Journal of Range Management

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The Trail Boss

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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."

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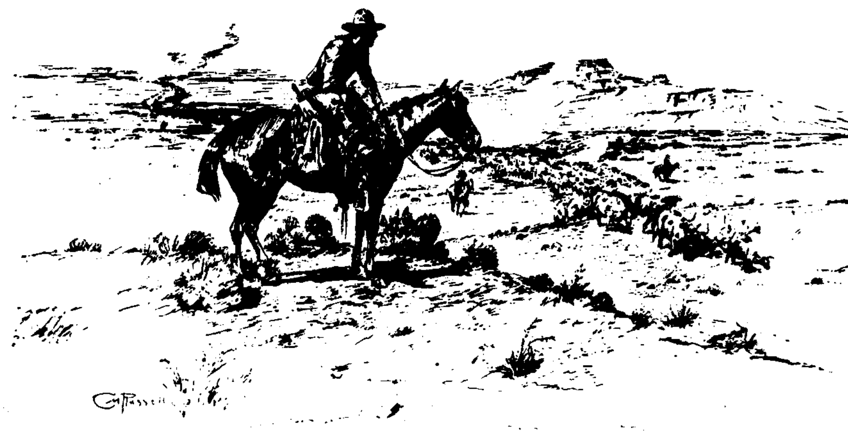
SOCIETY FOR RANGE MANAGEMENT



THE TRAIL BOSS

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

The objectives for which the corporation is established are:

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

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

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

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

—to promote professional development of its members.

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

Contribution Policy

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

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

President's Address

EDWARD A. MCKINNON

By the year's end, all of my objectives have been implemented to some degree, but on the whole, things turned out better than I thought they might. For example, the budget worked out nearly as planned, due mostly to the team work provided by the Executive Vice-President and the loyal support of the Denver office, the committee members, and the Board.

The SRM meeting in Washington, D.C., with the Joint Council of the USDA on Food and Agriculture has shown its worth in the increased interest in grants for range and forestry. The people at the session were supportive and this resulted in continuing discussion and correspondence which has certainly been of benefit to the Society.

The Policy Handbook has been distributed and I am sure it will be used by all. I think it was a job well done. The Long-Range Plan has been approved with provisions made to update it annually so that there will always be a guide for the members of the Society and their elected representatives to follow.

The increase in membership did not reach the objectives for 1985. It will be lucky if it just holds its own. The need to send in dues early in order not to miss the journals is still important.

A standing committee was appointed to look after the archives and history of the Society on an ongoing basis. Thanks is due to the committee for the hard work and long hours they put in to get the materials in order and the procedures set up. It is now ready for future committees to carry on and to secure our history in the proper manner.

Negotitions are continuing in regards to the sale of the present office. An offer was made for its purchase and was countered by our negotiators. Also, other locations have been studied but they are on hold pending the outcome of the sale. The mortgage on the building is now paid and a number of notes have been donated by dedicated SRM members. 1986 will start with rental income to use for repairs and improvement of the present building, with the balance to bolster our general fund. This puts us in a position that we have not been in before. It makes me think that we should really look carefully before we make a move.

The Cowboy Cookbook is selling well. The first printing has sold out, yielding a nifty profit. This income will be divided as per agreement with:

Endowment Fund (50%)
National Capital Section (10%)
and Sections (40%)

(The Sections' income will be divided according to the number of books they sold.)

The SRM Endowment Fund portion was left with the National Capital Section to pay for the second printing, which has now been completed. The money will be repayed to the Denver office as soon as sales will allow. It should be in order for a second edition to be printed soon, as I am sure the demand is there and the sales will prove it.

The ***Range Research—Basic Problems and Techniques,*** a book by C. Wayne Cook and James Stubbendieck, is now available from the Denver office. I am looking forward to getting one of these myself and I encourage other members to do likewise. Printing is a very important activity of the Society and also a source of income which is needed to carry on and extend our various programs. The *Range Research* book and our other publications were advertised in the December *Rangelands.*

Barbara H. Allen was appointed chairperson of a Rangeland Cover Type Committee to develop a proposal for completing "rangeland cover type descriptions" for the U.S., Canada, and Mexico. Barbara has her first report for the meeting in Orlando.

We are really expanding internationally. *Australia* has a society that is off and running and seems to be doing well. They are expanding their area and are a credit to their country. *East Africa* is slowly gaining with a society established as a committee in 1963. They had a meeting in Nairobi, Kenya, last November. There were 50 some members attending out of which they established a Board, and it looks as if now they are making progress. In *South America* last year, a meeting was held in Chile under the direction of Donald L. Huss, Regional Animal Production officer in that area. Doctor Bobby Ragsdale represented our Society and will be reporting on their progress at the Annual Meeting. In *Canada-Alberta* the Alberta Chapter of the International Mountain Section has contacted the Cabinet Ministers and agriculture representatives of the government and the University of Alberta, in Edmonton, in regard to the possibility of accreditation of the U of A for a range curriculum that would allow graduates in the degree of range management. All replies were in a positive mood. The Chapter is continuing to press for action along that line, as well as for more recognition throughout the rangelands of Alberta and the rest of Canada. In *India*it looks as if the Third International Rangeland Congress in New Delhi, India, in November, 1987, may become a reality.

A Disappointment—the North American Wildlife and Resources Conference is being held this year in Reno, Nevada, on March 24–26. The program is very interesting and pertains to most of the various subjects that our Society is concerned with. It would be well if the Society for Range Management had some listeners there and it is too bad that we are not to be represented on the program.

The February issue of *Rangelands* has been designated as a "producer's edition. "It is promoted to generate more interest by range operators in our Society. There will be articles highlighting operational programs of ranching. It could be developed into an annual edition that would attract more producers to our Annual Meetings.

At the close of the year, I attended the Annual Section Meeting in Albuquerque, New Mexico. Their hospitality is easy to take and their program was very good. I like their style. They have a way of honoring their workers with an awards system that instills interest and gains results.

From Albuquerque, I went to Orlando and had a good look at the facilities at the headquarters hotel. The convention center is good and the accommodations there and in the surrounding area seem very adequate. The Annual Meeting Committee and Florida Section members have gone all out to project their area and put on a good meeting. I only hope we have enough members there from our Society to overwhelm their expectations. Florida is a wonder-

This address was presented on February 12 at the 39th Annual Meeting of the Society for Range Management, Orlando, Florida.

ful state and I am sure that no one who has come to our 1986 Meeting will be disappointed.

After Orlando, I attended the National Range Conference in Oklahoma City. It was well organized with an extensive program. SRM was well represented and played a key part in the program which gave us excellent exposure. I did find out, too, that our Second Vice-President, Jack Miller, really has the ability to ferret out the right place to tie up and put the feed bags on. Thanks, Jack.

I left the Range Conference before the summary of the information that came from the sessions, to take part in the Colorado Section Meeting. This meeting, like most, was excellent and all too short to do any more than just meet the people and visit a minute or two and then leave. It would be nice and be able to stay longer and spend more time to really get to know our members better.

It is now recognized that the Society for Range Management can be depended upon to provide reliable and useful information. Our Society should be prepared to render this service, where and when it is requested and in such a manner that will reflect credibility to the areas of rangelands and the people who use them.

In reflecting on the happenings of the last three years, I am pleased to see the continuing enthusiasm and dedication of the members. It is the greatest. Their willingness to serve and the desire to get their teeth into something are very evident from the committee members in the Sections to the members of the Board. The method the Society operates under, using the committee system, is a good way to involve these members, but it also encumbers the actions of the Board. It takes considerable time to act, due mostly to the geographical extent of the Society's operations, e.g. U.S., Canada, Mexico, which brings members long distances and, mail being what it is, causes long delays. The Board has the power to act. Occasionally when time is of the essence, the Board should act quickly. True, it makes for greater understanding all around if the Board refers the matter back to the Advisory Council or one or two of the committees before taking action, but there are times when action is needed immediately and at such times, the Board must accept the responsibility and act.

I would like to thank the Board of Directors, committee members, and members at large who have helped me through this year: Pete Jackson and the Denver staff without whom I could not have survived; a special thanks to the two Past Presidents, Gerald Thomas and Joe Schuster, who have shown me how to operate; and, to the two Vice-Presidents, Fee Busby and Jack Miller, whose enthusiasm kept me on the go. I have enjoyed the Society for Range Management since I joined in the early 1950's and the last three years have been like the icing on the cake. I would like to give thanks to the good Maker up above for creating this wonderful world (I should say the universe) with all of its bounties and beauties and, especially for the rangelands and all of the people interested in the care and preservation of them. If I could be granted one wish it would be that I die young, at a ripe old age, helping them to do it.—Your 1985 President, **Ed McKinnon**

Influence of Climatic Conditions on Production of *Stipa-Bouteloua* Prairie over a 50-year Period

S. SMOLIAK

Abstract

Range forage yields obtained over a 50-year period at the Research Substation near Manyberries in southeastern Alberta were analyzed in relation to several climatic factors. The basic variables were precipitation, pan evaporation, temperature, hours of sunlight, and wind velocity. The precipitation from April through July was highly correlated with range forage production and this relationship could be utilized to predict the annual forage production by 1 August each year. A slightly better correlation was obtained when range forage production was related to the total of the previous September plus the current April through July precipitation. Pan evaporation totals, mean temperature, and hours of sunlight were negatively correlated with forage production, while wind velocity during the growing season showed a low relationship to forage production. Stepwise regression analysis showed that the inclusion of May and June mean temperatures with June and July precipitation accounted for 63% of the variation in range forage production. The predicted forage yield would be useful in making management decisions or adjustments, especially during drought periods, while the long-term forage yield data can be utilized in range forage models or in validating their effectiveness.

Studies on the response of mixed prairie to weather and climatic fluctuations have been mostly concerned with changes in floristic composition, with less attention to the relationship between climatic variations and range forage yields. Such relationships could provide ranchers with some method of predicting suitable stocking rates on native rangelands and aid ecologists in understanding short-term and long-term rangeland ecosystem dynamics.

The relationship between precipitation and yield of range vegetation was investigated as early as 1922 in north-central Montana by Patton (1927). More recent studies by Rogler and Haas (1947) in North Dakota, Smoliak (1956) in southeastern Alberta, Rauzi (1964) in Wyoming, Hulett and Tomanek (1969) in western Kansas, and Ballard (1974) in Montana explored the relationship between precipitation during the growing season and range forage yields. The good correlations that they found could be utilized to predict seasonal range forage production as early as 1 July. Other studies showed that fall-through-summer precipitation better explained the variation in total forage production but spring precipitation best predicted grass production (Noller 1968, Whitman and Haugse 1972).

Range forage production has also been related to soil type. In a study of 14 sites, Cannon (1983) found that thickness of mollic epipedon of range soils was significantly related to forage production and that using thickness and mean annual precipitation improved the estimate of range forage production.

Weather fluctuations on Mixed Prairie grassland in the Northern Great Plains were shown to result in a dominance of xeric species during drought periods and mesic species under more favorable growing conditions (Coupland 1958, 1959). Provision of more favorable growing conditions through weather modification may be a possibility with cloud seeding to increase precipitation. Hausle (1972) concluded that the amount of forage production that could result from additional precipitation could be predicted by statistical methods where long-term production and climatological data are available. Ballard and Ryerson (1973) indicated that increased precipitation resulting from weather modification will probably have a significant effect on range forage production only when combined with good livestock and grazing management practices. They suggested that such an increase should not be used as a basis for increasing stocking rates but rather should be used for increasing production efficiency and as a forage reserve in low production years. The response of Northern Great Plains grasslands to added water is complex and highly variable (Perry 1976) and timing of added precipitation is very important (Collins and Weaver 1978).

A rangeland production model has been developed (Wight 1983) to provide a basis for management decisions by predicting herbage yields, livestock production, runoff, and erosion. However, testing of the model has been a major problem as useable long-term field data are limited.

Most investigations on the relationship of range forage production to several meteorological factors have been based on relatively short terms of 20 years or less. However, the study reported here relates range forage production of a *Stipa-Bouteloua* prairie to several meteorological factors over a period of 50 years.

Methods

The study area was located on the Agriculture Canada Research Substation, Manyberries, in southeastern Alberta. The soil was a loamy Aridic Haploboroll. The vegetation belongs to the *Stipa-Bouteloua* faciation of the Mixed Prairie Association. Principal forage species include needle-and-thread (*Stipa comata* Trin. and Rupr.), western wheatgrass (*Agropyron smithii* Rydb.), blue grama (*Bouteloua gracilis* (HBK) Lag.), junegrass (*Koeleria cristata* (L.) Pers.), Sandberg's bluegrass (*Poa secunda* Presl.), and threadleaf sedge (*Carex filifolia* Nutt.), in order of decreasing yield. Abundant forbs are moss phlox (*Phlox hoodii* Richards.) and clubmoss (*Selaginella densa* Rydb.), while common shrubs include fringed sage (*Artemisia frigida* Willd.) and silver sagebrush (*A. cana* Pursh.).

Meteorological data during the study period were recorded at the Substation. Although several fields were used in the study, all clipping sites were less than 4.5 km away from the official weather station.

From 1930 to 1943, 36 plots (3.34-m^2) were clipped annually, and in 1947 and 1948, 15 (1-m^2) plots were clipped in a field protected from grazing. During 1949 to 1983, 15 (0.84-m^2) plots, protected from grazing by portable cages, were clipped annually. The portable cages were randomly distributed in large fields that were grazed by cattle at a moderate rate throughout the study period. All plant growth was removed prior to protection with portable cages the previous fall, thus the harvested vegetation was the current year's growth. Forbs and shrubs were included with grasses to represent total production. Vegetation was clipped at ground level with hand shears after the forage was mature, usually in late September. The 1930 to 1943 harvested samples were air-dried, while the 1947 to 1983 samples were oven-dried. No forage yield data were available for 1941, 1944, 1945, and 1946.

The analytical methods used to determine the effect of the meteorological factors on range forage production employed simple correlation and regression and stepwise multiple regression analyses. A total of 45 variables, mainly those during the growing season, were used in the analysis. The basic ones were precipitation, pan evaporation, temperature, hours of sunlight, and wind velocity.

Results

There were considerable fluctuations in range forage production and the measured meteorological factors over the 50-year period

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(Table 1). Forage yields varied from a low of 96 kg/ha in 1961 to a high of 925 kg/ha in 1942, with a mean of 388 kg/ha. Highest precipitation amounts were recorded in 1965 for the period April through July, annual, and previous year plus January through July while the lowest amounts recorded were in 1936 for April through July and the previous year plus January through July, and in 1943 for annual. Mean amounts of precipitation were 164 mm for April through July, 327 mm for the annual, and 558 mm for the previous year plus January through July total. Evaporation during May through July averaged 584 mm, but ranged from a low of 322 mm in 1955 to a high of 947 mm in 1973. Mean temperature during April through July was 12.8° C, with a low of 10.0° C in 1967 and a

Table 1. Forage production and selected meteorological values at Manyberries, Alberta, over a 50-year period.

Year	Forage yield (kg/ha)	Precip. (mm) Apr. - July	Evap. (mm) May - July	Mean temp. (°C) Apr. - July	Sunlight (hr) Apr. - July	Mean wind speed (km/hr)* Apr.-July	Annual precip. (mm)	Precip. (mm) previous year plus Jan. - July
1930	257	138	546	13.6	1051	—	294	508
1931	280	148	580	13.6	1055	—	237	462
1932	409	195	435	13.4	994	—	339	450
1933	295	160	607	13.2	1088	—	313	513
1934	247	116	560	14.0	1189	—	243	468
1935	325	132	499	11.5	1057	—	209	421
1936	183	67	683	15.4	1141	19.0	237	325
1937	280	96	503	13.9	1106	20.9	230	390
1938	434	158	374	13.2	968	15.9	370	456
1939	350	129	576	13.6	1003	18.7	249	599
1940	444	186	512	13.0	930	16.2	327	500
1942	925	291	537	12.2	910	16.4	416	691
1943	252	102	494	12.8	909	19.0	194	560
1947	343	109	565	13.6	1099	17.7	246	506
1948	213	157	337	12.7	1006	—	252	448
1949	101	113	539	14.6	1117	19.0	284	430
1950	303	148	484	11.6	930	19.3	283	487
1951	471	155	412	11.8	1016	18.8	459	538
1952	460	132	398	12.8	1055	19.0	281	675
1953	547	213	356	10.7	941	18.3	305	547
1954	567	202	361	10.7	875	20.6	428	569
1955	695	337	322	11.2	913	20.0	408	802
1956	549	208	394	12.6	996	24.1	365	669
1957	426	112	430	13.3	1054	22.7	350	534
1958	419	128	508	13.3	1029	17.0	334	564
1959	276	148	558	12.4	1108	21.1	306	539
1960	270	137	574	13.1	1080	17.0	285	506
1961	96	78	721	13.8	1003	17.5	215	386
1962	214	167	494	13.2	943	17.8	287	437
1963	267	146	544	13.1	972	18.0	266	500
1964	279	159	568	13.2	998	19.6	384	513
1965	736	419	483	11.6	861	18.7	600	851
1966	558	155	802	12.2	1097	22.5	345	814
1967	518	178	762	10.0	1080	—	430	693
1968	519	126	779	11.4	840	20.3	320	600
1969	308	100	755	13.3	933	19.8	243	508
1970	359	219	763	13.2	1067	20.0	352	514
1971	354	157	731	12.6	1128	18.7	316	595
1972	296	125	750	12.6	1100	21.1	334	526
1973	188	98	947	12.7	1147	—	219	442
1974	476	216	757	13.4	1144	19.3	385	500
1975	593	295	604	10.7	1051	18.7	572	755
1976	439	175	737	13.4	1231	18.8	300	795
1977	257	114	851	13.7	1252	—	286	431
1978	707	220	576	12.4	1110	19.6	513	632
1979	558	117	710	11.9	1209	17.5	342	752
1980	222	162	767	14.8	1342	17.9	333	570
1981	362	190	622	12.7	1143	20.3	311	582
1982	437	189	653	11.4	1144	19.5	459	655
1983	326	153	697	12.5	1049	—	290	668
Mean	388	164	584	12.8	1049	19.1	327	558

*39 years only.

high of 15.4°C in 1936. Total hours of sunlight during April through July ranged from a low of 840 in 1968 to a high of 1,342 in 1980, with a mean value of 1,049. Mean wind velocity during April through July over a 39-year period was 19.1 km/hr, and ranged from 15.9 km/hr in 1938 to 24.1 km/hr in 1956.

Correlations between forage production and the various meteorological measurements at selected periods are shown in Table 2. Forage production was significantly correlated with precipitation for the months of April, May, June, and July, but a better correlation (0.74) was obtained with the April through July total, or seasonal precipitation. In a previous study (Smoliak 1956), May plus June precipitation was more closely related to forage production than was seasonal precipitation. Annual precipitation, when correlated with yield, also showed a correlation coefficient of 0.74, but as indicated by Le Houerou (1984), although it has no predictive value for the current summer grazing season, it does have a probabilistic value for long-term planning. Seasonal precipitation therefore gives a better predictive value of the current year's forage production than the annual total and could be used more effectively in management application especially if rangelands are grazed during the growing season (Shiflet and Dietz 1974). The various combinations of seasonal precipitation did not improve the relationship when correlated with forage yield.

The regression equation derived from the relationship of forage yield and April through July precipitation is Y = 72.2 + 1.93 X, where Y is the estimated yield of forage in kilograms per hectare and X is the total April through July, or seasonal, precipitation in millimeters. This equation may be used as an estimate of annual forage production as early as 1 August each year to make management adjustments in the event of drought, to devise grazing plans for fall or winter grazing, or to prepare grazing management plans for the next year.

There was a low but significant relationship between precipitation recorded the previous year, the total previous winter snow, precipitation recorded the previous September or during the previous two years, and forage production. The inclusion of several monthly totals of precipitation improved the above relationships greatly with the highest correlation coefficient (0.77) being obtained with the addition of April through July precipitation to the previous September total (Table 2). The regression equation for this relationship was Y = 36.6 + 1.87 X, where Y is the estimated forage yield and X is the precipitation for the previous September plus the April through July total. The relationship between the previous year through July precipitation and forage yield also showed a high correlation (r = 0.74).

Pan evaporation totals, mean temperature, and hours of sunlight were negatively correlated with forage production (Table 2). The highest correlation coefficient (-0.62) was obtained between the relationship of April through July mean temperature and forage production. Wind velocity recorded during the growing season did not show any relationship to forage production.

Stepwise multiple regression analyses conducted on yield and the monthly values of precipitation, pan evaporation, hours of sunlight, mean temperature, and average wind velocity during the growing season (April through July) which meet the 0.15 significance level required for entry into the model, are shown in Table 3. The inclusion of temperature improved the relationship between precipitation and forage yield. However, the inclusion of hours of sunlight, wind velocity, or evaporation did not improve the correlation significantly. The best relationship was with the June and July precipitation totals and the May and June temperatures which accounted for 63% (r = 0.79) of the variation in range forage yields.

Table 2. Single correlation coefficients (r) between certain meteorological factors and forage production over a 50-year period.

	Precipitation (mm)											Evap. (mm)	Temperature (°C)			Sunlight (hr)		Wind speed[2] (km/hr)		
Independent variable	Apr.	May	June	July	Aug.	Sept.	May + June	Apr.-July[1]	Annual	Prev. Yr. -July	Prev. Sept. +Apr. - July	May - Sept.	May	June	Apr.-July	June	Apr. - July	June	Apr. July	Forage Yield kg/ha
Apr. ppt (mm)	1.00	0.20	-0.20	0.13	-0.08	-0.05	-0.03	0.42**	0.43**	0.42**	0.45**	0.05	-0.46**	-0.10	-0.52**	0.27	-0.03	-0.01	-0.07	0.40**
May ppt (mm)	—	1.00	0.12	0.28	0.04	0.14	0.68**	0.71**	0.59**	0.35*	0.65**	-0.17	-0.36*	-0.04	-0.28*	0.24	-0.10	-0.09	-0.23	0.46**
June ppt (mm)	—	—	1.00	-0.05	0.22	0.33	0.81**	0.53**	0.41*	0.34*	0.47**	-0.23	-0.01	-0.37**	-0.19	-0.44**	-0.31*	-0.08	0.04	0.42**
July ppt (mm)	—	—	—	1.00	-0.24	-0.12	0.12	0.51**	0.28*	0.34*	0.56**	-0.30*	-0.16	0.08	-0.17	0.15	-0.21	0.45**	0.19	0.41**
Aug ppt (mm)				—	1.00	0.21	0.18	0.03	0.38**	0.14	-0.06	-0.06	-0.05	-0.16	-0.18	-0.02	0.05	0.26	0.42**	0.12
Sept. ppt (mm)						1.00	0.32*	0.20	0.41**	0.08	0.14	-0.21	-0.14	-0.12	-0.19	-0.11	-0.19	-0.02	0.01	0.26
May + June ppt (mm)							1.00	0.81**	0.65**	0.46**	0.73**	-0.27	-0.22	-0.30*	-0.31*	-0.18	-0.29*	-0.11	-0.11	0.58**
Apr. - July[1] ppt (mm)								1.00	0.78**	0.62**	0.96**	-0.31*	0.40**	-0.25	-0.50**	-0.01	-0.34*	0.05	-0.03	0.74**
Annual ppt (mm)									1.00	0.61**	0.69**	-0.18	-0.32*	-0.24	-0.53**	0.12	-0.16	0.05	0.05	0.74**
Prev. yr-July ppt (mm)										1.00	0.66**	0.08	-0.34*	-0.44**	-0.55**	0.01	-0.06	0.15	0.15	0.74**
Prev. Sept. + Apr. - July ppt (mm)											1.00	-0.28*	-0.41**	-0.29*	-0.50**	-0.05	-0.35*	0.03	-0.05	0.77**
May-Sept. evap. (mm)												1.00	0.11	0.18	0.12	0.34*	0.48**	-0.09	-0.01	-0.25
May temp (°C)													1.00	0.16	0.74**	-0.01	0.33*	-0.14	-0.03	-0.41**
June temp (°C)														1.00	0.48**	0.54**	0.25	0.18	-0.01	-0.46**
April-July temp															1.00	-0.16	0.42**	-0.15	-0.15	-0.62**
June sunlight (hr)																1.00	0.65**	0.16	-0.02	-0.11
April-July sunlight (hr)																	1.00	0.03	0.05	-0.34*
June wind (km/hr)[2]																		1.00	0.80**	0.09
April-July wind (km/hr)[2]																			1.00	0.04
Forage yield (kg/ha)																				1.00

[1]April through July, inclusive
[2]39 years only
*,**significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Stepwise multiple regression equations for production (Y in kg/ha) of native rangeland as a function of monthly precipitation (mm) and temperature (° C).

	r
Y_1 = 286.0 + 3.85 × July precipitation	0.49
Y_2 = 1128.6 + 4.18 × July precipitation −55.6 × June temperature	0.70
Y_3 = 815.5 + 1.46 × June precipitation + 4.22 × July precipitation − 41.5 × June temperature	0.76
Y_4 = 1021.8 + 1.40 × June precipitation + 3.83 × July precipitation − 22.2 × May temperature −37.7 × June temperature	0.79

Discussion

Forage production of the *Stipa-Bouteloua* prairie in southeastern Alberta can be predicted with some confidence from the total of April through July, inclusive, or seasonal precipitation. For greater precision, the precipitation total recorded the previous September plus the April through July total could be utilized. Such predictions, based upon precipitation, could be used effectively in planning grazing operations after 1 August. In a previous study (Smoliak 1956), based upon 20 years of data, the May and June total of precipitation showed the best relationship when correlated with range forage yield. However, the data may be of more use in determining management schemes for the next year rather than for predicting forage yields for the current year.

The high correlations between the relationships of precipitation the previous year, or the previous September through June or July, and forage production is likely the response to accumulated soil moisture during the fall and spring periods. Soil moisture data were not available for this long-term study but Rogler and Haas (1947) and Johnston et al. (1969) found that range forage yields were greatly influenced by fall soil moisture. Caprio and Williams (1973) also noted that the amount of soil moisture at the start of the growing season is highly variable from year to year and that this available soil moisture is largely a function of the previous season's precipitation. The dependency between the previous year's and current year's yields found by Hanson et al. (1982) was attributed to soil moisture, as well as plant vigor and other biological factors.

During the 50 years that forage yields were obtained, 12 years were above-average, 26 years were average, and 12 years were below-average. The below-average and above-average values included all yields less than 0.7 or greater than 1.3 of the long-term average, respectively, as used by Hanson et al. (1982). The frequency of below-average range forage production, about once in 4 years, indicates that greater attention must be given to establishing proper stocking rates which would provide an adequate carry-over of forage during average years.

The yield data presented, in conjunction with meteorological records, can be used in range forage yield models to forecast range forage production (Wight et al. 1984, Wisiol 1984) and to prepare management plans during the grazing season. The data also can be utilized in the study of the feasibility of weather modifications in rangeland areas and in predicting the effectiveness of such manipulations. However, the predictive equations may be applicable only to the particular site as different range vegetation types or range soils would show varied estimates of production (Looman 1980; Cannon 1983; Cannon and Nielsen 1984).

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Nutrient Composition of *Atriplex* Leaves Grown in Saudi Arabia

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Abstract

Leaves of 6 *Atriplex* species (saltbush) grown in Saudi Arabia were studied for their nutritive characteristics. Crude protein contents varied between 16.7 - 25.2%, crude fat between 1.0 - 1.6%, crude fiber between 7.8 - 10.4%, and ash between 18.5 - 27.2%, on a dry matter basis. *A. undulata* had the lowest and *A. nummularia* had the highest protein and fiber contents. Ash content was lowest in *A. canescens* and highest in *A. undulata.* The level of Na was extremely low (0.21%) in *A. canescens* compared to that in the other species (2.38 - 5.57%). The level of K (6.06%) was highest in *A. canescens* compared to 2.48 - 3.54% in other species. Ca content was significantly higher in *A. vesicaria* (2.48%) than that in the remaining species (1.12 - 1.50%). Variations in the levels of P, Mg, Fe, Zn, Cu, and Mn were only minor. Sulphur amino acids (methionine + cystine) were the most deficient essential amino acids in all species (chemical score = 45 - 61) while lysine contents were 75 - >100% of the FAO/WHO (1973) reference protein. Predicted digestible dry matter ranged between 74.5 - 78.8% and digestible energy (M Cals/Kg) between 3.215 - 3.399. These data suggest that *Atriplex* leaves as a range forage for livestock would have good nutritive value.

Atriplex species commonly known as saltbush are strong candidates for plant establishments in saline areas and for increasing productivity in arid or semiarid regions of the world because of their salt tolerance and high productivity (Kleinkopf et al. 1975). Hence these plants have been grown as a forage shrub for many years in marginal agricultural lands in South Africa, Australia, USA and the Middle East (Goodin and McKell 1970). In the Kingdom of Saudi Arabia, where prolonged drought and excessive salinity are common, several species of *Atriplex* were grown successfully on marginal agricultural lands (Hyder 1981). *Atriplex* species are reported to show considerable variation in their chemical composition (Smit and Jacobs 1978) and differ considerably in their responses to sodium salts (Goodin and McKell 1970). Considerable information on the chemical composition and nutritional characteristics of the *Atriplex* species is available in the literature (Beadle et al. 1957, Goodin and McKell 1970, Chatterton et al. 1971, NAS 1971, Welch 1978, Smit and Jacobs 1978, Davis 1981, Welch and Monsen 1981, McArthur et al. 1984). However, such information on *Atriplex* species grown in the Kingdom of Saudi Arabia was lacking except for the protein and ash contents of some species reported by Hyder (1981). The present investigation was undertaken in an attempt to characterize the forage value of the leaves of six *Atriplex* species grown under the environmental conditions of Saudi Arabia. *Atriplex* leaves alone were included in this study because goats, which along with sheep and camels are the major grazing animals, show unique preferences for shrub and tree leaves (NRC 1981). Moreover, compositional information on the leaves alone was scarce for most of the *Atriplex* species under study especially those grown in Saudi Arabia.

Materials and Methods

Preparation of Samples

Mature dry leaves were collected from 6 *Atriplex* species, *A. nummularia* Lindl., *A. rhagodioides* F. Muell., *A. vesicaria* Heward., *A. canescens* (Pursh) Nutt., *A. lentiformis* (Torr) S. Wats and *A. undulata* (moq.) Dietr. The plants were exotic introductions from Australia and U.S.A. The seeds of *A. nummularia, A. rhagodioides* and *A. vesicaria* were supplied by C.V. Malcolm, Research Officer, Department of Agriculture, Perth, Western Australia. Seeds of the other *Atriplex* species were obtained from Dr. L.R. Green, range scientist, Forest Fire Laboratory, Riverside, California, U.S.A. Plants were grown at the Regional Agriculture and Water Research Center, Riyadh (Hyder 1981). Seeds were sown in the greenhouse in November 1977 in earthern pots (30 cm in diameter and 12 cm deep) with 1:1 mixture of sand and peat. Pots were watered regularly. All species germinated within 1 month. When large enough, individual seedlings were transferred to separate containers (12 cm diameter and 6 cm deep) having the same mixture of sand and peat. After 3 weeks in the greenhouse, the seedlings (12-16 cm in height) were transferred to the field plots in January 1978. The transplants were placed 1.75 m apart in rows which were 2 m apart and irrigated immediately. The plants were harvested in April 1980. All the plants had completed phenological stages of flowering, fruit, and seed production. Leaves were collected from 10-15 plants of each species, air dried and ground in a micro mill (Technilab Instruments, Pequannock, N.J., Model #502) to pass 1 mm-sieve, and stored in a freezer (-5°C) until analysed.

Chemical Composition

Analysis for moisture, crude protein (N × 6.25), crude fat, crude fiber, ash and nitrogen-free extract (NFE) (by difference) were done by methods of AOAC (1980). Acid detergent fiber (ADF) values were determined following the procedure by Goering and Van Soest (1970). For mineral analysis, the dry ash was dissolved in 20% HCl and necessary dilutions made with deionized water. Na and K were estimated with a flame photometer (Beckman, Klina flame). Ca, Mg, Fe, Zn, Cu and Mn were determined with an atomic absorption spectrophotometer (Perkin-Elmer, Model 603). P was determined by the procedure of Watanabe and Olsen (1965). For Ca and Mg, the final diluted solutions contained 1% lanthanum to reduce interferences.

For amino acid analysis, duplicate samples containing 5 mg protein were hydrolysed with 6N HCl for 24 hours at 110°C. Cystine was determined as Cysteic acid (Moore 1963) and tryptophan by the alkaline hydrolysis procedure of Hugli and Moore (1972). All the hydrolysates were analysed with an automatic amino acid analyser (Beckman, 119 CL). The chemical scores were determined by dividing the contents of the essential amino acids in the *Atriplex* leaf proteins by the contents of the same amino acid in the FAO/WHO reference protein (FAO/WHO 1973).

Nutritional Characteristics

Digestible dry matter (DDM), digestible energy (DE), and metabolizable energy (ME) were calculated from the chemical data. DDM was calculated from the ADF values and DE from the DDM values using the following equations reported by Fonnesbeck et al. (1984) for alfalfa hay:

$$\text{DDM\%} = 88.9 - 0.779\ (\text{ADF})$$
$$\text{DE\%} = 0.628 + 0.984\ (\text{DDM\%})$$
$$\text{DE (M cals/kg)} = 0.027 + 0.0428\ (\text{DDM\%})$$

For the calculation of the ME, the following equation was used (Gonzalez and Everitt 1982):

$$\text{ME (M cals/kg)} = \text{DE (M cals/kg)} \times 0.8210$$

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Results and Discussion

Proximate Composition

Proximate analysis data are reported in Table I. Considerable variations in the crude protein, ash, and carbohydrate contents were observed among the leaves of the 6 *Atriplex* species. The percentage values of fat and fiber showed relatively small variations. The protein content varied from 16.7% in *A. undulata* to 25.2% in *A. nummularia;* mean was 19.4% for the 6 species. Smit and Jacobs (1978) also reported considerable variations in the protein content among *Atriplex* species, as well as seasonal variations within species. Welch and Monsen (1981) reported winter crude protein levels of 6–14% of dry weight in 43 accessions of fourwing saltbush *(A. canescens)* and indicated that genetic variation plays an important role in determining the level of protein in this *Atriplex* species. McArthur et al. (1984) reported seasonal variations in the protein content of 'Rincon' fourwing saltbush *(A. canescens)* ranging from 17.9% in November to 26.5% in June in the leaves with intermediate values for other seasons. Goodin and McKell (1970) indicated a decrease of approximately 2% in the protein content of *A. lentiformis* and 3% in *A. polycarpa* between the first and second harvest separated by 1-month intervals. The National Research Council (NRC 1976) recommended 9.2% and 5.2% crude protein for lactating and dry beef cows, respectively. The protein content of the dry leaves of the 6 *Atriplex* species exceeded these requirements. Moreover, the data suggest that these leaves could be used as a protein supplement with other forage crops such as dormant grasses which usually are deficient in this nutrient (Gonzalez and Everitt 1982). The crude protein content of the leaves of *Atriplex* species was also higher than the requirements for sheep (8.9–16%, NRC 1975). Similarly, it exceeded the protein needs suggested for maintenance, live weight gain of goats, and for pregnant and lactating does (NRC 1981).

The percentage of fat varied between 1.0–1.6%. The fat values

Table 1. Proximate composition[1] of *Atriplex* leaves.

Atriplex species	Protein (N×6.25)%	Fat %	Fiber %	Ash %	Nitrogen-free extract
A. nummularia	25.2	1.1	10.4	24.3	39.0
A. canescens	17.4	1.6	9.0	18.5	53.5
A. vesicaria	17.8	1.6	8.3	34.1	38.2
A. rhagodioides	17.2	1.0	10.2	22.8	48.8
A. lentiformis	21.9	1.1	8.0	22.0	47.0
A. undulata	16.7	1.3	7.8	27.2	47.0
Mean	19.4	1.3	9.0	24.8	45.6

[1]Dry weight basis.

Table 2. Mineral element content[1] of *Atriplex* leaves.

Atriplex species	Na	K	Ca	P	Mg	Fe	Zn	Cu	Mn
			%				µg/g		
A. nummularia	4.85	2.49	1.44	0.24	0.76	420	54	24	74
A. canescens	0.21	6.06	1.31	0.19	0.72	370	59	20	84
A. vesicaria	4.95	2.86	2.48	0.18	0.84	350	58	23	78
A. rhagodioides	2.38	2.48	1.50	0.22	0.59	335	66	25	82
A. lentiformis	4.91	2.76	1.12	0.28	0.79	250	59	26	75
A. undulata	5.57	3.54	1.45	0.24	0.66	485	70	26	89

[1]Dry weight basis.

Table 3. Amino acid composition of *Atriplex* leaves (g amino acid/100 g protein).

Amino acid	*A. nummularia*	*A. canescens*	*A. vesicaria*	*A. rhagodioides*	*A. lentiformis*	*A. undulata*	FAO/WHO (1973)
Aspartic acid	5.96	4.83	6.52	5.68	5.01	4.81	—
Threonine	2.90	2.52	3.27	2.90	2.57	2.50	4.0
Serine	3.12	2.56	3.61	3.05	2.62	2.85	—
Glutamic acid	6.89	5.62	7.28	6.69	5.54	5.33	—
Proline	3.22	2.62	2.47	3.68	2.13	2.08	—
Glycine	3.54	2.96	3.75	3.39	2.86	3.09	—
Alanine	3.79	3.03	3.99	3.68	3.26	3.25	—
Valine	3.65	2.84	4.04	3.39	2.83	3.16	5.0
Methionine (M)	0.87	0.91	0.94	0.85	0.80	0.80	—
Cystine (C)	0.69	0.74	0.85	1.18	0.80	1.32	—
M + C	1.56[1]	1.65[1]	1.79[1]	2.03[1]	1.60[1]	2.12[1]	3.5
Isoleucine	3.27	2.42	3.34	2.87	2.30	2.38	4.0
Leucine	5.04	4.00	5.41	4.97	4.14	4.02	7.0
Tyrosine (T)	1.99	1.58	2.15	1.93	1.59	1.67	—
Phenylalanine (P)	3.20	2.60	2.55	3.15	2.53	2.55	—
T + P	5.19	4.18	4.70	5.08	4.12	4.22	6.0
Lysine	5.44	4.22	5.71	5.04	4.08	4.09	5.5
Histidine	1.53	1.15	1.53	1.12	0.91	0.93	—
Arginine	5.30	2.50	3.57	2.79	2.63	2.27	—
Tryptophan	0.62	0.60	0.77	0.93	0.79	0.74	1.0
NH_3	2.53	2.86	2.70	1.14	1.22	1.37	—
Chemical score	45	47	51	58	46	61	100

[1]First limiting essential amino acid.

are slightly lower than those of NAS (1971) for *Atriplex* leaves (1.9–2.7%) and 2.5–3.5% reported by Chatterton et al. (1971) in the leaves of *A. polycarpa.* The ash contents varied between 18.5% in *A. canescens* to 34.1% in *A. vesicaria.* These values are in agreement with those reported by NAS (1971). Chatterton et al. (1971) reported considerable variation in the total ash content of *A. polycarpa* leaves (15–20%) with the highest value during late summer.

