawn-liveoak community (Edwards County) may be explained by limited availability of browse due to an elevated browse line.

Food Niche Dimensions

The mean number of different plant species in the diets of Rambouillet, Karakul, and Barbado sheep, averaged across all 3 plant communities and sampling periods, was 18, compared to 18.5 for Angora goats and 19 for Spanish goats, indicating no biologically important deviation among these breeds in respect to the number of different food plants. However, considerable variation was observed in numbers of different foods in diets of all breeds among plant communities and among sampling dates within plant communities. These differences were attributed to (1) difference in relative abundance of plant species among the 3 communities and among sampling dates, (2) changes in acceptability of certain plants to sheep and goats over time, and/or (3) inherent tendencies of the herbivores to voluntarily shift grazing behavior over time.

Association of Diets and Herbage Availability

Spearman's rank order correlation coefficients range from −1 to +1. A coefficient of −1 is interpreted as an inverse relationship of diet to availablity of foods, hence a high degree of food selectivity. A correlation coefficient of 0 indicates no relationship between diet and food availability, hence suggesting that diet is determined by inherent preference for certain foods, regardless of their relative availability. A +1 value is interpreted as a direct positive relationship between diet and food availability and indicates random feeding.

In most cases, Spearman's rank order correlation coefficients of sheep and goat diets with herbage availability were not significantly different from 0 ($P<0.10$) (Table 10) indicating selective grazing among the sheep and goat breeds studied. Spanish and Angora goats exhibited the strongest tendency to selectively graze in the plant communities studied, based on mean correlation coefficients of 0.12 and 0.14, respectively (Table 10). Karakul sheep exhibited the least tendency to selectively graze (mean = 0.31), where Rambouillet and Barbado sheep were intermediate in this regard (mean = 0.22).

Spearman's rank order correlation coefficients were lowest for sheep and goats grazing in the creosotebush-tarbush community (mean = 0.03) and highest in the common curlymesquitegrass-threeawn-liveoak community (mean = 0.36), apparently reflecting the variation in forage diversity among these two study sites. Forage diversity (the number of plant species) was much greater in the creosotebush-tarbush community than in the common curlymesquitegrass-threeawn-liveoak community during the periods diet samples were collected. The increased plant diversity in the creosotebush-tarbush community apparently allowed the phenotypic expression of the inherent tendency of all 5 breeds of sheep and goats to selectively graze; whereas, the lack of plant diversity in the common curlymesquitegrass-threeawn-liveoak community prohibited the phenotypic expression of diet selectivity among the breeds.

Table 6. Mean (±2SE) diet composition (%) of five different breeds of sheep and goats grazing in a mixed grass-mesquite community in Tom Green County, Texas.

	February 1981					April 1981				
	Sheep breeds			Goat breeds		Sheep breeds			Goat breeds	
Food items	Rambouillet	Karakul	Barbado	Spanish	Angora	Rambouillet	Karakul	Barbado	Spanish	Angora
Grasses and grasslike plants										
Bouteloua spp.	9±4.4	6±5.7	9±0.7	4±2.7	5±3.3	10±1.8	13±2.9	9±1.3	3± 1.2	10±1.0
Stipa leucotricha	17±4.7	17±8.9	42±4.5	38±5.8	42±7.3	8±1.8	14±4.0	15±2.2	11± 5.1	11±4.9
Sporobolus cryptandrus	5±2.1	9±3.1	8±2.4	13±4.3	13±3.0	13±3.4	11±2.0	7±1.9	1± 1.0	1±0.9
Aristida spp.	18±4.0	12±2.5	10±2.2	6±2.1	7±3.0	5±2.1	5±2.5	7±2.3	4± 1.3	4±2.4
Hilaria belangeri	10±3.4	17±5.5	6±3.5	3±2.0	4±1.9	2±1.0	1±0.4	<1±0.7	<1± 0.7	<1±0.7
Tridens spp.	—	—	<1±0.3	—	<1±0.2	7±4.0	18±2.8	19±1.4	16±14.0	12±1.5
Limnodea arkansana	<1±0.5	2±2.2	—	1±0.7	<1±0.3	9±1.8	5±1.1	7±1.9	3± 2.0	6±2.7
Buchloe dactyloides	4±2.9	7±2.6	2±2.0	2±1.2	1±0.9	1±0.4	<1±0.3	2±1.2	<1± 0.5	1±1.0
Hilaria mutica	2±1.5	3±0.9	<1±0.7	<1±1.1	1±1.0	<1±0.3	<1±0.3	<1±0.2	1± 0.9	<1±0.3
Bothriochloa saccharoides	10±5.5	3±1.5	1±1.2	<1±0.3	1±1.3	<1±0.5	<1±0.8	—	<1± 0.5	—
Panicum spp.	3±2.4	1±0.5	2±1.3	1±1.1	<1±0.6	1±1.0	<1±0.3	<1±0.2	<1± 0.5	<1±0.2
Total grasses	78±3.5	77±2.0	80±3.5	68±3.2	76±3.2	56±1.2	70±1.8	67±1.8	40± 1.5	45±1.4
Forbs										
Sphaeralcea spp.	<1±0.8	1±1.0	3±1.5	2±1.4	3±1.1	2±1.2	4±1.8	4±1.3	3± 1.1	2±2.8
Lesquerella gracilis	9±3.4	9±2.2	9±2.6	7±1.9	9±2.0	7±2.3	6±1.0	6±1.1	3± 2.4	3±2.7
Plantago rhodosperma	—	—	—	—	—	8±2.3	8±2.9	7±2.1	8± 2.3	7±2.8
Chenopodium album	—	—	—	—	—	7±2.0	3±0.5	2±1.3	—	—
Solanum elaeagnifolium	1±0.9	<1±0.4	<1±0.6	2±1.3	2±1.6	<1±0.7	<1±0.7	1±1.2	2± 0.5	3±0.5
Corydalis aurea	—	—	—	—	—	6±1.4	3±1.2	2±1.6	<1± 0.7	<1±0.3
Descurania pinnata	—	—	—	—	—	4±2.7	1±1.6	2±1.4	—	<1±0.2
Linum lewisii	—	—	—	—	—	3±2.9	—	—	—	—
Perezia nana	—	—	—	—	—	—	<1±0.4	<1±0.6	1± 1.1	<1±1.1
Erodium texanum	—	—	—	—	—	—	<1±1.0	<1±0.7	<1± 0.2	<1±0.4
Draba cuneifolia	—	—	—	—	—	<1±1.2	<1±0.3	<1±0.4	<1± 0.2	<1±0.2
Amblyolepis setigera	—	—	—	—	—	—	—	<1±0.3	<1±0.2	
Astragalus nuttallianus	<1±0.7	—	—	—	—	—	—	<1±1.5	<1± 0.3	—
Ambrosia spp.	<1±0.2	—	—	—	—	—	<1±0.2	—	—	—
Verbena bipinnatifida	—	—	—	—	—	<1±0.5	—	—	—	—
Englemannia pinnatifida	—	—	—	—	—	<1±0.2	—	—	—	—
Unknown forbs	<1±0.8	<1±0.2	—	<1±0.9	<1±0.6	3±1.0	3±1.3	4±0.4	1± 0.4	1±1.6
Total forbs	12±2.1	11±1.7	13±2.1	11±1.3	14±1.7	40±1.0	30±0.7	29±0.6	21± 1.6	17±0.7
Browse										
Rhus microphylla	<1±1.0	3±2.2	<1±0.8	9±2.2	1±1.9	<1±0.2	—	1±1.3	32± 7.4	32±4.5
Prosopis glandulosa	6±1.6	5±1.8	1±1.5	6±1.7	3±1.6	<1±0.4	<1±0.2	—	<1± 0.6	<1±0.2
Ephedra spp.	4±3.4	4±2.2	6±2.0	6±2.0	6±3.3	<1±0.7	<1±0.2	2±1.0	<1± 0.4	<1±0.2
Condalia obtusifolia	—	—	—	—	—	<1±0.5	—	1±1.0	6± 2.3	5±0.8
Acacia greggii	—	—	—	—	—	<1±0.2	—	<1±0.4	<1± 0.5	—
Berberis trifoliolata				<1±0.2	<1±1.4	—	—	—	<1± 0.3	<1±0.2
Total browse	10±1.4	12±1.2	7±1.4	21±1.3	10±1.3	4±2.1	1±0.2	4±0.7	39± 4.4	38±5.5
Succulents										
Opuntia spp.	—	—	—	—	<1±1.0	—	—	—	<1± 0.2	—

Table 8. Mean (±2SE) diet composition (%) of five different breeds of sheep and goats in a creosotebush-tarbush community in Pecos County, Texas.