The crude fiber content was highest in *A. nummularia* (10.4%) and lowest in *A. undulata* (7.8%). These values are comparable to those reported for *A. polycarpa* leaves by Chatterton et al. (1971). The fiber as well as ash content showed large seasonal variations in *Atriplex* species (Chatterton et al. 1971, Davis 1979). However, these seasonal variations in fiber content were lowest in the leaves compared to the stems or whole plant (Chatterton et al. 1971). NFE varied from 38.2% in *A. vesicaria* to 53.5% in *A. canescens.* These values are close to 40–45% reported by Chatterton et al. (1971) in the leaves of *A. polycarpa* and compare favorably with the values of NAS (1971).

Mineral Contents

Data on the mineral element contents are shown in Table 2. All the mineral elements showed a wide range of variation except Cu, which differed over a narrow range. The concentration of Na was lowest in *A. canescens* (0.21%) and highest in *A. undulata* (5.57%). Other investigators have also reported much lower Na levels in *A. canescens* compared to the Na levels in the leaves of other *Atriplex* species (Wallace et al. 1973, Smit and Jacobs 1978). Richardson (1982) showed that distinct biotypes of *A. canescens* exist with regard to Na accumulation. Na levels in all the species were well above the 0.06% level considered adequate for beef cattle (NRC, 1976). It was also much higher (except *A. canescens*) than 0.5% level considered adequate for goats (NRC 1981) and 0.04–0.1% of diet dry matter considered adequate for sheep (NRC 1975). Goats in particular can consume Na in excess of their requirements with no apparent ill effects (NRC 1981).

In contrast to Na, the concentration of K was maximum in *A. canescens,* and relatively much lower in other species. High levels of Na in the leaves tend to depress the K levels (Wallace et al. 1982). Richardson (1982) reported large ecotype differences in the leaves of *A. canescens* for K accumulation. K concentrations in leaves were high when Na concentrations were low. The K levels in all the species were well above the (0.6–0.8%) minimum requirement range for cattle (NRC 1976) and 0.5%–0.8% range for goats and sheep (NRC 1975, 1981).

The Ca content varied from 1.12 to 2.48%, with *A. vesicaria* containing significantly higher amounts of Ca compared to the other species. All species had Ca levels that exceeded the requirements (0.18%–0.44%) for beef cattle (NRC 1976), 0.138% for goats (NRC 1981), and 0.21–0.52% for sheep (NRC 1981). The levels of P (0.18–0.28%) were satisfactory in comparison to 0.18% considered adequate for dry cows (NRC 1976) but were below the 0.39% level considered adequate for lactating cows (NRC 1976). A similar situation existed for sheep with requirements of 0.16–0.37% (NRC 1975). This was also true for goats (NRC 1981). The concentration of Mg was lowest in *A. rhagodioides* (0.59%) and highest (0.84%) in *A. vesicaria.* The range of Mg was well above the Mg requirements (0.04–0.18%) of beef cattle (NRC 1976), sheep and goats (0.04–0.08%) (NRC 1975, 1981).

Among the micro-elements, the level of Fe ranged between 250–485 μg/g dry leaves, which is higher than the values reported for some *Atriplex* species (Wallace et al. 1982). Although minimal requirement for Fe has not been established, 80–100 μg/g feed is considered ample for beef cattle (NRC 1976) and 30–50 μg/g dry matter for sheep and goats (NRC 1975, 1981). *Atriplex* leaves are, therefore, adequate in Fe for beef cattle, sheep, and goats. In contrast to Fe, the contents of Zn and Cu tended to be lower than the values of Wallace et al. (1982). Only Mn levels were relatively comparable with the data of above authors. The level of Zn in *Atriplex* leaves was well above the suggested requirement level (20–30 μg/g of diet dry matter) for beef cattle (NRC 1976), 10 μg/g for goats (NRC 1981) and 35–50 μg/g for sheep (NRC 1975). Cu content was also well above the 4 μg/g of diet dry matter suggested as a requirement for beef cattle (NRC 1976) and 5 μg/g feed suggested for sheep (NRC 1975). Similarly, the Mn level exceeded the 1–10 μg/g requirement for beef cattle (NRC 1976) and 20–40 μg/g for sheep (NRC 1975).

Amino Acid Composition

The amino acid contents of *Atriplex* leaves have been studied as a possible source of plant protein (Silva and Pereira 1976) and for providing information for taxonomic studies (Cozic-Trichet and Goas 1969). In general, there is very limited information on the amino acid profile of *Atriplex* leaf protein. Because of these reasons, the amino acid composition of the 6 *Atriplex* leaf proteins was studied and the results are shown in Table 3. Considerable variations in the concentrations of some amino acids were observed. Total sulphur amino acids (methionine + cystine) were the first limiting essential amino acids in all the *Atriplex* species. The chemical score (FAO/WHO 1973) ranged between 45–61, with *A. undulata* showing the highest chemical score. Lysine, which is the most deficient essential amino acid in cereal proteins, was present in levels higher than those of cereal protein. However, it was slightly lower than the FAO/WHO reference protein (1973), except *A. vesicaria* protein, which contained slightly higher lysine than that in FAO/WHO (1973) pattern. In general, the lysine contents were between 75 – >100% of the reference protein. These results indicated that *Atriplex* leaf protein has a good amino acid profile and these proteins could supplement those of cereal proteins. In general, these findings are similar to those of Silva and Pereira (1976).

ADF, DDM, DE and ME

The ADF values (Table 4) ranged from a minimum value of 13.0% in *A. undulata* to a maximum value of 18.5% in *A. lentiformis.* The DDM values ranged between 74.5%–78.8%. Data on the DDM values for *Atriplex* leaves alone is scarcely reported in the literature. However, values for total digestible nutrients (TDN %) in *Atriplex* leaves are reported to be 40.2% and 45.5% for cattle and sheep, respectively (NAS 1971). The DDM values were comparable to in-vitro dry matter digestibility values (66.8%–77.0%) for moth bean plant *(Vigna aconitifolia),* a forage crop of the arid and semiarid areas (Arora et al. 1975). The DE (M cals/Kg) levels of all the species were higher than 2.20 and 2.50 M cals/Kg required to meet the needs of dry and lactating cows, respectively (NRC 1976) and approximate to the needs of sheep and goats (NRC 1975, 1981). The DE values, as expected, were generally higher than most other forage crops but comparable to that of prickly pear cactus (Gonzalez and Everitt 1982). The ME values were also higher than values, 1.82–1.86 ME/kg dry matter, for the whole browse (*Atriplex* species) (Gohl 1981). Although the methods used to estimate

Table 4. Acid Detergent Fiber (ADF), Digestible Dry Matter (DDM), Digestible Energy (DE) and Metabolizable Energy (ME) of *Atriplex* leaves (dry weight basis).

Atriplex species	ADF[1] %	DDM[2] %	DE[2] %	DE[2] (M cals/Kg)	ME[3] (M cals/Kg)
A. nummularia	15.5	76.8	74.9	3.314	2.717
A. canescens	14.1	77.9	76.0	3.361	2.756
A. vesicaria	13.8	78.2	76.3	3.373	2.765
A. rhagodioides	15.2	77.1	75.2	3.326	2.727
A. lentiformis	18.5	74.5	72.6	3.215	2.636
A. undulata	13.0	78.8	76.9	3.399	2.787

[1]ADF determined following the procedure of Goering and Van Soest (1970).
[2]Calculated by the prediction equation of Fonnesbeck et al. (1984).
[3]Calculated by the equation, ME (M cal/Kg) = DE (M cals/Kg) × 0.82 (Gonazalez and Everitt 1982).

energy value are based on an alfalfa equation, these data suggest that *Atriplex* leaves have good digestibility and energy values.

In conclusion, leaves of *Atriplex* species have a good nutritional potential as a feed for livestock. However, feeding trials are needed to determine their palatability and, if necessary, to ascertain means of increasing their palatability.

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Seasonal and Annual Changes in Biomass Nitrogen and Carbon of Mesquite and Palo Verde Ecosystems

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Abstract

Biomass components of mesquite (*Prosopis juliflora*(Swartz)DC) and palo verde (*Cercidium* floridum (Benth)) soil-plant systems were collected during spring, winter, and fall for 3 years to study the temporal distribution of the mass of understory vegetation and litter and the dynamics of nitrogen and carbon in all biomass components. Mass of palo verde litter changed seasonally while that of mesquite did not change. With exception of mesquite litter, mass of understory vegetation and litter did not change annually for either shrub. Seasonal and annual changes were observed in both N and C of selected shrub, understory, and litter components, but these changes were more prevalent in mesquite than palo verde. Seasonal changes appeared primarily related to N and C demand in regions of rapid growth. Annual changes appear related to weather phenomena which regulate decomposition, uptake, and growth.

Research on shrubs has been extensive in the western United States. It has covered a broad subject matter (McKell et al. 1972) including productivity, value as browse, reestablishment, control or removal of unwanted species, and other subjects. Several studies have examined the carbohydrate dynamics of shrubs (Coyne and Cook 1970, Menke and Trlica 1983) and some have looked at nutrient relations of soil-plant systems (Garcia-Moya and McKell 1970, Youngberg and Hu 1972, Tiedemann and Klemmedson 1973, Klemmedson 1979), mostly from the standpoint of nutrient cycling and nitrogen fixation.

Studies of the internal nutrient dynamics of woody species have concerned either silviculturally important trees (e.g., Sampson and Samisch 1935, Mitchell 1936, Tamm 1951) or horticultural crops (Kelley and Shier 1965, Hansen 1967, Meyer and Splittstoesser 1969). Comparable studies on western shrubs have emphasized value of shrubs as herbivore browse (Dietz 1972).

Research reported here was part of a larger study of nitrogen and carbon distribution in soil-plant systems of important shrubs of the Sonoran Desert, much of which has been previously reported (Barth and Klemmedson 1978, 1982). The objective of the research reported here was to measure seasonal and annual changes of nitrogen (N) and carbon (C) in shrub and understory components of velvet mesquite (*Prosopis juliflora* (Swartz) DC) and blue palo verde (*Cercidium floridum* Benth)) ecosystems.

Study Area

The study area was at the Santa Rita Experiment Range about 32 km south of Tucson, Ariz. The study site, a grass-shrub community typical of this part of the Upper Sonoran Desert, was selected for its uniformity. It was located at 975 m elevation on an alluvial plain with slopes of 1 to 5%. Velvet mesquite and palo verde were the dominant woody species. Both shrubs occurred on upland sites, but shrub density was greater along numerous arroyos that dissect the plain. Mature velvet mesquite shrubs averaged 3 m height and had from 1 to 3 main stems; mature palo verde shrubs were slightly smaller and were generally single stemmed. Understory vegetation was dominated by Arizona cottontop *Digitaria californica* (Benth.) Chase, needle grama (*Bouteloua aristidoides* H.B.K.), bush muhly (*Muhlenbergia porteri* Scribn.) and burroweed *Aplopappus tenuisectus* (Green) Blake. Sampling was restricted to upland sites and to the Sonoita soil series. This soil is derived from recent mixed alluvial deposits and is a loamy, mixed thermic Typic Haplargid. For the previous 50 years, the site had been lightly and uniformly grazed; disturbance from other causes was not visible.

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Field Methods

Thirty-four velvet mesquite and 24 palo verde shrubs were randomly selected from a large pool of candidate shrubs encompassing the size range of each species and sampled at phenologically similar seasons each year according to the following schedule: 1971, five mesquite in spring (May) and fall (Sep. - Oct.); 1972, five mesquite and five palo verde in winter (Feb.), spring (Apr.–May), and fall (Sep.–Oct.; 1973, three mesquite and three palo verde in winter (Jan.), spring (May), and fall (Sep.). Recognizing the large inherent variation of range ecosystems, field sampling was designed to hold environmental factors other than time variables constant or to vary within narrow limits. For each shrub sampled, six 0.093 m^2 plots were located on a north-south line running through the center of the shrub. Understory vegetation and litter were sampled in these plots under the shrub canopy at points 1/3, 2/3, and 3/3 of the north and south canopy radii (CR). At each plot location live and dead standing understory vegetation was collected separately by harvesting plants at ground level. Litter from the overstory shrub (shrub litter) and from the understory vegetation (understory litter) also was collected from each plot. Material collected from north and south sides of each shrub was combined, by positions, thus making the combined plots 0.186 m^2 in size. Weighted means for each shrub component were calculated based on the area represented by the sample for each canopy position under each shrub.

Shrub roots were extracted from 8 × 10 cm soil columns collected to 60 cm depth under each vegetation-litter plot and from a plot located at each shrub center. Samples from comparable north and south plots of each shrub were combined; weighted means for shrubs were calculated as above.

Each shrub was harvested at ground level and separated into leaves, flowers, fruit, current growth (woody growth <1 year old), branches <1 cm in diameter, branches >1 cm diameter, and deadwood. Branches and deadwood were weighed in the field to the nearest 0.5 kg; other components were weighed to the nearest gram. Random samples were taken of all shrub components for moisture content and laboratory analyses.

Samples were oven-dried at 70° C, weighed, and ground to pass a 40-mesh screen. Total N was determined by macro-Kjeldahl (Bremner 1965). Organic C was determined by dry combustion in a high-frequency induction furnace (Allison et al. 1965).

Analysis of variance and separation of means by Duncan's new multiple range test for significant effects were performed at the 0.05 probability level.

Results and Discussion

Seasonal Changes in Ecosystem Components

Mass

The mass of understory vegetation beneath mesquite and palo

Table 1. Mass of understory vegetation, shrub litter, and understory litter for velvet mesquite and palo verde ecosystems by seasons and years.

Component	Seasonal			Year		
	Spring	Fall	Winter	1971	1972	1973
	g • m⁻²					
	Velvet Mesquite Ecosystem					
Understory vegetation[1]	148a[2]	119a	162a	103a	166a	130a
Mesquite litter	271a	346a	255a	143b	360ab	497a
Understory litter	157a	144a	143a	167a	128a	159a
	Palo Verde Ecosystem					
Understory vegetation[1]	308a	188a	154a	—	296a	166a
Palo verde litter	271a	129ab	113b	—	143a	296a
Understory litter	260a	256a	329a	—	266a	244a

[1]Values for understory vegetation are weighted means of standing live and standing dead vegetation.
[2]Within any row for seasonal or annual data, values that lack one or more common letters are significantly different at the $p<0.05$ level.

verde did not change significantly from season to season (Table 1), evidently reflecting the 2 growing seasons of the Sonoran Desert and high variance among the population sampled. The primary growing season occurs during summer when herbaceous perennials maximize growth. A second growing season occurs in winter or early spring for shrubs, succulents, and annual herbs if sufficient winter precipitation is received (Martin 1964). Most herbaceous perennials make little growth during this season (Culley 1943). Apparently these different growing seasons created a rather constant standing crop of understory vegetation from season to season.

Mass of palo verde litter declined significantly between spring and winter (Table 1), thus reflecting the shedding of fruit and small branches between the winter and spring sampling dates and accelerated decomposition during summer (Santos and Whitford 1981). By contrast, there was no difference among seasons for mesquite litter. Shedding of leaves and fruit of mesquite was not distinctly seasonal. In some years leaves were shed in December, while in other years leaves were retained until late spring. Small dead branches were shed at all seasons and may have masked the expected rapid decomposition during summer.

Litter derived from the understory vegetation showed no significant seasonal pattern for either shrub. The transfer of understory litter from standing crop to litter occurred throughout the year, thus keeping the mass of understory litter relatively constant.

Nitrogen

Leaves and current growth of mesquite and palo verde displayed significant seasonal changes in percentage N (Table 2). The decline in N concentration from a spring peak began some time after the spring flush of growth and continued into winter dormancy; seasonal decline of N in leaves is commonly observed (Tamm 1951, Grigal et al. 1976). Protein turnover can be rapid in young leaves (Bidwell 1979) as well as in older storage organs (McKee 1962, Meyer and Splitstoesser 1969). These nitrogen reserves are translocated in spring to regions of actively growing tissue and metabolized to support new growth (Meyer and Splittstoesser 1969). Losses of leaf N through leaching by precipitation also may contribute to the observed pattern (Tukey 1970).

Table 2. Nitrogen and carbon for components of velvet mesquite and palo verde ecosystems by seasons.

Ecosystem component	Nitrogen			Carbon		
	Spring	Fall	Winter	Spring	Fall	Winter
	percent					
	Velvet Mesquite Ecosystem					
Shrub Components						
Leaves	3.51a[1]	2.82b	2.25c	46.7a	47.3a	45.3b
Current growth	2.27a	1.77b	2.00ab	44.7b	45.9a	44.9ab
Branches<1 cm	1.36c	1.52b	1.74a	43.3a	43.3a	42.9a
Branches>1 cm	1.03c	1.16ab	1.26a	42.8a	43.3a	41.7b
Roots	1.56a	1.55a	1.52a	45.9a	46.0a	45.3a
Standing Understory[2] Vegetation	1.08b	1.21a	1.20a	40.8a	40.6a	41.6a
Shrub litter	1.64ab	1.50b	1.73a	40.0a	38.6b	40.6a
Understory litter	1.17a	1.30a	1.29a	38.4a	36.6b	36.9ab
	Palo Verde Ecosystem					
Shrub Components						
Leaves	4.18a	3.48b	—	43.2a	41.6b	—
Current growth	3.20a	2.15b	2.48b	43.5a	43.3a	43.4a
Branches<1 cm	1.63a	1.48a	1.63a	42.1a	42.6a	42.2a
Branches>1 cm	1.15a	1.19a	1.02a	42.9a	43.7a	42.7a
Roots	1.28a	1.18a	1.04a	44.2a	44.1a	44.0a
Standing Understory[2] Vegetation	1.07a	1.21a	1.14a	41.5a	41.4a	42.2a
Shrub Litter	1.44a	1.31a	1.31a	38.8a	37.2b	38.9a
Understory Litter	1.24a	1.25a	1.13a	37.7ab	36.2b	38.6a

[1]Within any given row for N or C, figures that lack one or more common letters are significantly different at the $p<0.05$ level.
[2]Values for standing understory vegetation are weighted means of standing live and standing dead vegetation.

The decline in percentage N of current growth (twigs) during the early growing season is similar to that observed for other shrubs (Grigal et al. 1976) and horticultural species (Kelley and Shier 1965). This also can be associated with cyclic protein metabolism described above for leaves. This decrease also can be explained by the expected increase in structural carbohydrate as current growth takes on a woody character with the maturing process. Presumably, the two processes occur simultaneously.

Both small and large branches of mesquite had significantly lower N concentrations in the spring than in fall or winter (Table 2). Apparently, N in these components was translocated during spring to growing regions when demand for N was large. By fall and winter, N concentration had been restored in these woody tissues, presumably by translocation and resynthesis of proteins from regions of active photosynthesis and cyclic protein metabolism. This pattern was not evident in branches of palo verde; perhaps the higher N content associated with the photosynthesizing bark of this species masked seasonal translocation of N. Moreover, growth (and perhaps N translocation) in palo verde appeared to be more related to actual periods of higher precipitation (Table 3) than to the seasonal sampling periods. We detected no seasonal changes in N content of roots for either species.

Standing vegetation in the understory of mesquite shrubs was significantly higher in N during the fall and winter than in spring (Table 2). The same trend occurred for palo verde, but differences were not significant; the smaller sample size, hence higher variance, for palo verde may have been responsible. Timeliness of N availability, growth stages of the vegetation, and seasonal differences in species composition may have been important factors in the low N concentration of understory vegetation in spring. Uptake of N by understory species can be expected to be higher during late summer and winter when soil moisture is more conducive to N mineralization than in spring when upper soil layers are normally dry. A spring understory vegetation composed of species characteristically lower in N percentage may be another factor contributing to low N percentage of the understory in spring. Nutrient dynamics of the complex understory vegetation defies simple explanation.

The N concentration of mesquite litter was higher in winter than in fall (Table 2). This seasonal pattern may have reflected differential shedding of plant components. Most mesquite leaves were shed in winter, thus enriching litter with N. In fall, only scattered seed pods were added to litter. Tarrant et al. (1969) found seasonal changes in N content of red alder (*Alnus rubra* Bong.) litter and

Table 3. Monthly precipitation for the study area.

Month	Year 1971	1972	1973
	millimeters		
Jan	0	0	9
Feb	20	0	36
Mar	0	0	71
Apr	12	0	1
May	0	3	0
June	0	38	17
July	54	91	52
Aug	113	54	20
Sep	37	29	8
Oct	28	120	0
Nov	24	40	12
Dec	68	18	0
Total	356	393	226

Table 4. Nitrogen and carbon for components of velvet mesquite and palo verde ecosystems by years.

Ecosystem Component	Nitrogen 1971	1972	1973	Carbon 1971	1972	1973
	percent					
	Velvet Mesquite Ecosystem					
Shrub Components						
Leaves	3.06ab[1]	2.96b	3.69a	47.1a	46.7a	47.6a
Flowers	3.67b	3.16b	4.88a	45.3a	43.6b	42.0b
Fruit	2.33a	2.45a	1.75a	44.9a	43.6a	44.3a
Current growth	2.11ab	1.76b	2.28a	46.0a	44.9a	44.8a
Branches<1 cm	1.38a	1.51a	1.43a	43.2a	43.2a	43.6a
Branches>1 cm	1.21a	1.11a	0.87b	42.6a	43.0a	44.1a
Roots	1.47a	1.48a	1.82a	44.3c	46.4b	47.6a
Standing Understory[2] Vegetation	1.07b	1.17ab	1.23a	42.4a	38.9b	41.1a
Shrub Litter	1.49a	1.58a	1.68a	40.2a	38.9a	38.4a
Understory litter	1.14b	1.14b	1.56a	36.3a	39.3b	36.7a
	Palo Verde Ecosystem					
Shrub Components						
Leaves	—	3.69b	4.51a	—	42.1b	43.9a
Flowers	—	3.35b	3.91a	—	45.8a	44.9a
Fruit	—	3.07a	2.55a	—	44.5a	44.7a
Current Growth	—	2.61a	2.78a	—	43.4a	43.4a
Branches<1 cm	—	1.50a	1.65a	—	42.3a	42.4a
Branches>1 cm	—	1.27a	1.01b	—	43.1a	43.5a
Roots	—	1.19a	1.31a	—	44.1a	44.1a
Standing Understory[2] Vegetation	—	1.02b	1.36a	—	42.1a	41.0b
Shrub Litter	—	1.31b	1.49a	—	38.4a	37.5a
Understory Litter	—	1.10b	1.50a	—	37.6a	35.8a

[1]Within any given row for N or C, figures that lack one or more common letters are significantly different at the $p<0.05$.
[2]Values for standing understory vegetation are weighted means for standing live and standing dead vegetation.

attributed the differences to phenological events of the overstory. Bocock (1963) attributed the increase of N in forest litter from fall through spring to the seasonal pattern of N transfer from tree canopies via throughfall.

Nitrogen percentage of palo verde litter did not change seasonally. Leaf biomass of palo verde shrubs was only 12 g m^{-2} compared to 148 g m^{-2} for velvet mesquite. Addition of this small amount of palo verde leaves to the shrub litter had no measurable effect on its N concentration. Moreover, leaf shedding in palo verde appeared more dependent on precipitation events than on seasonal periods.

The N percentage of litter from understory vegetation for both velvet mesquite and palo verde did not change on a seasonal basis. Understory vegetation apparently contributed to litter throughout the year, thus maintaining a constant N concentration in the understory litter.

Carbon

Statistical analyses disclosed small but significant changes in percentage C in 3 of 5 shrub components of mesquite but only in leaves of palo verde (Table 2). In mesquite, C in leaves declined by about 2% from fall to winter, while that in current branches increased approximately 1% from spring to fall. Although these differences were statistically significant, it seems prudent to question their biological significance. The decline of C in leaves could be associated with translocation or throughfall loss of water soluble carbohydrates or volatile fats and oils as leaves matured (Tukey 1970). The gain in C in current branches may have been associated with the gradual development of woody tissue as new twigs matured. Grigal et al. (1976) associated a simultaneous decline of leaf biomass and increase in stem biomass in fall with translocation of carbohydrates. Meyer and Splittstoesser (1969) observed rapid changes in carbohydrates of roots, stems and buds of lilac (*Syringa vulgaris* cv. Charles Joly) during the spring flush of growth.

The decline in C percentage in large branches of mesquite from fall to winter (Table 2) was unexpected. We have no explanation for this change in C percentage in what would appear to be the most biologically stable component of the shrubs.

The C concentration of shrub and understory litter of both species reached their lowest levels in fall. Based on the work of Hopkins (1966), Comanor and Staffeldt (1978) and Santos and Whitford (1981), the C percentage of litter on the Arizona desert should reach an annual low during late summer because of peak microbial decomposition during the hot summer rainy season. Similarly, the annual peak of C percentage in litter should occur following leaf fall and decline slowly until conditions suitable for rapid decomposition resume.

Annual Changes

Mass

Mass of standing understory vegetation did not change from year to year (Table 1), despite substantial differences in annual precipitation (Table 3). High variance among years undoubtedly contributed to this result. High production during wet periods apparently compensated for low production during dry periods within years, thus keeping the annual dry matter production fairly constant.

No annual differences were found in palo verde litter or the litter associated with understory vegetation beneath palo verde and velvet mesquite. Although litterfall of shrubs and understory vegetation may vary annually (we did not measure litterfall), differences are at least partially masked by litter accumulation of prior years. Work by Santos and Whitford (1981) suggests that annual decomposition does not consume the entire litter layer beneath shrubs in the Sonoran Desert. During the course of this study (1971 to 1973) there was a significant buildup of velvet mesquite litter (Table 1).

Nitrogen

Annual changes in the N concentration of shrub components were noted for both velvet mesquite and palo verde (Table 3). Leaves, flowers and current growth of mesquite, and leaves and flowers of palo verde had significantly higher concentrations of N in 1973 than in 1972, but no differences were noted between 1971 and 1972. The high values recorded for 1973 appear associated with high precipitation during the Feb.–Apr. period of that year (108 mm) compared with the average (16mm) for the similar periods in 1971 and 1972 (Table 3). It seems reasonable to argue that this large difference in precipitation could have resulted in a significantly different environment for mineralization and uptake of soil N.

Percentage N of large branches (>1 cm) was significantly lower in both mesquite and palo verde in 1973 than in the previous years (Table 4). This response may indicate a higher level of N mobilization and translocation out of large branches in 1973 than in 1971 and 1972 to satisfy the demand for increased N in younger, growing tissues.

Standing understory vegetation of mesquite was higher in N in 1973 than in 1971 while that of palo verde was greater in 1973 than in 1972 (Table 4). Following the reasoning used as above, we associate these responses with greater precipitation during the late winter-early spring of 1973, more available soil N, and greater plant uptake of N. An abundant crop of spring annuals in 1973 (compared with that in 1971 or 1972) manifests the supply of soil N and moisture during that period.

The N content of mesquite litter did not change from year to year, but that for palo verde was significantly higher in 1973 than in 1972. The high N concentration of palo verde leaves and flowers in 1973 presumably accounted for this observation.

For both shrubs, N concentration of litter derived from understory vegetation was significantly higher during 1973 than in preceding years. This probably reflected the wet spring of 1973, good conditions for N mineralization and luxurious production of herbaceous understory vegetation, especially annuals. Understory vegetation was high in N in 1973 and much of the 1973 crop was transferred to litter during the year.

Carbon

Significant annual differences in C percentage were detected in leaves of palo verde, in flowers and roots of mesquite, and in understory vegetation of both shrubs and understory litter of mesquite (Table 4). In every case, the differences were small, never exceeding 3% of the component dry mass. Thus, the differences are of uncertain biological significance. However, because the differences were always associated with components of the shrub system where active metabolism, senescence, or decomposition could be expected, they can be reasonably explained by change in the nonstructural carbohydrate fraction of the components involved.

Implications

Calculations of C:N ratio for the various component with data from the tables demonstrates that litter substrate quality is dynamic in these systems. It follows that decomposition and subsequent nutrient transfer to the underlying soil varies, not only between seasons but perhaps between years as key environmental factors, chiefly amount and timeliness of precipitation, fluctuate to make conditions more or less favorable for litter decomposition and nutrient release. In turn, the pool of available N may vary to such extent than N uptake and accumulation by shrubs is altered seasonally and annually.

However, if a significant portion of current demand for N in perennial herbs and shrubs is satisfied by internal translocation (Clark 1977), then perhaps these species can resupply internal N levels as external supplies become available without a marked cost in growth and development. Longevity of the major species in the community studied here suggests these species are well adapted to annual and seasonal variations in external N supply.

The variation in N and C level of shrub system components appears complex and presumably involves the interaction of most system processes having to do with gains, losses and translocation of elements. Studies which deal with nutrient composition of these shrubs should account for the dynamic nature of these variables in experimental designs.

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Growth of Forbs, Shrubs, and Trees on Bentonite Mine Spoil Under Greenhouse Conditions

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Abstract

Revegetation on raw bentonite spoil with or without treatments is often more practical than replacing topsoil in areas where it is scarce or nonexistent. The effect of raw bentonite spoil treated with ponderosa pine sawdust on plant survival and growth was compared to other treatments including perlite, gypsum, straw, vermiculite, and no treatment. Plants tested were the drought- and salt-resistant species of fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), rubber rabbitbrush (*Chrysothamnus nauseousus* (Pallo) Britt.), big sagebrush (*Artemisia tridentata tridentata* Nutt.), common winterfat (*Ceratoides lanata* (Pursh) Moq.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), Russian olive (*Elaegnus angustifolia* L.), common yarrow (*Achillea millifolium* L.), and desert globemallow (*Sphaeralcea ambigua* Gray). Desert globemallow, fourwing saltbush, and rubber rabbitbrush had substantial growth and survival on sawdust, perlite, and vermiculite treated spoil. The growth promoting effect of sawdust is particularly promising; it is readily available and cost is minimal.

Bentonite, a cream to greenish-gray colored clay consisting of the mineral montmorillonite (Gries 1974), occurs in much of the northern Great Plains as widespread beds interstratified with the dark gray marine shales. Bentonite mine spoil is commonly described as shales containing sodium montmorillonite. When wet, the bentonite spoil swells, and infiltration, permeability, and aeration approach zero. Excessive salt concentrations increase the osmotic potential of the spoil solution to a level that can be toxic to plants. Because of these problems, revegetation of bentonite mine spoil in arid and semiarid regions of the northern Great Plains, is extremely difficult (Bjugstad 1979).

Several factors can be employed to improve revegetation efforts: (1) improving the physical and chemical conditions of the spoils, (2) covering bentonite spoils with topsoil and more favorable overburden, (3) using the most salt adaptable plants (Shannon 1979), (4) developing new genetic strains of salt adaptable plants for the future (Epstein et al. 1980), or (5) utilizing drip irrigation systems, but this may be expensive.

Replacing the original topsoil to bentonite spoil has improved plant survival somewhat (Bjugstad 1979, Dollhopf et al. 1980, Dollhopf and Bauman 1981). However, much of the bentonite land has only shallow surface soil—less than 15 cm. In many places it is not practical to restore the original soil to bentonite-mined lands. This study was initiated to determine, based on greenhouse trials, the plant species most adaptive to spoil conditions and spoil amendments conducive to plant growth and establishment without topsoil.

Methods

Spoil Collection and Analysis

Bentonite spoil substrate for the greenhouse trials was collected from 6 sites (20 cm depth) on the property of the American Colloid Company in Upton, Wyo. The spoil is shale of the cretaceous Belle Fourche and Mowry formation (USGS 1975). Spoil from the sites was air dried, composited for greenhouse trials. Chemical and physical properties of the composite 6 spoil samples were analyzed at the United States Testing Company, Inc., Richland Laboratory, Richland, Washington, following agricultural soil analysis procedures (USTC n.d.). These analyses included NO_3-N, NH_3-N, P, K, Ca, Mg, S, B, Zn, Mn, Cu, Fe, electrical conductivity (EC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), pH, organic matter (OM), and cation exchange capacity (CEC). Clay minerals were identified at the Engineering and Mining Experiment Station of the South Dakota School of Mines and Technology.

Spoil Treatments

Each spoil treatment included gypsum, fertilizer (nitrogen (N), phosphate (P), potassium (K)), and a surface mulch of ponderosa pine woodchips. Physical amendments of organic (sawdust, woodchips) and inorganic materials were added in all but one of the spoil treatments. An 11-5-6 (NPK) fertilizer was added at 84 kg/ha. When sawdust and straw were incorporated into the spoil, additional nitrogen (dry pellet) was added, equivalent to 12 kg/MT (metric ton) of dry ponderosa pine sawdust and 8 kg/MT of dry wheat straw, respectively. For the gypsum treatment, gypsum was added equivalent to 20 MT/ha to a 30-cm depth of spoil (USSLS 1954). Gypsum was applied at 10 MT/ha to adjust for the 50% reduction in spoil volume, for sawdust, straw, perlite, and vermiculite treatments (Table 1).

Table 1. Six bentonite spoil treatments for greenhouse trials.

Treatment	Amendments
Control	Spoil with no treatment
Gypsum	Gypsum and NPK fertilization
Sawdust	Gypsum and NPK fertilization with sawdust mixed into spoil at 50:50 volume ratio.
Straw	Gypsum and NPK fertilization with wheat straw mixed into spoil at 50:50 volume ratio.
Perlite	Gypsum and NPK fertilization with perlite mixed into spoil at 50:50 volume ratio.
Vermiculite	Gypsum and NPK fertilization with vermiculite mixed into spoil at 50:50 ratio.

Plant Species Accessions

The 8 plant species selected on the basis of potential drought and saline-alkali tolerance (Wright and Bretz 1949, Gill 1949, McKell 1978) were: fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), rubber rabbitbrush (*Chrysothamnus nauseousus* (Pallo) Britt.), big sagebrush (*Artemisia tridentata tridentata* Nutt.), common winterfat (*Ceratoides lanata* (Pursh) Moq.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), Russian olive (*Elaegnus angustifolia* L.), common yarrow (*Achillea millifolium* L.), and desert globemallow (*Sphaeralcea ambigua* Gray).

Rocky Mountain juniper and Russian olive were respectively 1½- 3-year-old bare root seedlings, obtained from U.S. Forest Service, Bottineau, N.Dak. The remaining species were 1-year-old seedlings, obtained as container grown stock from a commercial supplier in Salt Lake City, Utah. All plants were planted in 9.5-liter pots with 1.3-cm-square drainage vents. Each plant was thoroughly watered, then placed in the middle of the pot and backfilled with the spoil mix (Table 1). The spoil surface was then covered with 3.8 cm of woodchip mulch, and each pot was watered

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to saturation. Plants were started in May, and the study ended 17 months later.

Greenhouse Culture

No regular watering scheme was followed since tensiometers in each pot did not work well in the bentonite spoil. In addition, the plants were used as indicators (leaf color, wilting, soil) of water need. All treatments were monitored equally on a daily basis. During the first month (May) after planting, the controls required watering once a week with 250 to 500 ml of deionized water. The treated pots required little water during this period. From mid-June through August, all pots required an average of about 250 to 400 ml of water once per week. Watering needs gradually diminished after September to about 200 ml per plant per week. This watering regime was repeated for the summer months of the second year until the end of the study in September. The air temperature in the greenhouse ranged from 8.3°C to 26.7°C. Soil temperature within the pots varied from 8.3°C to 22.8°C. The relative humidity ranged from 47% to 70% during this study. Air temperature and relative humidity were measured by a hygro-thermograph recorder. Thermometers in several pots were used to measure soil temperature.

A latin square design (6 plants/species/treatment) provided the statistical randomization necessary to isolate the variations (light, temperature, humidity) in the greenhouse in excess of those differences being tested.

Morphometric characteristics of plants were measured at the beginning of the study and end of 17 months. These measurements were: plant height, length, (length of widest section of plant), and width (measured at right angle to length), leaf length, twig length (including terminal twig), number of branches, and number of leaves. Twenty-four measurements of each parameter were taken of each shrub. All plants were harvested at spoil level and were separated into leaves and stems. Plant parts were oven dried at 60°C for 96 hours and were weighed. Survival counts also were taken.

Statistical Methods

Differences in morphometry and biomass between treated and control plants were analyzed using analysis of variance and the F-protected LSD (Carmer and Swanson 1973). Differences were accepted at $\alpha = 0.10$. A log transformation was used to remove variance heterogenity among treatment groups when it occurred. Treatment effects on plant survival were analyzed by Chi square techniques. The Bonferroni t statistic was used to test differences ($\alpha = 0.10$) in spoil pH between treatments and control (Miller 1966).

Results

Physical and Chemical Properties

Average chemial and physical properties of bentonite spoil from Belle Fourche and Mowry shale are presented in Table 2. Of special note was the fact that sulfur, a micronutrient in the spoil, was present in large quantities (326 ppm), and the spoil material was slightly acidic, pH 6.8. Total salt concentration, as indicated by an EC of 0.92 (S m^{-1}), was high for most plants. Sodium adsorption ratios (15 to 56) and exchangeable sodium percentages (15 to 46) were high. Mineral analysis showed that montmorillonite, illite, and kaolinite clays were the major components of the spoil, followed by quartz and feldspars. Spoil texture analyses showed clays were the major components (48.0–70.0%), followed by silt and sand.

The pH of control spoil (8.1) was significantly ($P \leq 0.10$) greater than sawdust treated spoil (7.3) at the end of this study. No other amendments at the end of 17 months produced significant differences with the untreated spoil. The pH of raw ponderosa sawdust ranged from 4.6 to 4.7, and contributed to the buffering of saline-alkali spoils to near neutral (pH 7.3).

Plant Survival

Survival rates on controls (6 plants/species/treatment) are

Table 2. Chemical, mineral, and textural properties of Belle Fourche and Mowrey shale spoil (composite sample from six randomly selected points; 0–20 cm depth; Voorhees (1984) and Sieg et al. (1984) present variability for chemistry among spoil sites.)

Properties	Values
Macronutrients	
NO_3 – N, kg/ha – 30 cm[1]	19
NH_4 – N, kg/ha – 30 cm	55
P, ppm	39
K, ppm	170
Ca, meq/100g	17.4
Mg, meq/100g	3.7
Micronutrients	
S, ppm	326
B, ppm	2
Zn, ppm	3.2
Mn, ppm	31
Cu, ppm	4.2
Fe, ppm	102
Ec, electrical conductivity, S m^{-1}	0.92
SAR, sodium absorption ratio[2]	33.1
ESP, exchangeable sodium percentage, %[2]	31.8
pH	6.8
Om, organic matter, %	1.1
CEC, cation exchange capacity, meq/100g	30
Mineral analysis (%)	
Sample 1	
Clays: Montmorillonite (Na-Al-Mg-Si-O-OH-H_2O)	48
Illite (trioctohedra, K-Na-Ca-Mg-Al-Fe-Ti-Si-O)	
Kaolinite	
Quartz	20
Feldspars	32
Sample 2	
Clays: Montmorillonite (Na-Al-Mg-Si-O-OH-H_2O)	45
Illite [sodium, [Na,K) $Al_2SI_3A1O_{10}$) (OH_2)]	
Kaolinite	
Quartz	45
Feldspar	11

[1]Values extrapolated to a 30 cm depth.
[2]Average of 5 samples.

often, but not always, a clue to a plant's natural adaptability to a problem soil. Survival rates on the control (Table 3) indicate that: common yarrow, Russian olive, and Rocky Mountain juniper were the least adaptable to untreated spoils; big sagebrush, fourwing saltbush, and winterfat had intermediate adaptability; rabbitbrush and desert globemallow were the most adaptable. Survival of common yarrow, big sagebrush, fourwing saltbush, winterfat, and Rocky Mountain juniper was higher with spoil treatment. Overall survival with treatment indicated that desert globemallow (97%), fourwing saltbush (92%), and rubber rabbitbrush (89%) were the most adaptable species on bentonite spoil.

Collation of overall survival rates by treatments indicated that sawdust (83%), perlite, (81%), and vermiculite (79%) resulted in greater plant survivals than the other treatments (Table 3). Five species of plants had 100% survival with the sawdust bentonite spoil treatment.

Plant Response

The effect of spoil amendments upon plant growth is expressed by changes or compared to the control in morphological characteristics and biomass. Those characteristics give an indication of plant vigor and response to spoil treatment.

Fourwing Saltbush

Height of plants was significantly greater on sawdust, perlite, gypsum, and vermiculite amended spoil than on the control. Dif-

Table 3. Survival of plants by spoil treatments and species in the greenhouse.

Species	Treatment						% Survival
	Control	Gypsum	Perlite	Sawdust	Straw	Vermiculite	
Yarrow	0[1]	4	6	6	1	1	50[abc2]
Big Sagebrush	2	4	5	4	5	6	67[bcd]
Fourwing Saltbush	3	6	6	6	6	6	92[d]
Rabbitbrush	5	4	6	6	5	6	89[cd]
Russian olive	0	1	1	1	1	3	19[a]
Winterfat	2	3	4	5	4	5	64[bcd]
R.M. Juniper	1	0	5	6	0	5	44[ab]
Desert Globemallow	6	5	6	6	6	6	97[d]
% Survival	40[a]	56[ab]	81[b]	83[b]	60[ab]	79[b]	

[1]Numbers surviving 6 plants per treatment.
[2]Means followed by the same letter are not different at $\alpha = 0.10$.

ferences in twig length were observed with sawdust and vermiculite treatments. However, no differences were found among spoil treatments for number of branches and leaf length. Biomass of leaves and stems was greater with spoil treatment (Table 4). Greatest biomass was obtained with sawdust and vermiculite treatments for both leaves and stems.

Rubber Rabbitbrush

Morphological measurements of height, number of branches, twig length, and leaf length did not indicate a response to spoil treatments. However, leaf biomass was significantly higher on the sawdust treatment than on the control (Table 4). Stem biomass was greater with the vermiculite treatment.

Common Winterfat

Height, number of branches, twig length, and leaf length measurements of common winterfat did not differ between treatments and the control. Stem biomass was greater on all spoil treatments when compared to the control (Table 4). Sawdust, perlite, and vermiculite spoil treatments showed the highest stem biomass estimates. No differences were observed among treatments for leaf biomass.

Big Sagebrush

Big sagebrush showed a significant positive response in height and width measurements with sawdust, perlite, and vermiculite treatments. Biomass of leaves and stems increased with the same treatments (Table 4).

Desert Globemallow

The hardiness of desert globemallow was demonstrated by 100% survival on the control. It responded to spoil treatments with increased morphological measurements except for height. Biomass of leaves and stems showed the same significant positive response to treatments (Table 4).

Rocky Mountain Juniper

Rocky Mountain juniper was poorly adapted to bentonite spoil. After 6 months, many of the plants showed stress symptoms of bluish-green leaves which were coated with a waxy deposit. Survival was low except on perlite, sawdust, and vermiculite spoil treatments (Table 4).

Russian Olive

Russian olive performed most poorly of all the plant accessions. Survival was so low that reasonable morphometric and biomass evaluations were not possible (Table 3). The species commonly suffered from leaf chlorosis and lacked vigor throughout the test period.

Common Yarrow

Common yarrow plants flowered soon after planting, and stems died back and new stems emerged throughout the study period. Of the surviving plants, growth increases were more consistent with the sawdust treatment (Table 4).

Discussion

Revegetation of bentonite spoil is more difficult than generally recognized. The spoil material in itself is not conducive to growth of most plants. The physical and chemical properties of bentonite spoil are heterogeneous and generally difficult to characterize (Sieg

Table 4. Average biomass (g/plant) of shrubs and forbs grown in six treatments of bentonite spoils in the greenhouse.

Treatment	Plant Species					
	Fourwing saltbush	Rubber rabbitbrush	Common winterfat	Big sagebrush	Desert globemallow	Common yarrow
	Leaf Biomass					
Sawdust	5.4 ± 1.0*	0.8 ± 0.3*	2.8 ± 1.0	1.7 ± 0.5*	3.5 ± 0.4*	4.2 ± 0.2
Perlite	3.8 ± 0.4*	0.6 ± 0.2	2.6 ± 0.7	1.3 ± 0.3*	3.8 ± 0.3*	2.8 ± 0.7
Gypsum	3.4 ± 0.6*	0.4 ± 0.2	1.6 ± 0.4	0.3 ± 0.1	3.7 ± 1.2*	0.5 ± 0.2
Straw	4.8 ± 0.4*	0.3 ± 0.1	1.7 ± 0.6	0.4 ± 0.1	3.2 ± 0.4*	1.8
Vermiculite	5.9 ± 1.1*	0.6 ± 0.2	2.4 ± 0.3	1.4 ± 0.4*	3.4 ± 0.8*	2.8
Control	1.9 ± 0.2	0.4 ± 0.1	1.8 ± 0.2	0.2 ± 0.1	1.5 ± 0.2	
	Stem Biomass					
Sawdust	10.2 ± 1.8*	1.4 ± 0.5	3.9 ± 1.0*	0.8 ± 0.1*	2.9 ± 0.4*	2.0 ± 0.4
Perlite	8.2 ± 1.4*	1.8 ± 0.4	4.0 ± 1.0*	0.6 ± 0.2*	2.4 ± 0.3*	1.0 ± 0.4
Gypsum	7.3 ± 1.5*	1.2 ± 0.5	2.7 ± 0.2*	0.1 ± 0.0	3.1 ± 0.8*	0.6 ± 0.2
Straw	6.6 ± 0.6*	1.0 ± 0.4	2.5 ± 0.9*	0.3 ± 0.2	1.7 ± 0.2*	0.2
Vermiculite	10.2 ± 1.5*	2.1 ± 0.4*	4.0 ± 0.7*	0.5 ± 0.2*	3.6 ± 0.6*	1.7
Control	2.7 ± 0.3	1.1 ± 0.5	1.6 ± 0.1	0.1 ± 0.0	0.6 ± 0.2	

[1]Mean ± standard error, n = 6 plants/treatment
[2]Significantly different from control at $\alpha = 0.10$.

et al. 1983, Voorhees 1984). Spoil analysis shows high EC, SAR, and ESP values, indicating that revegetation problems are associated with high salt and sodium concentrations. Total salt concentrations, indicated by EC of 0.92 (S m^{-1}), were far above the threshold value of 0.4 for growth of most agronomic plants (USSLS 1954), suggesting that plant growth was restricted to salt tolerant species only. The ranges of SAR (15–56) and ESP (15–46) values indicate the great variability in problems associated with salt toxicity, osmotic potential, and exchangeable sodium.

Exchangeable sodium in shale spoils because of its course texture is related more to properties of swelling and less to structural dispersion and slaking as reported for alkali soils. Elevated pH values of 8.5 or higher are related to high SAR values in sodic soils (USSLS 1954). The pH value of 6.8 in bentonite spoil may result from the formation of sulfuric acid from inherent sulfate ions (USSLS 1954, Allen 1977, Sieg et al. 1983) which neutralizes the alkaline effects of the spoil. A high level of sulfur seems to support this supposition. The clay content amounts to nearly 50% of the total mineral composition. However, the cation exchange capacity of 30 meq/100g is nominal (Tisdale and Nelson 1975) in comparison to reported capacities of more than 100 meq/100g for bentonite clays (Grim 1953). The lower cation exchange capacity may result in the removal of exchangeable sodium (Grube et al. 1971). However, the fine texture and swelling inhibit rapid leaching of salts and sodium ions.

Spoil pH apparently changed with sawdust treatment because of the enhanced drainage which lowers the concentration of soluble salts in the spoil solution. The consensus from the literature is that saline-alkali soil may become more strongly alkaline upon dilution or leaching (Baver 1927, Snyder 1935, Carolus and Lucas 1943, USSLS 1954, Peech 1965). Soluble salts are leached downward and soil may become strongly alkaline because some of the exchangeable sodium hydrolyzes and forms sodium hydroxide. This is also true for the change in pH on the controls from 6.8 to 8.1. Nevertheless, the specific contribution of lowered pH to growth and survival is uncertain because (1) the plants responded equally well to the other treatments and (2) some species (e.g., fourwing saltbush) exhibit wide tolerance to chemical and ecological stresses.

Mulch, fertilizer (NPK), chemical binder (gypsum), and physical amendments (sawdust, straw, perlite, vermiculite) contributed in some degree to promoting establishment of plants in a saline-alkali spoil, which becomes essentially impermeable with swelling. The physical amendments were observed to provided rapid improvement in physical conditions that often are unattainable with chemical binder only. However, straw does not mix well with dry bentonite spoil, which is hard and crusty, unless the spoil is commuted to soil (<2 mm) or small gravel-size textures. Excessive communion was avoided because the increase in surface area increased swelling and thereby decreased permeability of the substrate.

Desert globemallow, fourwing saltbush, and rubber rabbitbrush were the most promising species for field testing on bentonite spoil based on this greenhouse trial. These species had the highest survival rates and substantial morphometric and biomass weight increases in response to spoil treatment. They apparently are adaptable to osmotic stress, ion toxicity (halophytic tolerance), and oxygen deficiency. Desert globemallow excreted salt crystals from leaf surfaces as an avoidance mechanism for excessive salt concentration (Levitt 1980). Schuman and Sedbrook (1984) reported fourwing saltbush seeding establishment in the field on bentonite spoils treated with sawdust, but no success with rubber rabbitbrush.

Overall survival rates of big sagebrush, winterfat, yarrow, Rocky Mountain juniper, and fourwing saltbush were markedly low on the controls. However, treatment effects on plant survival, morphometric growth, and biomass indicated that these species increased growth in response to treatment. Big sagebrush has a reported maximum salt tolerance of 17,984 ppm (EC 28.1 Sm^{-1}) (Billings 1949), and winterfat a reported maximum salt tolerance of 173,606 ppm (EC 27.1 S m^{-1}) (Shantz and Piemeisal 1940). Therefore, factors other than salinity appear to have influenced their poor control performance. It may be that the effect of sodium indirectly created an oxygen deficit (by swelling clays) in the root medium. Lunt et al. (1973) reported that big sagebrush has unusually high oxygen requirements for root growth, which accounts for its general absence from fine textured and poorly drained soils.

Russian olive and Rocky Mountain juniper performed most poorly of the tested species. Despite its reported tolerance of alkali and its ability to invade saline flats (Thornburg 1982, Gill 1949, Wright and Bretz 1949), Russian olive seemed to go into salt shock (Levitt 1980) from the onset of the study and never fully recovered its vigor throughout the study. Rocky Mountain juniper, unlike Russian olive, had high survival rates on spoil treated with perlite, sawdust, and vermiculite. Nevertheless, after 6 months, this species appeared to be in continuous stress, as evidenced by its greenish-blue, waxy foliation. Its survival in the future was doubtful.

Leaf morphometry, as measured by leaf length, was not a good index to growth for field and greenhouse plantings because of inherent physiological mechanisms that resist size increases, thereby limiting transpiration under drought conditions (Kozlowski 1972). Height, length, width, and twig length measurements are useful indices for measuring plant response, but are dependent upon the plant species. Leaf biomass and stem biomass are the best indicators of growth; however, these measurements involve destructive sampling.

This study documents that growth and survival of drought and salt resistant plants in bentonite spoil generally increased with treatment of spoil. Spoil treatment effects varied with plant species, and no one morphological measurement was best to assess plant growth responses in the greenhouse. However, sawdust, perlite, and vermiculite amendments in general resulted in most consistent increases in morphometric growth, aboveground biomass, and survival rates of the tested species. Sawdust as a bentonite spoil amendment is particularly promising; it is readily available and inexpensive (Voorhees et al. 1984, Schuman and Sedbrook 1984).

These trials demonstrate that under climatic conditions conducive to maximum growth (i.e., the avoidance of extreme temperatures, intense solar radiation, and moisture stress) plants can grow and survive on raw bentonite spoils. Some plants survived on nontreated spoils, and some species showed better growth than on treated spoils; but generally, survival on untreated spoils was not related to morphometric growth. Predictions as to field performance of tested plant species under similar spoil treatments remain speculative.

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Effects of N and P Fertilizer Placement on Establishment of Seeded Species on Redistributed Mine Topsoil

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Abstract

The effects of fertilizer on the establishment of seeded grass and legume stands when reclaiming coal strip mines have not been evaluated in northwest Colorado. Nitrogen (0, 28, 56, and 112 kgN/ha) and phosphorus (0 and 56 kgP/ha) were applied in all combinations to the spoils before topsoiling or to the surface after topsoiling. In the greenhouse, herbage yield and yield of roots in the 28 cm of topsoil replaced over the spoil increased as rate of N increased; phosphorus did not increase yield. Nitrogen content of the herbage increased from 1.02% to 1.33% as rate of N increased from 0 to 112 kgN/ha. In a field study in northwest Colorado, neither N nor P fertilizer improved stand establishment ratings. Both the amount and placement of N at time of seeding affected herbage yield during the third growing season. Alfalfa yields were increased 20% by buried P and 44% by surface P in the third growing season. Applying N fertilizer at time of seeding is not recommended.

Nitrogen (N) deficiency is believed to be a limiting factor in obtaining a productivity level for reclaimed strip mined lands that is comparable to that of the premining plant communities (Woodmansee et al. 1979). On leveled mine spoils in North Dakota, wheat (*Triticum aestivum* L.) grain yields increased with increasing topsoil depth, but N fertilization did not increase yields because adequate N was already present in the topsoil material (Bauer et al. 1978). DePuit and Coenenberg (1979) reported that increased application rates of both N (0 to 121 kg/ha) and phosphorus (P) (0 to 41 kg/ha) fertilizer tended to promote the establishment of introduced grasses at the expense of the less competitive native grasses in a study in eastern Montana. Estimating N or P requirements from chemical tests is difficult because laboratory data have not been substantiated by field trials (Berg 1978). This is particularly true in the semiarid West. Forage production of older seeded stands on rangeland can frequently be increased by fertilizing with N (McGinnies 1968), but the need for fertilizer to establish seeded stands for mined land reclamation is not documented, although current regulations (both federal and most states) require that nutrients and soil amendments be applied to the redistributed topsoil before seeding in amounts determined by soil tests so that it supports the postmining land use (U.S. Government 1985).

The authors (unpublished) have observed that relatively small amounts of N fertilizer applied to established seeded stands on either topsoil or spoil produced substantial increases in herbage yield. This would indicate that the moisture availability is sufficient for the mature plants to make use of more nitrogen than is available in the soil. The question is whether or not seedlings also could take advantage of additional N fertilizer, and, if so, would this result in a denser or more vigorous stand of seedlings.

This study was conducted to determine the effects of fertilizer on establishment of seeded stands on surface coal mines in northwest Colorado and to determine if fertilizer is necessary for successful establishment. The effects of N and P fertilizer on establishment and growth of seeded species in the greenhouse and in the field were studied.

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Methods

The field study was conducted at Energy Mine No. 1 owned by Colorado Yampa Coal Company (formerly Energy Fuels Corporation) located 32 km southwest of Steamboat Springs, Colo. Soil and spoil materials for the greenhouse study were obtained at the same site. Elevation was 2,250 m, and long-term average annual precipitation was 410 mm. The soil was a Routt loam (fine montmorillonitic Typic Argiboroll). The topsoil was from the A horizon which developed under sagebrush (*Artemisia tridentata* Nutt.) -mountain brush vegetation. Spoils were from the Williams Fork Formation of the Upper Cretaceous Mesa Verde group which consisted of mixed beds of shale and sandstone. The spoils used in these studies were a heterogeneous mixture of material from the various strata; mixing occurred during removal of the overburden and leveling of the spoil piles. Samples of soil and spoil were analyzed for nitrogen by a Kjeldahl procedure (Bremner 1965), and a bicarbonate extraction was used for determination of phosphorus (Olsen et al. 1954). Electrical conductivity (EC), sodium, calcium, and magnesium were measured on the saturation paste extract, and pH was measured on the saturated paste (Richards 1954). Particle size distribution was determined by the hydrometer method (Day 1945). Nitrate-N and organic matter analyses were made by Colorado State University Soils Testing Laboratory.

Greenhouse Study

Galvanized metal (stove) pipes 15 cm diam by 61 cm and closed at the bottom with a wood plug were used as pots for growing plants. Twenty-five cm of spoil was placed in the bottom of each can and 28 cm of topsoil was added to give a topsoil-over-spoil growth medium. Spoil material was passed through a 1.3-cm mesh screen before putting it in the cans to eliminate the large rock materials common to spoils.

Fertilizer treatments were applied to the spoil before the topsoil was placed in the pot (buried treatment). Fertilizer treatments, based on surface area of the pots, were:

None
28 kg N/ha
56 kg N/ha
112 kg N/ha
56 kg P/ha
28 kg N + 56 kg P/ha
56 kg N + 56 kg P/ha
112 kg N + 56 kg P/ha

Nitrogen was applied as ammonium nitrate and P as treble superphosphate. Because all fertilizer treatments were both buried and surface, a total of 16 treatments was used. The surface fertilizer treatment was applied after seeding.

Ten seeds were planted in each pot at a depth of 1.5 cm. Three species, intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), slender wheatgrass (*A. trachycaulum* (Link) Malte), and smooth brome (*Bromus inermis* Leyss.), were planted with 1 species per pot. The experiment was a randomized complete block design with 4 replications. Planting was on 8 Feb. 1979. On 22 March, the seedlings were thinned to 3 per pot. Water was applied 1 to 4 times per week as needed to maintain adequate soil moisture. Temperature in the greenhouse averaged about 22° C. Sunlight was augmented with high pressure sodium vapor lights; day length was 14 hr.

Herbage was harvested on 12 Apr. and 29 May; the herbage was oven-dried at 60° C and the weights of the 2 harvests combined. After the second herbage harvest, the pots were split open and the soil washed from the roots. Root material was partitioned into that part which had been growing in topsoil and that part growing in the spoil. Herbage (second cutting only) and root material were analyzed for N (Isaac and Johnson 1976) and P (Technicon Industrial Systems 1976) content.

All data were evaluated using standard analysis of variance or linear correlation techniques.

Field Study

The plots, 3.66 by 3.66 m in size, were established on leveled spoil material in September 1978. Fertilizer for the "buried" treatments was applied directly on the spoil material. Topsoil from a stockpile was then spread to a depth of 30 cm over the spoil and fertilizer, and the plots were restaked. The surface fertilizer treatments were applied after topsoiling and seeding. Fertilizer treatments and sources for both buried and surface treatments were the same as for the greenhouse study.

Rows 3.66 m long and 30 cm apart and each containing a single species were drill-seeded on 3 Oct. 1978 to a depth of 2 cm at a rate of about 100 seeds/m of row to 'Critana' thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), 'Whitmar' beardless wheatgrass (*A. spicatum* (Pursh) Scribn.), 'Arriba' western wheatgrass (*A. smithii* Rydb.), 'Regar' meadow brome (*Bromus biebersteinii* Roem and Schult), 'Lincoln' smooth brome, tall fescue (*Festuca arundinacea* Schreb.), timothy (*Phleum pratense* L.), 'Ladak' alfalfa (*Medicago sativa* L.), and 'Lutana' cicer milkvetch (*Astragalus cicer* L.). Legumes were inoculated with appropriate rhizobia.

Stand evaluations were made in July 1979, 1980, and 1981. Establishment of the seeded species was evaluated using a stand rating scheme of 0 to 100% where 100% was a solid stand of plants in the seeded row, or the maximum stand that could be expected on this site. On 21 July 1981, herbage production was measured by harvesting, oven drying, and weighing a 61-cm length of row that was representative of each seeded row.

The experiment was a randomized complete block design with 3 replications. Data were evaluated by analyses of variance and linear correlation techniques.

Table 1. Physical and chemical characteristics of spoil and topsoil used in field and greenhouse studies.

	Spoil	Topsoil
Sand (%)	19	13
Silt (%)	39	44
Clay (%)	42	43
Textural Class	Clay	Silty clay
Kjeldahl-N (μg/g)	998	951
NO_3-N (μg/g)	5.2	6.7
P (μg/g)	7.2	13.7
Organic matter (%)	5.5[1]	3.1
pH	6.3	5.9
Electrical Conductivity (EC) (S/m)	0.198	0.062
Sodium Adsorption Ratio (SAR)	0.30	0.18
Na (meq/l)	0.83	0.32
Ca (meq/l)	9.60	4.73
Mg (meq/l)	5.33	1.62

[1]Sample probably contained coal fragments which produced this high value.

Results and Discussion

Examination of the soil physical and chemical analyses revealed nothing that would restrict germination or growth of the seeded species (Table 1). The Colorado Mined Land Reclamation Division has recommended that the "Guide to Fertilizer Recommendations in Colorado" (Soltanpour 1978) should be consulted for fertilizer requirements. This guide states that if soil organic matter exceeds 2% on native and improved range grass dryland sites, no additional fertilizer N need be added, and that when soil test P exceeds 7 μg/g, no fertilizer P is recommended for dryland alfalfa. The topsoil used in this study exceeds these values for both organic matter and P. Much of the nitrogen in the mine spoil material may be unavailable for plant growth (Reeder and Berg 1977), and the high organic matter value for the spoil resulted from coal fragments in the spoil. The P levels may be slightly low but no evidence of P deficiencies have been observed in plants growing on either spoil or topsoil. Core samples from the overburden were taken before mining and analyzed for heavy metals, and no excesses were found (Colorado Yampa Coal Company, unpublished data). The

Table 2. Effect of four levels of nitrogen on oven dry herbage and root biomass production (g) of three grasses grown in a greenhouse in 25 cm topsoil on top of 28 cm mine spoil material. (Average of buried and surface treatments).

Plant part	Level of N[1]	Intermediate wheatgrass	Smooth brome	Slender wheatgrass	Mean
Herbage	0	7.6	10.5	14.7	10.9[2]
	28	8.8	12.1	15.0	12.0
	56	10.2	12.7	19.3	14.1
	112	11.3	13.9	19.5	14.9
	Mean	9.5[3]	12.3	17.1	13.0
Roots	0	7.5	3.5	2.0	4.3[4]
	28	6.2	4.0	2.2	4.1
	56	6.7	4.8	2.8	4.8
	112	7.7	4.8	3.1	5.2
	Mean	7.0[5]	4.3	2.5	4.6
Roots in spoil	0	2.3	1.6	0.8	1.6[6]
	28	2.8	1.7	0.7	1.7
	56	2.6	2.0	1.1	1.9
	112	3.0	2.0	0.9	2.0
	Mean	2.7[7]	1.8	0.9	1.8

[1]Kg N/ha
[2]$LSD_{0.01}$ for column means = 1.1
[3]$LSD_{0.01}$ for row means = 0.9
[4]$LSD_{0.01}$ for column means = 0.8
[5]$LSD_{0.01}$ for row means = 0.7
[6]LSD for column means = NS
[7]$LSD_{0.01}$ for row means = 0.4

general character and productivity of the pre-mining native vegetation was a further indication of the suitability of the topsoil as a plant growth medium, but the authors (unpublished) observed that small amounts of N fertilizer applied to established seeded stands increased herbage yield and plant cover in spite of soil tests that indicated no additional fertilizer was needed.

Greenhouse Study

No seedling counts were made, but there were no obvious differences in number of seedlings emerged that could be related to fertilizer levels.

There were no significant differences in herbage yield or root production that could be attributed to P application or to fertilizer placement (surface or buried). Herbage yield and root production of all species tended to increase as rate of N increased (Table 2). Correlation coefficients between rate of N and herbage yield, and rate of N and root production were 0.93 and 0.58 ($p<0.05$), respectively. Herbage yield and root production also differed significantly ($p<0.01$) among species. Root production of slender wheatgrass in both topsoil and spoil was low compared to that of the other two species; this agreed with previous findings (Nicholas and McGinnies 1982). The relative increase in herbage production resulting from N was greater for intermediate wheatgrass than for the other two species; this interaction was significant ($p<0.01$). Nitrogen content of the herbage increased from 1.0% to 1.3% as rate of N application increased from 0 to 112 N/ha (r = 0.82, $p<0.01$). Neither N conent of the roots nor P content of herbage or roots were significantly influenced by N or P fertilizer.

Field Study

No germination was observed before a continuous snow cover occurred in autumn 1978. Within a few days after the snow melted in the spring of 1979, seedlings of most species emerged. Growing conditions during this early spring period were generally favorable for germination and seedling growth. During the first year, meadow brome, tall fescue, and timothy produced the best stands and the largest plants. Stands and growth of the two legumes were poorer than expected on this site, but they appeared to be heavily utilized by jackrabbits *(Lepus californicus)* and insects.

There were no significant overall effects of N or P on stand establishment. The authors (unpublished) have observed that higher levels of N sometimes have the effect of increasing abundance and growth of annual weeds which, in turn, compete strongly with the seedlings of the seeded species. Close observation indicated that there was no increase in numbers or production of annual weeds that was related to rate or kind of fertilizer; weed density was not high and growth was relatively uniform over the entire study area. Weeds did not appear to be a serious threat to establishment of the seeded species. Fertilizer did not appear to increase size or vigor of the seedlings, but any effects may have been partly masked by rodent and rabbit utilization of the seeded species. Herbage yield in 1981 was significantly ($p\leq.05$) affected by level of N and and by placement of N (Table 3). Placing the fertilizer on the spoil before topsoiling resulted in 15% lower yields than when the fertilizer was applied to the surface of the topsoil.

Table 3. Herbage yield (g/m of row) as affected by level and placement of nitrogen (N) fertilizer on field study plots.

Level of N (kg/ha)	Fertilizer placement		
	Surface	Buried	Mean[1]
0	82	67	74
28	102	97	100
56	96	72	84
112	92	87	89
Mean[2]	93	81	87

[1]$LSD_{0.05}$ = 16
[2]$LSD_{0.05}$ = 11

Because roots readily grew into the spoil under the topsoil, it is assumed that the N fertilizer placed on the spoil was leached downward in the early spring when both soil and spoil are completely saturated with water from snowmelt. Fertilizer applied to the surface of the topsoil was apparently somehow tied up in the topsoil and prevented from leaching. The effects of rate of N on yield were erratic, and this is attributed to experimental errors. Phosphorus did not affect herbage yield except for alfalfa. Buried P increased herbage yield of alfalfa 20% and surface applied P increased alfalfa yield 44%.

Stand ratings for 1979, 1980, and 1981 are shown in Table 4. These ratings are averages for all rates of fertilizer. There was no significant interaction between fertilizers and species. Although P increased yields of alfalfa significantly, P did not increase stand establishment of alfalfa. No species produced better stands because

Table 4. Stand ratings and oven dry herbage yields of 9 species planted in the fall 1978, in northwest Colorado. (Average of all fertilizer treatments).

Species	Stand Rating (%)			Yield (g/m of row)
	1979	1980	1981	1981
Meadow brome	88	88	90	138
Tall fescue	85	76	65	48
Timothy	74	75	73	77
Alfalfa	47	45	63	105
Smooth brome	46	56	68	201
Beardless wheatgrass	41	57	60	71
Cicer milkvetch	41	24	29	17
Western wheatgrass	36	36	45	70
Thickspike wheatgrass	28	36	46	57
$LSD_{0.01}$	7	7	7	16

of N fertilizer. Stands of tall fescue and cicer milkvetch declined between 1979 and 1981. There was no known reason for the decline in tall fescue, but the decline in cicer milkvetch is probably a direct result of heavy utilization by rodents and rabbits. Stands of alfalfa, smooth brome, and beardless, western and thickspike wheatgrass all improved. All of these species had less than full initial stands, so the improvement is not surprising. Stands that rated 60% or above would be classed as "good" and those rating 90% or above would be "excellent." Good and excellent stands are generally adequate to suppress excessive growth of annual weeds and to provide satisfactory erosion control after the second or third growing season.

There was a linear relationship (r = 0.64, $p<0.05$) between stand rating and herbage yield (Table 4). Tall fescue, timothy, and beardless wheatgrass had stand ratings of 60 or above but were below average in herbage yield. Meadow brome, while not the highest yielding species, has been an outstanding species during the 3 years of this study. The high yield of smooth brome may in part be due to its having less than a full stand. The more open stand (68%) permitted the individual plants to produce much more herbage than if they had been growing more densely in the rows. In 1981, smooth brome was the tallest of all species. Herbage yields of alfalfa and cicer milkvetch were reduced because of utilization by mule deer and rodents.

Conclusions

Federal regulations require that "Nutrients and soil amendments in the amounts determined by soil tests shall be applied to the redistributed surface soil layer, so that it supports the approved postmining land use and meets the revegetation requirements. . . ." before revegetation takes place (U.S. Government 1985). The mined-land-reclamation regulations for Colorado and most other western states contain similar wording. Because fertilizer needs for reclaimed surface mine soils have not been correlated with chemical analyses of the soils, most states have resorted to using predictive models for fertilizer requirements based on a few results where dryland grass and alfalfa are growing on soils much less disturbed than respread topsoil. The Colorado fertilizer recommendations (Soltanpour 1978) that are used as a guide by the Colorado Mined Land Reclamation Division indicated that no benefit could be expected from adding N or P fertilizer, but the recommendations for fertilizing range lands are based on such a few field trials that it would be no surprise if the results we obtained differed greatly from those predicted by the fertilizer recommendations. Although N did improve yields in this study, there is no reason to put it on at the time of seeding because it did not improve establishment and much of the N would probably be lost by volatilization and leaching before it could benefit the established plants. Applying N after the seeded stand becomes established would probably be a better plan. If alfalfa is planted, phosphorus should be applied at or before the time of seeding. Phosphorus increased alfalfa yields in spite of apparently adequate levels of P as determined by chemical tests. In contrast to N, very little P is lost from the soil, so it can be applied at or before the time of seeding. Nitrogen fertilizer applied to established seeded stands may provide some benefits in terms of increased ground cover and improved yields. Future research should be directed towards use of fertilizer under such conditions.

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Effect of 20 Years of Low N Rate Pasture Fertilization on Soil Acidity

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Abstract

Soil acidity resulting from nitrification of ammonium in fertilizer can limit plant growth. In this study on weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees) and Caucasian bluestem (*Bothriochloa caucasica* (Trin.) Hubb) pastures on sandy soil in northwestern Oklahoma, 20 years of N fertilization at an average rate of 37 kg N $ha^{-1}yr^{-1}$ reduced the pH of the surface 5 cm of soil from 6.7 to 5.3. Sweetclover (*Melilotus officinalis* (L.) Lam.) and alfalfa (*Medicago sativa* L.) had symptoms of manganese toxicity when grown in the acidified soil in a glasshouse. The growth of warm-season grasses was not adversely affected when grown in the acidified soil. The lime requirement of the acidified soil was 896 kg $CaCO_3$ ha^{-1} greater than the lime requirement of adjacent unfertilized pastures. The lime requirements in relation to the amount of acid producing N fertilizer applied was similar to or less than lime requirements reported in the literature for larger N applications to farmlands. Continued use of N fertilizer at low rates will eventually require that once near-neutral soils be limed if species sensitive to acid soil are grown.

The acidification of near-neutral and slightly acid soils by repeated application of ammonium or ammonium-producing (urea) fertilizer is recognized as an emerging problem in dryland grain-growing areas of western North America (Mahler and Harder 1984, McCoy and Webster 1977, Westerman 1981). A similar problem with repeated N application to grassland soils was suggested by Owensby and Launchbaugh (1971), who cautioned that range soils often are not tillable, precluding mixing in of lime. They suggested avoiding a situation that cannot be easily rectified.

Nitrogen fertilized introduced grasses seeded into old farmlands can be important components in overall range management in higher precipitation areas of both the northern (Rogler and Lorenz 1974) and southern Great Plains (Berg and Coyne 1983). Nitrogen fertilization of native grasslands may be economically feasible under some conditions, particularly when cool-season grasses predominate (Rogler and Lorenz 1974). Newer concepts in grazing management such as intensive-early stocking (Launchbaugh et al. 1983) will place a greater demand for N upon native range and eventually fertilizer N may be required to maintain productivity.

Nine years of fertilization with NH_4NO_3 at the rate of 34 kg N $ha^{-1}yr^{-1}$ reduced the pH of the surface 15 cm of a silt loam soil supporting native range from 6.5 to 6.1 (Smika et al. 1961). A similar soil pH change with comparable N rates was reported for another study also conducted near Mandan, North Dakota (Rogler and Lorenz 1969). Twenty years of N fertilization at the rate of 67 kg N $ha^{-1}yr^{-1}$ decreased the pH in the surface 15 cm from 5.9 to 5.2 in a silt loam soil supporting smooth bromegrass near Manhattan, Kansas (Owensby et al. 1969).

Plant species and selections within species vary greatly in their sensitivity to acid soil conditions (Foy 1984). Some tall warm-season grasses are somewhat tolerant of acid soils and may only be affected below soil pH 4.5 to 5.0. Many legumes and especially alfalfa are sensitive to acid soils and may be affected at soil pH below 5.5 to 6.0.

The amount of acid that can theoretically be generated if all the ammonium added in fertilizer is converted to nitrate is 2 equivalents H^+ per equivalent of NH_4^+-N applied. For the nitrogen sources most likely to be used in pasture or range fertilization, ammonium nitrate, urea, and anhydrous ammonia, the theoretical acidification potential is equivalent to 3.57 kg of $CaCO_3$ per kg of N applied (Adams 1984). In practice, soil acidification is usually less than, and is commonly about one half of, the theoretical (Adams 1984, McLean and Brown 1984).

The purpose of this study was to determine the effect of 20 years of low-rate N fertilization of grassland upon the pH and lime requirement of a sandy soil. A glasshouse study was then used to assess the effect of the acidified soil upon the growth of 5 forage species commonly used in the southern Great Plains in revegetation of old fields.

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Study Area

The study location was in Harper County, northwest Oklahoma, on the Southern Great Plains Experimental Range. Average annual precipitation is 55 cm; the frost-free period is usually from mid-April to mid-October. The soils are mapped as the Pratt series (sandy, mixed, thermic Psammentic Haplustalfs). The texture of the surface 15 cm ranged from sandy loam to loamy sand. Organic matter in the surface 15 cm averages about 1%. The cation exchange capacity of composite soil samples from the surface 15 cm was 6 me/100 g. Native perennial vegetation on the Pratt soils tends to be dominated by sand bluestem (*Andropogon gerardii* var. *paucipilus* (Nees) Kunth), switchgrass (*Panicum virgatum* L.), sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), blue grama (*Bouteloua gracilis* (H.B.K.) LAG.), and sand sagebrush (*Artemisia filifolia* Torr.).

The 1 × 4-km study area was initially plowed in about 1900 and farmed until 1910 when, because of severe wind erosion, cultivation was stopped and the area allowed to revegetate. In the 1940's the area was again plowed, cropped to annuals for several years, and then seeded to perennial forage species. The success in stand establishment and longevity varied, but by 1982 when the area was sampled, sand dropseed was the most abundant perennial species in these old fields. The old field pastures have been moderately grazed and have not been fertilized.

In the 1950's and early 1960's monocultures of weeping lovegrass or Caucasian bluestem were established in portions of the old fields. These 2 to 5 ha improved pastures were intensively managed (Shoop et al. 1976, Sims and Dewald 1982), receiving an average of 37 kg Na $ha^{-1}yr^{-1}$ as urea or ammonium nitrate over the period 1963 through 1982. The nitrogen was broadcast annually in April at the rate of 28 to 33 kg N ha^{-1}. In years with higher rainfall in late spring, a second N application was made in June. The N fertilized pastures were burned each spring in which enough residue remained to carry a fire, an estimated 1 in 2 years. The old field pastures were not burned.

Methods

Four sites, each about 2 ha in size, extending from an improved N fertilized pasture into an old field pasture were sampled. Each site was selected for uniform topography and soils. Two of the N fertilized pastures were in weeping lovegrass and two in Caucasian bluestem. Within each pasture on each site, 10 soil sampling locations were randomly located. To reduce edge effect, these locations were at least 10 m from the common fence between the N fertilized and old field pastures. Soil samples were taken in October 1982 by

5-cm depth increments to 20 cm and then by 10-cm increments to 40 cm. The samples were air dried and then screened through a sieve with 2-mm openings. Coarse fragments, which ranged from 0 to 3% of the sample mass, were discarded.

To determine pH, 20 ml of distilled water was added to 10 g of soil, the mixture was stirred, allowed to stand 1 hour, stirred again and the pH determined after inserting the electrodes of a pH meter into the supernatant liquid. To determine the lime requirement, 10 ml of a pH 8.0 buffer solution of p-nitrophenol, H_3BO_3, KCl and KOH (Adams and Evans 1962) was added to the 10-g soil + 20 ml water mixture used in the pH determinations. The mixture was stirred, allowed to equilibrate 1 hour, stirred again, and the pH of the liquid determined. Each 0.10 pH unit decrease in the mixture was equal to 0.089 me acid. The acidity generated in the N fertilized pastures was calculated as the difference in buffer consumed by soil samples from each fertilized pasture minus the buffer consumed by soil samples from the adjacent old field. To make lime requirement calculations on a soil mass/ha basis, the mean bulk density of 5-cm increments of soil from each pasture was used. The bulk density was measured by 5-cm increments to 15 cm by the excavation method (Blake 1965) near each sampling point in each pasture. The bulk density of samples taken from deeper than 15 cm was assumed to be 1.5 $g\,cm^{-3}$, which was the measured mean bulk density of the 5 to 15-cm increments.

To assess the impact of soil acidification on plant growth a glasshouse study was carried out. Alfalfa (*Medicago sativa* L. 'Cimarron'), common yellow sweetclover (*Melilotus officinalis* (L.) Lam.), Old World bluestem (*Bothriochloa ischaemum* (L.) Keng 'WW-Spar'), weeping lovegrass 'Morpa,' and sand bluestem 'Woodward' were seeded into 3 soils. The soils were from an old field pasture, a N fertilized pasture, and limed soil from the N fertilized pasture. The soils were collected to a depth of 5 cm from near each of the sampling points in the fertilized pasture and the old field pasture of site 3. Soil from within each pasture was composited, mixed, and air dried. A portion of the soil from the fertilized pasture was limed with $Ca(OH)_2$ (hydrated lime) at the rate of 1.18 g $Ca(OH)_2$ kg^{-1} soil, mixed, watered to field capacity, spread, and allowed to dry in the glasshouse. The limed soil was mixed and put through 3 more wet and dry cycles over a 6-week period to allow the $CA(OH)_2$ to react.