	September 1980					November 1980				
	Sheep breeds			Goat breeds		Sheep breeds			Goat breeds	
Food items	Rambouillet	Karakul	Barbado	Spanish	Angora	Rambouillet	Karakul	Barbado	Spanish	Angora
Grasses and grasslike plants										
Tridens spp.	19±4.6	34±2.7	15±4.5	32±5.5	26±5.2	3±1.4	4±1.4	1±1.1	<1±0.6	6± 3.0
Muhlenbergia spp.	31±1.4	11±4.1	21±4.2	4±1.9	17±4.5	8±1.2	9±2.5	7±1.6	9±4.2	3± 3.1
Bouteloua spp.	12±3.5	13±3.0	15±6.1	7±1.2	5±1.3	9±3.0	12±2.9	15±3.4	9±2.3	16± 6.4
Scleropogon brevifolius	5±0.6	12±2.6	12±3.5	8±2.2	10±2.1	2±1.0	3±1.4	7±1.4	5±0.8	6± 3.1
Erioneuron puchellum	7±3.5	4±3.0	18±4.5	3±0.7	5±2.3	<1±0.4	1±0.9	8±3.1	4±1.2	2± 0.7
Enneapogon desvauxii	9±2.6	4±1.5	4±1.1	6±1.1	4±2.3	<1±0.3	1±0.8	2±1.3	3±3.2	3± 2.8
Eragrostis spp.	5±2.1	6±2.7	1±2.1	<1±0.5	3±1.9	<1±0.3	<1±0.6	3±2.1	2±1.5	<1± 0.8
Aristida spp.	1±1.8	5±3.0	<1±0.7	1±1.6	2±2.2	<1±0.8	4±2.6	1±0.8	<1±0.2	<1± 0.2
Sporobolus cryptandrus	—	<1±0.9	1±0.8	1±1.2	1±0.8	2±1.0	2±1.9	2±2.1	<1±0.2	4± 1.4
Setaria leucopila	2±2.7	<1±0.8	—	—	<1±0.2	<1±0.2	<1±0.5	—	<1±0.6	<1± 0.2
Bothriochloa saccharoides	<1±0.9	<1±0.3	<1±0.2	<1±0.5	2±0.8	—	—	<1±0.3	<1± 0.2	<1± 0.2
Stipa leucotricha	—	—	—	<1±0.3	—	<1±0.2	—	<1±0.3	—	<1± 0.2
Unknown grasses	<1±0.2	<1±0.4	—	2±0.9	<1±0.4	<1±0.2	<1±0.2	<1±0.3	<1±0.5	<1± 0.3
Total grasses	92±2.5	90±2.4	87±2.4	65±2.2	76±2.1	26±0.8	37±1.1	46±1.2	34±0.9	42± 2.1
Forbs										
Sphaeralcea spp.	—	—	—	—	—	51±4.9	35±7.0	22±8.2	14±3.2	6± 1.3
Sida filicaulis	6±1.2	8±4.0	7±1.4	13±5.2	10±0.5	6±0.5	10±2.8	3±0.2	6±2.8	14± 3.7
Lesquerella gracilis	—	—	—	—	—	5±1.5	6±0.9	5±2.5	11±5.3	19±12.4
Abutilon incanum	—	—	—	—	—	7±1.7	5±2.8	2±1.4	<1±0.7	—
Solanum rostratum	—	—	—	—	—	4±2.0	5±0.7	2±0.8	<1±0.4	3± 2.6
Erodium texanum	—	—	—	—	—	—	1±0.7	2±0.7	<1±0.6	—
Dyssodia acerosa	—	—	—	—	—	—	—	3±0.9	—	—
Plantago rhodosperma	—	—	—	—	—	—	<1±0.2	—	<1±0.7	<1± 0.2
Zinnia anomala	—	—	—	—	—	—	—	—	—	<1± 0.2
Coldenia canescens	—	—	—	—	—	—	—	—	—	<1± 0.2
Unknown forbs	<1±0.5	1±0.8	2±0.6	1±1.1	<1±1.1	<1±0.2	<1±0.4	1±0.8	<1±0.4	—
Total forbs	7±1.9	9±3.0	9±2.0	14±4.6	10±2.3	73±6.5	62±3.6	40±2.3	32±1.8	42± 3.4
Browse										
Rhus microphylla	<1±0.3	—	3±2.8	18±3.6	11±1.5	<1±0.2	—	6±3.5	13±3.7	12± 4.7
Lycium texanum	—	—	—	—	—	—	—	6±2.0	10±4.0	—
Juniperus pinchotii	—	—	—	—	1±0.5	—	—	—	5±1.9	3± 3.1
Microrhamnus ericoides	—	<1±0.3	<1±0.3	2±1.5	<1±0.6	—	—	—	4±2.6	<1± 0.3
Prosopis glandulosa	—	—	<1±0.3	1±0.3	—	<1±0.2	<1±0.3	—	—	—
Bernardia obovata	—	—	—	—	—	—	—	1±1.2	2±2.1	—
Flourensia cernua	—	—	—	—	—	—	—	<1±0.2	—	—
Larrea tridentata	—	—	<1±0.5	—	—	—	—	—	—	—
Dalea formosa	—	—	—	—	—	—	—	—	—	<1± 0.3
Total browse	<1±0.3	<1±0.3	4±0.7	20±4.5	13±2.9	<1±0.1	<1±0.3	14±1.6	34±1.9	16± 2.2

Table 7. Mean (±2SE) standing crop of herbage (kg/ha) in a creosotebush-tarbush community in Pecos County, Texas.

Forage species	September 1980 (kg/ha)
Grasses	
Scleropogon brevifolius	846±215
Aristida spp.	67±67
Sporobolus cryptandrus	29±58
Setaria leucopila	26±48
Hilaria mutica	21±42
Muhlenbergia spp.	12±25
Total grasses	1,001
Forbs	
Croton dioicus	35±49
Salvia reflexa	32±64
Dyssodia acerosa	32±32
Sida filicaulis	27±53
Acleisanthes longiflora	11±81
Total forbs	137
Browse	
Larrea tridentata	257±82
Flourensia cernua	104±6
Dalea formosa	33±12
Microrhamnus ericoides	10±19
Total browse	404

Conclusions

Barbado sheep generally utilized more browse and less grass than Rambouillet or Karakul sheep, thereby occupying a food niche intermediate between the other sheep and goat breeds studied. In 2 cases, Barbado sheep and Angora goats consumed browse and forbs in similar proportions. The goat breeds, mainly Spanish goats, consistently utilized browse as staple foods, especially in pastures or seasons where forbs were not plentiful. Spanish goats exhibited the greatest tendency to utilize browse, even when availability appeared low due to an elevated browse line. Barbado sheep tended to consume more undesirable brush species, specifically lotebush, juniper, and catclaw acacia, than other sheep breeds. However, the major undesirable brush species on the study areas, including honey mesquite, creosotebush, tarbush, juniper, lotebush, catclaw acacia, and algerita, were not consumed in appreciable quantities by any of the sheep or goat breeds studied. Karakul sheep could apparently be substituted for Rambouillet sheep in most range types with little effect on the plant resource; however, they offer no advantage over Rambouillet sheep for suppressing undesirable shrubs.

Table 9. Mean similarity indices of diets of various breeds of sheep and goats grazing in three plant communities in west Texas, 1979-1981.

Breed relationship	Edwards County	Tom Green County	Pecos County	Means
Spanish vs. Angora	57	75	71	69
Spanish vs. Barbado	46	58	62	55
Spanish vs. Karakul	41	61	62	55
Spanish vs. Rambouillet	41	46	51	46
Angora vs. Barbado	66	81	62	70
Angora vs. Karakul	64	57	67	63
Angora vs. Rambouillet	65	54	53	57
Barbado vs. Karakul	81	78	68	76
Barbado vs. Rambouillet	76	74	65	72
Karakul vs. Rambouillet	85	83	76	81

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Table 10. Spearman rank order correlation coefficients of diets of five breeds of sheep and goats with food availability in three different plant communities in western Texas.[1]

Breeds	Edwards County Nov. 1979	Edwards County Feb. 1980	Tom Green County May 1980	Tom Green County Aug. 1980	Tom Green County Feb. 1981	Tom Green County Apr. 1981	Pecos County Sept. 1980	Pecos County Nov. 1980	Means
Rambouillet sheep	0.44 (0.05)	0.41 (0.11)	0.03 (0.37)	0.40 (0.10)	0.50 (0.02)	0.11 (0.53)	–0.13 (0.60)	–0.04 (0.82)	0.22
Karakul sheep	0.37 (0.10)	0.47 (0.06)	0.37 (0.14)	0.47 (0.02)	0.56 (0.01)	0.06 (0.73)	0.17 (0.50)	0.00 (0.99)	0.31
Barbado sheep	0.21 (0.36)	0.31 (0.22)	0.10 (0.71)	0.56 (0.02)	0.48 (0.03)	0.15 (0.38)	0.03 (0.91)	–0.05 (0.78)	0.22
Spanish goats	0.30 (0.19)	0.19 (0.47)	0.14 (0.61)	0.10 (0.69)	0.26 (0.25)	0.16 (0.36)	–0.04 (0.89)	–0.13 (0.51)	0.12
Angora goats	0.38 (0.09)	0.23 (0.37)	–0.13 (0.63)	0.17 (0.50)	0.36 (0.11)	0.16 (0.36)	–0.07 (0.79)	–0.01 (0.94)	0.14
Means	0.39	0.32	0.10	0.34	0.34	0.13	–0.01	–0.05	

[1]Values in parentheses beneath each correlation coefficient indicate probability of significance.

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Herbage Yields and Water-use Efficiency on a Loamy Site as Affected by Tillage, Mulch, and Seeding Treatments

WILLIAM A. BERG AND PHILLIP L. SIMS

Abstract

The effects of surface treatments alone and with seeding of an introduced bluestem *(Bothriochloa ischaemum)* on herbage yields and water-use efficiency on a loamy range site in poor condition were studied. The study was in a 560-mm average annual precipitation area in the Southern Great Plains. Prior to treatment, buffalograss *(Buchloe dactyloides)* and silver bluestem *(Bothriochloa saccharoides)* produced the bulk of the herbage on the site. Disking or furrowing the native range produced no measureable change in herbage yields or in water-use efficiency as compared to no treatment (control) over the 5-year study period. Furrowing plus sand fill in the furrows or a rock mulch resulted in greater ($P<.05$) herbage yields than from the control. However, most of the increased yield was by silver bluestem, a species that is ranked low in palatability. Establishment of the introduced bluestem 'Plains' increased herbage yield 2- to 4-fold and significantly increased water-use efficiency.

Sandy soils of the Great Plains have the potential to produce more aboveground phytomass than finer-textured soils (Heerwagen 1958, Harlan 1958, Tomanek 1964). This is apparently because on sandy soils the infiltration rate is greater, evaporation is less, and little water is lost to percolation because much of the precipitation is received during the growing season.

If herbage production on loamy soils in poor range condition is to be increased, an approach would be to emulate the more-favorable soil-moisture conditions of sandy soils. Thus, treatments or management to increase infiltration, decrease water loss by evaporation, and favor taller-growing grass species over the short grasses might be considered.

Soil surface manipulation, such as contour furrowing, to detain and infiltrate water has been successful in increasing forage production on some soils. The greatest plant growth responses have been reported on medium to fine-textured soils (Langley and Fisher 1939, Branson et al. 1966) and in areas where snow is a substantial part of the effective precipitation (Neff and Wight 1977). Rauzi (1975) hypothesized that more intensive treatments than pitting or furrowing were needed to improve some range sites. He found that moldboard plowing or rotovating increased herbage yields over a 5-year period on clay loam and fine sandy loam soils dominated by blue grama *(Bouteloua gracilis)* in northeastern Wyoming.

Mulches can enhance infiltration and reduce evaporation rates. Sand and gravel 2- to 5-cm thick over unvegetated clay loam soils conserved about 70% of the 58 cm of precipitation falling in a

Authors are soil scientist and research range scientist, U.S. Department of Agriculture, Agricultural Research Service, Southern Plains Range Research Station, 2000-18th Street, Woodward, Okla. 73801. This study was initiated by P.T. Koshi and E.H. McIlvain, both now retired. Their work in planning and setting up the study is gratefully acknowledged by the authors.
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1-year period as compared to 18% on bare fallow (Corey and Kemper 1968). Similar results were shown by Linden (1970), who found that 2.5 cm of gravel over a nonvegetated sandy loam soil in eastern Colorado resulted in soil retention of 50% of the precipitation over a 2-year period while retention in fallow was 13%.

Interseeding sideoats grama *(Bouteloua curtipendula)* into a mixture of grasses which had invaded abandoned cropland increased herbage yield by 60% on a clay loam soil on the Texas High Plains (Willard and Schuster 1971). Seeding and management of weeping lovegrass *(Eragrostis curvula)* or the Old World bluestems (*Bothriochloa* spp.) in monocultures have greatly increased forage and beef production on sandy soils in northwestern Oklahoma (Shoop et al. 1976, Sims and Dewald 1982).

In our study, tillage, sand and rock mulch treatments, and combinations of these treatments plus interseeding of an introduced bluestem were applied to a loamy range site which was in poor range condition. The objective was to measure herbage yields by major species as a function of the treatments which were applied to increase water-use efficiency.