The soils were fertilized with N and P to minimize fertility effects from past management. Monocalcium phosphate at the rate of 0.04 g P kg^{-1} soil was mixed into 2-kg batches of soil and placed in individual pots. Pots were seeded to individual species and watered to field capacity. The legume seed was inoculated prior to planting. After seedling emergence, ammonium nitrate was applied in solution to each pot at the rate of 0.05 g N kg^{-1} soil. The pots were watered daily with distilled water to bring the soil to field capacity. The plants were thinned to 5 plants/pot. Lighting in the glasshouse was supplemented 14 hr day^{-1} by high pressure sodium lamps giving an intensity of 340 μ mol $m^{-2}s^{-1}$ at the soil surface. Glasshouse temperatures were 25 ± 3° C. The plants were seeded on 18 January and harvested 28 days later by cutting 1 cm above the soil surface, freeze dried, and weighed. Four replications were used in the glasshouse study.

Analysis of variance for a randomized block design with subsamples was used to analyze the pH and liming requirement data for each depth increment in the field study. The herbage yields in the glasshouse study were subjected to analysis of variance by species, and then treatment means within species separated by Tukey's multiple range test. The standard errors of the difference between means in both the field and glasshouse studies are based on $n = 4$.

Results and Discussion

A mean pH of 5.3 found in the surface 5 cm of the N fertilized pastures was significantly lower than the pH of 6.7 in the old fields (Table 1). A measurably lower pH was found to 20 cm in the N fertilized pastures. These changes in pH are greater than the pH changes reported for long-term low-rate N fertilization of grassland in Kansas (Owensby et al. 1969) and North Dakota (Smika et al. 1961). In the Kansas and North Dakota studies pH was determined on wider (15 cm) soil depth increments and the soils were finer textured and thus had a greater buffer capacity to resist pH change than the sandy, low organic matter soils in this study. The localization of the acidification near the surface is in agreement with other studies on acidification of near-neutral soils by fertilizer ammonium nitrification under rangeland (Smika et al. 1961) and minimum till (Mahler and Harder 1984) conditions.

Table 1. The soil pH of pastures fertilized with an average of 37 kg N $ha^{-1}yr^{-1}$ for 20 years as compared to soil pH values in adjacent old fields.

Depth	Fertilized pastures	Old fields	Standard error of difference between means	Probability of >F
cm	-pH-			
0–5	5.3	6.7	0.2	0.003
5–10	5.8	6.7	0.1	0.004
10–15	6.2	6.6	0.1	0.05
15–20	6.6	6.8	0.04	0.01
20–30	6.6	6.7	0.07	0.31
30–40	6.8	6.8	0.04	0.34

The lime requirement, a quantitative measurement of soil acidification, was significantly increased to a depth of 15 cm in the N fertilized pastures (Table 2). When recalculated as one 0-15 cm increment, the lime requirement in the N fertilized pastures was 896 kg $CaCO_3$ ha^{-1} greater than in the old field pastures. The theoretical maximum amount of acidity that could have been generated by 740 kg N ha^{-1} applied over 20 years to the N fertilized pastures was 2,640 kg $CaCO_3$ ha^{-1}. The variability of the lime requirement (C.V.=54%) in this study precludes a close comparison to the lime requirement found in other N fertilization studies (McLean and Brown 1984). The trend is that the magnitude of the lime requirement in relation to the amount of ammonium-N applied is similar to or less than that reported in other studies. Although nitrification of fertilizer ammonium is assumed to be the major soil acidification factor in this study, other factors may enhance or ameliorate acidification. Recycling of N as urea in urine, and the decomposition of the increased amount of organic matter produced by fertilization could contribute to acidification. Ammonia volatilization from broadcast N fertilization is a loss to acidification potential. Pasture burning should produce an alkaline ash which would neutralize some acidity.

Table 2. The lime requirement of pastures fertilized with an average of 37 kg N ha^{-1} yr^{-1} for 20 years as compared to the lime requirement of unfertilized old field pastures.

Depth	Fertilized pastures	Old fields	Standard error of difference between means	Probability of >F
cm	-kg $CaCO_3$ ha^{-1}-			
0–5	1021	486	339	0.01
5–10	703	473	214	0.04
10–15	545	412	161	0.08
15–20	536	488	76	0.14
20–30	1021	987	111	0.60
30–40	1131	1079	206	0.51

Sweetclover had a distinct marginal chlorosis and cupping of leaves when grown in soil taken from the depth of 0 to 5 cm in the N fertilized pasture. These symptoms of manganese toxicity (Morris and Pierre 1949) were not present on sweetclover grown in limed soil from the N fertilized pasture or in soil from the old field. Herbage yields of sweetclover were significantly less when grown in the soil from the N fertilized pasture than in soil from the old field or limed N fertilized soil (Table 3). The smaller yield on the unlimed N fertilized pasture soil was probably due to a combination of aluminum and manganese toxicity resulting from the increased solubility of these elements under acid conditions.

Table 3. Glasshouse herbage yields of 5 forage species as affected by unlimed and limed soil taken from 0–5 cm in a N fertilized pature and an adjacent old field.

	Soil			Standard error of difference between means
	N Fertilized pasture		Old field	
	Unlimed pH 5.2	Limed to pH 6.9	pH 6.9	
	----- g pot^{-1} -----			
Sweetclover	1.77 b[1]	3.30 a	4.02 a	0.29
Alfalfa	2.19 b	2.15 b	2.84 a	0.22
Weeping lovegrass	2.29 a	1.43 b	1.80 ab	0.22
Sand bluestem	0.98 a	0.70 b	0.96 a	0.09
Old World bluestem	3.50 a	2.53 b	2.47 b	0.22

[1]Means within a species followed by the same letter or letters do not differ significantly at the 0.05 level of probability according to Tukey's test.

Leaves of about one-half of the alfalfa plants grown in the unlimed soil from the N fertilized pasture had a marginal chlorosis indicating manganese toxicity. Herbage yield of alfalfa grown in the unlimed soil was significantly less than the yield on the old field soil (Table 3). The similar alfalfa yields on the unlimed and limed soils taken from the N fertilized pasture was unexpected since the sensitivity of alfalfa to acid soils is well known. It may be that the liming treatment resulted in some microsites with high pH levels due to unreacted $Ca(OH)_2$ even though the pH of a composite sample after 4 mixing, wetting, and drying cycles was 6.9.

Yield of warm-season grasses in the glasshouse study was not adversely affected by the acidified soil. Weeping lovegrass produced similar yields on the unlimed soil from the N fertilized pasture and on the old field soil (Table 3). Sand bluestem followed the same pattern. Old World bluestem produced a greater yield on the unlimed soil from the N fertilized pasture than on the old field soil. The grasses all produced more herbage on the unlimed than on the limed soil from the N fertilized pasture.

These glasshouse results indicate that long-term low-rate N fertilization has acidified the surface of the sandy soil so as to adversely affect growth of sweetclover and alfalfa. Under field conditions the legumes might be less affected than in the glasshouse study as roots may penetrate into less acid subsurface soil. Toxicity effects to legumes under the field pH conditions shown in Table 1 could probably be negated by mixing the soil to a depth of 20 cm. However, soil mixing posses the risk of exposing the unvegetated sandy soil to wind erosion.

In the longer term, continued use of acid-producing N fertilizers will eventually require that the soil be limed if species sensitive to acid conditions are grown. Effective use of lime requires mixing it into the soil, and again this raises a potential wind erosion problem on the sandy soil. An amelorative action might be to broadcast lime on the soil surface to neutralize some of the acidity as it is generated. This might have some success since the data (Tables 1 and 2) indicate that most of the acid production occurs in the surface 5 cm. A drawback to the latter suggestion is that a higher pH at the soil surface can result in greater N volatilization from broadcast ammonium on ammonium-producing fertilizer.

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Sulfur or Sulfur Plus Nitrogen Increases Beef Production on California Annual Range

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Abstract

A 6-year study was conducted to evaluate the response of California annual range to triennial applications of sulfur only and sulfur plus nitrogen fertilizer. Range response was evaluated in terms of length of the green season, steer weight gain, total beef production and steer days of grazing/ha. Neither fertilization treatment consistently lengthened the green season nor influenced steer weight gain compared to nonfertilized range. Steer days of grazing and total beef production/ha were greatest on sulfur plus nitrogen-treated range, intermediate on sulfur only-fertilized range and least on nonfertilized range. Sulfur only-fertilized range increased beef production about 60 kg/ha compared to nonfertilized range, and range fertilized with sulfur plus nitrogen increased beef production nearly 50 kg/ha more than sulfur only-fertilized range.

On California's annual range, most of the herbage is produced between early February and mid-April, when soil moisture is generally abundant and rising temperatures foster rapid plant growth. Forage selected by cattle during this time of the year is well balanced nutritionally and produces the most rapid animal weight gains. However, as annual herbage matures and dries, generally during mid-June, the rate of animal weight gain drops rapidly. Wagnon et al. (1958) found that without supplements, weaner and yearling steers gained weight only during the green season; they maintained weight through the dry-forage season and lost weight during the winter season.

Conrad (1950) and Martin (1958) reported a widespread sulfur deficiency in several soils derived from a wide variety of parent materials at many locations throughout California. Bentley (1946) found that pit-run gypsum increased herbage production on the San Joaquin Experimental Range. Fertilization with sulfur every third year increased annual herbage yields, grazing capacities (Bentley et al. 1958), and steer gains (Wagnon et al. 1958) over those on nonfertilized range. Bentley and Green (1954) noted the first marked response to sulfur fertilization was a stimulation of legume growth. Grass production increased the year after stimulation of legumes and the beneficial effects held over for a few years after sulfur fertilization.

Martin (1958) reported that soil nitrogen deficiency was at least as widespread in California as sulfur deficiency. The first year after treatment, cattle weight gains were greater on nitrogen-fertilized range than on nonfertilized range, but less than where both nitrogen and sulfur had been provided (Martin and Berry 1970). Similar though reduced responses were reported the second year after treatment. Triennial applications of sulfur or sulfur plus nitrogen increased herbage yields and grazing capacity of annual ranges (Conrad et al. 1966). Woolfolk and Duncan (1962) reported that herbage production, grazing use, and animal weight gain were greatest on annual range fertilized with sulfur and nitrogen. Fertilization with sulfur alone was less beneficial. Benefits of range fertilization included earlier range readiness, increased herbage production, and increased herbage protein content (McKell et al. 1960).

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A number of scientists in the U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Fresno, California participated in the collection of data.

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This paper reports the effects of sulfur and sulfur plus nitrogen fertilizers on length of the green season, range stocking rate, beef production and steer weight response on annual range at the San Joaquin Experimental Range, Madera County, California.

Study Area

The Experimental Range is located approximately 32 km north of Fresno, Calif., in the low foothills on the Sierra Nevada Mountains. The climate is Mediterranean, with mild, rainy winters and hot, dry summers (Bentley and Green 1954). Precipitation, primarily rain, averages about 48 cm annually, 98% occurs from October through May.

From June through September, daily temperature averages 24° C, and daily maximum temperature averages 32° C. Soil is primarily Ahwahnee, coarse, sandy loam, (Alfisol, Mollic Haploxeralf), of granitic origin, and generally less than 76 cm deep. The vegetation includes about 400 introduced species of annual plants, (Bentley and Talbot 1951, Biswell 1956, Talbot and Biswell 1942). The more abundant species are soft chess *(Bromus mollis)*, ripgut brome *(B. rigidus)*, red brome *(B. rubens)*, slender oat *(Avena barbata)*, wild oat *(A. fatua)*, broadleaf filaree *(Erodium botrys)*, red-stem filaree *(E. cicutarium)* and bur clover *(Medicago hispida)*.

Methods

Range Units

The 12 range units used in the present study were used in earlier studies cited above (Woolfolk and Duncan 1962, Conrad et al. 1966). Residual effects from previous studies, if present, were considered innocuous. The units were judged as having nearly equal grazing capacities. Each range unit would carry a minimum of 10 yearling steers throughout an average green season and have 730 ± 170 kg/ha residual forage at the end of the grazing season.

Area of the units ranged from 7.3 to 31.8 ha. Disparity in unit size was needed to equalize grazing capacity because of differences in soil depth and topography. Two blocks of three range units were established on soil generally less than 10 cm deep with slopes generally greater than 25%, hereafter referred to as shallow-soil units. Two blocks of 3 units were established on soil which averaged about 60 cm deep with 10 to 25% slope, referred to as the deep-soil units.

Range units were stocked annually during the green season from 1969 to 1974, based on forage availability and range readiness. The green season within each range unit was judged independently. Each range unit was considered ready and was stocked when soft chess and broadleaf filaree were 6.4 and 3.8 cm tall, respectively. After a unit was stocked, test animals remained within the unit until the end of the green season for that unit. The green season was considered ended when cattle concentrated on soft chess and red-stem filaree on the lower slopes, on the summer-growing Spanish-clover *(Lotus americanus)*, and on green plants under trees as described by Bentley and Talbot (1951).

Treatments

Sulfur and sulfur plus nitrogen were applied to designated range units in the fall of 1968; treatments were repeated on the same units in 1971. Four units served as nonfertilized controls. One replication of the control and each fertilizer treatment was randomly assigned to the units in each of the 4 blocks. On the sulfur only

Table 1. Length of the green season and annual precipitation on California annual range from 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Green season, days							
Sulfur + Nitrogen	156a[1]	138a	144a	108a	160a	202a	151a
Sulfur only	156a	133a	116b	80b	135b	201a	137a
Non-fertilized	156a	134a	134ab	87b	141b	202a	142a
Average	156±0.3[2]	135+5.5	131±10.1	92+9.9	145+8.1	201+0.3	143+8.1
Precipitation, cm	82	45	40	27	61	58	52

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

treatment, sulfur was applied at the rate of 67 kg/ha, in the form of gypsum. The sulfur plus nitrogen treatment consisted of a 3 to 1 mixture, by weight, of ammonium sulfate and ammonium nitrate. The mixture, as applied, provided 67 and 90 kg/ha of sulfur and nitrogen, respectively.

Animals

Three hundred short yearling weaned steers, averaging about 190 kg, were purchased annually, just prior to range readiness. The animals, most with predominately Hereford lineage, were weighed and 120 steers of medium weight were selected as test animals. The 120 steers were separated by weight into 12 groups of 10 animals each so that total weight of test steers was equalized between groups. One group was randomly assigned to each range unit. All test groups were held in a common nontest unit until forage within each unit was judged ready for grazing. When forage within each test unit was ready for grazing, the preassigned test group of animals was released in the respective test unit.

Test animals were weighed at the beginning and end of the green season within the assigned range unit. Test animal weights were used to calculate average daily weight gain and seasonal weight gain per steer. When more herbage was available during the green season than test animals could consume, nontest animals were placed in range units as needed, to equalize use between units and to provide uniform use of herbage throughout the grazing season. Days of grazing by both test and nontest animals were used to calculate total steer days of grazing. Beef production was calculated from total steer days of grazing and the average daily weight gain of test steers.

Data were analyzed, following analysis of variance procedures, for a two-factor split-plot design. The 6-year average treatment means were compared by Gaines' and Howell's T-modification (Keselman and Rogan 1978). Differences were tested for significance at the 5% probability level.

Results and Discussion

Green Season

On nonfertilized range, average date of range readiness was 18 January, although during the 6 years of study, readiness occurred as early as 7 December and as late as 14 February. Range readiness occurred 2 to 4 weeks earlier in 1972 and 1973 on units fertilized with sulfur plus nitrogen than on nonfertilized or sulfur-treated units. Since range readiness was not influenced the first and second years after treatment in 1969 and 1970 as it was in 1972 and 1973, the response apparently was due to unique environmental conditions combined with supplemental nitrogen. Supplemental sulfur from ammonium sulfate may also have contributed to earlier range readiness on the sulfur plus nitrogen units. Range readiness was not influenced by the sulfur only treatment, apparently because sulfur in gypsum is released at a slower rate than sulfur in ammonium sulfate. Martin and Berry (1970) reported nitrogenous fertilizers stimulated early and continued winter and early spring growth of annual grasses, but supplemental nitrogen appeared effective only if adequate phosphorus and sulfur were present. McKell et al. (1960) also reported earlier range readiness on California annual range with sulfur plus nitrogen, but the present findings agree with those of Conrad et al. (1966), who found range readiness inconsistently influenced by sulfur plus nitrogen on the San Joaquin Experimental Range. Inconsistent findings were perhaps related to low soil fertility. Germination and growth of annual range plants were also dependent upon adequate soil moisture and temperature; when either was deficient, range readiness was delayed.

Fertilization did not affect the end of the annual plant range green season (plant maturity). Bentley and Talbot (1951) reported that most herbage does not dry until temperatures rise sharply and the upper soil dries. Adequate soil moisture delayed plant maturity and annual plants matured earlier in years with droughts.

Length of the green season was variable, depending upon the dates of range readiness and plant maturity. On nonfertilized range the green season averaged 142 days and was not different from the length of season on fertilized range (Table 1). The shortest green season (87 days) on nonfertilized range occurred in 1972, and the longest green season (202 days) occurred in 1974. Talbot and Biswell (1942) also reported considerable year-to-year variation in length of green season. Bentley and Talbot (1951) found the period of most dependable green forage to be approximately 4 months long, from January or February into June. In the present study, the cumulative precipitation during the months of October, December, March, and June gave the best fit between precipitation and length of season. The relationship between precipitation and length of the grazing season was described by the linear equation: $Y = 7.53 + 6.72X$, in which Y = length of the green season in days, and X = sum of October, December, March, and June precipitation in centimeters. The equation explained 80% of the variation in length of the season, standard error of the estimate = 16.4 days and $N = 24$. However, as a predictive tool the equation is inadequate and additional research is needed before the equation is useful to managers.

Table 2. Steer days of grazing on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Days of grazing/ha							
Sulfur + nitrogen	368a[1]	258a	221a	258a	303a	295a	283a
Sulfur only	215b	168b	162b	114b	204b	250a	190b
Non-fertilized	132b	96c	87c	66c	106c	145b	108c
Average	238±69[2]	174±45	157±46	146±58	204±57	230±49	192±21

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

Length of the green season was generally not influenced by fertilization treatment. Sulfur plus nitrogen increased the length of the green season compared with nonfertilized range only in 1972 and 1973, and length of the green season was similar all years on sulfur only and nonfertilized range. Sulfur plus nitrogen-treated range was green longer in 1971, 1972, and 1973 than sulfur only-treated range due to range readiness, which occurred up to a month earlier on sulfur plus nitrogen range. However, average length of green season during the 6-year study was similar on all treatments.

Range Stocking Rate

Steer days of grazing/ha varied substantially within and between fertilizer treatments (Table 2). For example, annual days of grazing/ha were the least on both sulfur only and nonfertilized range in the extremely dry year of 1972, and days of grazing more than doubled on both treatments in the moderately high precipitation year of 1974. Within treatment variation was less on the sulfur plus nitrogen treatment. The difference in maximum and minimum days of grazing, 1969 and 1971 respectively, on sulfur plus nitrogen-treated range was approximately 30%.

Sulfur plus nitrogen-fertilized units produced more days of grazing than sulfur only units every year except 1974, and sulfur only-fertilized units produced more days of grazing than nonfertilized units every year except 1969. These 2 exceptions, however, may have been due to a Type II error as described by Steele and Torrie (1960), since similar treatment means within years varied by as much as 45 to 83 grazing days. On an average annual basis, sulfur plus nitrogen produced over 90 days of grazing/ha more than sulfur only-treated range and the sulfur only treatment produced nearly 90 days of grazing/ha more than non-fertilized range. The increase in days of grazing/per ha was apparently due to increased herbage production. A direct estimate of herbage production by treatment was not made although the days of grazing/ha were dependent upon the amount of herbage available for use. Bentley and Green (1954) and Bentley et al. (1958) also reported increased herbage production on annual range following sulfur fertilization. The first apparent effect was a stimulation of legumes; in subsequent years increased production of grasses was attributed to a build-up of soil nitrogen by the legumes. Conrad et al. (1966) reported herbage production and animal days of grazing were generally greater on sulfur plus nitrogen-treated range than on either sulfur only or nonfertilized range.

During 1971 and 1972, steer days of grazing per ha were influenced by treatment-soil depth interactions (Fig. 1). Steer days of grazing were the least on nonfertilized range both years regardless of soil depth. In 1971, the third growing season after fertilization, sulfur only and sulfur plus nitrogen treatments produced more days of grazing than nonfertilized range. Days of grazing were similar with sulfur only and sulfur plus nitrogen on shallow soil, but sulfur plus nitrogen produced more days of grazing on deep soil than sulfur only. In 1972, the first green season after fertilization, sulfur plus nitrogen produced more days of grazing than the other treatments regardless of soil depth. On the shallow soil, sulfur only produced more days of grazing than nonfertilized range.

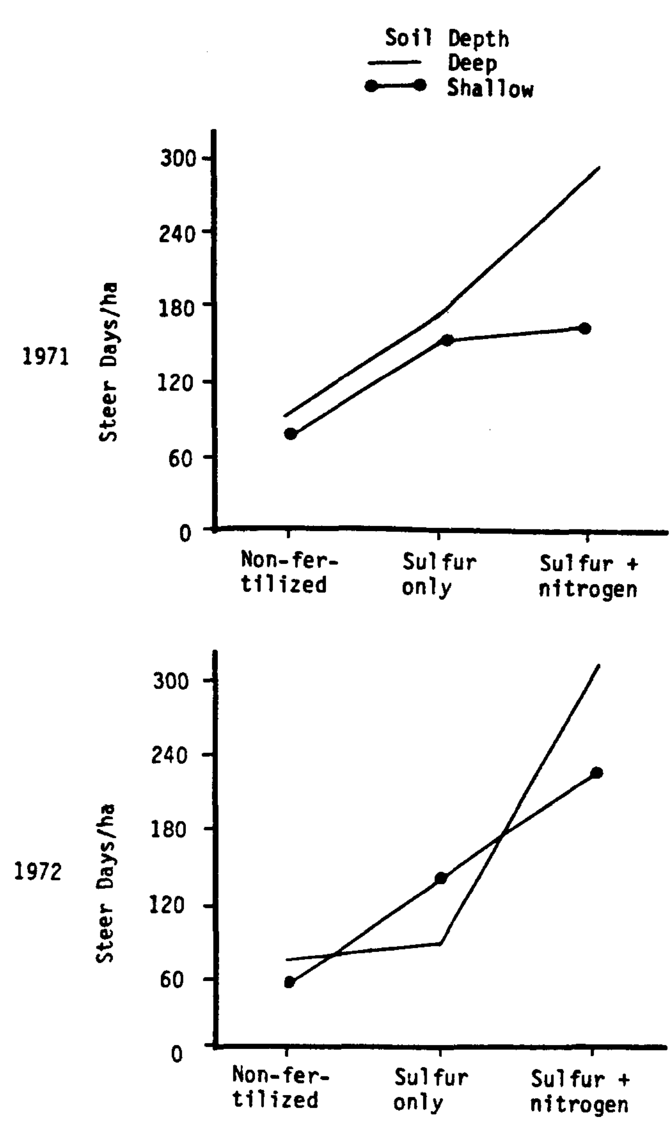

Fig. 1. *Steer days of grazing response to soil depth and fertilizer treatment in 1971 and 1972.*

Steer Weight Gain

The 6-year average steer weight gain was not enhanced by range fertilization (Table 3). Except for the drought year of 1972, steer gain on nonfertilized range equaled or exceeded the gain on sulfur- or sulfur plus nitrogen-fertilized range.

During 1969 and 1971, treatment-soil depth interactions influenced seasonal steer gains (Fig. 2). For example, in 1969 the largest steer gains on deep soil were produced on nonfertilized range, the smallest gains were obtained on sulfur plus nitrogen-fertilized range, and intermediate gains were obtained on sulfur only range.

Table 3. Average seasonal steer weight gain on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Steer gain, kg							
Sulfur + nitrogen	93b[1]	91a	75a	84a	96a	121a	93a
Sulfur only	101a	101a	73b	60b	99a	134a	95a
Non-fertilized	99a	102a	86a	60b	95a	128a	95a
Average	98±6[2]	98±6	78±6	68±8	97±4	128±53	94±9

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

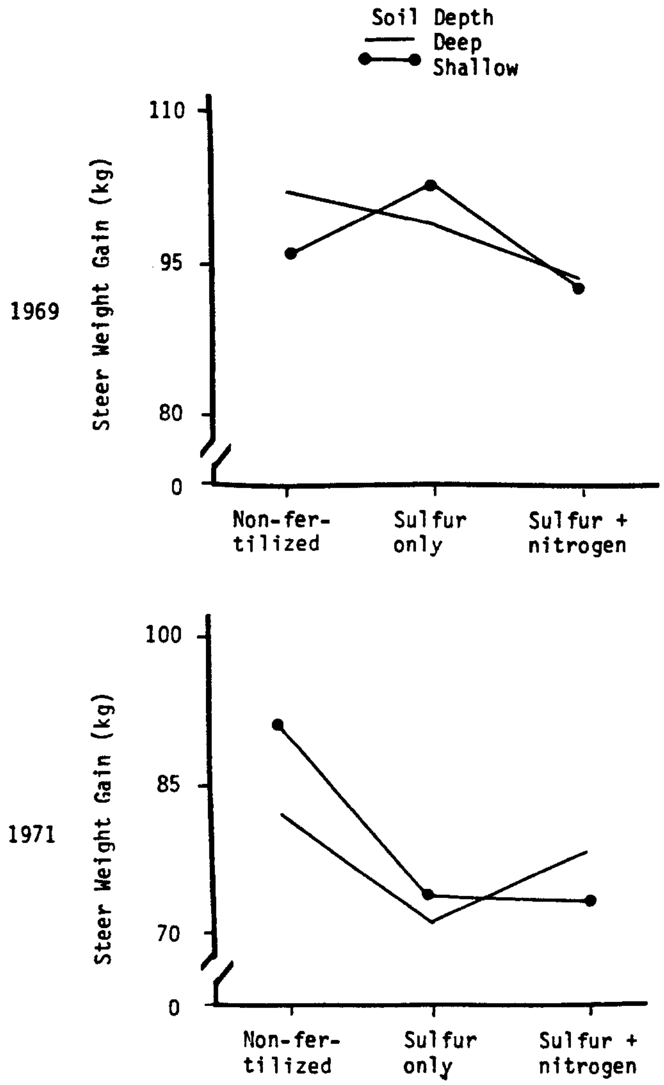

Fig. 2. *Steer weight gain response to soil depth and fertilizer treatment in 1969 and 1971.*

On shallow soil the greatest gains were obtained on sulfur only-treated range, while sulfur plus nitrogen and nonfertilized range produced similar but smaller seasonal steer gains. In 1971, steer gains produced on nonfertilized and sulfur plus nitrogen-fertilized deep soils were similar and both produced greater gains than sulfur only-fertilized range. Steer gains were larger on nonfertilized shallow soil than on fertilized shallow soil.

Within-year seasonal steer gains were influenced by a complex interrelationship between soil depth, treatment, length of green season, herbage nutritional value, days of grazing/ha, herbage production, timing of use, and perhaps other factors. However, from a practical management viewpoint, treatment influences tended to be nonconsequential since average seasonal steer gains during the 6-year study were similar on all treatments. Bentley and Talbot (1951) and Hart et al. (1945) reported heavy stocking, on annual ranges, even for only part of the year, resulted in lower production of a breeding-cow herd. As discussed earlier, the number of steers/unit of land was greater on sulfur plus nitrogen range than on sulfur-treated range, and sulfur only treatment supported more animals/ha than nonfertilized range. However, all units were stocked to obtain a uniform degree of use and there was no direct evidence to suggest an imbalance in forage/steer due to treatment. In fact, the similarity of within-year seasonal gains, as well as the similarity in the 6-year average gains, suggests that allocation of quality forage/steer was generally uniform across treatments.

Beef Production

The 6-year average production of beef was greater on sulfur-fertilized range than on nonfertilized range, and beef production was greater on sulfur plus nitrogen range than on sulfur fertilized range (Table 4). Sulfur alone increased beef production/ha nearly 80% and sulfur plus nitrogen increased production nearly 150% compared to non-fertilized range. These findings are in general agreement with those of Conrad et al. (1966), who reported increased herbage and cattle production on sulfur plus nitrogen-fertilized range; sulfur only also increased production but by a smaller amount.

Within-year beef production/ha of range was consistently enhanced by fertilization except in 1969. In 1969, production was similar on sulfur-fertilized and nonfertilized range. Sulfur applied as gypsum apparently was essentially unavailable for plant assimilation the first year after application due to a slow rate of release.

Beef production within treatments varied substantially over time, and in general, the trends appeared to be similar across treatments. For example, during 1969, 1970, and 1971 beef production declined annually regardless of treatment. Precipitation also declined annually (Table 1) although timing of precipitation may have been most limiting. In 1971, precipitation from early January through April was only 35% of normal, and precipitation during February was only about 10% of normal. Thus, the reduction in herbage and beef production was attributed to a reduction in the amount and frequency of precipitation. Beef production was also greater on deep soil (91 kg/ha) than shallow soil (80 kg/ha) in 1971. The deep-soil advantage may have been due to its ability to lengthen the growing season by storing additional amounts of water and nutrients available for plant growth. Beef production on non-fertilized range continued to decline with reduced precipitation in 1972, although the trend was reversed on fertilized range, particularly on sulfur plus nitrogen-treated range. The change in trend of beef production was probably due to an increase in herbage production. Conrad et al. (1966) also reported an increase in herbage production during a drought year on sulfur plus nitrogen-fertilized range. Beef production/ha was slightly above average in 1973 and 1974, as was precipitation, although factors other than precipitation may have also influenced beef production.

Table 4. Beef production on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Production/ha, kg							
Sulfur + nitrogen	229a[1]	180a	103a	215a	190a	170a	181a
Sulfur only	140b	131b	95a	112b	149b	165a	132b
Non-fertilized	88b	75c	59b	49c	71c	101b	74c
Average	152±41[2]	128±32	85±16	125±51	137±34	145±26	129±14

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

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Miserotoxin Levels in Fertilized *Astragalus miser* var. *serotinus*

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Abstract

The effect of fall application of urea fertilizer on toxicity of timber milkvetch was examined in 2 growing seasons at 2 rangeland sites in southern British Columbia. On the grassland site, aerial application of urea at 100 kg N/ha did not affect levels of miserotoxin in timber milkvetch. At the forest clearcut site, 200 kg N/ha reduced toxin levels at later stages of growth in the first growing season. In the second year, however, an increase in the level of miserotoxin was detected at the clearcut.

Timber milkvetch (*Astragalus miser* Dougl. ex Hook. var. *serotinus* (Gray) Barneby) is found mainly in the Douglas-fir *(Pseudotsuga menziesii)* forest and rough fescue *(Festuca scabrella)* grassland zones of southern British Columbia. A large part of this area accommodates grazing for 0.3 million beef cows and calves (B.C. Ministry of Agr. 1982). Timber milkvetch and other species of *Astragalus* synthesize large quantities of miserotoxin (Williams 1982, Williams and Davis 1982), a glycoside (3-nitro-1-propyl-β-D-glucopyranoside) that causes acute and chronic poisoning in ruminants (James et al. 1980). In 1981, the Research Branch of the B.C. Ministry of Forests initiated a study to determine the feasibility and biological consequences of aerial rangeland fertilization. Timber milkvetch was present at 2 of the 5 experimental sites and this provided an opportunity to examine the toxicity of the native legume after fall application of urea fertilizer. The objective of this study was to determine the effects of N fertilizer on miserotoxin levels in timber milkvetch.

Materials and Methods

The 2 sites were located at Beaverdam Lake, 16 km southwest of 70 Mile House, B.C., and at Lac du Bois, 11 km north of Kamloops, B.C. The 75-ha site at Beaverdam Lake (51° 16′ N lat.; 121° 35′ W long; elevation 1,067 m) was a lodgepole pine *(Pinus contorta)* clearcut. It was logged in 1977, drag scarified and seeded to domestic grasses in 1978. At Beaverdam Lake, the site was stratified into 3 vegetation units based upon cover of understory grasses and regenerating trees: lodgepole pine regeneration with native grasses, lodgepole pine regeneration with domestic grasses, and trembling aspen *(Populus tremuloides)* with native grasses. Pinegrass *(Calamagrostis rubescens)* and timothy *(Phleum pratense)* were the principal native and seeded grasses, respectively. The soil at Beaverdam Lake was a Degraded Eutric Brunisol (Eutrochrept). The 100-ha site at Lac du Bois (50° 48′ N lat.; 120° 26′ W long.; elevation 900 m), located in the rough fescue grass land was stratified into 3 vegetation units based upon sub-communities of native grasses dominated by either rough fescue, Kentucky bluegrass *(Poa pratensis)* or bluebunch wheatgrass *(Agropyron spicatum)* growing on a Black Chernozemic soil (Udic Boroll). Both sites were grazed by cows and calves, the grassland for 3 weeks in September and the clearcut continuously from May to mid-September, 1982. Grazed plants which showed residual stubble or delayed phenology were excluded from sample collections.

Forest grade urea was chosen because of its availability, low cost, and pellet size which was suitable for aerial dispersal by helicopter. The fertilizer was applied aerially during 22-24 September 1981 at 100 kg N/ha on the grassland site and at 200 kg N/ha on the clearcut. The higher rate at the clearcut was derived from previous fertilizer studies in the Douglas-fir zone of British Columbia (Freyman and van Ryswyk 1969). The lower rate on the grassland was based on studies which showed that, under less favourable moisture conditions, 100 kg N/ha is sufficient to produce a moderate forage dry matter response (A.L. van Ryswyk, unpublished data). Field traps placed at both sites determined that ground application rates were 99.5 ± 1.61 kg N/ha ($n = 45$) at the grassland site and 218 ± 1.55 kg N/ha ($n = 45$) at the clearcut. Fertilizer was applied once, in a single strip, so that each vegetation unit had fertilized and unfertilized treatment.

For miserotoxin determination, composite samples consisting of 10 timber milkvetch plants were collected at random from each strip in each vegetation unit from May to July 1982 at the following growth stages: bud, early bloom, full bloom, early pod, mature pod, and late pod. In 1983, samples were collected at the full bloom and mature pod stages to determine if residual fertilizer affected miserotoxin levels. All samples were stored in a freezer before analysis for miserotoxin by gas chromatography (Majak et al. 1977, 1983).

Toxin levels at each experimental site were examined separately using analysis of variance with a randomized block design. Vegetation units served as blocks for the source of experimental error and duplicated determinations were considered subsamples. Phenological stages and levels of fertilizer were factorially arranged within blocks. Initial tests indicated that the two-way interaction terms were not significantly different from the three-way interactions. Therefore the vegetation unit × fertilizer interaction (V × F) was a reasonable estimate for the error term used to test the effects of fertilizer (F) or vegetation unit (V). A pooled error term (V × P plus V × F × P) was used to test the effects of phenological stage (P) and the F × P interaction. Single degree of freedom contrasts were used to compare toxin levels at different stages of growth. Analysis of variance was also used to determine toxin differences among years, fertilizer treatments, and stages of growth. Means shown in the text are with standard errors.

Results and Discussion

Miserotoxin levels at the grassland site were not significantly ($P>0.05$) affected by the urea fertilizer at 100 kg N/ha. This is in agreement with an earlier study in the U.S. (Parker and Williams 1974). The toxin levels at the grassland site were inversely related to timber milkvetch maturity (Table 1). Higher concentrations ($P<0.01$) of the glycoside were detected during the bloom and bud stages of growth than during pod development. Similar trends were reported previously (Majak et al. 1974, Parker and Williams 1974).

Toxin levels were not detectably different ($P>0.05$) among vege-

Table 1. Average percent miserotoxin in timber milkvetch by fertilizer treatment and growth stage during 1982, data expressed on a dry matter basis.

	Grassland site		Clearcut site	
	Fertilized 100 kg N/ha	Unfertilized	Fertilized 200 kg N/ha	Unfertilized
Bud	5.86	5.58	3.59	3.44
Early bloom	4.39	4.36	4.43	4.74
Full bloom	4.17	4.02	3.75	3.71
Early pod	3.13	3.15	3.63	3.79
Mature pod	2.67	3.54	2.15	3.31
Late pod	2.49	2.75	2.83	3.50
SE (df)	0.29 (20)		0.17 (20)	

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tation units at the grassland site. However, a small but statistically significant difference ($P<0.01$) in miserotoxin levels was detected among vegetation units at the clearcut where the average miserotoxin values were 3.66, 3.41, and 3.66%. The slightly lower value for one of the units would not have a practical consequence.

Tests on treated and untreated plants at the clearcut showed a rapid increase in miserotoxin levels during bud to early bloom (Table 1). Thereafter, the concentration in untreated plants did not change significantly. With advancing stages of growth miserotoxin levels decreased rapidly in fertilized plants compared to controls. The most rapid change ($P<0.01$) occurred from early to mature pod stages when concentrations declined by 1.48 in treated plants compared to 0.48 percentage points in untreated ones. This rapid change was not accompanied by a parallel drop in timber milkvetch moisture (W. Majak, unpublished data). Therefore, the lower toxin levels could not be attributed to a more rapid desiccation of the fertilized plants. Lower toxin levels could result from shading of timber milkvetch by the vigorous growth of grasses in response to applied N. The production of grass was significantly enhanced in 1982 and its yield (g/m^2) showed an average increase of 64% and 182% on fertilized areas at the grassland and forest clearcut, respectively, compared to the control but increases in timber milkvetch on fertilized areas were not detected (B. Wikeem unpublished data). In previous studies, miserotoxin levels in timber milkvetch were inversely related to shading (Majak et al. 1977) and complete cover for 2 weeks reduced the toxin levels by 28 to 44% in *A. miser* var. *hylophilus* (Parker and Williams 1974).

On the clearcut site, a significant increase ($P<0.05$) was detected in miserotoxin during the late pod stage when the average level of the glycoside was 3.17% as compared to 2.73% at mature pod. A larger increase in toxin levels (31%) appeared to occur on treated areas compared to untreated ones (6%) but the interaction between fertilizer levels and these stages of growth was not significant. Increases in miserotoxin levels could be induced by the effects of rainfall as reported earlier (Majak et al. 1976, 1977). Timber milkvetch samples at the late pod stage were collected on 19 July and the precipitation for the previous week amounted to 34.0 mm, the average normal rainfall for the entire month of July (Atmospheric Environment Service 1982). In response to the rainfall, the plant moisture content increased significantly ($P<0.05$) from an average of 69.0% at mature pod to 72.2% at the late pod stage.

Significant differences in toxin levels between years were not detected at the grassland site. Fertilized sites at the clearcut, however, showed higher ($P<0.01$) toxin levels in 1983 (4.69% $\pm$ 0.36, averaged over full bloom and mature pod growth stages) than in 1982 (2.95%). The clearcut site also experienced heavy rainfall (51 mm in 8 days) during July 1983 just before sample collection (Atmospheric Environment Service 1983). It appears that rainfall may interact with the fertilizer treatment to enhance miserotoxin levels in timber milkvetch and this effect can occur in the second growing season after urea application.

Except for the bud stage of growth, large differences in miserotoxin levels were not observed between sites in the first year (Table 1). Urea applied at 100 kg N/ha did not intensify timber milkvetch toxicity and it can be safely used to increase forage production on grasslands. At 200 kg N/ha applied to a clearcut, toxin concentrations were not elevated in the first year but they may be enhanced in the second year as the vigor of the plant improves under reduced interspecific competition. Whether this is due to residual N, favorable moisture conditions, or an interaction between the two is unknown; but the results indicate a more hazardous situation for livestock grazing fertilized clearcuts in the second year.

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Honey Mesquite Control with Pelleted Hexazinone in Western Texas

R.L. POTTER, D.N. UECKERT, AND J.L. PETERSEN

Abstract

Hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*, 3*H*)-dione] applied as 1.2 cm^3 (20% ai) pellets in a grid pattern at 2.2 kg active ingredient (ai)/ha killed 11 to 22% of undisturbed honey mesquite *(Prosopis glandulosa* var. *glandulosa)* 26 months after treatment in experiments at 3 locations in western Texas. Honey mesquite plants <1 m tall were less susceptible to grid pattern applications of hexazinone than were larger plants, probably because the smaller plants lacked sufficient root systems to contact herbicide columns in the soil. Efficacy of hexazinone applied in grid patterns for honey mesquite control increased as soil clay and organic matter contents decreased and as the amount of rock increased. Results from a single experiment indicated that hexazinone pellets applied at 0.8 g ai/plant near the stem base killed 48 to 60% of the honey mesquite plants <2 m in height, but this treatment did not control plants >2 m tall.

Honey mesquite *(Prosopis glandulosa* var. *glandulosa)* is a management problem on 22.7 million ha of Texas rangeland (Fisher 1977). The most commonly used herbicide treatments for honey mesquite control have been foliar sprays of 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] or 1:1 mixtures of 2,4,5-T with picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) or dicamba (3,6-dichloro-2-methoxybenzoic acid) applied at 0.6 to 1.1 kg acid equivalent (ae)/ha. The recent termination of 2,4,5-T production in the United States prompted a search for alternative herbicides. Triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} may be effectively substituted for 2,4,5-T alone or in combination with picloram or dicamba for honey mesquite control (Jacoby and Meadors 1983). Clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) is also highly effective for honey mesquite control (Jacoby et al. 1981) but it is not registered for use on rangelands in Texas.

Pelleted formulations of herbicides have effectively controlled several rangeland brush and weed species not susceptible to foliar applications (Scifres 1980, Ueckert et al. 1983). Timing of applications of pelleted herbicides is less restrictive than with foliar sprays, and risk of herbicide drift onto susceptible crops is essentially eliminated (Scifres et al. 1978, Meyer and Bovey 1979, 1980, Scifres 1982). Grid pattern applications of pelleted, nonselective herbicides are intended to minimize damage to shallow-rooted desirable plants and to contact the deeper roots of woody plants (Scifres et al. 1978).

Hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione] pellets applied in a systematic grid pattern at 2 to 4 kg ai/ha selectively controlled oaks (*Quercus* spp.) and several associated species in the Post Oak Savannah of eastern Texas (Scifres 1982). Honey mesquite was controlled by grid pattern applications of hexazinone pellets at 2.2 kg ai/ha on a sandy clay loam and at 4.5 kg ai/ha on clay loam soils in the South Texas Plains (Scifres et al. 1984). Broadcast sprays of hexazinone are not feasible for honey mesquite control on rangelands because the herbicide is phytotoxic to forage plants at rates much lower than those effective for mesquite control (Meyer and Bovey 1980).

The short period in spring and early summer when honey mesquite is most susceptible to conventional foliar sprays is a serious constraint to rangeland improvement in Texas. The development of effective pelleted herbicides for honey mesquite control would increase the alternatives available to land managers. The major objectives of this study were to determine the efficacy of pelleted hexazinone applied in a systematic grid pattern (simulated broadcast application) for honey mesquite control in semiarid and arid regions of western Texas, and to relate hexazinone efficacy to selected soil properties. Considerable need also exists for effective individual plant treatments for maintenance control of honey mesquite on rangeland and improved pastures. Thus a secondary objective of this study was to evaluate pelleted hexazinone as an individual plant treatment for honey mesquite control.

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Study Areas

Experiments were established 11 km east of Bakersfield (Pecos County), 10 km north of San Angelo (Tom Green County), and 5 km west of Brady (McCulloch County), Texas. Long-term average annual precipitation is 31 cm at Bakersfield, 47 cm at San Angelo, and 59 cm at Brady. About 75% of the total precipitation typically occurs from April to October at each area. Precipitation records were obtained from the nearest official reporting station or from rain gauges maintained near the sites.

The dominant brush species on all areas was honey mesquite with lesser amounts of lotebush condalia *(Condalia obtusifolia)*, agarito *(Mahonia trifoliolata)*, and pale wolfberry *(Lycium pallidum)*. Additional brush species at Bakersfield were redberry juniper *(Juniperus pinchotii)*, tarbush *(Flourensia cernua)*, creosotebush *(Larrea tridentata)*, and broom snakeweed *(Xanthocephalum sarothrae)*. Important grasses at the Bakersfield site were sideoats grama *(Bouteloua curtipendula)*, cane beardgrass *(Andropogon barbinodis)*, vine mesquite *(Panicum obtusum)*, burrograss *(Scleropogon brevifolius)*, and red threeawn *(Aristida longiseta)*. Dominant grasses at the San Angelo site were sideoats grama, red threeawn, buffalograss *(Buchloe dactyloides)*, and tobosa *(Hilaria mutica)*. Major grasses near Brady were Texas wintergrass *(Stipa leucotricha)*, sideoats grama, red threeawn, and cane beardgrass.

All plots at the Bakersfield site occurred on Iraan silty clay loams (Rives 1980) (Cumulic Haplustolls, 20 to 29% clay, 2.2 to 2.6% organic matter, pH 7.5 to 7.7). Soils at the San Angelo site were Angelo clay loams (Wiedenfeld and Flores 1976) (Torrertic Calciustolls, 28 to 30% clay, 2.4 to 2.5% organic matter, pH 7.7). Dominant soils series at Brady were Owens (Typic Ustochrepts), Tarrant (Lithic Calciustolls), Kavett, Valera, and Mereta (Petrocalcic Calciustolls) (Bynum and Coker 1974) (25 to 38% clay, 2.7 to 3.9% organic matter, pH 7.6 to 7.7).

Methods

Experimental Design and Herbicide Applications

The formulation of hexazinone used in all experiments was the 20% ai pellet, approximately 2.1 by 1.4 by 0.8 cm in size and ellipsoidal in shape. The pellets displaced an average of 1.2 cm^3 of water and weighed an average of 1.87 g.

An experiment was established at each of the 3 study sites to evaluate the efficacy of grid pattern application of hexazinone pellets for control of undisturbed honey mesquite. The experiments were arranged as randomized complete blocks with 2 replications. Plots were 20.1 by 20.1 m with 10-m buffers between plots. Blocks were situated on different soils series where feasible. Hexazinone pellets were applied by hand in grids on 2.6-, 1.8-, or 1.3-m centers to achieve rates of 0.6, 1.1, or 2.2 kg ai/ha, and an untreated check plot was included in each block. These plots were located in honey mesquite stands which had no recent history of disturbance. Grid pattern applications of hexazinone were applied at San Angelo, Brady, and Bakersfield on 28 April, 30 April, and 22 July, 1981, respectively.

A single experiment, also arranged as a randomized complete block with 2 replications, was established at the Brady study area to evaluate the efficacy of hexazinone pellets for control of regrowth honey mesquite. This experiment was established within a dense stand of honey mesquite that had been shredded periodically until 1975. The shrubs were 0.1 to 2.5 m tall and included seedlings, saplings, and multiple-stemmed regrowth. Treatments were applied on 30 April 1981 and were the same as applied in experiments on undisturbed honey mesquite. Plots were 20.1 m by 20.1 m separated by 10-m buffers.

A single experiment to evaluate the efficacy of pelleted hexazinone as an individual plant treatment for honey mesquite control was established at the San Angelo site on 6 May 1981. The experiment was arranged as a completely randomized design with 3 replications. Plot sizes were 20.1 by 20.1 m with 20.1-m buffers between plots. Treatments included hexazinone at 0.4 g ai/plant (1 pellet) and at 0.8 g ai/plant (2 pellets). Pellets were applied by hand near the stem base of each honey mesquite plant in the plots. Three untreated check plots were included in the experiment. This experiment was located in a pasture that had been bulldozed in 1971. The dense stand included single-stemmed seedlings and saplings and multiple-stemmed re-growth. The soil was an Angelo clay loam (26% clay, 2.3% organic matter, pH 7.6).

Evaluation of Defoliation and Mortality

Defoliation and mortality estimates were made at the end of the first and second growing seasons, and during the third growing season after treatment. Honey mesquite trees were stratified into 3 height classes: <1 m, 1 to 2 m, and >2 m. Canopy reduction of honey mesquite plants was visually estimated and the estimates were averaged within height classes for each plot. These plot averages were subjected to statistical analysis. If a honey mesquite plant was completely defoliated with no green shoots, it was considered "apparently dead," and average percent apparent mortality was calculated separately for each height class in each plot. Plot averages were subjected to statistical analyses. Each mesquite plant in the undisturbed honey mesquite plots (grid pattern applications) and in the individual plant treatment experiment were examined. Mesquite densities in the "regrowth" experiment at the Brady site were very high (1,800 to 8,800 plants/ha) so these plots were sampled by examining only those honey mesquite plants within 3.1-m belt transects across the diagonal(s) of each plot.

Percentage canopy reduction and apparent mortality data were transformed by arcsin $\sqrt{p}$, where p = canopy reduction (%) or apparent mortality (%), then subjected to analyses of variance. Means from the transformed data were untransformed for presentation in the tabular data (Kempthorne 1979). Data from the 3 undisturbed honey mesquite experiments were analyzed as a split plot with locations as the whole plot effect and rates as the sub-plot effect. Duncan's multiple range test was used to determine significant differences among means.

Soil Analyses

Two soil samples from each of 2 depths (0 to 15 and 15 to 46 cm) were obtained from each block at each location for laboratory analyses. Soil samples were analyzed in duplicate for percent coarse fraction (material >2 mm), particle-size distribution by the hydrometer method (Day 1965), organic matter content by acid digestion and titration (Allison 1965), and pH measured in 0.01 M $CaCl_2$ (Peach 1965). Weighed averages for percentages of clay, organic matter, and rock for each block were used in regression analyses to determine their relationships to hexazinone efficacy for honey mesquite control. Regression models for mortality of honey mesquite in each height class based on herbicide rate and weighted soil properties were estimated. Additional models based on weighted soil properties were estimated separately for each herbicide rate. Data from the untreated plots were excluded from all regression analyses. Models were selected by the all regressions method (Graybill 1976).

Results and Discussion

Total precipitation received by 30 and 90 days after treatment was 3.8 and 16.6 cm, respectively, at the Bakersfield site; 4.0 and 13.8 cm, respectively, at the San Angelo site; and 5.8 and 18.3 cm, respectively, at the Brady site. Precipitation amounts received the first and second 12-month periods after treatment were 34.1 and 15.7 cm, respectively, at Bakersfield; 61.3 and 60.5 cm, respectively, at San Angelo; and 62.7 and 63.3 cm, respectively, at Brady, which were 110 and 51%, 130 and 128%, and 106 and 107% of the long-term annual averages, respectively, for the 3 locations.

Split-plot analyses of variance on data for undisturbed honey mesquite stands indicated no significant location by rate interaction, thus data from the 3 locations were pooled for presentation. Data on honey mesquite defoliation and apparent mortality at the end of the first growing season after hexazinone application were erratic because of recurring defoliation/refoliation cycles (data not shown). Significant canopy reduction had occurred 16 months after herbicide application on most treated plots but the maximum apparent mortality of undisturbed mesquite on plots treated with hexazinone at the high rate was only 7% (Table 1).

Table 1. Average defoliation (Def.) and mortality (Mort.) (%) of undisturbed honey mesquite 16 months and 26 months after grid pattern applications of pelleted hexazinone at three locations in western Texas.[1]

Height Class	Rate	16 months Def.	16 months Mort.	26 months Def.	26 months Mort.
	(kg/ha)	(%)			
<1 m	0.0	19 c	0 a	24 a	0 b
	0.6	27 bc	2 a	28 a	2 b
	1.1	37 b	5 a	37 a	4 ab
	2.2	52 a	3 a	42 a	11 a
1 to 2 m	0.0	18 c	0 b	30 c	2 b
	0.6	51 b	1 ab	35 c	5 b
	1.1	57 ab	4 ab	51 b	4 b
	2.2	77 a	7 a	66 a	22 a
>2 m	0.0	25 c	0 a	38 c	0 b
	0.6	38 bc	0 a	42 bc	2 b
	1.1	54 b	2 a	53 b	2 b
	2.2	79 a	2 a	72 a	21 a

[1]Means within a column for each height class followed by the same letter are not significantly different by Duncan's Multiple Range Test at the 5% level.

Honey mesquite plants <1 m tall were generally unaffected 26 months after grid pattern applications of hexazinone (Table 1), apparently because the small, young plants lacked sufficient root systems to contact herbicide columns in the soil. Hexazinone at 1.1 to 2.2 kg/ha caused significant defoliation of honey mesquite >1 m tall, but only the high rate caused significant mortality 26 months after treatment (11 to 22%).

Defoliation of regrowth mesquite in the single experiment at the Brady study site (Table 2) was similar to that observed in undisturbed mesquite (Table 1). Hexazinone applied in grid patterns at 0.6 to 2.2 kg/ha caused 31 to 47% apparent mortality of honey mesquite 1 to 2 m tall after 16 months, whereas significant mortality 26 months after treatment occurred only on plots receiving 1.1 or 2.2 kg/ha of hexazinone. Canopies of honey mesquite regrowth >2 m in height were reduced 94% 26 months after application of 2.2 kg/ha of hexazinone but no mortality had occurred in the large regrowth or in plants <1m tall.

Table 2. Defoliation (Def.) and mortality (Mort.) (%) of regrowth honey mesquite 16 and 26 months after grid pattern applications of pelleted hexazinone near Brady, Texas.[1]

Height Class	Rate	16 months Def.	16 months Mort.	26 months Def.	26 months Mort.
	(kg/ha)	----------(%)----------			
<1 m	0.0	11 b	0 a	23 b	0 a
	0.6	34 ab	1 a	23 b	1 a
	1.1	61 a	7 a	56 a	8 a
	2.2	65 a	8 a	77 a	23 a
1 to 2 m	0.0	8 c	0 b	19 b	0 b
	0.6	26 b	31 a	30 b	0 b
	1.1	73 a	32 a	69 a	36 a
	2.2	74 a	47 a	77 a	31 a
>2 m	0.0	4 c	0 a	15 b	0 a
	0.6	16 b	0 a	19 b	0 a
	1.1	58 a	0 a	46 b	0 a
	2.2	76 a	0 a	94 a	0 a

[1]Means within columns and height classes followed by the same letter are not significantly different by Duncan's Multiple Range Test at the 5% level.

Results from the single individual-plant-treatment experiment suggest that hexazinone can kill mesquite plants ≤2 m tall if the herbicide is selectively placed near the stem base (Table 3). Mortality of honey mesquite <1 m and 1 to 2 m tall receiving the 0.8 g ai rate was 48% and 60% respectively, 26 months after treatment. Pelleted hexazinone applied as an individual plant treatment at rates up to 0.8 g/plant did not control mesquite >2 m tall.

Table 3. Defoliation (Def.) and mortality (Mort.) (%) of honey mesquite 16 and 26 months after applications of pelleted hexazinone as individual plant treatments on May 6, 1981 near San Angelo, Texas.[1]

Height Class	Rate	Months post-treatment: 16 months Def.	16 months Mort.	26 months Def.	26 months Mort.
	(g ai/plant)	----------(%)----------			
<1 m	0.8	46 a	52 a	73 a	48 a
	0.4	41 a	27 a	31 b	33 b
	0.0	18 b	0 b	18 b	0 c
1 to 2 m	0.8	76 a	20 a	52 a	60 a
	0.4	66 a	19 a	41 a	30 ab
	0.0	17 b	0 a	20 a	0 b
>2 m	0.8	65 a	25 a	59 a	20 a
	0.4	25 b	0 a	39 a	0 a
	0.0	22 b	0 a	19 a	0 a

[1]Means within columns and height classes followed by the same letter are not significantly different by Duncan's Multiple Range Test at the 5% level.

Herbicide rate and weighed soil clay content accounted for 65 and 67% of the variation in mortality of small ($P \leq 0.01$) and intermediate sized ($P \leq 0.01$) honey mesquite 26 months after treatment, respectively. Herbicide rate, weighted rock content, and weighed organic matter content explained 83% of the variation in mortality of large honey mesquite ($P \leq 0.01$). Mortality of honey mesquite >2 m tall treated with hexazinone at 1.1 or 2.2 kg/ha was positively related to rock content and negatively related to clay or organic matter content of the soil (Table 4). Mortality of small honey mesquite treated with 1.1 kg/ha was negatively related to clay and organic matter contents.

The relationships of selected soil properties with hexazinone efficacy agree with those reported for soil-active herbicides in general and hexazinone in particular (Beste 1983). Negative relationships of hexazinone efficacy with clay and organic matter occurred because these soil constituents bind hexazinone, leaving

Table 4. Regression models for percentage mortality of honey mesquite 26 months after grid applications of hexazinone at 1.1 or 2.2 kg/ha based on selected soil properties. Data from experiments at three locations were pooled.

Height Class	Model[1]	R£	P
	1.1 kg/ha		
<1 m	% Mortality = 134.8 – 4.0 CL – 6.4 OM (0.007) (0.014) (0.355)	.85	0.022
>2 m	% Mortality = 25.4 + 0.7 RO – 10.1 CL (0.055) (0.015) (0.040)	.86	0.019
	2.2 kg/ha		
>2 m	% Mortality = 24.4 + 1.6 RO – 9.3 OM (0.092) (0.001) (0.077)	.95	0.003

[1]CL = weighted percentage clay, OM = weighted percentage organic matter, and RO = weighted percentage rock. Regression models for honey mesquite 1 to 2 m tall were not significant. Parenthetical numbers are the significance levels for t-tests for the intercept and coefficients.

less available for root uptake. Duncan and Scifres (1983) found activity of soil-applied tebuthiuron {*N*-[5-(1,1-dimethylethyl 1,3,4-thiadiazol-2-yl]-*N*-*N*′-dimethylurea} inversely related to clay and organic matter contents in 10 different rangeland soils in a greenhouse study. Positive relationships of hexazinone efficacy with percent rock content of soils can be explained by the reduced volume of soil colloids in the presence of rocks, which resulted in a higher concentration of hexazinone in the available soil water solution.

Hexazinone killed all herbaceous plants within 15 to 30 cm of each pellet and these areas were generally bare in most plots after 26 months. These spots were recolonized by herbaceous plants 2 to 3 years after hexazinone pellets were applied in areas receiving more rainfall (Meyer and Bovey 1980, Scifres 1982).

Grid pattern applications of hexazinone pellets at rates up to 2.2 kg/ha did not control undisturbed or regrowth honey mesquite as satisfactorily as is usually attained with properly timed applications of foliar sprays of 2,4,5-T or mixtures of 2,4,5-T with picloram or dicamba. Foliar sprays usually cause 90% or greater defoliation and 20 to 50% mortality of honey mesquite (Jacoby and Meadors 1983). Data from a single experiment suggest that hexazinone may be useful as an individual plant treatment for honey mesquite seedlings or saplings ≤2 m in height. A liquid formulation of hexazinone was registered for use as an individual plant treatment for control of honey mesquite and other undesirable shrubs on Texas rangelands in January 1983. Our data also suggest that hexazinone may be most effective for controlling honey mesquite on soils with low clay and organic matter contents and on rocky soils. However, caution should be exercised in extrapolating results of our regression analyses to other environments because these equations were estimated from a small data set.

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Flora and Fauna Associated with Prairie Dog Colonies and Adjacent Ungrazed Mixed-grass Prairie in Western South Dakota

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Abstract

Vegetation, small rodents, and birds were sampled during the growing seasons of 2 years on prairie dog *(Cynomys ludovicianus)* colonies and adjacent mixed-grass prairie in western South Dakota. Prairie dog grazing decreased mulch cover, maximum height of vegetation, plant species richness, and tended to decrease live plant canopy cover compared to that on ungrazed mixed-grass prairie. Buffalograss *(Buchloe dactyloides)* was the dominant plant on prairie dog towns and western wheatgrass *(Agropyron smithii)* and blue grama *(Bouteloua gracilis)* were most common on mixed-grass prairie sites. Prairie dog towns supported greater densities of small rodents but significantly fewer species compared to undisturbed mixed-grass sites. Deer mice *(Peromyscus maniculatus)* and northern grasshopper mice *(Onychomys leucogaster)* were more abundant on prairie dog towns than on undisturbed mixed-grass sites. Density and species richness of birds were significantly greater on prairie dog towns. Horned larks *(Eremophila alpestris)* were most common on prairie dog towns, whereas western meadowlarks *(Sturnella neglecta)* were most common on mixed-grass prairie.

The black-tailed prairie dog *(Cynomys ludovicianus)* originally inhabited prairies from southern Canada to Mexico and from the eastern foothills of the Rocky Mountains to the tallgrass prairie (Hall 1981). Prairie dog colonies may occupy large areas of rangeland. A single prairie dog colony occupied about 64,750 square kilometers in Texas (Merriam 1902).

Because prairie dog feeding and burrowing activities conflict with the interests of livestock producers and some assume that prairie dogs reduce the quality of habitat for wildlife (Merriam 1902, Uresk et al. 1981, Hansen and Gold 1977), control of prairie dog populations has become a common practice (Merriam 1902, Uresk and Bjugstad 1983, Collins et al. 1984). However, little or no information is available on small rodents or birds inhabiting prairie dog towns or the impact of prairie dog control on associated fauna. The objectives of this study were to compare small rodents, birds, and vegetation on and off prairie dog colonies and provide baseline information on potential nontarget impacts from prairie dog control programs.

Study Area and Methods

The study area was located in Badlands National Park in west central South Dakota, 80 km east of Rapid City and 13 km southwest of Wall. The climate is semiarid-continental and is characterized by cold winters and hot summers. The average annual precipitation for the area is 40 cm, most of which falls as high-intensity thunderstorms during the growing season (April–September). Snowfall accumulations average 62 cm per year. Mean annual temperature is 10° C, ranging from −5° C in January to 26° C in July.

Soils are primarily sedimentary deposits of clay, silt, gravel and volcanic ash (Raymond and King 1976). The landscape includes steep gullies, sharp ridges, flat-topped buttes, spires, and pinnacles that are partly covered with vegetation and upland areas of mixed-grass prairie. Gently sloping mixed-grass sites are scattered

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Table 1. Mean (±SE) percent plant cover, mulch cover and maximum height of plants on a seasonal basis on prairie dog towns and on adjacent mixed-grass prairie sites without prairie dogs in western South Dakota in 1981 and 1982.

	Season					
	Late spring		Summer		Late summer	
Year	Prairie dog towns	Mixed-grass prairie	Prairie dog towns	Mixed-grass prairie	Prairie dog towns	Mixed-grass prairie
Canopy cover (%)						
1981	46 ± 6	51 ± 7	59 ± 7	52 ± 3	60 ± 7	58 ± 4
1982	35 ± 5	67 ± 3**	64 ± 6	75 ± 3	60 ± 6	76 ± 3*
Average	41	59	62	64	60	67
Mulch cover (%)						
1981	21 ± 2	40 ± 4**	19 ± 2	50 ± 6**	17 ± .5	48 ± 7**
1982	22 ± 6	30 ± 4	6 ± 1	28 ± 7**	8 ± 1	34 ± 6**
Average	22	35	13	39	13	34
Maximum vegetation height (cm)						
1981	8 ± .6	29 ± 1**	12 ± .6	34 ± .9**	12 ± .3	36 ± .8**
1982	6 ± .2	24 ± .3**	13 ± .4	62 ± 1**	12 ± .4	66 ± 1**
Average	7	27	13	48	12	51

* = Prairie dog towns vs. mixed-grass prairie significantly different at $P<0.05$.
** = Prairie dog towns vs. mixed-grass prairie significantly different at $P<0.01$.

throughout the area and are the major sites occupied by prairie dogs. The elevation of the study sites ranged from 820 m to 900 m. The study area was neither farmed nor grazed by domestic livestock but portions have been grazed and farmed in the past. Native ungulates inhabiting the area are American bison *(Bison bison)*, pronghorn *(Antilocapra americana)*, mule deer *(Odocoileus hemionus)*, and white-tailed deer *(O. virginianus)*.

The dominant grasses of the area are western wheatgrass, blue grama *(Bouteloua gracilis)*, buffalograss, needleleaf sedge *(Carex eleocharis)*, needle and thread *(Stipa comata)*, and green needlegrass *(Stipa viridula)*. Scarlet globemallow *(Sphaeralcea coccinia)*, American vetch *(Vicia americana)*, lanceleaf sage *(Salvia reflexa)*, and prairie sunflower *(Helianthus petiolaris)* are the most abundant forbs; fringed sage *(Artemisia frigida)* is the dominant shrub.

Vegetation, small rodents, and birds were sampled in 1981 and 1982. Six permanent 80- by 80-m (0.64 ha) study sites were selected for sampling small rodent densities, composition, and vegetation characteristics. Six permanent 805- by 62-m (4.9 ha) transects were established adjacent to the vegetation and small rodent plots to inventory birds. Three sites were established on prairie dog towns and 3 sites on mixed-grass prairie adjacent to each prairie dog town. The mixed-grass prairie sites were 200 to 1,000 m from the prairie dog towns. Soils were fine, montmorillonitic, mesic Aridic Argiustolls of the Norrest-Blackpipe (silty clay loam) and Nunn (loam) series. Prairie dog towns selected had similar burrow densities.

Plant canopy cover, maximum plant height, and percent mulch cover were estimated. Plant canopy cover was estimated in 150, 20 by 50-cm quadrats placed at 1-m intervals along 3, 50-m line transects at each site. Line transects were spaced 20 m apart. Canopy cover was visually estimated into 6 cover classes (Daubenmire 1959). The height of the tallest plant in each quadrat was measured. Percent mulch cover was visually estimated by cover classes. Sampling was conducted in June (late spring), July (summer), and August (late summer) during 1981 and 1982.

Estimates of small rodent (not including prairie dogs) densities were evaluated on unique captures from live trapping. Sixty-four Sherman live traps, spaced at 10-m intervals, were arranged in a grid design on each site. The grids were arranged so that a 10-m border of similar habitat surrounded each trapping grid. Trapping began in May and continued at 3-week intervals through September of each year. Each sample consisted of 1 night of prebaiting followed by 4 consecutive nights of trapping. A mixture of peanut butter and rolled oats was used both inside and outside the traps to attract small rodents. Rodents were removed from the traps, identified as to species, assigned a unique number by toe amputation, then released at the capture site.

Bird censusing was conducted using a method similar to Emlen (1971, 1977). A permanently marked 805- by 62-m strip transect was established on each site. Surveys were conducted on 4 consecutive days every 3 weeks, starting at sunrise and continuing for 5 hours. Average walking time was 25 to 40 min per transect. All birds within each transect were identified visually or by vocalization and included birds which flew over the transect.

Factorial analyses of variance (Nie et al. 1975) were used to compare abundance of small rodents captured. One-way analyses of variance examined differences within year and treatment. Two-way analyses of variance included year by treatment. Paired T-tests were used for total percent canopy cover, mulch, maximum plant height measurements, and species richness between years and between treatments. Type I error level at $\alpha = 0.05$ was adapted for all tests unless stated otherwise.

Results and Discussion

Vegetation

Plant canopy cover on mixed-grass prairie sites was significantly greater in late spring and late summer of 1982 compared to that on prairie dog towns (Table 1). Cover values were similar during 1981 and in summer 1982. Plant species richness (no. of plant species) was greater on mixed-grass prairie vegetation types (75) than on prairie dog towns (54) in 1981 and 1982. Koford (1958) and Bonham and Lerwick (1976) reported a greater number of plants, primarily forbs, on prairie dog towns than on native shortgrass prairie sites in Colorado.

Buffalograss provided 34% cover and was the dominant plant on prairie dog towns, providing significantly greater cover than on mixed grass sites. Koford (1958) also reported that in mixed-grass prairie, prairie dogs alone can both produce and maintain a shortgrass association. Western wheatgrass and blue grama were the dominant plants on mixed-grass sites (24 and 17% canopy cover, respectively) and their cover values were significantly lower on prairie dog towns. The dominance of these two plants over buffalograss was attributed to lighter grazing by herbivores. Forb cover was significantly greater on prairie dog towns than on mixed-grass sites while, mulch cover was significantly less on prairie dog towns in most seasons. Maximum plant height was consistently greater on undisturbed mixed-grass sites compared to that on prairie dog towns.

Small Rodents

Rodent abundance was greater on prairie dog towns than on

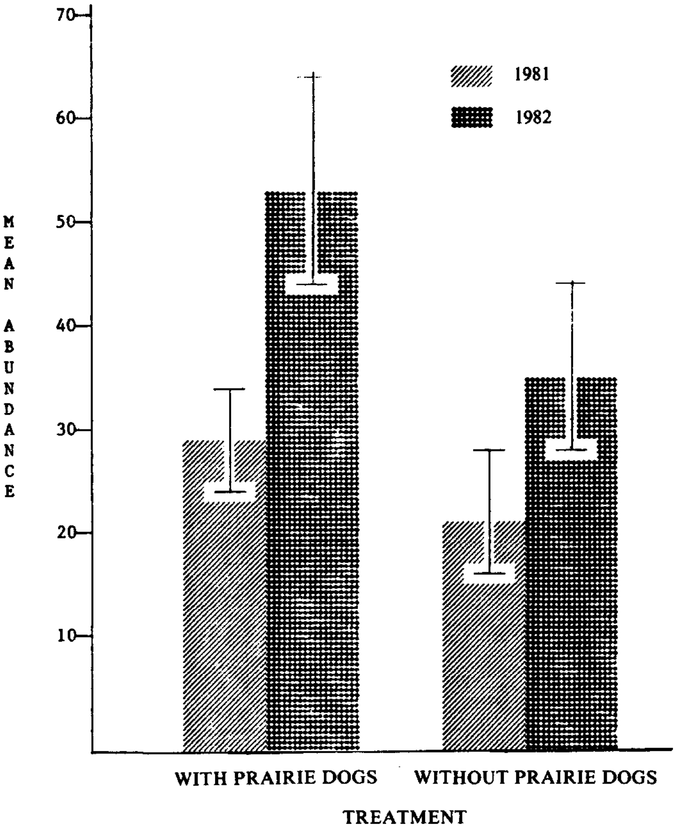

Fig. 1. *Mean abundance (numbers/1,000 trap nights ± SE) of small rodents on prairie dog towns and on adjacent mixed-grass prairie sites without prairie dogs in western South Dakota in 1981 and 1982.*

mixed-grass sites (Fig. 1); however, rodent species richness was significantly higher on mixed-grass prairie sites than on the prairie dog towns. O'Meila et al. (1982) reported similar results in Oklahoma. Decreased plant canopy cover, mulch cover, and vegetation height on prairie dog towns influenced inhabitation by certain small rodent species. Small rodents captured, in decreasing order of abundance, were deer mice *(Peromyscus maniculatus),* northern grasshopper mice *(Onychomys leucogaster),* prairie voles *(Microtus ochrogaster),* thirteen-lined ground squirrels *(Spermophilus tridecemlineatus),* western harvest mice *(Reithrodontomys megalotis),* hispid pocket mice *(Perognathus hispidus),* and house mice *(Mus musculus).* The abundance of small rodents did not vary significantly among seasons except for northern grasshopper mice.

Abundance of deer mice over 2 years was significantly greater on prairie dog towns than on mixed-grass sites (Table 2). Northern grasshopper mouse populations were greatest on prairie dog towns and stayed relatively constant between years on each of the treatments. Unused prairie dog burrows provided nesting and escape cover for these species (Blair 1940, Koford 1958, Smith 1967), and prairie dog clipping and maintenance of vegetation in a lower seral stage was particularly favorable to deer mice (Birch 1977).

Prairie voles were only captured on mixed-grass prairie sites (Table 2). Prairie voles generally inhabit areas with dense stands of vegetation (Jameson 1947, Carroll and Getz 1976). Birney et al. (1976) found increased canopy cover had an important influence on increasing Microtine populations. Thirteen-lined ground squirrels were captured most often in association with mixed-grass sites and occurred infrequently on prairie dog towns. This contrasts with Jones et al. (1983), who reported that thirteen-lined ground squirrels are most commonly found in grass that is short. Western harvest mice and hispid pocket mice occupied mixed-grass prairie

Table 2. Mean[1] abundance (numbers/1000 trap nights) of small rodents on prairie dog towns and on adjacent mixed-grass prairie sites without prairie dogs in western South Dakota during 1981 and 1982.

Common name	Prairie dog towns	Mixed-grass prairie
deer mouse	29[a]	9[b]
northern grasshopper mouse	12[a]	3[b]
prairie vole	0[a]	8[b]
thirteen-lined ground squirrel	<1[a]	5[b]
western harvest mouse	0[a]	2[b]
hispid pocket mouse	0[a]	1[b]
house mouse	<1[a]	<1[a]
Total	41[a]	28[b]

[1]Means within a row with the same superscript are not significantly different ($P<0.01$).

sites only. House mice occupied both prairie dog towns and mixed-grass sites in low numbers.

Birds

Bird species diversity was significantly higher on prairie dog towns than on mixed-grass sites. A total of 36 avian species were observed on prairie dog towns compared to 29 on mixed-grass prairie sites without prairie dogs in 1981 and 1982. Bird abundance was higher, in both years and throughout the growing season, on prairie dog towns than on mixed-grass sites (Fig. 2). Total avian densities were 171 and 73 individuals per 5 ha on prairie dog towns and mixed-grass prairie sites, respectively (Table 3). Higher avifauna numbers on prairie dog towns can be attributed to "patchiness" or structural diversity, increased seed production, primarily by forbs (Agnew 1983, Uresk and Bjugstad 1983, Rotenberry and Wiens 1980), and possibly differences in plant biomass. Grzybowski (1980) found that avian estimates were higher on heavily grazed grasslands than lightly grazed grasslands in Oklahoma and Texas. The abundance of birds on prairie dog towns was variable, with a low of 112 in summer 1982 to a high of 298 in late summer 1982. Bird numbers on mixed-grass sites ranged from a high of 152 in summer 1981 to a low of 34 in late summer 1981. These wide

Table 3. Mean (±SE) abundance (number/5 ha) of birds on prairie dog towns and on adjacent mixed-grass prairie sites without prairie dogs in western South Dakota during 1981 and 1982.

Common name	Prairie dog towns	Mixed-grass prairie
horned lark	97±23	2±<1*
western meadowlark	34±7	43±6
mourning dove	13±4	6±1*
killdeer	7±2	<1±<1*
barn swallow	7±4	<1±<1*
burrowing owl	3±1	0*
common grackle	3±2	<1±<1
red-winged blackbird	2±1	6±1*
rock dove	1±1	0
upland sandpiper	<1±<1	3±1*
lark bunting	<1±<1	4±1*
grasshopper sparrow	<1±<1	2±<1
common nighthawk	0	2 ± 1
unidentified	4 ± 1	5 ± 1
Total	171	73*

* = Significantly different from prairie dog towns at $\alpha = 0.05$.
Bird species <1 per 5 ha include: northern rough-winged swallow, European starling, American crow, house sparrow, eastern kingbird, marsh hawk, northern pintail, western kingbird, chestnut-collared longspur, American kestrel, yellow-headed blackbird, loggerhead shrike, red-tailed hawk, mallard, Says phoebe, Swainson's hawk, ferruginous hawk, long billed curlew, blue-winged teal, prairie falcon, sharp-tailed grouse, turkey vulture, buteo spp., vester sparrow, great horned owl, sora, Wilson's phalarope.

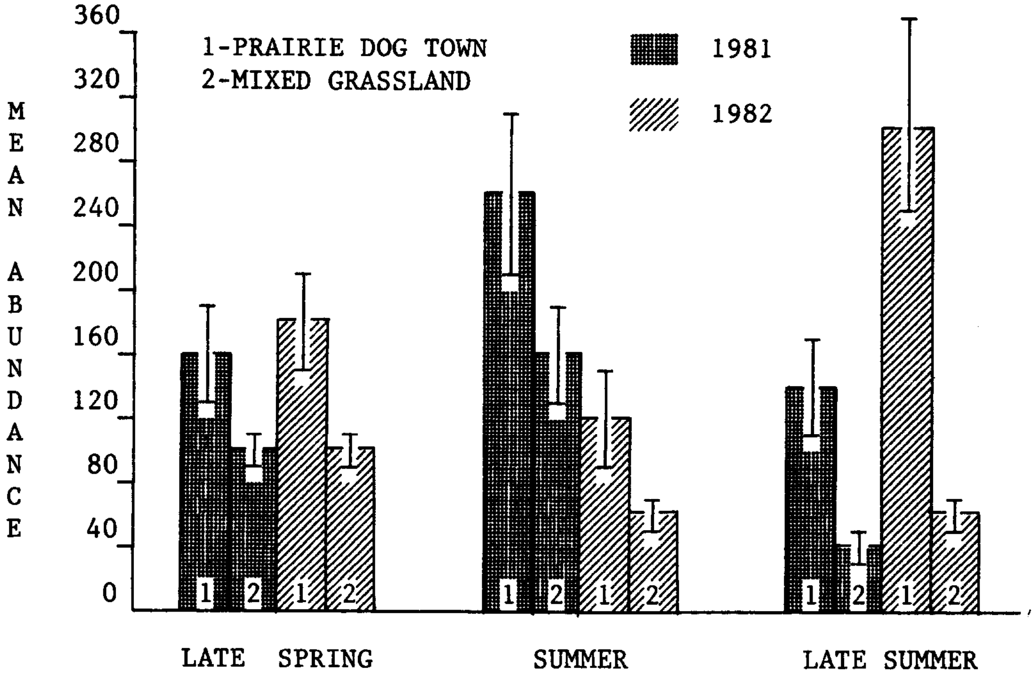

Fig. 2. *Mean abundance (numbers/5 ha ± SE) of birds on a seasonal basis on prairie dog towns and on adjacent mixed-grass prairie sites without prairie dogs in western South Dakota in 1981 and 1982.*

ranges are not uncommon for birds and similar results have been reported by Wiens and Rotenberry (1981).

Horned larks *(Eremophila alpestris)* were the most common species observed on prairie dog towns in 1981 and 1982. Abundance of horned larks varied significantly among seasons in both years and this species was significantly more abundant on prairie dog towns (97) compared to mixed-grass prairie sites (2) (Table 3). Horned larks commonly inhabit open country with low, sparse vegetation (Behle 1942, Trost 1972, Skinner 1975, Grzybowski 1980). Wein (1973) and Skinner (1975) found that horned lark densities were greater in grazed areas than ungrazed areas, apparently in response to the lower vegetative height and patchiness (Rotenberry and Wiens 1980).

Other birds commonly observed on prairie dog towns were western meadowlarks *(Sturnella neglecta)*, mourning doves *(Zenaidura macroura)*, killdeers *(Charadrius vacitenus)*, barn swallows *(Hirundo rustica)*, and burrowing owls *(Athene cunicularia)*. Burrowing owls utilize abandoned prairie dog burrows as nest sites and escape over (O'Melia 1982, MacCracken et al. 1985).