Study Area and Design

The study site was on an upland with a 7% north-facing slope in Harper County, northwestern Oklahoma. The plots were on the middle third of a smooth, 160 m long slope. Moderate to heavy grazing and major drouths in the 1930's and 1950's probably influenced the species composition, which was dominated by buffalograss *(Buchloe dactyloides).* Other perennial species present in decreasing order of aboveground phytomass production were silver bluestem *(Bothriochloa saccharoides),* blue grama, purple threeawn *(Aristida purpurea),* sand dropseed *(Sporobolus cryptandrus)* and sideoats grama. The annual, Japanese brome *(Bromus japonicus),* was common in years with greater fall and winter precipitation. Although Japanese brome is naturalized, its yield is included as part of the native vegetation in this discussion. Western

Table 1. Herbage yields on native range as affected by surface treatments.

Treatment	Year	Buda & Bogr†	Bosa	Spcr	Arpu	Other grasses	Forbs	Total
					kg/ha			
Control	1976	495	330	60	150	20	105	1160
	1977	1120	300	185	165	40	75	1885
	1978	690	245	60	135	45	135	1310
	1979	750	540	40	50	100	300	1780
	1980	720	510	20	35	55	170	1510
	5 Year Mean							1530c‡
Disking	1976	430	300	135	100	40	175	1180
	1977	985	250	340	120	110	100	1905
	1978	755	310	250	90	75	110	1590
	1979	670	420	145	50	85	295	1665
	1980	630	580	70	50	115	195	1640
	5 Year Mean							1595bc
Furrowing	1976	345	365	70	110	90	130	1110
	1977	910	600	230	115	235	140	2230
	1978	690	390	160	65	80	105	1490
	1979	600	745	65	40	265	325	2040
	1980	560	650	45	20	145	175	1595
	5 Year Mean							1695abc
Sand Mulch	1976	405	305	120	85	50	200	1165
	1977	1210	410	335	110	105	45	2215
	1978	845	235	100	100	20	70	1370
	1979	845	410	75	85	75	200	1690
	1980	790	405	50	95	65	155	1560
	5 Year Mean							1600bc
Disking + Sand	1976	250	330	165	75	75	210	1105
	1977	775	435	410	145	100	415	2280
	1978	520	410	195	110	95	245	1575
	1979	750	320	85	55	380	365	1955
	1980	505	755	30	75	90	135	1590
	5 Year Mean							1700abc
Furrowing + Sand in Furrow	1976	170	495	110	100	70	200	1145
	1977	630	430	465	130	425	355	2435
	1978	410	450	210	85	125	150	1430
	1979	445	1320	110	65	415	335	2690
	1980	390	1160	20	35	460	210	2275
	5 Year Mean							1995a
Rock Mulch	1976	355	74	110	110	75	250	974
	1977	645	530	380	150	145	115	1965
	1978	480	430	150	75	85	225	1445
	1979	400	1710	100	10	240	245	2705
	1980	270	1230	145	10	325	150	2130
	5 Year Mean							1845ab

Species columns: Buda & Bogr†, Bosa, Spcr, Arpu, Other grasses, Forbs.

†Buda = *Buchloe dacyloides,* Bogr = *Bouteloua gracilis,* Bosa = *Bothriochloa saccharoides,* Sper = *Sporobolus cryptandrus,* Arpu = *Aristida purpurea.*
‡ 5 year means followed by the same letter are not significantly different ($P<0.05$).

ragweed *(Ambrosia psilostachya)* was the most abundant forb on the site.

The soil, which developed from calcareous, fine-grained, soft sandstone, is representative of extensive areas of weakly developed, moderately deep soils on Permian redbeds in the Southern Plains. The soil is classified as a coarse-silty, mixed, thermic Typic Ustochrept of the Woodward series. The texture to a depth of 0.5 to 1 m was a loam. Organic matter in the top 15 cm was 2.4%. Depth to $CaCO_3$ ranged from 10 to 29 cm, and depth to redbed ranged from 0.5 to 1 m. The redbeds are very weakly consolidated; strata may range from a few centimeters to a meter or more in thickness, and from sandy loam to clay loam in texture.

The range condition of this loamy range site (Soil Conservation Service 1960) is poor as most of the herbage production is by buffalograss (herbage production up to 5% allowed as an increaser) and silver bluestem (an invader). Tomanek and Albertson (1957) described an ungrazed mixed prairie on soils derived from Permian redbeds near Ashland, Kans., (60 km north of our study site) as being dominated by sideoats grama and little bluestem *(Schizachyrium scoparium)*. They also reported that the basal area of buffalograss increased from less than 5% of all vegetation to 90% under heavy grazing.

Precipitation measured at the study site was 560 mm in 1976, 490 mm in 1977, and 360 mm in 1978. Precipitation was not measured at the study site in 1979 and 1980. For these years, precipitation measured at the USDA Southern Plains Experimental Range 4 km to the south was 670 and 430 mm, respectively. The long-term average annual precipitation at the Experimental Range is 560 mm with 70% received from April through September. Pan evaporation from April through September averages 1,320 mm per year.

Precipitation received during the growing season was 392, 325, 487, and 196 mm for the periods 25 Apr. to 10 Oct. 1977, 30 Mar. to 5 Oct. 1978, 20 Apr. to 9 Sept. 1979, and 29 Apr. to 6 Sept. 1980, respectively. Soil water depletion over these same periods was estimated by using the neutron scattering technique to determine water present to a depth of 1.8 m by 20-cm increments on the given spring date minus water present on the fall date for each plot. Water-use efficiency was calculated by dividing herbage production by the sum of growing season precipitation and soil water depletion. Installation of the neutron probe access tubes was not completed until the fall of 1976; thus water-use efficiencies were not calculated for that year.

The treatments applied to the native vegetation in April 1976 were:

1. Control. No treatment.
2. Disking. Use of a heavy-duty double disk which severed an estimated 50% of the crown cover of existing vegetation.
3. Furrowing. Small furrows 5 cm deep and 10 cm wide on 27 cm spacing made on the contour.
4. Sand mulch. Two cm of medium and fine sand (99% passed a 5 mm sieve) was placed directly on the vegetation.
5. Disking + sand mulch. The treatment was disked as in treatment 2 and then 2 cm of sand was applied to the surface.
6. Furrowing + sand in furrows. The treatment was furrowed as in treatment 3 and then the furrows were filled with sand.
7. Rock mulch. Flat, fine-textured sandstones 15 to 30 cm in diameter and 4 to 8 cm thick were placed on the vegetation to give about about 70% ground cover.
8. Introduced bluestem + sand mulch. An Old World bluestem (*Bothriochloa ischaemum* var. 'Plains') (Taliaferro et al. 1972) was broadcast at a rate of 2 kg/ha pure live seed and then 2 cm of sand was placed over the seed.
9. Disking, introduced bluestem + sand mulch. Disked as in treatment 2 then broadcast seeded with 'Plains' bluestem and the seed covered with 2 cm of sand.
10. Furrowing, introduced bluestem + sand in furrow. Furrowed as in treatment 3, broadcast seeded with 'Plains' bluestem and then the furrows were filled with sand.

Each treatment plot was 4 × 4 m assigned randomly within replication with the limitation that disking treatments or furrowing treatments were adjacent to each other to facilitate use of the equipment. Five replications were used. Each replication was on the contour separated by a 9-m buffer of native vegetation from the adjacent replication. The plots were fenced to exclude livestock. In the early spring of each year the standing vegetation was mowed to a height of 3 to 5 cm, with the exception of the rock mulch plots which were not mowed.

Yields were estimated by micro-unit forage inventory (Shoop and McIlvain 1963), which is a weight-estimate method using a 29.2 × 66.0-cm quadrat. Twenty-four quadrats were read on each plot in October, 1976 through 1980.

Analyses of variance on herbage yields and on water-use efficiency were made using data from all 10 treatments and again using only the data from the 7 surface treatments on the native species. This was done because yields on the 3 introduced bluestem treatments were 2- to 4-fold greater than yields of the native species. The greater yields on the introduced bluestem treatments were accompanied by greater absolute variability which gave an unrealistically large error term for testing the lower-yielding native range treatments. Means for significant ($P<.05$) main effects in the analysis of variance on herbage yields were separated using Duncan's multiple range test.

Results and Discussion

Native Vegetation

Disking or furrowing of native range, the 2 surface treatments which could be applied over extensive areas, resulted in no significant differences in herbage yields as compared to the control within any 1 year or over the 5-year period (Table 1). After 5 years, the disked plots were not discernable and the furrows were faint. Thus, although the disking and furrowing treatments appeared drastic when applied, they had little impact on total herbage yield or the proportion of herbage produced by the major individual species. The sand mulch or disking plus sand mulch treatments also resulted in herbage yields similar to those on the control.

Furrowing plus sand-fill in the furrows or the rock mulch treatments resulted in greater ($P<.05$) herbage yields than from the control over the 5-year period but not within any 1 year (Table 1). The greater herbage yields on the rock mulch and sand-filled furrow treatments was largely due to an increase in production of silver bluestem. This midgrass is regarded as an invader on this site (Soil Conservation Service, 1960) and is rated low in palatability (U.S. Department Agriculture, 1948). These data (Table 1) indicate that a change in species composition to midgrasses should result in greater herbage yields. However, there was no indication of invasion or increased forage yields by more-desirable midgrasses such as sideoats grama or little bluestem. Sideoats grama was present in minor amounts on many of the plots but showed no measurable change in forage yields with the surface treatments. Little bluestem was abundant on shallower soils within 100 m of the treatments. Thus, it appears that any relatively short-term attempt to increase forage production by the more-desirable native midgrasses will need to include seeding them as well as intensive treatment to reduce competition from buffalograss and silver bluestem.

Introduced Bluestem Seeding

Herbage yields during the 1977 through 1980 growing seasons were 2- to 4-fold greater on treatments interseeded to the introduced bluestem than on the native range treatments (Table 2). In 1976, the year that the bluestem was interseeded, the introduced bluestem produced 29% of the herbage on the bluestem seeding treatments; native species produced the remainder. In 1977, 1978, 1979, and 1980 the introduced bluestem produced 72, 79, 84, and 92% of the herbage on the interseeded bluestem treatments, respectively.

Table 2. Mean herbage yields on all surface treatments on native range as compared to mean yields on treatments interseeded to an introduced bluestem.

Treatment	1976	1977	1978	1979	1980
			———kg/ha———		
Native range	1130a	2130b	1460b	2075b	1750b
Introd. bluestem	1255a	3705a	3425a	5465a	6545a

Treatment means within years followed by the same letter are not significantly different ($P<.05$).

There were no significant ($P<.05$) differences among the herbage yields produced on the 3 surface treatments combined with broadcast seeding of the introduced bluestem. In retrospect, a treatment of seeding the introduced bluestem into disked or furrowed native range without a sand mulch should have been included in this study for comparison purposes.

The much greater herbage yields on the introduced bluestem treatments as compared to native range treatments were not unexpected as they are similar to yields of Old World bluestems grown on sandy soils on the Southern Plains Experimental Range 4 km to the south. (Sims and Dewald 1982). The introduced bluestems are more readily established by seeding than are the native grass species. However, mixed stands of Old World bluestems and native grasses could pose grazing management problems in that cattle may selectively graze many of the native species. The principal use of the Old World bluestems now appears to be in reestablishment of grasslands on marginal farmlands.

Soil Water

Soil water recharge from 8 December 1976 to 8 June 1977 averaged 5.3 cm of water among all treatments as measured by the difference in volumetric soil water between these 2 dates (Table 3).