Western meadowlarks were abundant on mixed-grass prairie sites and prairie dog towns (Table 3). Lanyon (1956) reported that western meadowlarks exhibited tolerance for a wide variety of plant associations, preferring large fields with short vegetation and good drainage. Grzybowski (1980) associated western meadowlarks with more dense vegetation. Other birds commonly observed on mixed-grass sites included mourning doves, red-winged blackbirds *(Agelaius phoeniceus)*, lark buntings *(Calamospiza melanocorys)*, upland sandpipers *(Bartramia longicauda)*, and grasshopper sparrows *(Ammodramus savannarum)*.

Conclusions

Prairie dogs act as ecosystem regulators by maintaining shortgrass plant associations with less mulch cover and lower vegetation height. These vegetative features, combined with high burrow densities, provide quality habitat for some species of small rodents, such as deer mice and grasshopper mice. However, vegetative manipulation by prairie dogs negatively impacts rodent species associated with dense vegetation of mixed-grass sites. Greater avian densities and species richness on prairie dog towns can be attributed to patchiness due to prairie dog activity, lower amounts of mulch and lower vegetation height which may result in greater visibility of macroarthropods and seeds than that on mixed-grass sites. Although the role of prairie dogs as ecosystem regulators is not fully assessed, these results indicate that prairie dogs influence birds, small mammals, and vegetation. Prairie dog control programs can potentially influence birds and small rodents common on prairie dog towns.

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Rumen Digestive Capability of Zebu Steers in Wet and Dry Seasons

R.M. HANSEN

Abstract

Most authors have suggested that the rumen's capability to digest foodstuff is influenced by the conditions resulting from microbial populations which are regulated by composition of the diets. Presumably the greatest ecological differences within the rumens of cattle grazing tropical semiarid range plants would be during wet and dry seasons. Rumen dry matter digestion indexes were determined by the nylon bag technique during wet and dry seasons for 4 different plant materials at the National Range Research Station near Kiboko, Kenya. The rumen digestive capability of 3 Zebu steers was not different between wet and dry seasons when these rumen fistulates selected their own foods from natural range vegetation.

Much confusion exists relative to the conditions within the rumen which allow normal digestion to occur. One assumption is that different kinds of diets may cause different rumen dry matter digestion (RDMD) rates. Most researchers using the nylon bag technique (Van Dyne 1962) have offered the rumen fistulates an assigned diet (Weakley et al. 1983) in order to minimize any variation between animals and/or dates that could be suspected to have been caused by diets.

At the National Range Research Station (NRRS) near Kiboko, Kenya, rumen fistulated animals during nylon bag digestion trials select their own diets while grazing range vegetation (Hansen et al. 1984). The general decline in nutritive value of forages with age is most obvious at the NRRS proceeding from "wet seasons" to "dry seasons." I have assumed in this study that the greatest diet difference would occur when rumen fistulates graze wet and dry season range vegetation.

The purpose of this paper is to present RDMD values obtained by the nylon bag technique at different times during wet and dry seasons of 1984. An objective was to rumen digest the same 4 plant materials in all of the trials and to compare the results to determine if the trials were different. General observations of results obtained during 1983 led me to hypothesize that there was no significant difference between RDMD indexes for wet and dry season trials.

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Methods

Three rumen fistulated steers weighing about 300 kg were used in each trial. Two steers were Kenya Boran and one was East African Sahiwal. Throughout their life and during the 6 trials they grazed on bushed grasslands at the NRRS. Two trials were during the short dry season, 2 trials in the long dry season, 1 trial in the long wet season and 1 trial in the short wet season.

Four plant materials were tested during the 6 trials. Tests run in 1983 gave mean RDMD indexes that ranged from about 17% to 74% (Table 1). The test materials were the aboveground parts of a forb *(Chrysanthemum cineariaefolium);* the aboveground parts of a grass *(Cynodon dactylon);* leaves shed from a tree *(Kigelia aethiopum);* and the brown, shattered pods of a shrub *(Leucaena leucocephala).* All materials had been ground in a mill over a 1-mm screen. At least 4 bags of each kind of plant material were placed in each rumen during each trial.

The procedures of Van Dyne (1962) and Quinton (1972) were followed. The nylon cloth bags were about 5 cm × 10 cm in size. The cloth had no pores. There were 50 threads per cm and openings (pores) between the threads could not be seen using 400X magnification. This cloth was used to prevent solids from entering or leaving the nylon bags (Johnson et al. 1982). Prior to placement in the rumens each bag plus its contents (2.0g) was oven dried at 65° C until no further weight loss before weighing to the nearest 0.01g.

After removal from the rumens, the 3 sets of samples for each trial were thoroughly washed and rinsed with tap water in the same large bucket. Previous trials had suggested that RDMD values from different rumens were alike if handled and washed in the same way. Without proof, I suspect that the greater differences between RDMD values between trials (about 5%) than comparable values between different rumens in the same trial (about 1%) are due to the thoroughness of washing. Because of the subjective judgment for detecting "no color" in rinse water, some variation probably results. Presumably most technicians cannot detect when all the solubles have been removed by this technique. The bags plus their residues after cleaning by washing were dried in an oven at 65° C until no further weight loss before weighing to the nearest 0.01g.

Table 1. Some general characteristics of the 4 forages used in nylon bag digestion trials.

Plant Materials	Percentage ± Standard Deviations		
	RDMD[1]	Crude Protein	Mineral Ash
Chrysanthemum cineariaefolium	74.3 ± 1.8	11.3 ± 0.1	7.9 ± 0.1
Cynodon dactylon	58.5 ± 3.6	15.6 ± 0.3	13.2 ± 0.1
Kigelia aethiopum	57.3 ± 1.6	4.0 ± 0.5	32.8 ± 1.3
Leucaena leucocephala	16.8 ± 2.9	5.9 ± 0.1	5.9 ± 0.2

[1]Average rumen dry matter digestion indexes estimated for trials in 1983.

T-tests and paired *t*-tests were used to determine statistically significant differences between means at the 95% confidence level.

Results

No statistically significant differences ($p>0.05$) were found between comparable mean RDMD of the 3 rumen fistulates within a trial. Therefore, the mean percentage dry matter losses from each of the 4 plant materials were calculated across digestors for each trial date (Table 2). There were no differences ($p>0.05$) in the mean RDMD indexes of any 1 of the 4 plant materials which appeared to have resulted from wet and dry season diets.

Discussion

The difference between animals during the same trial in RDMD averaged less than 1% and averaged 1.3% between comparable forages between the 6 trials. Presumably the small differences observed between animals and between trials were because of the thoroughness in extracting the solubles from the nylon bags and their rumen digested residues.

The type of rumen inoculum has been reported to affect in vitro digestion (Van Dyne 1962). The type of forage fed to the animal has been reported to influence in situ digestion of forages (Van Keuren and Heinemann 1962, Hopson et al. 1963, Uden et al. 1974, Weakley et al. 1983). However, Welch et al. (1983) detected no in vitro differences ($p>0.05$) among the inocula of mule deer *(Odocoileus hemionus)*, elk *(Cervus elaphus nelsoni)*, pronghorn *(Antilocapra americana)*, cattle (steers), goats (nannies), and domestic sheep (ewe lambs). He reported that the sheep and cattle were being fattened on a diet of alfalfa hay, rolled barley, corn and pasture, goats were fed only a maintenance ration of alfalfa hay and pasture, and the rumen fluids of the mule deer were from native fall ranges and those of elk and pronghorn from native winter ranges. At the NRRS the RDMD values of diets collected using esophageal fistulated cattle grazing bushed grasslands have varied between 65 and 75% in the wet seasons and have been about 55% in the dry seasons before the rains come. In my study I assume the fistulates were adapted to the range vegetation of the NRRS, as opposed to having to comply with human choices within a metabolic laboratory. Much of the uniformity between digestors during the same trial and between trials at different seasons could have resulted from the ability of the test animals to select a uniform diet of the highest quality available.

The rankings of forage digestibilities determined by in vivo and in vitro procedures seems to be nearly the same (Welch et al. 1983). Certain authors have emphasized statistically significant differences in forage digestion indexes even when the biological importance was minimal or even nutritionally unimportant. The major conclusion of this study is that the rumen digestive capability of cattle may vary little between seasons provided the digestor is able to select its own food from natural range vegetation. Because intake and passage rates are reduced as the fiber fraction increases at the end of a growing season, true digestion rates are lower at this time than they are during other periods. Additional research is needed in order to settle controversy about the variation in intraruminal conditions for animals penned versus those selecting forages from a range ecosystem.

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Table 2. Mean percentage (± standard error) dry matter loss from 4 plant materials digested in the rumens of 3 Zebu steers by the nylon bag technique on different dates while grazing bushed grasslands at the Kenya National Range Research Station, Kiboko.[1]

Dates and Seasons Number of Samples	*Chrysanthemum cineariaefolium*	*Cynodon dactylon*	*Kigelia aethiopum*	*Leucaena leucocephala*
28/03/84, dry season N = 20	73.2 ± 0.7 a		56.3 ± 0.5 b	18.2 ± 0.7 b
05/04/84, dry season N = 30	74.9 ± 0.3 cd	58.7 ± 0.5 bc	58.1 ± 0.4 a	16.7 ± 0.9 ab
15/05/84, wet season N = 20	73.4 ± 0.5 ab	56.9 ± 0.5		16.2 ± 0.9 ab
10/07/84, dry season N = 16	74.4 ± 0.7 abc	57.8 ± 0.8 c	57.6 ± 0.7 ab	17.0 ± 0.5 ab
30/09/84, dry season N = 18	75.4 ± 0.9 abcde	60.6 ± 1.0 ab		16.5 ± 0.9 ab
25/11/84, wet season N = 18	75.3 ± 0.3 cde	61.6 ± 0.7 a	54.5 ± 0.5	16.0 ± 0.3 a

[1]Means of the same forage and column with a common suffix are not statistically different at the 95% confidence level.

Responses of Vegetation and Ground Cover to Spraying a High Elevation, Big Sagebrush Watershed with 2,4-D

DAVID L. STURGES

Abstract

Total production of aboveground biomass on a 238-ha watershed was not affected when big sagebrush *(Artemisia tridentata)* was controlled by aerial application of 2,4-D (2,4-dichlorophenoxyacetic acid). Grass production increased in the 5 years following treatment, but forb production was not affected by treatment because forbs were in an early phenological stage when sprayed. Five years after treatment, there was a 37% decrease in bare ground, and a 29% and 61% increase in litter and grass cover, respectively, on the treated watershed compared to an adjacent untreated watershed.

A cost effective method of increasing the quantity of forage available for livestock on big sagebrush *(Artemisia tridentata)* rangeland involves application of 2,4-D (2,4-dichlorophenoxyacetic acid) to control shrub growth (Nielsen 1979, Kearl and Freeburn 1980, Schmisseur and Miller 1980).[1] Spraying is feasible for sites that have valuable herbaceous species capable of fully utilizing site resources (Pechanec et al. 1965). Grass production commonly doubles or triples after treatment (Hyder and Sneva 1956, Hedrick et al. 1966, Tabler 1968, Schumaker and Hanson 1977, Sturges 1977, Miller et al. 1980). Forbs are adversely affected by 2,4-D, so that increases in grass productivity are partially offset by decreases in forb productivity (Blaisdell and Mueggler 1956, Laycock and Phillips 1968, Tabler 1968, Schumaker and Hanson 1977, Miller et al. 1980).

The influence of sagebrush control on ground cover characteristics has received little attention compared to changes in vegetation production. Basal area of grasses increased about one-third when big sagebrush was controlled by spraying or grubbing and most of the increase occurred the first year after treatment (Hyder and Sneva 1956). Reseeding two small sagebrush-dominated watersheds that had been depleted of herbaceous species, to beardless bluebunch wheatgrass *(Agropyron inerme)*, greatly reduced the area of bare soil (Shown et al. 1972). The reduction in bare soil was believed influential in reducing surface runoff generated by summer rainstorms, and in reducing the sediment concentration of runoff water (Lusby 1979).

The objective of this study was to measure changes in vegetation production and composition, and changes in watershed ground cover characteristics on a watershed sprayed with 2,4-D to control big sagebrush. The study was part of a long-term paired watershed investigation, in which hydrologic and wildlife responses to spraying also were evaluated.

Study Area

The study was conducted at the Stratton Sagebrush Hydrology Study Area, in southcentral Wyoming, about 32 km west of Saratoga. Loco and Sane Creek watersheds, 663 ha and 238 ha, respectively, were utilized. The watersheds ranged between 2,340 m and 2,470 m in elevation. Loco Creek flows easterly, and the watershed has primarily north and south exposures. Sane Creek drains in a southerly direction, and the watershed has east, south, and west exposures (Fig. 1). Perennial flow in Loco Creek begins at a spring about 1.6 km above the stream gage, while Sane Creek begins at a spring 45 m above the stream gage. The Loco Creek drainage remained in an undisturbed state throughout the study while the Sane Creek drainage was sprayed.

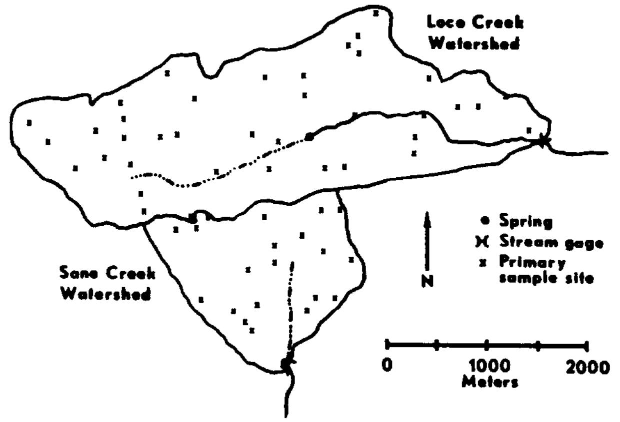

Fig. 1. *The Stratton Sagebrush Hydrology Study Area. Vegetation and ground cover characteristics were sampled at 38 primary sampling locations on Loco Creek watershed and 20 primary sampling locations on Sane Creek watershed, indicated by an X.*

Annual precipitation from 1969 through 1982 was 52.6 cm. About 75% of precipitation fell as snow; summer rainfall (June–September) was 10.6 cm. Average annual temperature was 2.7° C; maximum daily temperatures were well below freezing from mid-November through March. Average monthly wind speed exceeded 5 m/s between November and April. Wind speed was at a maximum in January, with a speed of 8.3 m/s, and fell to about 3.5 m/s in July and August.

Soils developed in place from the Brown's Park Formation and are primarily Argic Cryoborolls. A and B horizons typically have a loam texture, but there are wide differences in profile development. The combined depth of A and B horizons of the Haggerty series located in areas of moderate snow accumulation extends to 1.2 m. Areas of little snow accumulation typically have soils belonging to the Kimmons series where A and B horizons have a combined depth of 0.5 m, or to the less well-developed Roxal series, where the A horizon is 15 cm deep and a B horizon is lacking.

Mountain big sagebrush *(A.t.* ssp. *vaseyana)* up to 1 m tall characterizes areas of deeper soils, while Wyoming big sagebrush, (*A.t.* ssp. *wyomingensis*) or mixed stands of Wyoming big sagebrush and black sagebrush *(A. nova)* indicate areas of shallow soil development. Herbaceous vegetation in mountain big sagebrush stands is composed primarily of grasses such as Idaho fescue *(Festuca idahoensis)*, blue grass (*Poa* sp.), needlegrass (*Stipa* sp.) and sedge *(Carex interior)*. June grass *(Koeleria macrantha)*, bluebunch wheatgrass *(Agropyron spicatum)*, and bottlebrush squirreltail *(Sitanion hystrix)* are typical of more xeric sites. Forbs are a minor vegetation component evident primarily in the spring. The more abundant forbs associated with mountain big sagebrush are

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[1]This article reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended. Use all pesticides selectively and carefully; read and follow directions on the label.

silky lupine *(Lupinus argenteus)*, buckwheat *(Eriogonum ovalifolium)*, yarrow *(Achillea millifolium* ssp. *lanulosa)*, and groundsel *(Senecio integerrimus)*. The cushion plants, goldenweed *(Haplopappus acaulis)*, sandwort *(Arenaria hookeri)* and phlox (*Phlox* sp.), are common on windswept upland and ridge sites.

The study site lies within a sheep allotment administered by the Bureau of Land Management, USDI. Sheep typically moved onto the Stratton area in late May and grazed 1 month, then returned for another 4 to 8 weeks of grazing in August. Vegetation utilization was light to moderate throughout the study. The treated watershed was deferred from grazing in the treatment year and for 2 years after treatment.

Methods

Vegetation Sampling Network

A two-stage sampling design was used to estimate watershed ground cover characteristics and vegetation production. Primary sample units consisted of square blocks 127 m on a side (1.6 ha). Thirty-eight primary units were randomly placed in Loco Creek watershed and 16 primary units were randomly placed in Sane Creek watershed. Subsequently, 4 additional units were added to the Sane Creek network to provide 20 primary sample units (Fig. 1). Five secondary locations were randomly selected within each primary unit for measuring vegetation production and ground cover.

Ground Cover

The 5 secondary locations within each primary sample unit served as the reference end for 30-m long ground cover transects. Transects were oriented in a north-south direction, and the ends were permanently marked with pipe. A steel tape was stretched between the pipe at sagebrush canopy height and ground cover measurements were taken at 0.3-m intervals along the tape (Fig. 2). Thus, 100 measurements of ground cover were made on each transect, which provided 500 values at each primary site.

Ground cover was determined using a brass rod tapered to a point on one end. The rod was 76 cm long and 4.7 mm in diameter and was lowered to the ground surface in a vertical plane with the aid of an attached bubble level (Fig. 2). Material encountered at the ground surface was classified as bare ground, rock, litter, erosion pavement, grass (including sedge), forb, cushion plant, sagebrush, or other shrub. Erosion pavement was defined as rocks smaller than 13 cm in maximum length. Only basal hits on the live and rooted portion of a plant were recorded as vegetation. Aerial hits on the sagebrush canopy were also recorded.

Analysis of the initial ground cover data collected in 1968 indicated that Loco and Sane Creek watersheds had similar characteristics for all parameters. Further, it was necessary to sample only about 20 primary sites to achieve a sampling precision within 20% of the mean at the 95% confidence level. Time and manpower constraints prevented annual measurements of ground cover on Loco and Sane Creek watersheds and a triannual sampling program was adopted. The 2 watersheds were considered to be a common population before treatment; therefore, sampling was conducted at randomly selected primary sites from both watersheds in 1971 and 1974. Watersheds were independently sampled after spraying, but ground cover measurements on Loco Creek watershed were made the year after measurements on Sane Creek watershed.

Vegetation Productivity

Pipe marking the ends of ground cover transects served as corners of permanent plots used for measuring aboveground biomass. Data collection began in 1968 and ended in 1981 and all primary sites on both watersheds were measured each year. Data were collected in late August or early September from 1968 to 1971, and in mid-July, as most grass species were maturing, in succeeding years.

An electronic capacitance meter that sampled a plot 30 × 61 cm

Fig. 2. *Ground cover was measured at intervals of 0.3 m on transects 30 m in length (upper). A rod was lowered to the ground surface in a vertical plane with the aid of a bubble level to measure sagebrush canopy and ground cover characteristics (lower).*

was used to measure total herbaceous biomass. Use of the meter was feasible because woody stem and trunk material of sagebrush contributes little to the capacitance value (Morris et al. 1976). Meter values were converted to vegetation weight by a regression relationship developed each year by double sampling. Data to establish the regression were gathered on 2 plots at each primary site. Plots were randomly located from the ends of ground cover transects. These plots were measured with the capacitance meter and then clipped at a 2.5-cm stubble height. Thus, 12 locations were measured at each primary site each year to estimate production on a watershed.

The 3-dimensional technique described by Currie et al. (1973) and Morris et al. (1976) was utilized in clipping leaves and current annual twig growth of sagebrush as well as grasses and forbs. Vegetation subsequently was oven-dried at 105°C for 24 hours before weighing. Beginning in 1972, herbage on clipped plots was separated into sagebrush, grass, and forb categories to determine vegetation composition. Sedges were included with grasses because of morphological similarities and because of their minor importance as a vegetation component.

Analysis of data collected in 1968 indicated that the regression relationship between capacitance value and vegetation weight for Loco and Sane Creek watersheds belonged to a common population. Consequently, a single regression relationship developed from data collected on both watersheds was used to convert meter readings to herbage weight in years before spraying Sane Creek watershed. Thereafter, independent regression relationships were developed for the 2 watersheds.

Sagebrush Density and Mortality

Sagebrush density on Loco and Sane creek watersheds was determined 2 years before treatment by counting the number of plants rooted within belt transects 7.6 m long and 1.3 m wide (0.001 ha). One ground cover transect at each primary sampling unit was randomly selected for sampling. Belt transects originated at the south end of the ground cover transect and extended toward the north end.

The effect of spraying on individual sagebrush plants was assessed in July 1977, 14 months after Sane Creek watershed was sprayed. The same sampling procedure used to estimate sagebrush density before treatment was used, except that measurements were taken on 2 randomly selected transects at each primary sampling unit. The canopy area of individual sagebrush plants rooted within a belt transect was classified as 0–25%, 26–50%, 51–75%, 76–99%, or 100% dead. Average sagebrush mortality for each transect was calculated using the midpoint percentage value for each category of canopy damage and the number of plants within the category.

Sagebrush Control on Sane Creek Watershed

Sane Creek watershed was treated in 1976 to control sagebrush. Loco Creek watershed remained undisturbed throughout the study to provide a basis for assessing posttreatment changes on Sane Creek watershed. Standard Bureau of Land Management practices for aerial application of 2,4-D were followed. A buffer strip of unsprayed sagebrush that was 60 m in width and 300 m long was left immediately above the stream gage as wildlife habitat. The 2,4-D was applied in 28 liters of diesel oil/ha at an average rate of 2.2 kg acid-equivalent/ha. The maximum concentration of 2,4-D detected in water leaving Sane Creek watershed was 5 parts/billion at the completion of spraying (Schroeder and Sturges 1980). These levels are far below concentrations identified as toxic to fish (Juntunen and Norris 1972, Woodward and Mayer 1978). Herbicide was not detected in water 9 days after treatment.

Statistical Analysis

Mean values of ground cover and the associated 95% confidence interval were determined each year a watershed was sampled, utilizing analysis procedures for a two-stage sampling design. Analyses were based on the number of occurrences of each parameter on individual transects. There was a 1-year difference in measurement dates on Loco and Sane Creek watersheds in years after treatment, but mean ground cover values are believed representative of changes occurring on a watershed between the triannual sampling dates.

The analysis for total herbaceous production was based on data collected with the capacitance meter. Eight years of information (1968–1975) were available prior to spraying, and 5 years (1977–1981) were available after treatment. Information from 1976, when Sane Creek watershed was sprayed, was excluded from analysis. Data from clipped plots collected from 1972 to 1975 and 1977 to 1981 were used in the analysis of percentage composition data, and for analysis of sagebrush, grass, and forb production. Percentage composition data were transformed using the arcsin transformation before analysis.

Vegetation production and composition data were tested for statistical significance using a two factor analysis of variance (Green 1979). One factor compared watersheds, and the other factor compared pretreatment and posttreatment time periods. A significant interaction between watersheds and treatment time periods indicated that spraying altered the posttreatment average on Sane Creek watershed compared to the average for Loco Creek watershed. Significant annual differences in vegetation composition data were identified using a *t* test. A 0.05 probability level was used to indicate statistical significance throughout this study.

Results

Sagebrush Mortality

In 1974 the density of sagebrush on Loco and Sane Creek watersheds was 36,800 and 35,600 plants/ha, respectively. Spraying reduced sagebrush canopy cover 77% of the Sane Creek drainage the year after treatment, and reduced the number of live plants 62% (Table 1).

Table 1. Canopy kill of individual sagebrush plants the year after Sane Creek watershed was sprayed with 2,4-D.

Percent of plants	Percent canopy kill
16	0–25
7	26–50
9	51–75
6	76–99
62	100
Avg.	77

Vegetation Composition and Productivity

The composition of vegetation on Loco and Sane Creek watersheds, as determined from clipped plots, was similar before treatment (Fig. 3). Sagebrush contributed about 60% of total vegetation production, grasses 25%, and forbs the remaining 15%. The response of vegetation on Sane Creek watershed to application of 2,4-D was typical of areas with adequate residual popula-

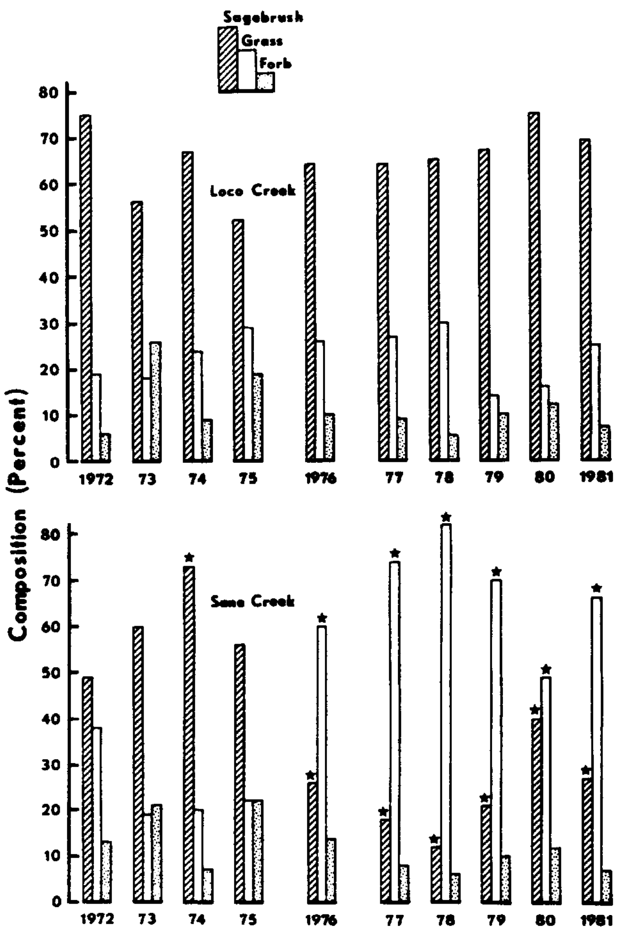

Fig. 3. *Percentage composition of vegetation on Sane and Loco Creek watersheds. A star indicates that differences in composition between watersheds for the class of vegetation were significant at the 0.05 level of probability.*

tions of herbaceous species. Sagebrush contributed an average of 23% of total production in the 5 years after treatment, while grasses provided 68% of the total. Sagebrush and grass composition on the 2 watersheds were significantly different beginning in 1976, with treatment of Sane Creek watershed (Fig. 3). Percentage forb composition was not affected by spraying as it decreased 7% on both Sane and Loco Creek watersheds in years after treatment compared to the average pretreatment value.

Total annual production, including that of sagebrush, is shown in Table 2 for the 2 watersheds. Total production averaged 926 kg/ha for Loco Creek watershed and 846 kg/ha for Sane Creek watershed prior to spraying. Total production was approximately 100 kg/ha less on both watersheds after spraying. Thus total herbaceous production was not significantly affected by treatment.

Table 2. Total annual herbaceous production and 95% confidence interval for Loco and Sane Creek watersheds, based on plots read with electronic capacitance meter.

Year	Annual watershed production: Loco Creek	Annual watershed production: Sane Creek
	kg/ha	
	Before treatment	
1968	1,017±109	680±116
1969	699±133	827±136
1970	772±111	790±124
1971	1,085±111	1,174±128
1972	1,033±249	568± 94
1973	960±104	765±141
1974	814± 92	921±212
1975	1,024±105	1,044±128
Avg.	926	846
1976	907± 97	591± 90
	After treatment	
1977	691± 95	519± 66
1978	782± 84	831± 84
1979	880±102	668± 68
1980	905± 96	663± 93
1981	923± 83	859± 92
Avg.	836	708

While total yield of herbaceous matter was unaffected by spraying, data from clipped plots indicated that the herbicide treatment increased the quantity of forage available for livestock. Grass production on Sane Creek watershed more than doubled after spraying on comparison to Loco Creek watershed, while sagebrush production decreased 71%. Both changes were statistically significant (Table 3). Average forb productivity was almost identical on Loco and Sane Creek watersheds in years before and after spraying (Table 3).

Table 3. Herbaceous productivity of sagebrush, grass and forb vegetation on Loco and Sane Creek watersheds between 1972 and 1981, based on data from clipped plots.

Year	Sagebrush: Loco	Sagebrush: Sane	Grass: Loco	Grass: Sane	Forb: Loco	Forb: Sane
			kg/ha			
			Before treatment			
1972	645	245	168	193	49	63
1973	528	507	174	157	245	174
1974	515	818	188	230	73	82
1975	521	543	289	215	194	215
Avg.	552	528	205	199	140	134
1976	550		232		84	
			After treatment			
1977	400	78	166	315	55	36
1978	408	87	192	585	29	45
1979	515	110	180	370	72	50
1980	609	244	130	293	69	74
1981	556	199	204	484	48	55
Avg.	498	144*	174	409*	55	52

*Value for Sane Creek significantly different from Loco Creek

Ground Cover

Average watershed ground cover values for each parameter are tabulated in Table 4. Average values for bare ground, litter, grass, and aerial sagebrush cover, with their associated confidence intervals, are shown in Figure 4. At the beginning of the study in 1968, no significant differences were present between watersheds for any ground cover parameter. As expected, aerial sagebrush cover on Sane Creek watershed significantly declined the year after treatment compared to Loco Creek watershed. Sagebrush canopy cover on Sane Creek watershed increased 68% between the first and fourth year after spraying. Cushion plants also were damaged by herbicide application, and their cover significantly decreased from the 1968 pretreatment level. Litter cover on the Sane Creek watershed increased significantly in years after spraying, while bare ground decreased.

Ground cover of grasses steadily declined between study initiation and treatment of the Sane Creek drainage. Data collected in 1977 on Sane Creek watershed and in 1978 on Loco Creek watershed, indicated that grass cover on both watersheds was about 50% less than at the beginning of study. During the next 3 years, grass cover on Sane Creek watershed nearly doubled, but changed little on the untreated Loco Creek watershed (Fig. 4).

Hydrologic cover, taken as the sum of vegetation cover plus litter cover, is an indication of the potential for rainfall runoff; values throughout the study are tabulated in Table 4. Hydrologic cover values for Sane Creek watershed increased after spraying, but remained relatively constant on Loco Creek watershed. At the

Table 4. Ground cover and aerial sagebrush cover on Loco and Sane Creek watersheds from 1968–1981, and number of primary sites that were sampled.

Watershed	Year	No. primary sites	Bare ground	Erosion pavement	Rock	Litter	Grass	Forb	Cushion plant	Sage-brush	Other shrub	Aerial sagebrush	Hydro-logic cover
			Percent ground cover									Percent	
Loco	1968	38	28.27	9.66	3.88	43.42	7.12	0.23	5.24	2.07	0.12	18.66	58.19
Sane	1968	16	28.95	6.65	3.18	45.88	6.39	0.15	7.03	1.73	0.06	17.85	61.23
Combined	1971	17	26.00	10.16	4.74	45.95	6.06	0.94	5.36	0.75	0.02	18.06	59.09
Combined	1974	20	27.29	9.02	6.28	48.35	4.63	0.61	3.26	0.55	0.01	16.25	57.41
Loco	1978	20	24.17	9.14	4.38	55.76	3.40	0.51	1.98	0.65	0.01	14.09	62.31
Sane	1977	16	16.99	12.05	3.64	63.09	3.10	0.71	0.28	0.13	0.03	2.58	67.33
Loco	1981	20	20.99	14.26	5.49	51.75	3.63	0.56	2.73	0.58	0.01	13.30	59.26
Sane	1980	20	13.27	9.69	3.06	67.00	5.86	0.36	0.59	0.17	0.00	4.34	73.98

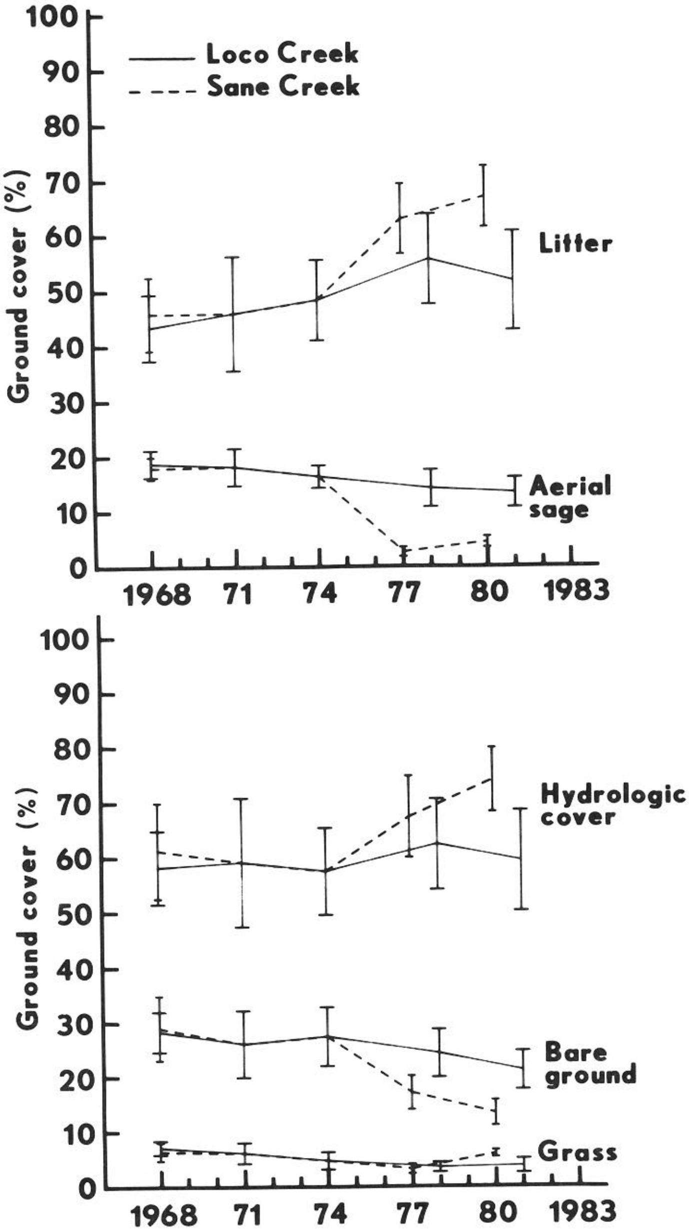

Fig. 4. *Average ground cover and associated 95% confidence intervals for selected measurement parameters on Sane and Loco Creek watersheds from 1968–1981.*

end of the study, differences between watersheds were significant at a 0.10 probability level.

Loco Creek watershed was untreated throughout the study and received reasonably uniform grazing use. Nevertheless, significant changes in some ground cover characteristics did occur between 1968 and 1981. Bare ground, cushion plant, and grass cover significantly decreased as did aerial sagebrush cover which declined about 30%.

Discussion and Conclusions

Spraying Sane Creek watershed with 2,4-D increased forage available for livestock and improved soil surface conditions as measured by hydrologic cover. Improvement in hydrologic cover resulted primarily from an increase in litter cover and a reduction in bare soil. The differential effects of 2,4-D on grasses and broadleafed plants tended to be somewhat offsetting. Grass cover on the treated watershed increased after spraying in relation to the

Fig. 5. *A snowmold fungus active on Loco Creek watershed in later years of study was effective in controlling mountain big sagebrush in areas of deep snow accumulation.*

untreated watershed.

Total production of aboveground biomass on Sane Creek watershed was not changed by spraying compared to production on the untreated watershed, but vegetation composition was altered significantly. Grass production increased an average of 135% in the 5 years after spraying, and sagebrush production decreased 71%, thus increasing the quantity of forage available for livestock. Because spraying occurred before most forb species were actively growing, it had little effect on forb productivity. Increased growth by grass plants present at the time of spraying was responsible for the large increase in grass production the year after treatment, rather than establishment of new plants. An additional 3 years were required for ground cover of grasses to similarly increase (Fig. 4). Hyder and Sneva (1956) also attributed the marked increase in grass production after sagebrush control primarily to vigorous growth by existing grass plants rather than enlargement of their basal area or establishment of new plants. Basal intercept of grasses was about a third greater 3 years after treatment in their study and most of the increase occurred the first year.

Sagebrush control within Sane Creek watershed was erratic. Complete kill of individual sagebrush plants ranged from 32% to 90% at individual primary sampling units. Sagebrush plants were at different phenological stages when sprayed because of differences in length of time required for snow to melt. Sagebrush on the east side of the watershed, where little snow accumulates, was a healthy green color, characteristic of sagebrush prior to twig elongation. Vegetation development was not nearly as advanced on the west side of the watershed, which is largely a snow depositional zone. However, sagebrush plants that had just emerged from the snowpack were as susceptible to the herbicide as plants in a vigorous growth stage. Neither were there readily apparent differences in mortality between the mountain and Wyoming subspecies of big sagebrush. The incomplete kill of sagebrush probably resulted from storage of the herbicide concentrate in an unheated warehouse the winter preceding treatment. Partial freezing of the concentrate at this time probably reduced its effectiveness.

Vigorous regrowth of partially killed sagebrush plants resulted in a rapid increase of sagebrush production on Sane Creek watershed in years after spraying. The effective treatment life will probably be shorter than if the degree of sagebrush control had been greater. Production of herbaceous matter by sagebrush was less then 100 kg/ha the first 2 years after spraying, but increased to

244 and 199 kg/ha in the fourth and fifth year after spraying, respectively (Table 3). The percentage contribution of grasses to the production total decreased in direct proportion to increasing sagebrush productivity (Fig. 3).

The decline of sagebrush cover on Loco Creek watershed between 1968 and 1981 was attributable primarily to a snowmold fungus that was first observed in 1973. Damage was especially severe between Loco Creek and the southern watershed boundary where snow accumulates in deep drifts (Fig. 5). The fungus develops on leaves and herbaceous stems while plants are snow-covered and a cottony-appearing mycelium covers infected branches when snow melts. The incidence of infection progressively increased as maximum snow depth increased from 40 cm to 120 cm (Sturges and Nelson 1986). Snowmold damage was confined to stands of mountain big sagebrush, because stands of Wyoming big sagebrush or black sagebrush were typically covered by less than 40 cm of snow.

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Differences in Big Sagebrush (*Artemisia tridentata*) Plant Stature along Soil-water Gradients: Genetic Components

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Abstract

Genotypic and phenotypic variations are characteristic among big sagebrush *(Artemisia tridentata)* plants. One obvious expression is the variability of big sagebrush plant stature along soil-water gradients. Large plants are usually associated with mesic habitats such as drainages or swales, while small plants occupy the xeric portions of the gradients. The purpose of this study was to investigate the genetic influence on big sagebrush plant stature along soil-water gradients. Leaf morphological, phenological, chromatographical, and cytological investigations evaluated potential genetic differences and examined possible subspecies status of the large and small plants. The results of these studies revealed a genetic difference between the large and small plants and confirmed subspecies status. The large plants were identified as basin big sagebrush *(A. tridentata* spp. *tridentata)* while the small plants were Wyoming big sagebrush *(A. tridentata* spp. *wyomingensis)*. Three additional studies examined possible differences in growth potential between the subspecies. A greenhouse and uniform garden study compared seedling and juvenile plant growth. Annual leader growth of mature plants was measured in native populations. Basin big sagebrush plants outgrew Wyoming big sagebrush in the greenhouse, uniform garden, and leader growth experiments. Difference in growth potential between the subspecies may be a consequence of ploidy differences.

The most common, important, and widely distributed woody sagebrush (*Artemisia* L. subgenus *tridentatae* (Rydb.) E.D. McArthur) is big sagebrush (*Artemisia tridentata* Nutt.). Big sagebrush is common on millions of hectares throughout western North America from southern Canada to northern Mexico (Beetle 1960, McArthur et al. 1981). This shrub has a wide range of adaptability and grows in various soil types and is associated with numerous plant species from low elevation valleys and plains to high mountain slopes and ridges (Morris et al. 1976, Winward and Tisdale1977, Winward, 1980). Big sagebrush provides browse and habitat for an array of wildlife and livestock, minimizes soil erosion, and is of value in mined-land reclamation.

Big sagebrush, as do other plant species, adapts to diverse environments through a combination of phenotypic plasticity and genotypic variation. As Caldwell (1979) theorized, the phenotypic diversity of plants is remarkable, but it is not sufficient to accommodate extensive environmental conditions that are found in the range of a widely distributed species such as big sagebrush. Presently, the big sagebrush complex consists of 4 subspecies (Beetle 1960, Beetle and Young 1965, Goodrich et al. in press, McArthur 1983) which are: basin big sagebrush *(A. tridentata* Nutt. ssp. *tridentata),* Wyoming big sagebrush (*A. tridentata* Nutt. ssp. *wyomingensis* Beetle and Young), mountain big sagebrush (*A. tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle), and subalpine sagebrush (*A. tridentata* Nutt. ssp *speciformis* (Osterhout) Goodrich and McArthur).

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Genotypic and phenotypic variation is characteristic of big sagebrush (Beetle 1960, Hanks et al. 1973, McArthur et al. 1981, West et al. 1978). An obvious expression is the variability in big sagebrush plant stature along soil-water gradients (Beetle 1960, Hall and Clements 1923, Hanks et al. 1973). Large plants may reach a height of 3.5 to 5.0 m in mesic habitats such as drainages or swales, while plants less than 1.0 m tall are associated with the xeric portions of moisture gradients.

Considering the differences in big sagebrush plant stature, a logical question arises: Are the differences in plant stature due to genetic or environmental influences? The research herein discusses the influence of genetics on big sagebrush plant stature. Edaphic differences associated with the large and small big sagebrush plants are reported elsewhere (Barker 1981, Barker and McKell 1983).

Study Sites

Three sites were selected for study because of differences in plant stature that were observed within relatively short distances (Barker and McKell 1983). At each site, plant height decreased with distance along a transect at a right angle to a drainage. Plant height along the drainages averaged 2.5 m and decreased to less than 1.0 m. The distance of the plant height gradient transects were 60, 40, and 100 m for Sage Creek, Greasewood Wash, and Maeser, respectively.

The Sage Creek study site is located 4.8 km west of Sage Creek Junction on Highway 30 in Rich County, Utah. Average annual precipitation ranges from 25 to 30 cm. The frost-free period is from 55 to 65 days (personal communication, Soil Conservation Service, Logan, Utah). The site has an elevation of 1,950 m, northern exposure, and slope variation of 2 to 5%. Soils associated with the large and small plants are respectively, Xeric Torrifluvent and Typic Haplargid.

The Greasewood Wash study site is located 10.2 km north of the Jim Bridger Coal Mine along Sweetwater County Road 4-17 in southern Wyoming. Average annual precipitation varies from 12 to 22 cm. The frost-free period ranges from 80 to 110 days (personal communication, Soil Conservation Service, Rock Springs, Wyoming). The site has an elevation of 2,063 m, western exposure and slope of about 3%. The soils associated with the large and small plants are respectively, Xerollic Torrifluvent and Typic Camborthid.

The Maeser study site is located in the Uinta Basin, 11.2 km north of Maeser, Utah along Taylor Mountain Road. Average annual precipitation is 25 to 30 cm. The frost free period ranges from 110 to 140 days (personal communication, Soil Conservation Service, Vernal, Utah). The site has an elevation of 2,296 m, southern exposure, and slope of 3%. The soil associated with the large and small plants is an Ustic Torrifluvent.

Methods and Materials

To evaluate genetic differences and verify possible subspecific status between the large and small big sagebrush plants, leaf morphological, phenological, chromatographical, and cytological investigations were conducted. Three additional studies examined potential differences in growth rates between the large and small statured plants. Greenhouse and uniform garden experiments compared seedling and juvenile plant growth, respectively. Also, annual leader growth of mature plants was measured at each study site.

Leaf Morphology

Leaf length, leaf width, and leaf length/width ratios were compared to evaluate morphological differences between the large and small plants at each study site. Twenty plants per size class per study site were randomly selected. Leaves for measurement were randomly selected from the top portions of the plants. Data were statistically compared using analysis of variance and Duncan's new multiple range test (Ott 1977).

Phenology

To compare the phenological progression during the 1980 growing season, 10 plants per size class per site were randomly selected. The methods described by West and Wein (1971) for phenological plant comparisons were followed. The phenological index used was modified from DePuit and Caldwell (1973). Phenological observations were conducted every 2 weeks starting in May 1980. To reduce variability, the southwest portion of each plant was marked and used for determining phenological development. Data were compared using analysis of variance and Duncan's new multiple range test (Ott 1977).

Chromatography

A portion of annual growth was harvested from 20 plants equally spaced along a transect (3 transects per site). Plant materials were collected on 23 and 24 September 1980 at Greasewood Wash and Maeser and 1 October 1980 at Sage Creek. A total of 60 plants per study site were analyzed. Two-dimensional, ascending, paper chromatography as described by Hanks et al. (1973) was followed. The unweighted paired group method using arithmetic averages (UPGMA) cluster analysis with the Jaccard primary resemblance coefficient grouped the chromatograms into meaningful results (Sokal and Sneath 1973).

Cytology

Mitotic chromosome analyses were made for 5 plants per size class at each site to ascertain if ploidy differences existed using methods described by McArthur et al. (1981). Plants were randomly selected from the ends of each gradient. Mitotic spreads were prepared by squashing root tips of 2- to 3-day old seedlings. To avoid the problem of endoploidy, somatic chromosomes were counted in 3 root tips per parent plant and 3 to 4 cells per root tip. A Zeiss RA research microscope with 100 × oil immersion and phase contrast was used to observe the chromosomes.

Greenhouse Study

The objective of this study was to compare seedling growth under 3 soil-water regimes. Seeds were collected 3 and 4 November from each study site. At the same time, the surface top 15 cm of soil was collected to serve as the plant growth medium.

In the greenhouse, the amount of water at field capacity (F.C.), field capacity minus 5% water content (F.C.–5%), and field capacity minus 10% water content (F.C.–10%) was estimated for each of the 6 soils.

Plastic lined, 973 ml (1 quart), paper milk cartons were used as plant containers. One kilogram of air-dried soil was placed in each container. Enough water was then added to bring the soil to F.C., F.C.–5%, or F.C.–10%. A plastic bag was placed over the containers to reduce evaporation. Seeds were sown on 26 January 1980. The plastic bags were maintained over the containers until the seedlings were about 1.0 cm tall. Then, the plastic bags were cut and laid directly on the soil with a small hole to allow seedling growth. At this time, seedlings were thinned to one per container.

To maintain the proper water content, containers were weighed every 2 to 3 days and then brought up to weight with water. Seedling height was measured every 2 weeks until harvest. Seedlings were then oven-dried at 80° C for 24 h and weighed. Data were compared using analysis of variance and Duncan's new multiple range test (Ott 1977).

Uniform Garden Study

The uniform garden experiment compared growth of juvenile plants associated with each size class per site. The garden was in the Green Canyon Research Area of the Ecology Center, Utah State University, located northeast of Logan, Utah.

Seeds were collected on 3 and 4 November 1979 from 10 randomly selected plants per size class per study site. Seeds were germinated in plastic trays and then 12 seedlings per parent plant per size class per site were planted into containers on 4 February 1980. The growth medium was peat moss, vermiculite, and native soil (2:2:1 by volume). On 5 May 1980, seedlings were placed out-of-doors for hardening. Six seedlings per parent plant were transplanted on 5 June 1980. A completely randomized field-plot design was used. Plant height was measured 7 November 1980. Data were analyzed using analysis of variance and Duncan's new multiple range test (Ott 1977).

Leader Length

Leader length was used to assess the annual growth of mature plants at each site. Twenty plants per size class per site were randomly selected to be measured in the fall, 1980. The five-longest stems growing on the top portion of a plant were measured. Data were statistically compared by analysis of variance and Duncan's new multiple range test (Ott 1977).

Results

The morphological, phenological, chromatographical, and cytological investigations confirmed that the large and small plants were, respectively, basin big sagebrush and Wyoming big sagebrush. Hereafter, the large and small plants will be referred to as basin big sagebrush and Wyoming big sagebrush, respectively.

Leaf Morphology

Leaf-length/width ratios were significantly different ($P<0.05$) between basin and Wyoming big sagebrush plants (Table 1). Basin

Table 1. Leaf morphological comparisons between ssp. *tridentata* and *wyomingensis*.

Characteristic	*Tridentata*	*Wyomingensis*
Leaf length (mm)	12.7a[1]	10.3a
Leaf width (mm)	2.9a	3.0a
Leaf length/width	4.6a	3.5b

[1]Each mean is the average of 60 plants. Those means that are followed by the same letter for each characteristic are not significantly different ($P>0.05$).

big sagebrush had larger ratios than Wyoming big sagebrush. Leaf length and width were statistically similar for the subspecies. The site, subspecies interaction was not significant ($P<0.05$).

Phenology

Phenological progression for the 2 subspecies was similar with the exception of flower initiation and seed development (Fig. 1). On 15 April, leaf buds were beginning to swell. From 13 May to 8 July, vegetal growth was rapid, but by 25 July, vegetal growth was reduced. However, reproductive shoot and flower bud growth was underway. By 5 September, both basin and Wyoming big sagebrush plants were flowering. Seed development was underway on 23 September. Differences in phenological development were found on 10 August, 5 September, and 23 September with Wyoming big sagebrush being significantly more advanced ($p<0.05$) than basin big sagebrush.

Chromatography

Chromatographic differences were found between the subspecies (Table 2). All spots were common to both subspecies except number 3, which did not occur on chromatograms of basin big sagebrush. Spots numbered 1, 5, 35, 37, and 38 were light colored on basin big sagebrush chromatograms and intensely colored on

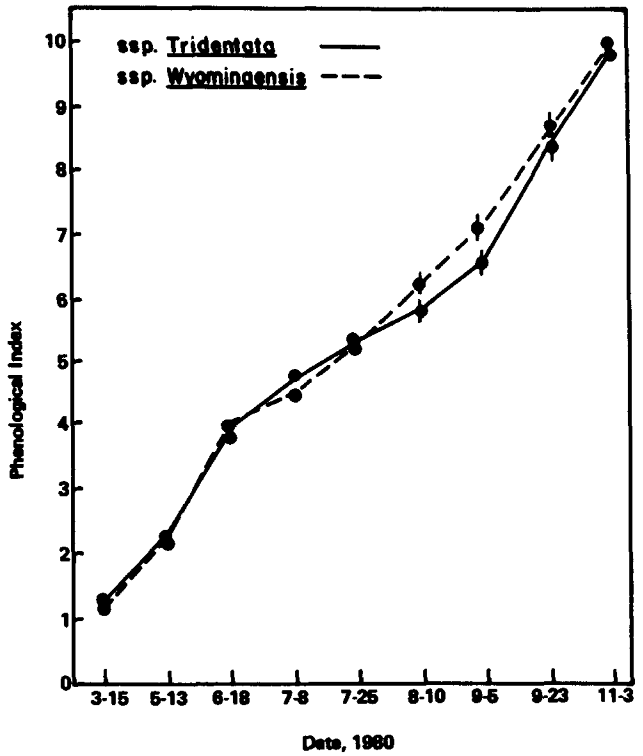

Fig. 1. *Phenological development of ssp.* tridentata *and* wyomingensis *plant populations during 1980. Data points are the average of 30 plants with confidence intervals formed at the 95% level. The phenological index is as follows: 0 = winter dormancy; 1 = leaf bud swell; 2 = leaf emergence; 3 = vegetal growth; 4 = floral shoot growth; 5 = flower bud swell; 6 = flowering begins; 7 = flowering; 8 = seed development; 9 = dispersion; 10 = senescence.*

Table 2. Chromatographic spot frequencies, colors, and color intensities for ssp. *tridentata* and *wyomingensis*.

	Spot color[1]		Color intensity[2]		Spot frequency	
Spot	UV	UV+NH3	*Tridentata*	*Wyomingensis*	*Tridentata*	*Wyomingensis*
1	yo	yo	1	3	0.89	1.00
3	yo	yo	-	1	0	0.26
5	yo	yo	1	3	0.93	1.00
7	y	y	1	1	0.27	0.26
10	v	vb	2	2	0.96	0.98
15	dv	dvb	3	3	1.00	1.00
20	lb	lb	1	1	0.22	0.12
25	lb	yg	1	1	0.68	0.60
30	bv	bv	1	1	0.57	0.70
33	—	v	1	1	0.07	0.12
35	bb	bb	1	3	0.68	0.88
37	-	o	1	3	0.21	0.46
38	-	v	1	3	0.49	0.75
39	-	v	1	1	0.67	0.64
40	b	y	2	3	1.00	1.00
45	bv	bv	1	1	0.02	0.09
47	-	v	1	1	0.44	0.43
50	p	yp	1	1	0.02	0.09
55	dv	vb	3	3	1.00	0.98
58	db	yg	1	1	0.21	0.23
65	b	yg	2	2	1.00	1.00
70	lb	yg	1	1	0.07	0.02
75	v	vb	1	1	0.92	0.88
80	-	bg	1	1	0.77	0.79

[1]uv = ultraviolet light, NH3 = ammonia vapor, [illegible]
vb = violet brown, dv = deep violet, dvb = deep [illegible]
green, bv = blue violet, bb = bright blue, o = ora[illegible]
db = dark blue, bg = blue green.
[2]1 = light, 2 = average, 3 = intense

Wyoming big sagebrush chromatograms.

Cluster anslysis used chromatogram spot frequencies to separate the subspecies for each study site. Basin and Wyoming big sagebrush were found to be about 60, 50, and 55% similar at Sage Creek, Greasewood Wash, and Maeser, respectively.

Cytology

At each study site basin big sagebrush plants were diploid ($2n$=18) and Wyoming big sagebrush plants were tetraploid ($2n$=36). One triploid ($2n$=27) seedling was identified from the Maeser study site, indicating some hybridization.

Greenhouse Study

Under uniform growing conditions basin big sagebrush seedlings grew taller than Wyoming big sagebrush seedling (Fig. 2). During the first 9 weeks, growth was the same for both subspecies. After that time, basin big sagebrush seedlings grew significantly ($P<0.05$) taller than Wyoming big sagebrush.

Seedlings responded differently to the 3 water treatments (Fig. 2). Seedling growth at F.C. was the tallest while at F.C.–10% seedling growth was the shortest. The subspecies, water treatment interaction for seedling height was not significantly different ($P>0.05$).

Seedling shoot biomass varied significantly ($p<0.05$) between subspecies and among water treatments. Basin big sagebrush and Wyoming big sagebrush mean seedling shoot production was 1.3 and 1.0 g, respectively. Seedlings grown at F.C. produced the most biomass while seedlings at F.C.–10% produced the least. Seedling biomass production at F.C., F.C.–5%, and F.C.–10% was respectively 1.9, 1.1, and 0.4 g. The subspecies, water treatment interaction for shoot biomass was not significantly different ($P>0.05$).

Uniform Garden

Juvenile plants showed differential growth in the uniform garden. Overall basin big sagebrush plants were significantly ($P<0.05$) taller than Wyoming big sagebrush plants; average height was 22.8 and 18.0 cm, respectively. There was also a significant difference ($P<0.05$) in the subspecies, site interaction (Table 3). Basin big sagebrush plants were taller than Wyoming big sagebrush plants from Greasewood Wash were taller but not significantly ($P>0.05$) so, than Wyoming big sagebrush plants from that location.

Table 3. Mean seedling height after one growing season in a uniform garden. Parent plants of the seedlings are located at the Sage Creek, Greasewood Wash, and Maeser Study sites.

Site subspecies	Height (cm)
Sage Creek	
Tridentata	24.1a[1]
Wyomingensis	18.9bc
Greasewood Wash	
Tridentata	18.3bc
Wyomingensis	15.4c
Maeser	
Tridentata	26.0a
Wyomingensis	19.7b

[1]Each mean is the average of at least 40 plants. Means followed by the same letter are not significantly different ($P>0.05$).

Leader Length

Annual leader growth of mature plants was significantly different ($P<0.05$). Subspecies leader length for basin and Wyoming big sagebrush plants was 14.5 and 8.5 cm, respectively. The subspecies, site interaction was not significant ($P>0.05$).

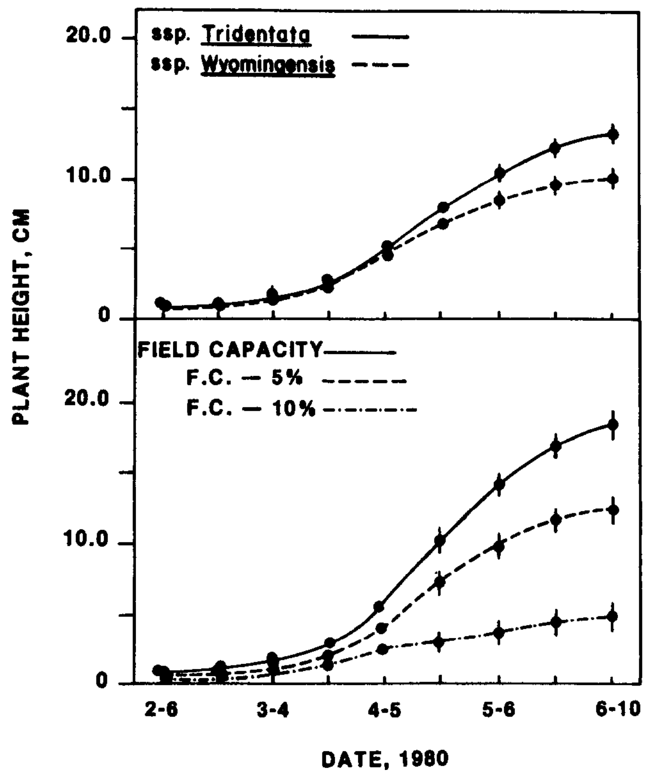

Fig. 2. *Growth of ssp.* tridentata *and* wyomingensis *(Top). Seedling growth on soil at field capacity, field capacity minus 5 and 10% water content (bottom). Data points are the average of 144 (top) and 96 (bottom) seedlings with confidence levels formed at the 95% level.*

Discussion

The leaf morphological, phenological, cytological, and chromatographical studies indicate genetic differences between the large and small plants along the soil water gradients and confirm subspecies status (McArthur et al. 1979, Winward 1980). Basin big sagebrush occurs mainly in the mesic habitats while Wyoming big sagebrush is restricted to the xeric habitats along the soil-water gradients (Barker and McKell 1983).

Leaf morphological features are one criterion used to separate the subspecies (Beetle and Young 1965, McArthur et al. 1979, Winward 1980). In the present study, differences in the leaf length/-width ratios were found. This supports the research of the beforementioned scientists.

Subtle differences were found in the phenological development between the 2 subspecies. Wyoming big sagebrush plants flowered earlier than basin big sagebrush. Winward and Tisdale (1977) reported no consistent differences in phenological development between basin and Wyoming big sagebrush plants in Idaho. However, Winward (1970) reported that Wyoming big sagebrush plants matured earlier when growing on extreme xeric sites. Perhaps the arid soil conditions associated with Wyoming big sagebrush at the current study sites induced early flower and seed set (Barker and McKell 1983).

As pointed out by various researchers, morphological differences among big sagebrush subspecies are subtle and variable (Beetle and Young 1965, West et al. 1978, Winward 1980). Thus chromatography has been suggested to be a helpful tool in separating the subspecies (Hanks et al. 1973, West et al. 1978). Two-dimensional, paper chromatography consistently separated the 2 subspecies at each of the current study sites.

The chromatographic study also was of value in elucidating the relationship of the subspecies along the soil water gradients. At each study site basin big sagebrush plants occurred in the mesic habitats while Wyoming big sagebrush plants occurred in the xeric habitats (Barker 1981, Barker and McKell 1983). Apparently, soil-water is the driving force that partitions the subspecies along the gradients. Wyoming big sagebrush in wildland situations usually occupies the more xeric soils than basin big sagebrush when the 2 subspecies are associated together (Barker and McKell 1983, Morris et al. 1976, Winward and Tisdale 1977). Other researchers have shown the effectiveness in soil water as a force in segregating plant genotypes (e.g., Brown et al. 1974, Freeman et al. 1976, Hamrick and Allard 1972).

Polyploidy confirms that genetic differences exist in big sagebrush plants along the soil water gradients. Winward and Tisdale (1977) found that Wyoming big sagebrush plants are tetraploid and that basin big plants are both diploid and tetraploid. McArthur et al. (1981) in an extensive chromosomal study of the woody sagebrushes reported Wyoming big sagebrush to be essentially tetraploid with occasional hexaploid plants. They also found diploid and tetraploid basin big sagebrush plants, but the diploid condition was the most common.

An interesting note is the relationship of ploidy level to soil moisture condition found in the current study. The diploid plants, basin big sagebrush, occurred in the mesic portion of the gradients. The tetraploid plants, Wyoming big sagebrush, occurred in the xeric portion of the gradients. There is evidence that polyploidy within a big sagebrush subspecies may increase with aridity (.E.D McArthur, personal communication). Furthermore, both creosotebush *(Larrea divaricata)* (Barbour 1969) and fourwing saltbush *(Atriplex canescens)* (H.C. Stutz, personal communication; Stutz et al. 1975) seem to show an increase in polyploidy with aridity. Perhaps polyploidy endows shrubs with the ability to withstand increased aridity.

The differences in growth potential between the subspecies may also be a result of polyploidy. In the greenhouse, uniform garden, and leader growth studies, basin big sagebrush outgrew Wyoming big sagebrush. However, Harniss and McDonough (1975) reported no differences in seedling growth between these subspecies during a 10-week period. Growth differences between basin and Wyoming big sagebrush in a multi-year uniform garden study were reported by McArthur and Welch (1982). They found that plant height, crown, cover, production, and annual leader growth for basin big sagebrush were greater than for Wyoming big sagebrush. They also showed that the faster growing basin big sagebrush plants were diploid while the slower growing plants were tetraploid. Furthermore, creosote bush (Barbour 1969), fourwing saltbush (Stutz et al. 1975), and shadscale *(Atriplex confertifolia)* (Stutz and Sanderson 1983) also seem to show a decrease in growth potential with an increase in ploidy level.

Summary and Conclusions

Leaf morphological, phenological, chromatographical, cytological, and growth studies evaluated genetic and growth potential differences between large and small statured big sagebrush plants growing along soil-water gradients. The large and small plants were identified as basin and Wyoming big sagebrush, respectively. Basin and Wyoming big sagebrush plants were located respectively in the mesic and xeric portions of the gradients. Basin big sagebrush has a greater growth potential than Wyoming big sagebrush as indicated by the growth studies. The differential growth between the subspecies may result from polyploidy. Difference in growth potential and habitat selection between the subspecies should be considered in planning for range improvement, wildlife habitat enhancement, and plant breeding programs.

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Impacts of Black-tailed Jackrabbits at Peak Population Densities on Sagebrush-Steppe Vegetation

JAY E. ANDERSON AND MARK L. SHUMAR

Abstract

In the northern Great Basin, populations of black-tailed jackrabbits *(Lepus californicus)* are cyclic, reaching high densities at approximately 10-year intervals. This project examined impacts of jackrabbits during a peak in their cycle on sagebrush-steppe vegetation in southeastern Idaho. Total vascular plant cover was significantly lower on plots open to jackrabbit herbivory than on exclosure plots, but in no case was cover of a specific species significantly reduced on open plots. The most severe impacts were on shrubs during winter; most aboveground tissues of both winterfat *(Ceratoides lanata)* and green rabbitbrush *(Chrysothamnus viscidiflorus)* plants were completely eaten by spring. However, these impacts were largely ameliorated by compensatory growth during the following growing season, and there was no difference in total biomass for either species between the open and protected plots by July. New growth of winterfat plants that had been browsed the previous winter was significantly greater than that of protected plants. Thus, although the cumulative effects of herbivory reduced total plant cover, no single species was irreparably impacted. Over a year, jackrabbits exert feeding pressure on nearly all of the important species in these communities; therefore, these hares do not appear to apply differential grazing pressure that would alter the course of vegetation development on northern Great Basin rangelands.

The black-tailed jackrabbit *(Lepus californicus)* is an important native herbivore on rangelands in the western United States (Vorhies and Taylor 1933, Dunn et al. 1982). In northern portions of the species' range, populations are cyclic, reaching high densities at approximately 10-year intervals (Gross et al. 1974, Johnson and Peak 1984). Numerous studies of food preferences and seasonal dietary trends for black-tailed jackrabbits provide a reasonably complete picture of feeding behavior (see Johnson and Anderson 1984), but the effects that black-tailed jackrabbits have on native plant populations are not completely understood.

It is generally assumed that peak population densities will have severe impacts on range ecosystems (Vallentine 1971, MacCracken and Hansen 1984), but speculation about such impacts has been based largely upon casual observation. Vorhies and Taylor (1933) argued, "Under all but the most conservative stocking with cattle the tendency of grazing by jackrabbits will be to accentuate overgrazing, to eliminate the more palatable grasses and favor their replacement by somewhat less desirable species and by weeds." In contrast, Bond (1945) speculated that jackrabbits would "exert a force in favor of succession toward the climax" on range that was only moderately deteriorated, whereas on range "deteriorated to the point of having more weeds than grasses, their effect would be towards further deterioration." More recently, Rice and Westoby (1978) found that protection from jackrabbits for periods of 5 to 15 years had no consistent effects on vegetation. The impacts of jackrabbit herbivory on long-term vegetation trends are complicated because jackrabbits may suppress or eliminate certain species (Westoby 1974, McKeever and Hubbard 1960) or enhance propagule dispersal of others (Riegel 1941, 1942; Timmons 1942).

This project was initiated to assess the impacts of a high population density of black-tailed jackrabbits on sagebrush-steppe vegetation and to examine those impacts in relation to long-term trends in vegetation development. In this paper, we describe the short-term impacts of a peak in a jackrabbit population on cover, biomass, and leaf length of several important plant species and discuss the implications of these measurements in relation to vegetation dynamics.

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Study Area

The study was conducted on the Idaho National Engineering Laboratory (INEL), which occupies over 2,300 km² of cold-desert rangeland on the upper Snake River Plain in southeastern Idaho. The area, at an elevation of about 1,500 m, lies in the rain shadow of the Lost River Mountains. Mean annual precipitation is 21 cm, and about 40% of that typically falls during April, May, and June. July is predictably hot and dry (Anderson and Holte 1981). Average annual temperature is about 5.5° C, and the frost-free period averages 91 days. Soils are mostly shallow, calcic *Aridisols* of eolian origin that have accumulated on top of basalt.

The vegetation of the INEL is generally dominated by 2 subspecies of big sagebrush *(Artemisia tridentata)* (authorities for nomenclature are in Table 1). Other conspicuous shrubs include winterfat *(Ceratoides lanata)*, green rabbitbrush *(Chrysothamnus viscidiflorus)*, prickly phlox *(Leptodacylon pungens)*, and various species of *Atriplex*. The most important grasses are bottlebrush squirreltail *(Elymus elymoides)*, Indian ricegrass *(Oryzopsis hymenoides)*, needle-and-thread grass *(Stipa comata)*, and thickspike wheatgrass *(Elymus lanceolatus)*.

Table 1. Plant species composition as measured in 1979 on all 12 permanent plots at study areas C1 and C2, Idaho National Engineering Laboratory.

Species[1]	Relative Cover	
	Study Area	
Shrubs:	C1	C2
Ceratoides lanata (Pursh)J.T. Howell	29.12	
Artemisia tridentata Nutt. ssp. *wyomingensis*	25.60	
Artemisia tridentata Nutt. ssp. *tridentata*		10.68
Chrysothamnus viscidiflorus (Hook.) Nutt.	6.03	26.12
Leptodactylon pungens (Torr.)Nutt.	0.34	1.38
Atriplex spinosa (Hook.) Collotzi	5.86	
Other shrubs	0.32	
Grasses:		
Elymus lanceolatus (Scribner & J.G. Smith) Gould	22.80	3.97
Elymus elymoides (Raf.) Sweezy	3.58	3.28
Oryzopsis hymenoides (R. & S.) Ricker	2.02	35.72
Stipa comata Trin. & Rupr.		16.93
Poa nevadensis Vasey		0.25
Forbs:		
Phlox hoodii Rich.	3.47	0.79
Other Forbs	0.86	0.88

[1]Nomenclature follows Hitchcock and Cronquist (1973) except for grasses of the Triticeae, where we have used the taxonomic revision proposed by Dewey (1983).

Methods

In 1979, 2 clusters of study plots were chosen to assess effects of feeding by jackrabbits on important shrub and grass species. One cluster, C1, is in an area where winterfat is abundant (Table 1). The C1 study area has not been grazed by domestic livestock since 1950, but the area supports considerable numbers of pronghorn *(Antilocarpa americana).* The second cluster, C2, is in an old burn site that is dominated by Indian ricegrass and green rabbitbrush (Table 1). This second area is open to spring/fall grazing by sheep. Specific locations of the clusters and descriptions of the plot layouts are found in Anderson and Johnson (1983).

Each cluster of study plots consisted of 6 pairs of 5 m × 5-m plots. To establish each pair of plots, we subjectively chose two 5 m × 5-m areas of vegetation that were as similar as possible. All 12 plots were permanently staked, and then 1 member of each pair was selected by a coin toss to be fenced with a 15 m × 15-m rabbit-proof exclosure. Because cluster C2 is in area that is open to spring/fall grazing by domestic sheep, the open plots were also fenced, but with the fence suspended about 30 cm above the ground to preclude access by livestock but not by jackrabbits. Pellet counts inside and outside the livestock exclosures confirmed that these fences were not a significant barrier to jackrabbits ($P>0.1$, paired t test).

In July of 1979, perennial vascular plants were mapped in 15 1-m^2 quadrats on each plot. Maps were drawn freehand; a sighting frame consisting of superimposed dm^2 string grids was used to facilitate vertical projection of the plants. Cover of each species was estimated from the completed maps. In 1982, plant cover on the same 1-m^2 quadrats was estimated by point interception (Floyd and Anderson 1982). The methods changed between 1979 and 1982 because Floyd (1982) showed that point interception was a reliable and objective method that was also less tedious. Because of this change, we will not compare 1979 cover data with that for 1982.

For statistical comparisons, the 5 m × 5-m plot was the sample unit, and the cover estimate for each species was the mean value from the 15 quadrats. Paired t tests were used to compare cover of open vs. fenced plots for a given year. The *a priori* alternative hypothesis was that cover would be significantly reduced on the open plots; thus, a one-tailed test (alpha = 0.05) was used.

On 26 May 1982, crown volume of randomly selected winterfat plants from both inside and outside the permanent exclosures at the C1 study area were measured. In order to measure the growth of the plants outside the exclosures without complications from further browsing, half of the plants outside the exclosures were protected by a temporary exclosure aprroximately 1 m in diameter. All plants were tagged and then remeasured 1 month later. Crown volume was calculated by assuming the crown to be a cylinder. The average radius of the cylinder was equal to the sum of perpendicular crown diameters divided by 4. The height of the cylinder was measured from the ground to the top of the crown. Growth of winterfat plants was expressed as the ratio of average crown volume on 29 June 1982 to that on 26 May 1982. A ratio of 1.0 would indicate that no growth occurred in that 1-month interval. Ratios among the permanent exclosures, the temporary exclosures, and the open plots were compared using an one-way analysis of variance (ANOVA) and a Student-Newman-Keuls (SNK) multiple range test.

Aboveground biomass of winterfat plants at C1 and green rabbitbrush plants at C2 was measured on randomly selected plants from both inside and outside the permanent exclosures. Plants were clipped at ground level, separated into current year vs. older tissues, dried at 80° C for 24 h, and weighed. Leaf length of spiny hopsage *(Atriplex spinosa)* plants was measured on the longest leaf on 10 arbitrarily chosen twigs on each of 10 randomly selected plants from both inside and outside the C1 exclosures. All biomass and leaf length measurements were made in mid July 1982.

The densities of the jackrabbit population at C1 and C2 were estimated from pellet counts on 12 5-m^2 quadrats (two 1 m × 5-m quadrats per permanent 5 m × 5-m open plot). Density was calculated assuming that 1 jackrabbit deposits 530 pellets per day (Arnold and Reynolds 1943). Overall population trends from 1980–1984 were monitored by counting jackrabbits at night, using a vehicle equipped with spotlights, along a 45-km backroads route on the INEL (Johnson and Anderson 1983). All jackrabbits within a 50-m strip on both sides of the vehicle were tallied. Counts were made in early June each year. Population densities were estimated by the method in Flinders and Hansen (1973).

Results

Population Trends and General Observations

The black-tailed jackrabbit population on the INEL peaked during 1981 (Fig. 1). Jackrabbit density increased by 3.4 fold in the year from June 1980 to June 1981. The population density then

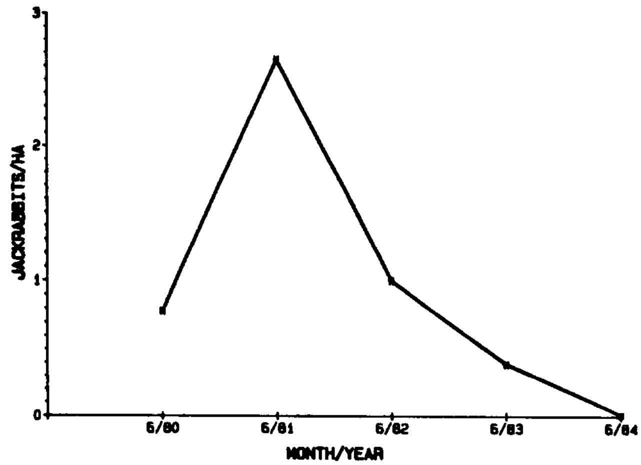

Fig. 1. *Mean densities of black-tailed jackrabbits along a 45-km backroads route on the Idaho National Engineering Laboratory, based on spotlight counts made each June, 1980 – 1984.*

dropped precipitously during the next 3 years. The average density along the backroads route in June 1984 was 0.02 jackrabbits/ha, which is less than one-hundredth of the average peak density of 2.7 jackrabbits/ha. Population densities at the 2 exclosure sites, estimated from pellet counts, were 6 to 8 jackrabbits/ha during the summer of 1981 and about 2 jackrabbits/ha during the following fall, winter, and spring. The density estimates from the 2 techniques should not be compared because the backroads spotlight counts provided an average for a large area whereas pellet counts were used to assess numbers at local study areas. Local densities along the backroads route varied widely (Anderson and Johnson 1983).

During the summer of 1981, distinct rabbit trails became ubiquitous, and, in some areas, heavy use of perennial grasses was observed. July and August of 1981 were exceptionally dry, which may have forced the hares to make greater than normal use of shrubs. By fall, evidence of browsing on shrubs was common. Snow cover blanketed the INEL from mid-December through February, and it was obvious that food supplies were very limited. Hundreds of jackrabbits could be observed at night feeding on lawns around INEL facilities, and heavy damage was inflicted on ornamental shrubs growing there. Thousands of jackrabbits were killed by farmers in rabbit drives near Mud Lake and Howe, Idaho, which lie to the north and northwest of the INEL. By April, 1982, evidence of browsing could be found on most plants of any shrub species on the INEL. On sagebrush, the rabbits would clip and discard the youngest shoots and then eat the older shoots just beneath. Similar observations were reported by Vorhies and Taylor (1933), Currie and Goodwin (1966), and Westoby (1973). Piles of clipped sagebrush shoots were common beneath sagebrush plants.

Table 2. Percent cover of key species groups in July 1982 at area C1, Idaho National Engineering Laboratory. Each value is the mean for six plots; 15 m² were sampled on each plot. Results of pairing-design *t* tests are shown under 'statistics' heading.

	Cover (%)		Statistics[1]		
	Open Plots	Exclosure Plots	D	s_D	*t*
All vascular plants	14.9	18.3	−3.38	1.59	2.13*
Total grasses	2.91	3.07	−0.16	0.45	0.37
Ceratoides lanata	3.00	4.33	−1.33	0.75	1.78
Artemisia tridentata	5.53	5.60	−0.30	1.32	0.07
Chrysothamnus viscidiflorus	1.40	1.86	−0.43	0.70	0.61
Atriplex spinosa	1.15	1.96	−0.81	0.59	1.38
Oryzopsis hymenoides	0.53	0.40	0.14	0.20	0.67
Elymus lanceolatus	1.81	2.03	−0.22	0.30	0.74

*$P<0.05$; one-tailed test, 5 d.f.
[1]D and s_D are the mean difference and standard deviation of the difference respectively.

Vegetal Cover

In 1979, no significant difference was found in total cover or cover of any common species between the exclosure and open plots at either C1 or C2 ($P>0.05$; pairing design *t* test). In July of 1982, total vascular plant cover was significantly greater on the exclosure plots than on the open plots at both C1 and C2 (Tables 2 and 3). However, there was no case of a significant difference between open and exclosure plots in the cover of specific species at either site (Tables 2 and 3).

Table 3. Percent cover of key species or species groups in July 1982 at area C2, Idaho National Engineering Laboratory. Each value is the mean for six plots; 15 m² were sampled on each Plot. Results of pairing-design *t* tests are shown under 'statistics' heading.

	Cover (%)		Statistics[1]		
	Open Plots	Exclosure Plots	$\bar{D}$	s_D	*t*
All vascular plants	15.3	18.5	−3.06	1.25	2.44*
Total grasses	9.5	10.1	−0.59	1.22	0.48
Artemisia tridentata	3.73	5.67	−1.92	1.11	1.75
Chrysothamnus viscidiflorus	1.87	2.13	−0.25	0.84	0.29
Stipa comata	2.53	2.53	−1.02	0.98	1.04
Oryzopsis hymenoides	5.87	5.53	0.36	0.82	0.43
Elymus elymoides	0.73	0.67	0.06	0.18	0.33

*$P<0.05$; one-tailed test, 5 d.f.
[1]D and s_D are the mean difference and standard deviation of the difference respectively.

Crown Volume, Biomass, and Leaf Length

During the winter of 1981–82, all of the winterfat plants outside the exclosures were completely eaten to their woody bases. In the month following 26 May 1982, growth of winterfat plants that had been browsed the previous winter (temporary exclosures and open) was significantly greater than that of protected plants (permanent exclosures) (Table 4). There was no difference in growth of plants protected by temporary exclosures compared to those in the open (Table 4), suggesting minimal browsing on this species during the month. There was no significant difference in mean aboveground biomass for winterfat plants protected from jackrabbits (6.2 ± 3.2 g; mean ± 95% C.I.) vs. those exposed (3.6 ± 1.6 g), although there was a significant difference in the amount of old biomass between protected plants (1.6 ± 1.1 g) and those subject to browsing (0.3 ± 0.1 g). Thus, current-year growth constituted a much larger proportion of total aboveground biomass of winterfat plants outside the exclosures compared to that of protected plants.