Table 3. Winter and spring recharge of soil water over the periods 8 December 1976 to 8 June 1977, and 22 December 1977 to 7 June 1978 as affected by surface and seeding treatments on native range.

Treatment	Recharge period 12/8/76 to 6/8/77	12/22/77 to 6/7/78
	--cm of water ± 1 std. error--	
Control	6.0 ± 0.4	10.9 ± 0.4
Disking	4.2 ± 0.6	10.9 ± 0.6
Furrowing	4.4 ± 0.7	11.5 ± 0.5
Sand mulch	6.5 ± 0.5	11.8 ± 0.9
Disking + sand mulch	5.1 ± 0.6	11.6 ± 0.4
Furrowing + sand in furrows	2.6 ± 0.7	12.0 ± 0.3
Rock mulch	6.7 ± 0.4	12.2 ± 1.0
Introduced bluestem + sand mulch	6.9 ± 0.2	12.6 ± 0.6
Disking, introduced bluestem + sand mulch	7.2 ± 0.6	12.1 ± 0.7
Furrowing, introduced bluestem + sand in Furrows	4.0 ± 0.8	13.7 ± 0.5
Trt. (ANOVA)	**	NS

**indicates 0.01 level of significance

The recharge from 22 December 1977 to 7 June 1978 averaged 11.9 cm. Although there were differences ($P<.01$) in recharge among treatments in June 1977, there appear to be no consistent differences in recharge among treatments over the years. In this study there was usually a good cover of vegetation over the soil as the plots were mowed only once a year and then late in the dormant season. Under these conditions the effect of a rock or sand mulch in limiting evaporation would be minimized. The recharge data are subject to the limitation that transpiration in April, May, and early June reduced recharge, and that water lost by transpiration may not have been the same for all treatments. In 1979 and 1980, years with above-average spring rain, nearly all plots recharged to 1.8 m, the depth to which neutron probe access tubing was installed. Runoff was not measured on this study, but averaged 3 cm/yr over the 1977-1980 period from areas with similar soils, vegetation, and topography at Woodward, Okla., 25 km south of the study site (unpublished data, S.J. Smith, USDA-ARS, Durant, Okla).

Water-use efficiencies calculated for the 6 different surface treatments on the native range were not different ($P<.05$) from the control (Table 4). Establishing the introduced bluestem significantly ($P<.01$) increased water-use efficiency as compared to the

Table 4. Water-use efficiency in herbage production during four growing seasons as affected by surface treatments or seeding an introduced bluestem plus surface treatments on native range. Expressed as kg herbage per hectare per cm water depleted ± one standard error of the mean.

Treatment	1977	1978	1979	1980
Control	45 ± 3	38 ± 4	32 ± 4	39 ± 3
Disking	43 ± 2	46 ± 16	30 ± 3	40 ± 4
Furrowing	51 ± 4	43 ± 2	37 ± 4	37 ± 16
Sand mulch	54 ± 14	36 ± 2	31 ± 4	36 ± 4
Disking + sand mulch	52 ± 1	43 ± 5	34 ± 2	39 ± 6
Furrowing + sand in furrows	55 ± 5	42 ± 4	51 ± 11	49 ± 13
Rock mulch	49 ± 4	37 ± 4	49 ± 13	49 ± 8
Surface treatments on native species (ANOVA)	NS	NS	NS	NS
Introd. bluestem + Sand Mulch	78 ± 17	96 ± 20	77 ± 9	142 ± 37
Disking, introd. bluestem + sand mulch	86 ± 10	117 ± 16	106 ± 12	169 ± 15
Furrowing, introd. bluestem + Sand in furrow	82 ± 15	93 ± 16	105 ± 20	156 ± 10
All treatments (ANOVA)	**	**	**	**

**Indicates 0.01 level of significance

efficiency of water used in producing herbage from the native stands (Table 4). In general, water-use efficiency paralleled herbage yields (Table 1 and 2). This was because differences in soil water depletion among the 10 treatments within a growing season tended to be small in relation to growing season precipitation.

Depletion of soil water was most-readily measured in 1980 when above-average spring precipitation resulted in recharge of the soil to a depth of 1.8 m, this was followed by an exceptionally dry summer. Over the period 22 May to 6 September 1980 an average of 25.5 cm (±1.0 cm std. error) of water was depleted to a depth of 1.8 m from the treatments, with no differences ($P<.05$) among the treatments. The pattern of soil water depletion with depth appeared similar for all treatments with most of the water depletion occurring above 160 cm (Data from two treatments are shown in Table 5). Considerable variability in water depletion was found

Table 5. Soil water depletion with depth over the period 22 May to 6 September 1980 on the control and the introduced bluestem + sand mulch treatments.

Depth of Measurement —cm—	Treatment: Control	Introduced bluestem + Sand Mulch
	—% by volume ± 1 std. error—	
20	20 ± 1	21 ± 1
40	21 ± 1	21 ± 1
60	19 ± 2	19 ± 1
80	14 ± 4	17 ± 2
100	15 ± 1	14 ± 4
120	11 ± 3	11 ± 3
140	7 ± 3	10 ± 2
160	5 ± 4	4 ± 1
180	3 ± 3	2 ± 1

within treatments at depths of 80 to 180 cm (Table 5), this probably is a reflection of varying permeability of the substratum (Permian redbed) to roots.

Conclusion

Disking or furrowing of native range dominated by buffalograss (an increaser) and silver bluestem (an invader) had no measureable effect on herbage yields or water-use efficiency. More intensive surface treatments increased the yield of silver bluestem but not of more-desirable midgrasses. It appears that seeding of desired midgrasses and control of competition from buffalograss and silver bluestem will be needed to increase forage production by native species on such sites.

Establishment of 'Plains' bluestem, an introduction from Asia, into native range greatly increased forage yields and water-use efficiency. However, grazing management of a mixture of native species and the introduced bluestem would be difficult as many of the natives would be preferentially grazed.

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Impact of Presowing Seed Treatments, Temperature and Seed Coats on Germination of Velvet Bundleflower

M.R. HAFERKAMP, D.C. KISSOCK, AND R.D. WEBSTER

Abstract

Seeds with both smooth and rough, apparently scarified, seed coats occur in harvested samples of velvet bundleflower (*Desmanthus velutinus* Scheele.). To determine the degree of scarification, germination responses of rough and smooth seeds were investigated at 4 night/day temperature regimes, 5/15° C, 10/20° C, 15/25° C, and 20/30° C with a 12-hour photoperiod during the high temperature and with 3 seed treatments, cutting, acid scarification and hot water soak. Rough seed coats appear to be caused by peeling of the cuticular layer on the seed surface. Moisture was imbibed more rapidly by smooth seeds, and total germination of smooth seeds was 31% without treatment, 4 times greater than rough seed germination. Treatments increased germination of smooth seeds two- to four-fold and rough seeds over 10-fold. After treatment, rough seeds germinated significantly ($P<.05$) better than smooth seeds at all temperature regimes except 5/15° C. Cut and scarified seeds generally germinated more rapidly than water-treated seeds, but total germination was similar for all treatments at warmer temperatures. Germination was only 31% at 5/15° C.

Velvet bundleflower (*Desmanthus velutinus* Scheele.), a spreading somewhat decumbent perennial forb, grows mostly on calcareous and limestone soils of central, south, and west Texas (Rechenthin 1972). The forage is favored by goats, sheep, and deer, and seeds may be eaten by quail and other birds. Seed samples of one accession being evaluated for use in rangeland seedings and wildlife habitat plantings by the Soil Conservation Service contained seeds with smooth and rough appearing seed coats. This variation in seed coat, observed in seed lots harvested in 1977, 1979, and 1980, suggested a potential for differences in moisture imbibition and subsequent germination, since the rough appearance of the seed coats could be evidence of seed coat scarification. Hard, impervious seed coats are barriers to moisture and gas movement, as well as, a restriction to seedling development in many legumes (Crocker and Barton 1957, Latting 1961, Villiers 1972).

These studies were designed with the objectives to: (1) evaluate the effects of seed coat characteristics on moisture imbibition and seed germination and (2) evaluate the effects of temperature and presowing seed treatments on seed germination.

Materials and Methods

Seed of PMT-2406 velvet bundleflower was obtained from the USDA Plant Materials Center, Soil Conservation Service, Knox City, Texas, in 1979. These seeds were harvested in 1977 with a combine and subsequently run through a scalper and three-screen seed cleaner. After harvest seeds were stored in a warehouse for 3 or 4 months and then they were stored at 60° F and 40% relative humidity. Once we received the sample, seeds were stored in cloth sacks at room temperature. Germination trials were conducted with 3-year old seed, sorted by hand, so only uniformly large sized, fully developed and undamaged rough and smooth seeds were used.

Seeds were treated by cutting the seed coat with a razor blade (Latting 1961, Martin et al. 1975), immersion of seeds in hot water (80° C) for 3 minutes (Halls et al. 1970, Latting 1961), and acid scarification by immersion in concentrated sulfuric acid (H_2SO_4) for 17 minutes (Latting 1961). Acid scarification was conducted in test tubes with acid just covering the seeds. After treatment excess acid was poured from the sample, and the remaining acid was washed from the seeds with distilled water. Washing with a large amount of water reduced the heating that occurs with the dilution of the acid.

Germination trials were conducted in a controlled environmental chamber. Night/day temperatures were 5/15°C, 10/20°C, 15/25°C, or 20/30°C with 12-hour photoperiods during the high temperature. All experiments were conducted in a light regime of 237 $\upsilon Em^{-1}sec^{-1}$ photosynthetic active solar radiation. One trial was conducted at each temperature regime, and 3 replications of 50 seeds per seed treatment were arranged in a randomized complete block design.

A sample of 50 seeds per dish was dusted with fungicide N[(trichloro-methyl)thio]-4-cyclohene-1,2-dicarboximide and imbibed on 2 pieces of filter paper in a 100-mm diameter petri dish. The paper was supported by a 5-mm thick piece of polyurethane foam with a cotton wick in the center (Haferkamp et al. 1977). Filter paper was kept moist with sterile distilled water (pH 6). One piece of moistened filter paper was placed beneath the dish cover to increase moisture availability.

Response to treatment was evaluated by counting germinated seeds daily for 14 days. Germination criteria were based on the Association of Official Seed Analysts (Crosier 1970) definition of germination, i.e., the seed embryo must develop essential structures to produce a normal plant in favorable conditions. Normal germination was assumed when at least one cotyledon was exposed and the radical was at least 5 mm long.

Seed moisture content after 0, 2, 4, 8, and 12 hours of imbibition was determined gravimetrically on samples of smooth and rough seeds imbibed in the 15/25°C regime. Following imbibition seeds were blotted dry, weighed, oven-dried for 48 hours at 105°C and reweighed.

Electron microscope photographs were also taken of untreated seeds to permit closer observation of seed coats. These seeds were mounted on aluminum studs, coated with gold palladium in a vacuum evaporator, and examined with a scanning electron microscope.

Authors were assistant professor and graduate research assistants, Texas Agr. Exp. Sta. (Dept. of Range Science), Texas A&M Univ., College Station, Texas 77843. Present addresses are Eastern Oregon Agr. Res. Center-Squaw Butte Sta., Burns, Oregon 97720; Brown and Associates, College Station, Texas 77843; and Research School of Biological Sciences, Taxonomic Unit, the Australian National Univ., P.O. Box 4, Canberra, A.C.T., Australia 2600.

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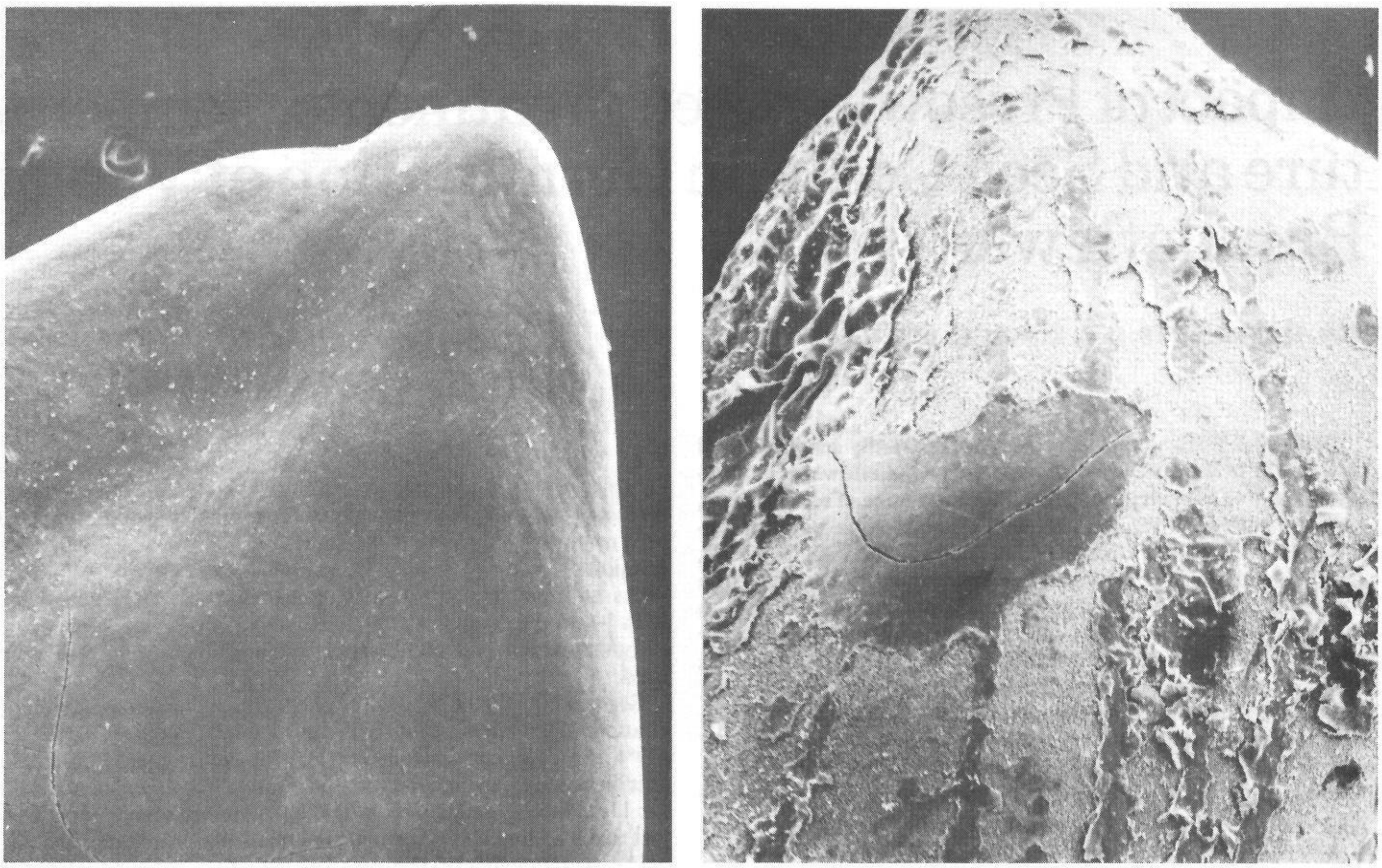

Fig. 1. *Seed coat of smooth (left) and rough (right) velvet bundleflower seeds, magnification 60X.*

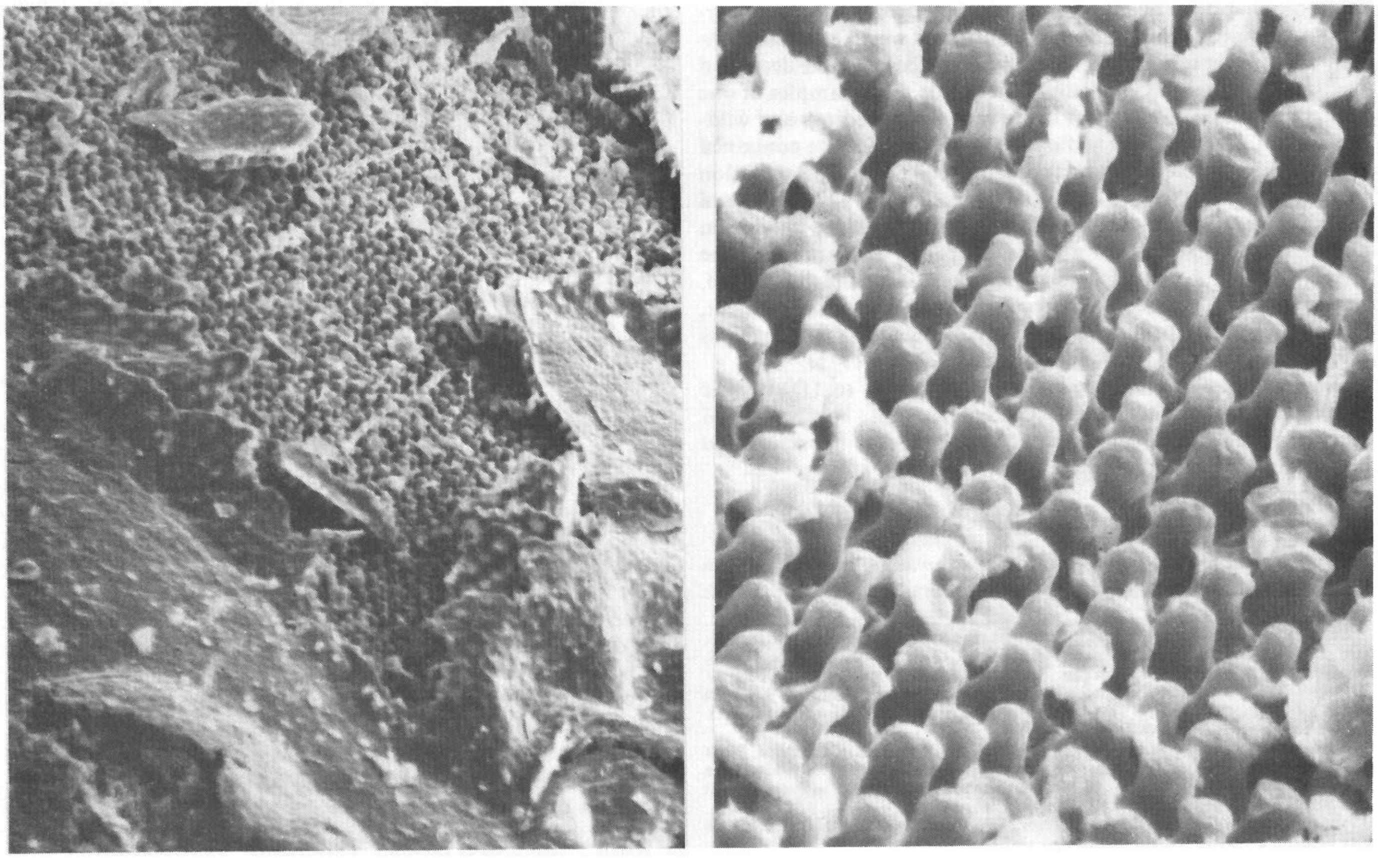

Fig. 2. *Rough seed coat with a peeling cuticular layer, magnification 400X (left), and caps of macrosclerid cells, magnification 2000X (right).*

statistical analyses were conducted with the ANOVA procedure to determine if significant differences ($P<0.05$) in germination existed between types of seed coats and among presowing treatments within temperature regimes. Means were separated using Duncan's multiple range test. Counts were transformed prior to analysis using the following relationship:

$$X' = \sqrt{(n + 1/2)} \arcsin \sqrt{\frac{f + 3/8}{n + 3/4}}$$

where the proportion (germinated seeds/total number of seeds) is f/n (Zarr 1974). Untransformed data are presented in the text.

Results and Discussion

Electron Micrographs

The rough appearance of velvet bundleflower seeds is caused by peeling of the seed surface (Fig. 1 and 2). Projections on the rough seeds appear to be caps of macrosclerid cells of the pallisade layer or Malpghian cells as reported by Hamly (1932). The impermeable region of the seed coat of sweet clover *Melilotus alba* Desr. is composed of a layer of tightly appressed suberin caps (Hamly 1932). He reported that the cuticle and subcuticular layers could be removed without improving moisture imbibition, but when caps were removed or breaks were formed in the layer, moisture imbibition could occur.

Moisture Imbibition

Deterioration of the cuticle and subcuticular layers of velvet bundleflower seed did not improve moisture imbibition. Smooth seeds imbibed moisture more rapidly during the initial 12 hours than the rough seeds (Fig. 3). The cuticle is apparently permeable, and when intact enhances imbibition. When the cuticle begins to separate from the seed and an air space is formed, imbibition may be reduced. The possibility of moisture imbibition occurring through other openings in the seed coat exists, but this was not examined.

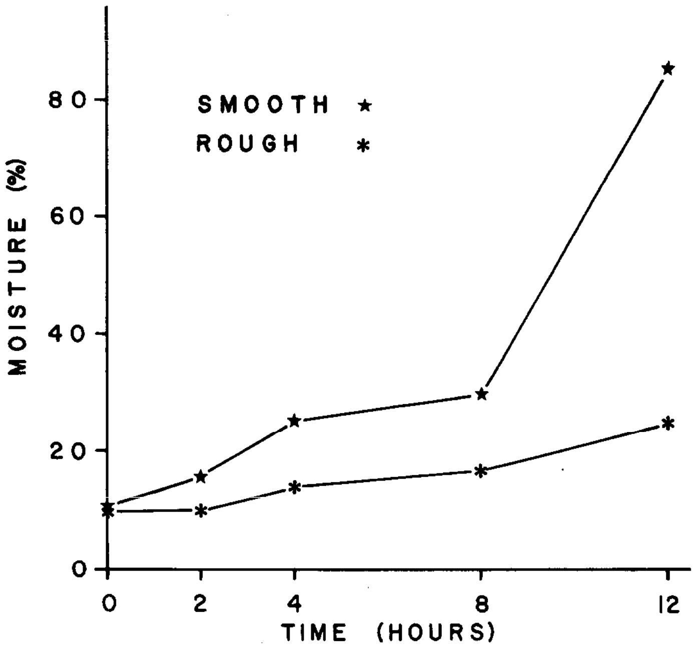

Fig. 3. *Moisture content (% of dry weight) of rough and smooth velvet bundleflower seeds imbibed at 15/25° C for 12 hours. Moisture contents were significantly different (p0.05) between seed types at each sampling time.*

Seed Germination

Untreated Seeds

Smooth seeds consistently germinated as well or better than rough seeds (Fig. 4). Highest total germination of rough and smooth seeds was 9% and 31%, respectively. Seed germination was poorest at 5/15°C for both seed types. Differences between seed types were small and nonsignificant ($P>0.05$) at 5/15°C and 10/20°C, but smooth seeds germinated 2 to 4 times better ($P<0.05$) at 15/25°C and 20/30°C.

Physiological activity was apparent by day 1 at 20/30°C and day 2 at 10/20°C and 15/25°C when approximately 2 to 5% of the seeds had either one cotyledon or a short radicle exposed (data not shown). Activity was not apparent until day 6 to 8 at 5/15°C. Germination rate was most rapid at 15/25°C and 20/30°C, intermediate at 10/20°C and slowest at 5/15°C.

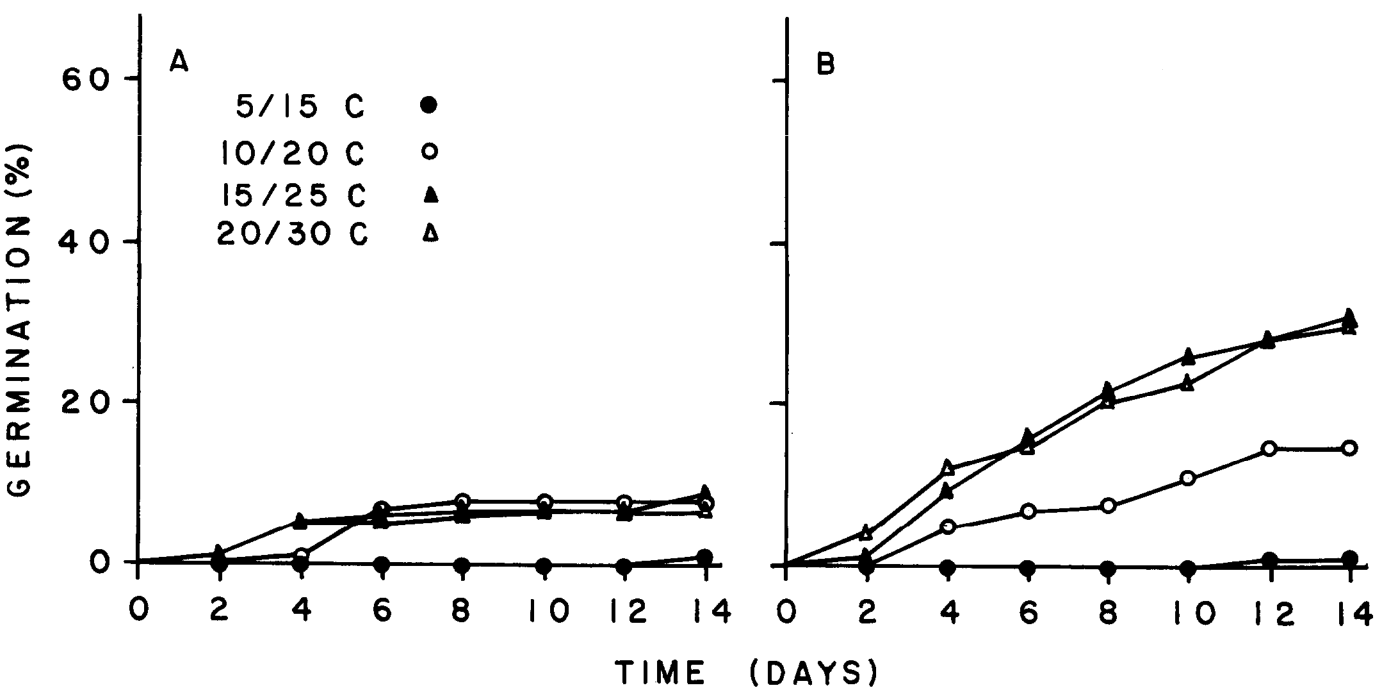

Fig. 4. *Cumulative germination of rough (A) and smooth (B) velvet bundleflower seeds in four temperature regimes.*

Treated Seeds

Seed treatments generally improved germination of rough and smooth seeds at all temperature regimes (Fig. 5). Rough seeds germinated significantly ($P<0.05$) better than smooth seeds at all temperature regimes except 5/15°C. Germination of rough seeds averaged 73, 93, and 90% on day 6 at 10/20°C, 15/25°C and 20/30°C, respectively. Over 87% of these rough seeds had germinated by day 14. Approximately 45, 77, and 72% of the smooth seeds had germinated by day 6 at 10/20°C, 15/25°C, and 20/30°C, respectively. Over 80% of the treated seeds had germinated after 14 days at 15/25°C, but less than 70% of the water soaked and acid scarified seeds germinated at 20/30°C. The decrease was not explained by the study.

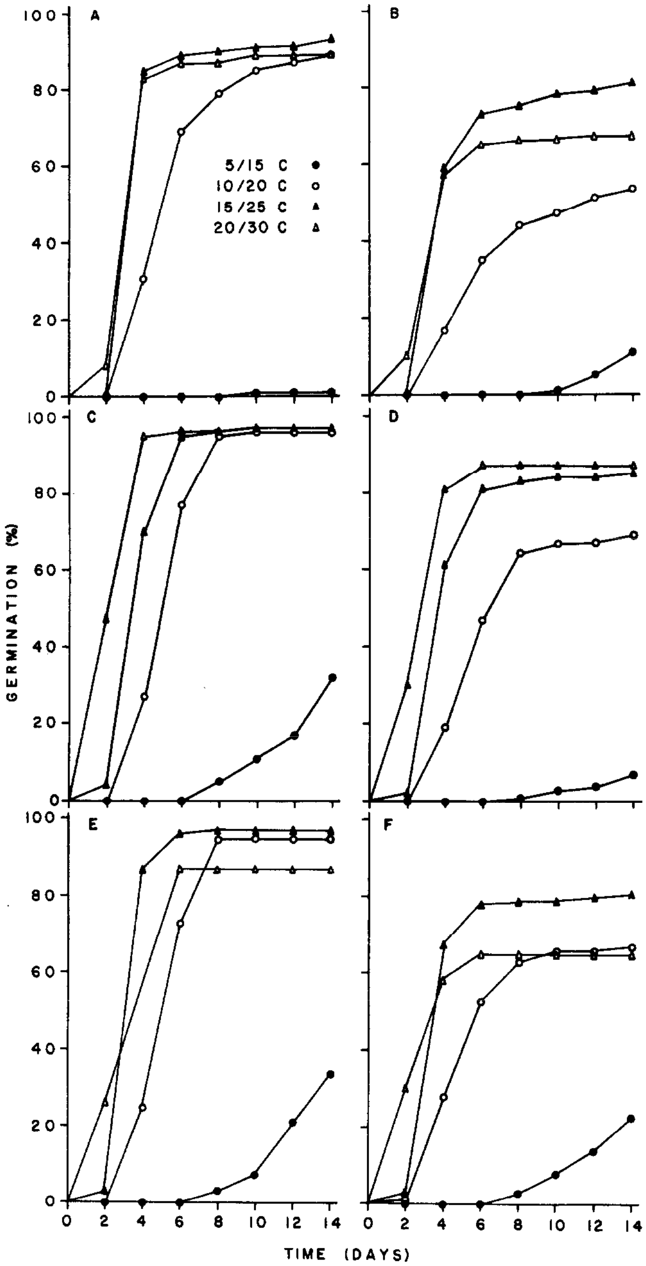

Fig. 5. *Cumulative germination of hot water soaked rough (A) and smooth (B), cut rough (C) and smooth (D), and acid scarified rough (E) and smooth (F) velvet bundleflower seeds in 4 temperature regimes.*

Cut and acid scarified seeds generally germinated more rapidly than the water treated seeds (Fig. 5). However, total germination of water treated seeds was similar to that of cut and scarified seeds at 15/25°C and 20/30°C. Hot water was apparently not as effective as cutting or scarification in improving imbibition and subsequent germination.

At 5/15°C germination of all seeds was relatively poor (Fig. 5). Cut and scarified rough seeds germinated best at the low temperature regime with over 30% germination. Germination consistently began sooner at the warmest temperature regime, and during the initial 2 to 4 days seeds germinated most rapidly at 15/25°C and 20/30°C. Germination was usually apparent by day 2 at 10/20°C, and the maximum rate of germination occurred during days 2 to 8. Total germination was attained 2 to 4 days earlier at 15/25°C and 20/30°C than at 10/20°C.

Summary and Conclusion

Rough seed coats appeared to be caused by peeling of the cuticular layer on the seed surface. Disturbance of the cuticular layer did not appear to be due to natural causes. Established stands of velvet bundleflower were examined at Knox City, Texas, in fall 1980, and researchers found only smooth seeds in pods. Rough seeds were found in harvested seed lots in 1977, 1979 and 1980, suggesting disturbance of the cuticular layer may have occurred during harvesting or post-harvesting drying. Slight abrasion during harvesting and handling may have disturbed the seed coats. Peeling may also be initiated with post-harvest drying since smooth seed coats were observed to become rough when smooth seeds were imbibed for less than 12 hours and then dried for 48 hours at 105°C.

Researchers utilizing velvet bundleflower seeds should be aware that rough and smooth seeds imbibe and germinate at different rates. Differences, however, can be reduced by applying presowing seed treatments such as cutting and acid scarification or soaking in hot water. Data suggest cutting was an effective treatment, and this treatment would probably be more practical for field plantings if a method of mechanically scarifying bulk seed lots was available. Planting mixtures of untreated smooth and rough seeds should provide seeds that germinate rapidly and seeds that germinate later with subsequent moisture. Germination of rough seeds, however, may be improved through natural weathering processes occurring in the soil.

Data also suggest germination of rough and smooth seeds was low at 5/15°C and began sooner, proceeded more rapidly and total germination was generally higher in warmer temperature regimes. Planting prior to moist periods when the warmer temperatures occur could enhance germination in field plantings. If, however, natural, weathering was found effective in reducing the amount of hard seed, then earlier plantings might suffice as effective means to enhance germination.

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Germination of Texas Persimmon Seed

J.H. EVERITT

Abstract

Seed of Texas persimmon germinated in excess of 90% at constant temperatures from 20 to 30° C, and in an alternating temperature regime of 20–30° C. Seeds germinated equally well in light and dark. No seed dormancy mechanisms were observed, and viability was not reduced after storage at room conditions for 2 years. Germination percentages of seeds collected from 2 contrasting range sites did not differ. Germination did not differ over a broad range of pH values (4 to 11), but radicle elongation was inhibited at pH 11. Germination and radicle length were sensitive to osmotic potentials of 0.2 MPa or more, and no seed germinated at 1.2 MPa. Germination was restricted in a 5 g/l NaCl solution and nearly ceased at 10 g/l NaCl. Radicle length was more sensitive to NaCl solutions than was germination. Ion toxicity of salt solutions appeared to be more detrimental to germination and radicle growth than the osmotic potential of salt solutions. Seeds were not dependent on soil cover for seedling establishment, but the highest emergence occurred when seeds were covered with 1 cm of soil. Percent of germination was not reduced by passage through the digestive tracts of coyotes.

Texas persimmon *(Diospyros texana),* also called "black" and "Mexican" persimmon is a native shrub or small tree found in rocky open woodlands, open slopes, arroyos, and other such places throughout the western two-thirds of Texas (Correll and Johnston 1970). Highest densities occur in a group of 13 counties in south-central Texas from the southern edge of the Edwards Plateau into the northern South Texas Plains (Scifres 1975). It is usually 2 to 3 m tall, but may attain a height in excess of 6 m. Texas persimmon fruits are an important wildlife food (Vines 1960, Arnold and Drawe 1979), but this species is often a deterrent to effective range management. Although usually considered a minor component of range vegetation, Texas persimmon may become one of the primary problems following use of mechanical brush control methods such as chaining and root plowing (Scifres 1975, 1980). Moreover, it is a hard-to-kill species that is essentially resistant to conventional herbicides applied as broadcast sprays. Because its roots extend laterally a great distance from the parent plant, it is also resistant to most mechanical control methods (Scifres 1980).

Little is known of the life history or biology of Texas persimmon. The major objective of this study was to determine the germination response of Texas persimmon seeds in the laboratory to certain environmental factors encountered in the seedbed. The effect on seed germination after passing through a coyote digestive tract was also studied.

Materials and Methods

Texas persimmon seeds were collected in August 1980 from several plant populations growing on a gray sandy loam range site (Aridic Ustochrepts) near La Joya in Hidalgo County, Texas. Only fully developed, undamaged seeds were used for germination experiments. Prior to use in experiments, seeds were stored at room conditions (20 to 27°C, and 50 to 75% relative humidity). With the exception of periodic determination of germination over a 2-year period, the various experiments were conducted when the seeds were less than 1 year old.

All experiments were conducted in small growth chambers with automatic temperature and fluorescent light (200 $\mu E/m^2/s$) controls. Unless otherwise stated, experiments were conducted at a constant temperature of 25° C (optimum) with an 8-hr light period. An experimental unit was 10 seeds in a 15-cm petri dish that had 2 filter papers wetted with 20 ml of distilled water or an appropriate test solution. Experiments were designed as randomized complete blocks unless otherwise stated. Treatments were replicated 10 times, and each experiment was conducted twice. Seeds with 2-mm long radicles were considered as germinated. Germination was recorded 14 days after the initiation of each experiment. Radicle lengths were recorded in selected experiments.

Seeds were germinated under continuous temperatures of 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, and 40°C (8-hr light period, 16-hr darkness) and alternating temperatures of 10–20, 15–25, 20–30, and 25–35°C (16-hr low temperature in darkness, 8-hr high temperature with light) (Mayeux and Scifres 1978, Mayeux 1982, Everitt 1983a).

The effects of simulated moisture stress on seed germination were evaluated by adding polyethylene glycol (PEG-6000) to distilled water for the substrata—PEG-6000 concentrations required to give osmotic potentials over a wide range of temperatures are given by Michel and Kaufman (1973). Their results were used to prepare solutions ranging from 0 to 1.2 MPa at 25°C (1 MPa = 10 bars). The pH of these PEG solutions was 6.7.

Tolerance to salinity during germination was evaluated with aqueous solutions of NaCl at concentrations of 0, .25, .5, .75, 1, 2.5, 5, and 10 g/l. The influence of substrate pH on germination was investigated by adjusting the pH of distilled water with HCl and KOH (Mayeux and Scifres 1978). Percent germination was evaluated at pH values of 2, 3, 4, 5, 6, 7, 8, 9, 11, and 12.

Light requirements for seed germination was investigated by comparing germination in petri dishes covered with aluminum foil with germination in uncovered dishes. The effect of age on germination was investigated by comparing germination at 1, 6, 12, 15, 18, 21, and 24 months after seed collection.

The influence of planting depth on seed germination was studied in the greenhouse. Temperatures in the greenhouse ranged from 21 to 28°C. Ten seeds were planted in soil in large pots (16 cm diameter × 16 cm height). A potting mixture of 3 parts sandy loam :1 part peat moss: 1 part perlite was used to prevent crusting. Seeds were placed on the soil surface and also covered to depths of 1, 2, 4, 5, and 7 cm. Seedling emergence and height were recorded after 60 days.

Seeds were also collected from several plant populations growing on a shallow sandy loam range site (Ustollic Paleorthids) in northern Hidalgo County in August 1980, and their germination was compared with that of plants from the gray loam site.

During August 1979, seeds were recovered from fresh coyote feces from the gray sandy loam site near La Joya and their germination was compared with that of control groups of seeds from this same site. Seeds were taken from approximately 50 fecal samples. Three-hundred seeds from fecal samples and 300 control seeds

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were placed in a growth chamber at 30° C. Each experimental unit consisted of 10 seeds in a 15-cm petri dish containing 2 filter papers wetted with 20 ml of distilled water. Treatments were replicated 10 times and each experiment was conducted 3 times.

Percentage germination and emergence data were transformed (Arcsin) before statistical analyses. Data from 2 or 3 experiments were pooled prior to analyses. Data were subjected to analysis of variance and Student's *t*-test. An LSD was calculated in selected experiments (Steel and Torrie 1960). All statistical comparisons were made at $P > 0.05$.

Results and Discussion

Germination of Texas persimmon seed appears to be restricted to a relatively narrow temperature range (Fig. 1). Germination was $\geq$93% at constant temperatures of 20–30° C, but decreased abruptly

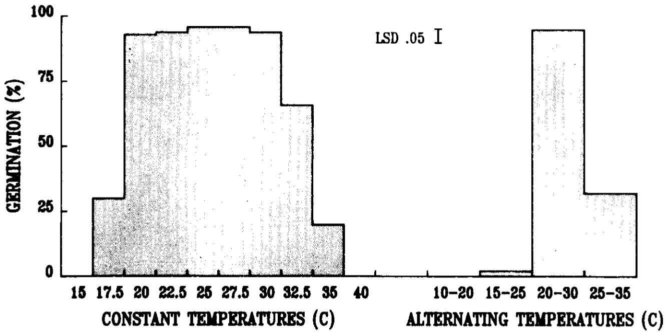

Fig. 1. *Average germination percentage of Texas persimmon seed after 14 days exposure to 14 constant and alternating temperatures.*

or ceased outside this range. Germination is apparently less tolerant of cold than warm temperatures. Germination dropped from 93% at 20° C to 30% at 17.5° C. Only 2% of the seeds germinated at an alternating temperature of 15–25°C, and none of the seeds germinated at a constant temperature of 15°C. The temperature requirements for Texas persimmon seed germination are apparently more specific than that reported for other troublesome woody plant species from central and southern Texas (Mayeux and Scifres 1978; Everitt 1983a, b.)

The percentage of seeds that germinated in light did not differ from those germinated in darkness. These results are in agreement with those reported for other woody plant species from Texas rangelands (Scifres and Brock 1972; Scifres 1974; Whisenant and Ueckert 1981; Everitt 1983a,b).

Texas persimmon seeds germinated over a broad range of pH values. Seed germination ranged from 93 to 97% at pH values from 4 to 11. None of the seeds germinated at pH 2 or 3, and only 12% of the seeds germinated in the most alkaline solution, pH 12, but these values rarely exist under field conditions. Seedling radicle lengths followed a similar trend to germination, but were suppressed in the pH 11 solution. These findings support those reported for numerous other woody plant species that may occur in association with Texas persimmon (Scifres 1974; Mayeux and Scifres 1978; Everitt 1983a, b).

Germination and radicle growth were sensitive to osmotic potentials of PEG solutions (Fig. 2). Both germination and radicle length were inhibited at only 0.2 MPa and continued to be progressively reduced as the osmotic potentials of the solutions were increased. Apparently, germination is dependent on high adequate water availability, indicating that seedling establishment is probably confined to periods of high soil moisture. The highest rainfall in central and southern Texas occurs in late spring and early fall, and temperatures during these periods are generally mild, which probably favors germination and establishment (National Oceanic and Atmospheric Administration 1974).

Germination was not adversely affected by NaCl concentrations

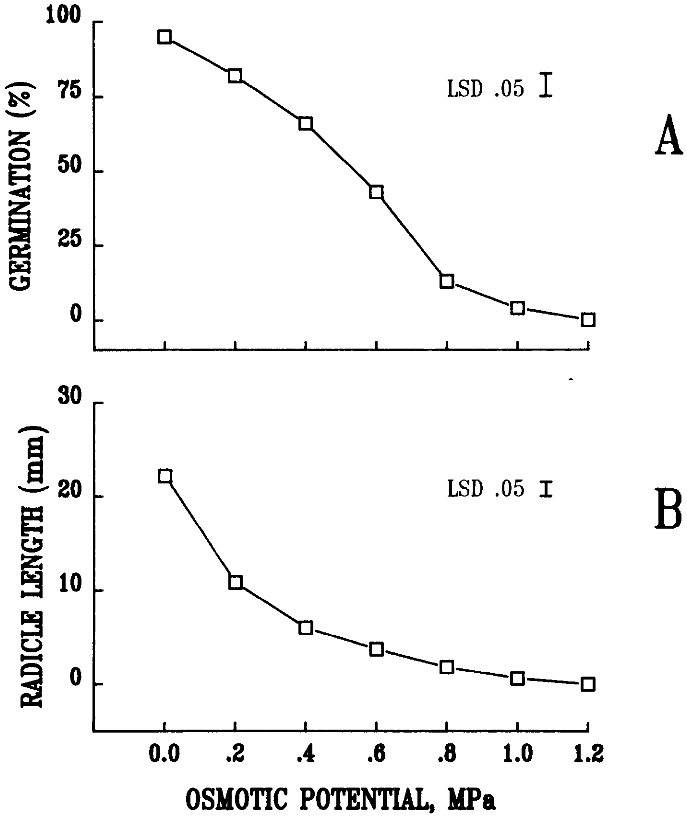

Fig. 2. *Texas persimmon percentage seed germination (A) and radicle length (B) after 14 days exposure to germination media of various omsotic potentials.*

up to 2.5 g/l (Fig. 3). However, germination was suppressed in the 5 g/l solution and nearly ceased in the 10 g/l NaCl solution.

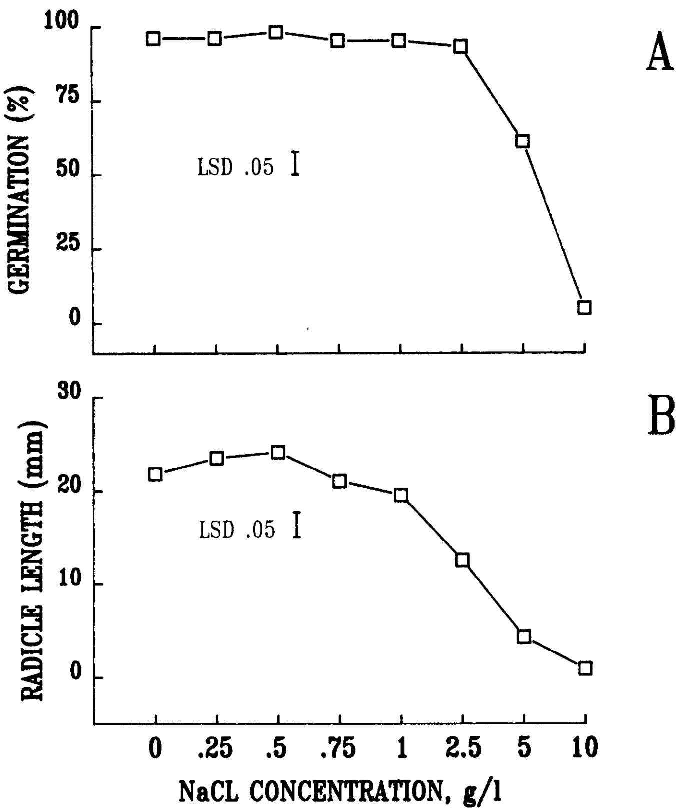

Fig. 3. *Texas persimmon percentage seed germination (A) and radicle length (B) after 14 days exposure to various NaCl concentrations.*

Seedling radicle length was apparently more sensitive to salinity than germination. Radicle elongation was restricted when NaCl concentration reached 2.5 g/l, and severely inhibited at a concentration of 5 g/l. Soil salinity may have an inhibitory effect on germination and establishment of Texas persimmon. This may explain the absence of this species on saline range sites in southern Texas (Everitt et al. 1984). Sodium chloride is the dominant salt in the saline soils of southern Texas and the electrical conductivity in the upper 30 cm of these soils ranges from 6.9 to 12.6 mmhos/cm (4.4 to 8.1 g/l) (Fanning et al. 1965; Everitt et al. 1982).

Germination in saline soil is influenced not only by direct ion effects, but also by osmotic interference (Uhvits 1946). The relationship between osmotic potential and concentrations of various salts was presented by Richards (1954). Mayeux (1982) used this information in conjunction with germination response to osmotic potentials of PEG solutions to determine which effect, osmotic potential or toxicity of salt solutions, was most responsible for suppressed germination and seedling vigor. This same comparison was used in this study. Germination and seedling radicle length in the 10 g/l concentration of NaCl was 5% and 0.9 mm, respectively (Fig. 3). The osmotic potential of this solution is about 0.6 MPa. Germination and seedling radicle length in the 0.6 MPa PEG solution was 43% and 3.7 mm, respectively (Fig. 2). This comparison suggests that the toxic effect of ions predominated in the reduction of germination and radicle growth rather than osmotic potential.

Germination after storage for 1, 6, 12, 15, 18, 21, and 24 months showed no changes in viability. Germination was ≥91% throughout the 2-year period. Apparently no dormancy or after-ripening requirements exist for this species.

The germination of seeds collected from plants growing on the gray sandy loam site did not differ significantly from those collected from plants on the more droughty shallow sandy loam site. Plants on the shallow sandy loam site were generally shorter in stature and less vigorous in appearance than those on the gray sandy loam site, but this apparently had no effect on germination.

Seedling emergence (73%) and height (20.8 mm) were greatest when seeds were planted 1 cm deep in soil, but burial of seeds at depths from 2 to 7 cm did not severely restrict emergence or seedling height (Fig. 4). Only 11% of the seeds left exposed on the soil surface produced seedlings and their height was lower than that of seedlings that emerged from buried seeds. However, since seedling emergence is not dependent on seed burial, this may contribute to the establishment of this species under natural conditions.

Passage of seeds through coyote digestive tracts had no significant effect on their germination. Germination of seeds from coyote feces averaged 96% as compared to 94% for the control. These findings are not in agreement with those reported for honey mesquite *(Prosopis glandulosa)* seeds. Honey mesquite seed germination was significantly reduced after passage through the digestive tracts of both coyotes and peccaries *(Pecari tajacu)* (Meinzer et al. 1975, Everitt and Gonzalez 1981). Apparently coyote digestive juices had no effect on Texas persimmon seed germination. Little information is available on coyote diets in southern Texas, but during late summer Texas persimmon fruits comprise a major portion of the diet (Bob Schumacker, Biologist, U.S. Fish and Wildlife Service; Personal Communication). I observed that Texas persimmon fruit comprised over 50% of the mass of coyote feces from which seed were removed. These data suggest that the coyote serves as an agent of seed dispersal for this species.

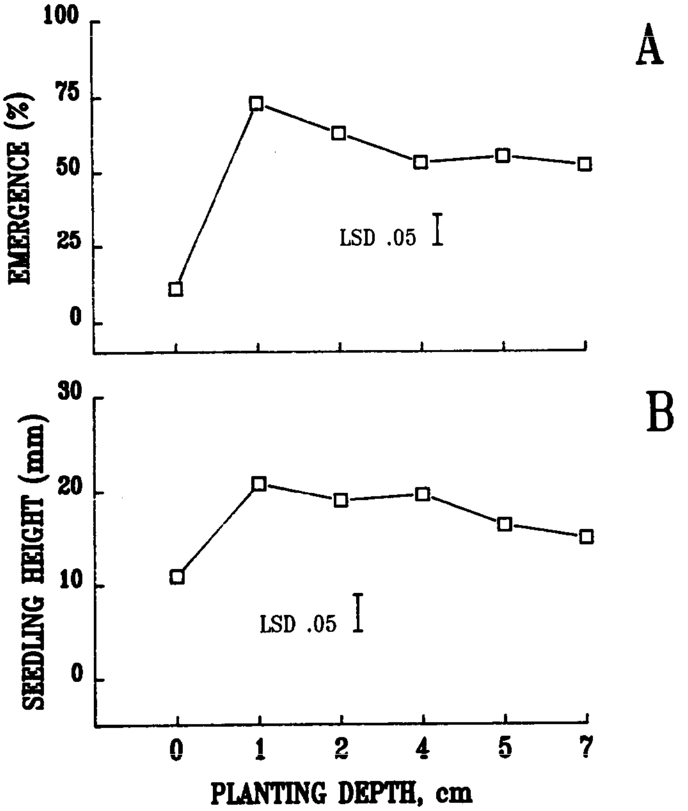

Fig. 4. *Percentage seedling emergence (A) and seedling height (B) 60 days after planting Texas persimmon seeds at various soil depths in pots in the greenhouse.*

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BOOK REVIEWS

Temperate Deserts and Semi-Deserts (Ecosystems of the World 5). Edited by Neil E. West. 1983. Elsevier Scientific Publishing Co., 52 Vanderbilt, Ave., New York, NY 10017. 522 pp. $170.25.

Temperate Deserts and semi-deserts cannot easily be separated from steppes and other vegetation that adjoin or have become desertified by man and his pastoral animals. Thus, the contributors of this book wisely adopt an ecogeographical approach in presenting their material. The reader is lead on a tour de force through little known parts of the world; about 4% of the earth's land area is temperate desert or semi-desert. The largest area is in Eurasia with about 15% of that continent consisting of vast reaches of the Kazakho-Dzungarian, Irano-Turanian, and central Asian deserts, as well as numerous high mountain deserts in southern U.S.S.R., Afghanistan and Iran. The North American temperate deserts are presented entirely by Dr. West and cover most of the Intermountain West. Dr. West gives chapters on the Great Basin-Colorado Plateau sagebrush, Mohavian blackbrush, intermountain salt desert shrublands, and a small area of southeastern Utah shrub-steppe. In South America, a host of authors contribute an overview of the deserts and semi-deserts of Patagonia.

The ecogeography of this volume follows a classification by H. Walter and E.O. Box (*Vegetatio* 32:75-81) who are the major contributors to chapters on the Eurasian continental deserts. The best feature of this book is that it gives the reader familiarity with the common features of temperate deserts on the global scale. There are consistencies of "harsh" climates, portrayed in every region by climatic diagrams. The problems of overgrazing, desertification, and wildlife decimation are ubiquitous. The machinery of nature obeys the same rules in Iran as in Utah. Each chapter assembles together information on floristics, vegetation zones, vegetation structure, soil-vegetation relationships, geographic locations, production, and land use. But, as Dr. West points out, detailed research is highly aggregated at comparatively few locations such as relict areas, experimental stations, or Biosphere Reserves.

There is not much management insight into these ecosystems of arid and semiarid, continental environments. The adaptive life-styles of nomadic pastoralists are either no longer politically possible or have resulted in dominance of such desert genera as *Artemisia, Euphorbia, Ephedra,* or *Alhagi* - plants with morphological or biochemical traits disliked by man and his livestock. It is clear that this 4% of the land will continue to be sparsely occupied. The problem viewed from the wealth of informaton provided in this volume is to keep the adjoining, more productive steppes and shrub-steppes from being done in by hungry herds.

Although some photographs were of compelling interest, most of them were of mediocre quality and often lacked scale. Overall, however, I think this book is an excellent reference especially for those unfamiliar with the ecological literature of other continents.—*W.H. Moir,* Albuquerque, New Mexico.

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Preface

Although not intended as an exhaustive presentation on manuscript preparation, this *Handbook and Style Manual* was prepared with the less experienced author in mind. Points of style, however, must be followed by all authors. Manuscripts submitted after 30 June, 1984, and not conforming to *JRM* style as designated here, will be returned to authors for correction before being sent out for review.

From time to time, this manual will be revised. The inside back cover of the *Journal* will carry brief instructions for authors and will advise them of style changes or a new edition of the style manual.

Introduction

Eligibility

The *Journal of Range Management* is a publication for reporting and documenting results of original research. Previously published papers are unacceptable and will not be considered for publication. Exceptions to this criterion are research results that were originally published as Department Research Summaries, Field Station Reports, Abstracts of Presentations, and other obscure and nontechnical handout publications. Manuscripts submitted to the *JRM* are the property of the *Journal* until published or released back to the author(s). Manuscripts may not be submitted elsewhere while they are being considered for this journal. Papers not accepted for publication are automatically released to the authors.

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Manuscript Submission

Contributions are addressed to the Editor, Journal of Range Management, 2760 West Fifth Avenue, Denver, Colorado 80204. Manuscripts are to be prepared according to the instructions in this handbook. If the manuscript is to be one of a series, the Editor must be notified. Four copies of the complete manuscript, typed on paper with numbered line spaces, are required. Authors may retain original tables and figures until the paper is accepted, and send good quality photocopies for the review process. Receipt of all manuscripts is acknowledged at once, and authors are informed about subsequent steps of review, approval or release, and publication.

Manuscripts that do not follow the directives and style in this handbook will be returned to the authors by the Editor. A manuscript number and submission date will be assigned when the paper is received in the appropriate format.

Manuscript Review

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Basic Writing Style for Journal Articles

Every paper should be written accurately, clearly, and concisely. It should lead the reader from a clear statement of purpose through materials and methods, results, and to discussion. The data should be reported in coherent sequence, with a sufficient number of tables, drawings, and photographs to clarify the text and to reduce the amount of discussion. Tables, graphs and narrative should not duplicate each other.

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