At both clusters of plots, aboveground portions of most green rabbitbrush plants were completely eaten during the 1981–82 winter. Regrowth on these plants was typically vigorous. Because of the large differences in morphology between protected plants and those subjected to browsing, we could not compare growth of crown. Growth of protected plants was restricted to the ends of old branches. The average length of the longest new shoots on a sample of 35 protected plants was 11 ± 1.2 cm, whereas on plants exposed to browsing, new shoots averaged 21 ± 2.4 cm in length. There was no significant difference in total aboveground biomass of green rabbitbrush plants inside (15.2 ± 6.4 g) vs. those outside (18.8 ± 8.7 g) the exclosures, but most of the aboveground biomass of plants outside the exclosures was new growth (old biomass for exclosure plants = 2.9 ± 1.4 g compared to 0.5 ± 0.3 g for unprotected plants).

Table 4. Growth of winterfat *(Ceratoides lanata)* plants expressed as the ratio of average crown volume on 29 June 1982 to that on 26 May 1982, Idaho National Engineering Laboratory. A ratio of 1.0 would indicate that no growth occurred.

	Crown Volume Ratio		
Location	Mean	Range	*n*
Permanent Exclosure	1.08*	0.85 – 1.63	11
Temporary Exclosure	1.66	1.04 – 3.30	18
Open	1.72	0.79 – 4.02	18

*Significantly different from the other two means at $P<0.05$ by ANOVA and SNK multiple range test.

Productivity of spiny hopsage plants may have been significantly reduced, because unprotected plants typically had more dead stems and branches and far fewer live stems than protected plants. However, mortality of plants that had been heavily browsed seemed rare, and growth of new shoots of unprotected plants was vigorous. Leaf morphology was very different on new shoots of browsed plants compared to that on protected plants. Average leaf length of spiny hopsage plants outside the exclosure was 2.7 ± 0.5 cm, compared to 1.5 ± 0.3 cm on protected plants.

Discussion

Gross et al. (1974) reported a 10-fold difference in population densities between highs and lows over 3 population cycles in the Curlew Valley of northern Utah. Our data show a 7-fold decrease in population density between 1981 and 1983 and another order of magnitude decrease by the summer of 1984, indicating a fluctuation of about 100-fold over a cycle in the jack rabbit population on the INEL.

Following the peak in the cycle, total plant cover was reduced at both exclosure study areas (Table 2 and 3), but we were unable to document any case in which the cover of a particular species was significantly reduced. This suggests that the overall difference in cover may reflect the cumulative impacts of herbivory on numerous species, rather than heavy use of one or a few species. The variance is much higher for cover comparisons involving individual species than for total plant cover; thus the failure to reject the null hypothesis in the case of individual species despite differences in overall cover may be a result of the small sample size. Certainly, however, there was no case where the cover of a dominant shrub or perennial grass species was drastically reduced, despite the facts that shrubs were heavily used during the previous winter and grasses are the preferred foods during the spring and summer (Johnson and Anderson 1984).

Many of the native perennial bunchgrasses of this region are very susceptible to damage by heavy grazing, especially spring grazing (Caldwell et al. 1981, Mack and Thompson 1982). Indian ricegrass and needle-and-thread grass are important forage species throughout the Great Basin and elsewhere, and they are among the preferred foods of black-tailed jackrabbits (Currie and Goodwin 1966, Hayden 1966, Uresk 1978, Johnson 1979). The C2 site was selected specifically to assess impacts on those species.

Data from our exclosures provide no evidence for a significant impact of jackrabbits on any perennial grass populations. Jackrabbits and their impacts are patchily distributed, however, and it is quite possible that in other localized areas the effects could be significant. Such impacts would be extremely difficult to quantify. We have observed heavy cropping on individual Indian ricegrass and needle-and-thread plants while neighboring plants were left untouched. In one area, there was an obvious reduction in standing crop of the rhizomatous grass *Leymus triticoides*. Nearby stands of Indian ricegrass and needle-and-thread grass showed evidence of rabbit grazing, but the cropping was not severe. Diet studies (Johnson 1982) and our field observations indicate that *L. triticoides* and thick-spiked wheatgrass *(E. lanceolatus)*, another rhizomatous species, are both important in the jackrabbit diets. These species appear to be well adapted to heavy grazing.

During the spring and early summer of 1981 and 1982, periods when the native cool-season grasses were most susceptible to herbivore damage, the supply of grass forage was generally abundant on the INEL. Although evidence of jackrabbit grazing was common, severe cropping or damage was seldom observed. When dormant, later in the summer or during fall and winter, the grasses are much less susceptible to damage, and the shrubs become the staple foods of the jackrabbits.

The 3 species of shrubs included in our studies showed a remarkable ability to recover following severe cropping of above-ground tissues. Whether comparable responses could be effected under repeated winter browsing over several years is questionable, but the cyclic nature of the jackrabbit population would probably preclude that necessity. Indeed, the theoretical analysis of Hilbert et al. (1981) suggested that compensatory growth would be more likely under infrequent cropping events than under repeated browsing at short intervals. Stevens et al. (1977) noted that winterfat was remarkably tolerant to winter grazing. Cook and Child (1971) reported that winterfat plants made a full recovery of crown cover in 7 years after 90% herbage removal in winter and spring for 3 years.

Cook and Child (1971) found that nonsuffrutescent shrubs were more susceptible to damage by their clipping treatments. The compensatory response of the nonsuffrutescent green rabbitbrush in our study was certainly comparable to that of winterfat; both were generally cropped to the ground and both showed vigorous regrowth. Spiny hopsage plants appeared to be more susceptible to damage from heavy browsing, possibly because of girdling of larger stems (McKeever and Hubbard 1960), but this species too showed vigorous compensatory growth.

McNaughton (1979b) reviewed numerous studies indicating that ". . .compensatory growth upon tissue damage by herbivory is a major component of plant adaptation to herbivores." He pointed out that grasses are particularly well adapted to grazing pressures because growth is primarily from intercalary meristems that are less accessible to large herbivores than the terminal meristems of dicots (McNaughton 1979a, 1979b). Compensatory growth or stimulation of productivity in response to browsing or clipping has also been reported for shrubs (Garrison 1953, Lay 1965, Ferguson and Basile 1966), and many shrubs sprout vigorously following top removal by fire (Wright et al. 1979). McNaughton's (1979a, 1979b) studies also suggest that productivity may be maximized at some moderate level of herbivory.

What are the implications of these results and observations in terms of long-term vegetation development? Although they are selective feeders at a given time, jackrabbits may not apply differential grazing pressure that would influence the course of vegetation development in this ecosystem. Over the course of a year jackrabbits feed on most if not all of the important plant species in these communities. The most severe impacts appear to be on shrubs when the rabbit's winter food supply becomes limiting, but compensatory growth ameliorates these impacts. The cyclic nature of the jackrabbit population would provide ample time for recovery of species or individuals. Thus, it appears that a peak in the jackrabbit cycle has little impact on the overall structure or development of these plant communities. It should be emphasized, however, that this conclusion may apply only to rangelands that are in good to excellent condition where there is not heavy competition with livestock for forage.

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Gradient Analysis of Vegetation Dominated by Two Subspecies of Big Sagebrush

MARK L. SHUMAR AND JAY E. ANDERSON

Abstract

Stands of vegetation dominated by basin big sagebrush (*Artemisia tridentata* Nutt. subspecies *tridentata*) intergrade with stands dominated by Wyoming big sagebrush (*Artemisia tridentata* Nutt. subspecies *wyomingensis*) on the Idaho National Engineering Laboratory in southeastern Idaho. Detrended correspondence analysis and correlation were used to elucidate potential relationships between vegetation patterns and soil factors along a gradient from stands having only the subspecies *tridentata* to stands having only the subspecies *wyomingensis*. Distributions of the subspecies were consistently associated with gradients in soil texture. Basin big sagebrush was most abundant on sandy soils and Wyoming big sagebrush was dominant on finer textured soils. Mixed stands occurred on central portions of the gradient. Similar results for 3 study areas were observed, despite differences in soil texture between areas. Thus, the distributional patterns are associated with changes in soil texture rather than actual amounts of sand, silt, or clay.

Sagebrush shrublands of the Intermountain West and Great Basin regions are managed for a variety of uses, such as livestock grazing, wildlife habitat, and recreational activities. Because management practices often affect biotic and abiotic components of the environment, the relationships between various plant species on these shrublands and the environmental factors that the plants experience is of interest. The relationships between *Artemisia* species and environment have commanded particular attention. Distributions of various species of *Artemisia* are correlated with a variety of soil and climatic factors (e.g., Robertson et al. 1966, Fosberg and Horonaka 1964, Sabinske and Knight 1978, West et al. 1978).

A study of sagebrush distribution at the Idaho National Engineering Laboratory (INEL) in southeastern Idaho (Shumar 1983) identified both pure and mixed stands of basin big sagebrush (*Artemisia tridentata* Nutt. subspecies *tridentata;* Beetle 1960) and Wyoming big sagebrush (*Artemisia tridentata* Nutt. subspecies *wyomingensis*; Beetle and Young 1965). (Pure refers to species assemblages containing one subspecies or the other but not both; mixed stands contain both subspecies.) The size of the basin big sagebrush stands was unexpected because previous reports suggested that the expansive lava flows and flats of the upper Snake River Plain were predominantly occupied by Wyoming big sagebrush (Harniss and West 1973, McBride et al. 1978) and contained "patches" of basin big sagebrush (Winward 1970). However, some of these basin big sagebrush patches on the INEL may be as large as 65 km^2 (Shumar 1983).

General descriptions of the soil properties associated with the distributions of basin big sagebrush and Wyoming big sagebrush occur in the literature. Basin big sagebrush occurs on deep (Beetle 1960, Hironaka 1978, Winward and Tisdale 1977), well-drained (Tisdale and Hironaka 1981), often sandy soils (Morris et al. 1976), in valley bottoms, on foothills, or along drainages. Its distribution often coincides with high water tables or deep moisture accumulations (Morris et al. 1976). Wyoming big sagebrush can be found on moderately deep to shallow soils (Hironaka 1978) of medium texture that often limit water penetration (Morris et al. 1976). These plants sometimes occur on immature soils (Morris et al.

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1976) or slightly saline soils (Tisdale and Hironaka 1981). This subspecies is found on lower slopes of major drainages (Winward and Tisdale 1977) or on hilltops and flats (Beetle and Young 1965).

Because of the extent of the pure and mixed stands of the 2 sagebrush subspecies on the INEL, and because of the generalized nature of the information on their relationships to environment, it seemed that an intensive study employing ordination procedures might provide insights into the factors affecting their distributions. The objective of this study was to generate hypotheses about relationships between the distributions of the sagebrush subspecies and characteristics of the soil using ordination and correlation analyses.

Study Area

The INEL occupies 2,315 km^2 of the upper Snake River Plain near the southeastern ends of the Lemhi and Lost River mountain ranges in eastern Idaho. Soils of the INEL are primarily aeolian sands and loess and are derived from silicic volanics and paleozoic rocks from the surrounding mountains (McBride et al. 1978).

The climate is semiarid and principally affected by the rainshadow of the central Idaho mountains (Harniss and West 1973). The average annual precipitation is 21 cm and the average annual temperature is 5.5°C (Anderson and Holte 1981). The average frost-free period is 91 days (Harniss and West 1973).

The vegetation of the INEL is primarily sagebrush-bunchgrass associations, although the other shrubs (*Chrysothamnus viscidiflorus* (Hook.) Nutt., *Ceratoides lanata* (Pursh) J.T. Howell, *Tetradymia canescens* DC., *Atriplex confertifolia* (Torr. and Frem.) Wats., *Atriplex nuttallii* Wats., *Leptodactylon pungens* (Torr.) Nutt., and *Gutierrezia sarothrae* (Pursh) Britt. and Rusby.) are locally important (McBride et al. 1978, Anderson and Holte 1981). The common grass species are *Elymus elymoides* (Raf.) Sweezy, *Psuedorogeneria spicata* (Pursh) A. Love, *Elymus lanceolatus* (Scribner and J.G. Smith) Gould, *Oryzopsis hymenoides* (R. and S.) Ricker, *Stipa comata* Trin. and Rupr., and *Leymus cinereus* (Scribn. and Merrill.) (Anderson and Holte 1981). Additional information on the past use of the area can be found in Harniss and West (1973) and Anderson and Holte (1981).

Three areas, each containing pure and mixed stands of basin big sagebrush and Wyoming big sagebrush, were selected for study. The first area included the southeastern ends of 4 rows of sand dunes (identified as D-1, D-2, D-3, and D-4). Each dune row was a complex of linear, stabilized dunes that extended in a northeasterly direction across a large flat basin. Basin big sagebrush occurred as pure stands on the dunes, Wyoming big sagebrush occurred as pure stands on the slacks (areas between dune rows with little or no sand), and mixed stands of both subspecies occurred on dune margins. Soils of this area were generally loams and dune sands. Although only D-4 was within an area closed to livestock grazing, only D-1 had evidence of recent sheep grazing.

The second study area, T-22, was on the northern-most extension of a large lava flow that covers most of the eastern part of the INEL. The area was characterized by deep sand accumulations in swales between lava ridges. A mosaic of pure and mixed stands of Wyoming big sagebrush and basin big sagebrush was associated with the undulating pattern of the lava surface. Soils ranged from sandy loams to sands. This area probably had been grazed by sheep in the recent past.

The third study area, T-24, was in an eastern extension of a large depression surrounded by lava flows. Pure and mixed stands of basin big sagebrush and Wyoming big sagebrush formed a mosaic pattern on the bottom and sides of this depression. Soils of this area were mostly sandy loams, but ranged from silt loams to sands. This site was within an area closed to grazing since at least 1957.

Methods and Materials

Vegetation Sampling

Vegetative cover at each study area was estimated by point interception. Twenty point frames (Floyd and Anderson 1982) placed systematically at 2.5-m intervals along a 50-m transect constituted a sampling unit. Floyd (1982) determined that 20 frames in sagebrush-grass vegetation provided a reasonably accurate and expedient estimate of cover for all but the rarest species.

At the 4 dune complexes, baselines were established perpendicular to the long axis of the dune rows. The baselines extended from the slack on one side of the dune row to the slack on the other side. Transects were placed at regular intervals perpendicular to the baseline (parallel to the long axis of the dune row) such that the dunes and the slacks on both sides would be sampled. The 4 dune complexes contained 8, 7, 14, and 9 transects (D-1, D-2, D-3, and D-4 respectively), all at 50-m intervals.

At the T-22 study area, a baseline was placed in a southeast-northwest direction and traversed approximately 1,500 m of the north edge of the lava flow. Thirty transects were established perpendicular to this baseline at 50-m intervals. The transects paralleled the long axes of the lava ridges and depressions. Some transects were more or less than 50 m apart to avoid crossing sharp changes in topography.

The T-24 study area included 21 transects at 50-m intervals. Twenty were placed perpendicular to a baseline that began at the bottom of the depression and extended in a northeasterly direction, up a lava ridge, across a plateau, to the base of a second lava ridge. Transect 21 was south of the baseline on the second lava ridge. Again, transects were placed such that they ran parallel to the lava ridges.

Soil Sampling

Soil profiles were described and soil samples were taken from pits placed in an open area between shrubs. Soil pits were dug at 4 transects at D-4, 15 transects at T-22, and 12 transects at T-24. These transects were chosen on the basis of apparent vegetal differences to reduce the effort involved in sampling at every transect. Profile descriptions included texture, structure, consistency, horizon depth and classification, pH, moist and dry colors, root size and amount, and percent rock.

Soil samples were put into plastic bags and taken to the laboratory for soil nutrient analyses. At least one sample was taken from the A horizon(s) and at least one from the B horizon(s).

Laboratory Soil Analyses

The following soil analyses were performed by the Soils Laboratory, Department of Agronomy and Horticulture, Brigham Young University: electrical conductivity, cation exchange capacity, and exchangeable ions (phosphorus, calcium, magnesium, potassium, and sodium). Percent nitrogen, determined by the macro-Kjeldahl method (Black et al. 1965b), and percent sulfur (Tiedemann and Anderson 1971) were measured by the USDA Intermountain Forest and Range Experiment Station Shrub Sciences Laboratory in Provo, Utah, on all A horizons. We conducted the remaining analyses: percent organic carbon, determined by the Walkey-Black method (Black et al. 1965b), was analyzed for all A horizons. Particle size fractions were determined for all horizons by the hydrometer method (Black et al. 1965a).

Analysis of Data

Data for each study area were ordinated using detrended correspondence analysis (DCA) on cover values for all vascular plant species (Hill and Gauch 1980). Ordination is a technique of data exploration that reduces large matrices of sample-by-species data to graphs showing one or more axes of variation. Ordination reflects the patterns of variation of the species in the samples; these patterns are then subject to interpretation and correlation with environmental factors by the investigator (Peet and Loucks 1977, Gauch 1982). DCA is essentially the same as reciprocal averaging (RA) except that additional mathematical processes are added to correct some of the problems of RA. Both DCA and RA use an iterative mathematical process that simultaneously weights samples and species such that a sample weight is the average of all the species weights in that sample and reciprocally a species weight is the average of all the sample weights in which that species is found (Hill 1973).

RA has 2 shortcomings. The second axis of variation is a quadratic function of the first and thus produces an "arch" or "horseshoe" shape in 2 dimensions that may have no ecological meaning (Hill 1973). Also, sample distances in the middle of the RA ordination field may not reflect the same degree of variation as the sample distances at the ends of the field (Hill and Gauch 1980). DCA corrects these 2 shortcomings of RA by dividing the first axis into segments and adjusting the axis 2 scores in each segment to eliminate the "arch" effect (a process known as "detrending") and by "rescaling" within-sample species scores to equalize sample distances (Hill and Gauch 1980, Gauch 1982). However, Beals (1984) reported that one of the sources of the "arch" effect is bimodality of species distributions along environmental gradients, and hence, is the result of an ecological phenomenon. Thus, detrending of the second axis may result in loss of ecological information. DCA may also be overly sensitive to rare species and outlier samples in the data set, which may obscure overall patterns (Beals 1984).

Our ordinations were produced by the program DECORANA using the default values for rescaling, number of segments, and rescaling threshold (Hill 1979). Both DCA and RA ordinations of the data sets were produced and compared. In each case, the DCA results were similar to the RA results except for the elimination of arch shapes. We concluded that DCA, at the default settings, was adequate because of the consistency of the DCA and RA results, and, even though the arch may be the result of bimodal species distributions, the DCA results were interpretable in terms of the major axis of variation in the vegetation.

Spearman's correlation coefficients (R_s) were calculated using the DCA axis values for transects having a soil pit and the complementary soil nutrient and physical factor data. Those variables that were significantly correlated (alpha = 0.05) with the axis values are reported. The ordination axes were developed taking all species into account, not just the sagebrush subspecies. Thus, the correlations reflect changes in entire plant assemblages that are dominated by one sagebrush subspecies or the other.

It is important to note that it is impossible to determine cause and effect relationships with correlation. Our goal in using ordination and correlation is to elucidate potential relationships between environment and species, which in turn would need to be tested in some other manner.

Results

The ordinations for the three study areas produced similar results with respect to the subspecies distributions. In each case, the first axis (in the T-24 ordination, both axes 1 and 2) showed a gradient in shrub vegetation from one subspecies to the other (Figs. 1 and 2).

The ordination of the T-22 study area included all 30 transects and 27 species. Total variation that was explained by axes 1 and 2 was 64% and 25%, respectively. Cover of basin big sagebrush decreased from left to right on axis 1 while that of Wyoming big sagebrush increased, resulting in a zone of co-occurrence of the two subspecies at the center of the axis (Fig. 1).

Spearman's Rank test indicated that percent silt, nitrogen, and cation exchange capacity were positively correlated with axis 1 (Table 1). Percent sand was correlated negatively with axis 1, but it changed only slightly from 90% at the basin big sagebrush end to 73% at the Wyoming big sagebrush end of the axis (Fig. 1). Although clay content was low at all transects, there was a tendency for textures to become finer from left to right along axis 1, and this corresponded with the change in the dominant shrub from basin big sagebrush at the sandy end to Wyoming big sagebrush at the finer textured end (Fig. 1).

The ordination for the T-24 study area included all 21 transects and 33 species. Axes 1 and 2 explained 46% and 17% of the variation, respectively. Basin big sagebrush was the dominant

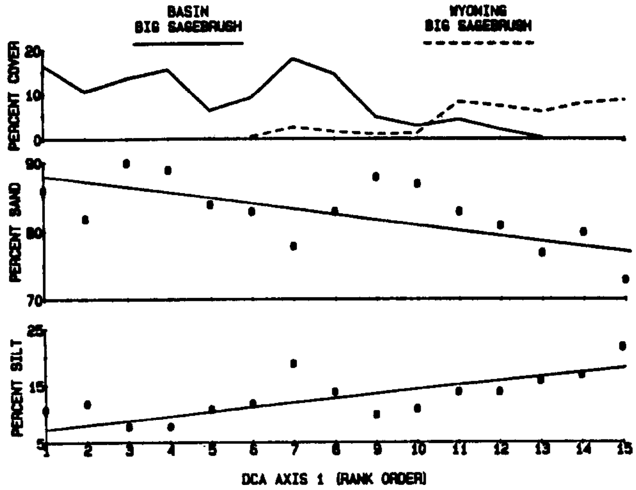

Fig. 1. *Relative cover of the 2 sagebrush subspecies (top), percent sand in the soil (middle), and percent silt in the soil (bottom) plotted as a function of the first DCA axis for the T-22 study area.*

shrub at this study area, occurring on 20 of the transects and having the highest cover on 18 transects. Wyoming big sagebrush occurred on 15 transects but was dominant on only 3 of them. Where the 2 subspecies co-occurred, Wyoming big sagebrush was generally subordinant.

Table 1. Spearman's rank correlation coefficients (Rs) for variables significantly correlated ($P<0.05$) with ordination axis values for the T-22 and T-24 study areas. (CEC = cation exchange capacity, OC = organic carbon)

T-22 AXIS 1		T-24 AXIS 2	
Variable	Rs	Variable	Rs
CEC	.59*	Ca	.89***
N	.62*	Mg	.75**
Sand	-.61*	OC	.90***
Silt	.68**	N	.85***
		S	.78**
		Sand	-.86***
		Silt	.80**

*,**,***Significant at the 0.05, 0.01, and 0.001 levels, respectively.

The sequence of transects, arranged by the ordination program, was similar for both axes 1 and 2. The distributions of the 2 subspecies along axis 2 was similar to that of axis 1; basin big sagebrush cover decreased and Wyoming big sagebrush cover increased from low axis values to high axis values (Fig. 2). This distributional pattern was similar to axis 1 of the T-22 study area.

No soil parameters were significantly correlated with axis 1, however amounts of calcium, magnesium, organic carbon, nitrogen, and sulfur in the A horizon, as well as percentages of sand and silt, were correlated with the second axis (Table 1). The distributions of the sagebrush subspecies on both axes were similar, thus their relationship to soil nutrients were still discernable. The nutrients listed above and percent silt were positively associated with axis 2 values; percent sand was negatively correlated with axis 2. Basin big sagebrush occurred on sandier soils and Wyoming big sagebrush was found on finer textured soil (Fig. 2). It should be noted that textures of soils at T-24 were finer than those at T-22. Mean sand and silt percentages differed significantly between the

T-22 and T-24 study areas (t = 3.14 and t = 3.05, respectively; n = 25). This did not, however, preclude the existence of a soil texture gradient that was significantly correlated with an ordination axis.

The ordination of the Dunes study area included 38 transects (D1 [8] + D2 [7] + D3 [14] + D4 [9]) from the 4 dune complexes and a total of 36 species. Axes 1 and 2 explained 57% and 20% of the variation in the vegetation, respectively. From left to right along the first axis, DCA separated the transects according to landscape position (i.e., dune tops, dune margins, and slacks). Basin big sagebrush had the highest cover on the dunes, lower cover on the margins, and was generally absent on the slacks. Wyoming big sagebrush cover was greatest on the slacks. Both sagebrush subspecies co-occurred with about equal but low cover at the center of the axis (i.e., dune margins).

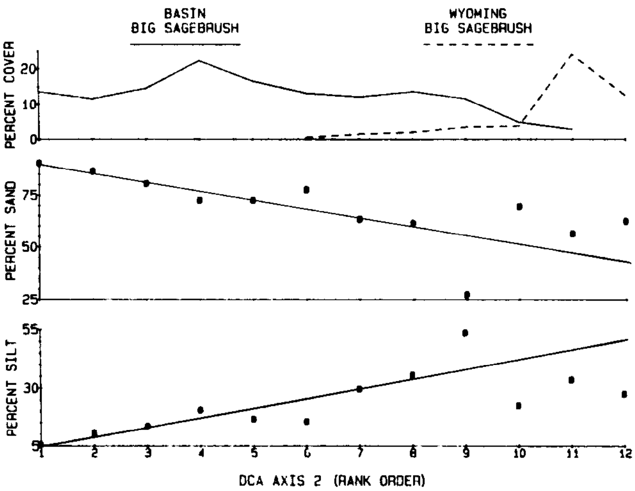

Fig. 2. *Relative cover of the 2 sagebrush subspecies (top), percent sand in the soil (middle), and percent silt in the soil (bottom) plotted as a function of the second DCA axis for the T-24 study area.*

The small sample size (4) of soils at the Dunes study area precluded environmental correlation; however, observation suggested that the first axis represented a soil texture gradient from areas of deep sand accumulations (dune tops) to areas with silty soil and no loose sand (slacks).

Discussion

The results of the DCA ordinations for the 3 study areas suggested that basin big sagebrush occupied the sandy end of a soil texture gradient Wyoming big sagebrush occupied the finer textured end (Figs. 1 and 2). Although the actual amounts of sand and silt differed among the study areas, the subspecies still responded to the changes in soil texture. For example, sand percentages of the T-22 study area were greater than those of the T-24 study area (Figs. 1 and 2), but the change in sand percentages was significantly related to the change from stands dominated by one sagebrush subspecies to stands dominated by the other at both study areas (Table 1). The changes in subspecies distributions sometimes occurred with slight changes (less than 20%) in sand or silt. Apparently, on these soils where both sagebrush subspecies have had access to the area, the subspecies have partitioned themselves on a textured gradient regardless of actual amounts of sand and silt.

A possible mechanism for this separation is competition for soil moisture, which we presume is more available in sandy soil. Sand dunes may be relatively mesic because of deep moisture infiltration, high storage capacity, and low evaporative loss as compared to finer textured arid and semiarid soils (Barnes and Harrison 1982, Bowers 1982, Tevis 1958, Pavlik 1980, Kirkpatrick and Hutchinson 1980).

Other soil characteristics, such as soil depth and nutrient concentrations, can also change concomitantly with the soil texture gradient. Measured soil depths were not correlated with the ordination axes, but they were difficult to determine accurately because of possible fissures in the lava rocks. We observed that silt soils were often aggregated and compact, whereas sandy soils were soft and often deep. Soil depth, probably because of its relationship to soil moisture, may influence the distributions of the sagebrush subspecies (Hironaka 1978, Winward and Tisdale 1977, Morris et al. 1976).

Nitrogen and cation exchange capacity increased with increasing silt at the T-22 study area, and calcium, magnesium, organic carbon, nitrogen, and sulfur increased with increasing silt at the T-24 study area. Thus, more nutrients may have been in the soil near Wyoming big sagebrush plants than near basin big sagebrush plants. This is contrary to previous information that indicates higher nutrients under basin big sagebrush communities (Winward 1970). We suspect that higher nutrients in our study were affected by the nutrients binding to finer textured soils, and were probably leached from sandy soils. Whether or not nutrients were more available to plants at the fine textured end as opposed to the sandy end of the soil texture gradient is not known.

This study was designed to elucidate potential relationships between the 2 sagebrush subspecies and environment in an objective manner. We suggest that the subspecies are responding to slight changes in soil texture, which presumably is related to soil water availability, regardless of actual amounts of sand and silt. This suggestion would have to be tested directly to be conclusive, but the hypothesis is consistent with the general observations made by others.

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Infiltration and Sediment Production Following Chemical Control of Sagebrush in New Mexico

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Abstract

Terminal infiltration rates under sagebrush canopies were about 35% higher than interspace areas at 3 study sites in northern New Mexico. Differences in infiltration rates among strata may largely be attributed to a greater amount of litter yield and basal cover, and 2 to 3 times higher percentage of organic carbon under the canopy of sagebrush compared to the interspace. Infiltration rates and sediment concentration of runoff within the canopy zone and interspace areas were not affected chemical control treatments. Total sediment production was about 29 to 41% higher under the canopy of tebuthiuron treated sagebrush compared to the canopy zone of untreated rangeland. However, these differences were not consistent and were significant at only 1 study site. Total sediment production was related primarily to a combination of soil texture, sagebrush canopy cover, and total vegetation production.

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Sagebrush *(Artemisia tridentata)* is an aromatic, evergreen shrub growing on an estimated 2.2 million ha of rangeland in northern New Mexico and an additional 37 million ha in the western United States (Berry 1979). Approximately 70% of the sagebrush-dominated rangelands in New Mexico are degraded and produce less forage than their potential (McDaniel and Garrison 1982). Reasons often given to justify renovation of the sagebrush rangelands include the need to increase forage for wildlife and livestock, and to reduce soil degradation (Scifres 1980).

Herbicide applications are an accepted tool to improve sagebrush rangelands, but have not been widely used in New Mexico. Control of sagebrush with 2,4-D [(2,4-dichlorophenoxy) acetic acid] at rates of 2.2 kg acid equivalence/ha, while reported elsewhere as successful in killing sagebrush (Elwell and Cox 1950, Hull and Vaughan 1951, Hyder 1953, Evans et al. 1979, among others), has not been successfully employed in New Mexico (McDaniel and Balliette 1984). Three years of repeated spray trials with 2,4-D at 2.2. kg a.e./ha did not kill more than 50% of Wyoming (*A.t.* var.

wyomenisis) or mountain *(A.t.* var. *vaseyana)* sagebrush in northern New Mexico (Balliette 1984).

Tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N′-dimethylurea) at 0.56 kg active ingredient/ha offers significant promise for sagebrush control in New Mexico. Date of application or phenological stage of sagebrush growth does not limit tebuthiuron activity, and the herbicide usually kills more than 80% of the plants (McDaniel and Balliette 1984). Similar levels of sagebrush control following tebuthiuron treatments have been reported in Oregon and Wyoming (Britton and Sneva 1984, Whitson and Alley 1984).

Increased forage production is a primary reason to control sagebrush with herbicides. Reduction of soil erosion is often given as an additional benefit; however, little information exists for New Mexico rangelands about the impact of sagebrush control on infiltration rates and sediment production. Sagebrush rangelands in poor condition lose considerable amounts of soil by wind and water erosion (Rosa and Tigerman 1951, Tisdale et al. 1969, and Blackburn 1973). Management and control of sagebrush can increase cover and yield of herbaceous species and reverse the soil degradation that has occurred over the past century (Young et al. 1980).

Our primary objective was to determine the short-term impact on infiltration rates, sediment concentration of runoff, and total sediment production from sagebrush rangelands treated with herbicides. A secondary objective was to identify vegetation and soil characteristics related to these watershed parameters.

Study Area

Experiments were conducted at 3 locations in New Mexico's northern desert land resource area (USDA-SCS 1982) near Aztec, Bloomfield, and Gobernador, New Mexico. Average annual precipitation is 226 mm at Aztec, with yearly variations of from one-half to more than 2 times the average. Major precipitation occurs between July and October from scattered, localized, and intense thunderstorms. Temperatures vary from highs that commonly exceed 40.5°C during June or July, to lows of −20.5°C or below in December or January. Soils of the resource area were formed from alluvial sediments or sedimentary rock. The geomorphology is typically that of moderate canyon dissection, broad valleys, and gentle sloping plateaus and mesas.

The Bloomfield and Aztec sites were established on deep and well-drained Doak loam soil (fine-loamy, mixed, mesic, Typic Haplargid). Soil samples collected from a core to 10 cm at Bloomfield contained 86% sand, 12% silt and 2% clay, with 1.3% organic carbon and a pH of 7.5. Soil at Aztec contained 72% sand, 24% silt and 4% clay, with 1.6% organic carbon and a 7.0 pH. Herbaceous vegetation at Aztec included squirreltail *(Sitanion hystrix)*, galleta *(Hilaria jamesii)*, cheatgrass *(Bromus tectorum)*, six-weeks fescue *(Vulpia octoflora)*, broom snakeweed *(Gutierrezia sarothrae)* and several annual broadleaf species. The Bloomfield site, included, in addition to the above herbaceous species, blue grama *(Bouteloua gracilis)*, sand dropseed *(Sporobolus cryptandrus)* and ring muhly *(Muhlenbergia torreyii)*. The average slope at both areas was 1 to 3% and elevation averaged 1,850 m.

The Gobernador site was on a Penistaja loam (fine-loamy, mixed mesic, Ustollic Haplargid) that is a well-drained soil with an effective rooting depth of 150 cm or more. Soils contained 74% sand, 23% silt and 3% clay, with 2.7% organic carbon and a pH of 6.9. Herbaceous vegetation included galleta, blue grama, sand dropseed, squirreltail, cheatgrass, six-weeks fescue and various annual broadleaf species. Slope at the site ranged from 2 to 5% and elevation was about 2,000 m.

The 3 study areas supported a uniform stand of Wyoming sagebrush as the sole dominant woody species. Sagebrush height ranged from 0.1 m to 1.5 m, not including seedlings. Sagebrush density and canopy cover averaged 22,977 plants/ha and 17.4% cover at Aztec, 33,300 plants/ha and 19.0% cover at Bloomfield, and 30,970 plants/ha and 14.9% cover at Gobernador.

Table 1. Mean terminal infiltration rates (cm/hr) for canopy-interspace areas as influenced by sagebrush control treatments, from three study areas in New Mexico in 1982 and 1983.

Site[1]	Treatment	Strata	Terminal Infiltration[2] 1982	1983
Bloomfield	2,4-D	Canopy	4.6[2]	4.9b
(4.2a, 4.1a)	(4.0a, 4.1a)	Interspace	3.4a	3.2a
	Tebuthiuron	Canopy	5.2bc	5.0b
	(4.4a, 4.1a)	Interspace	3.7a	3.2a
	Control	Canopy	5.0b	5.3b
	(4.3a, 4.1a)	Interspace	3.5a	2.8a
Gobernador	2,4-D	Canopy	4.9b	4.4b
(4.2a, 3.9a)	(4.2a, 3.7a)	Interspace	3.6a	2.9a
	Tebuthiuron	Canopy	4.3ab	4.4b
	(3.8a, 3.8a)	Interspace	3.2a	3.2a
	Control	Canopy	5.0b	4.9b
	(4.7a, 4.2a)	Interspace	4.3ab	3.4a
Aztec	2,4-D	Canopy	5.2bc	5.5b
(4.3a, 4.6b)	(4.1a, 4.6a)	Interspace	3.0a	3.6a
	Tebuthiuron	Canopy	5.7c	5.7b
	(4.5a, 4.5a)	Interspace	3.4a	3.4a
	Control	Canopy	5.5c	5.7b
	(4.3a, 4.6a)	Interspace	3.0a	3.5a

[1]Means under a site and treatment correspond to data collected in 1982 and 1983, respectively.
[2]Means under a column heading and within a site following by the same letter are not significantly different at the 0.05 probablity level.

Methods

Infiltration rates, sediment concentration of runoff, total sediment production, and soil and vegetation characteristics were measured in June 1982 and 1983 on areas treated with herbicides in May 1981 (McDaniel and Balliette 1984). Treatments replicated twice in a randomized complete block design included: (1) no treatment, (2) hand broadcast application of tebuthiuron 20% pellets at a 0.56 kg/ha rate, and (3) ground spraying of 2,4-D ester at 2.2 kg/ha. Within each 0.15-ha plot where a sagebrush control treatment was applied, an equal number of measurements were taken from shrub canopy (coppice dunes) or interspace areas. The same criteria defined by Blackburn and Skau (1974) to describe the shrub canopy zone and interspace areas were used. Each of these strata was sampled with 3 randomly located infiltration plots per replicated herbicide treatment (i.e., 6 total infiltrometer plots per herbicide treatment per year).

A mobile drip infiltrometer (Blackburn et al. 1974) simulated rainfall at a rate of 10.7 cm/hr for 45 minutes in square 1-m² plots. Average drop size was 2.5 mm diameter. Velocity of raindrops reaching the soil surface was 70% of natural rainfall. A large rainstorm event was used in order to ensure runoff. Rainfall of this intensity is similar to a short-duration, convectional thunderstorm that typically occurs in August or September in this region (USDA-SCS 1982). Before the simulated rainfall, each plot was pre-wetted to about a 15-cm depth at a constant rate (1.9 l/hr) and duration (1 hr). Saturated plots were then covered with plastic and sampled 24 hours later when soils were assumed to be near field capacity. Infiltration rates were determined by subtracting runoff volume from the simulated rainfall at 5-minute intervals and converting to cm/hr. Terminal infiltration was determined by averaging the 35, 40, and 45-minute time interval infiltration rates. Total runoff collected from a plot was thoroughly agitated and a one-liter subsample was taken. This subsample was filtered, oven-dried, and converted to sediment concentration (g/l) and total sediment loss (kg/ha/hr).

Soil characteristics measured for each plot included bulk density at 2 depths (0–5 cm and 5–10 cm) using a bulk density core. Surface soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos 1962). Soil organic carbon was determined using acid dichromate oxidation (Blake 1965). A microrelief meter was used to determine surface roughness (Kincaid and Williams 1966). The meter, consisting of 20 pins spaced at 5-cm intervals, was placed across each 1 m^2 plot 3 times. Differences in pin height were measured to the nearest cm and the average standard deviation was compared between herbicide treatments.

Vegetative characteristics measured for each plot included basal cover of vegetation, litter, and bare ground. Estimates of basal cover were obtained by using the pins of the microrelief meter. Cover values for grass, forbs, shrubs, litter, and bare ground were converted to percentages. After taking infiltrometer data, standing live and dead vegetation were clipped to ground level in the 1-m^2 plots and divided into classes of grass, forb, shrub, and litter. These materials were oven-dried, weighed, and converted to kg/ha. Visual estimates were made of the percentage of sagebrush canopy cover and percentage of live canopy reduction in each sampling area.

All data, except sediment concentration of runoff and total sediment production (Blackburn 1984), were assumed to be normally distributed and subjected to analysis of variance. Logarithmic transformations were made on the sediment concentration data. Data were analyzed separately by year, and Duncan's multiple range test was used to separate means where significant F ratios

Table 2. Mean and standard deviation (in parentheses) values for soil and vegetative characteristics determined from untreated rangeland at 3 study sites in northern New Mexico, 1983-84.

	Bloomfield							
	Canopy				Interspace			
	1982		1983		1982		1983	
	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)
Soil Characteristics								
Bulk density (g/cc):								
0–5 cm	1.4	(0.1)	1.3	(0.1)	1.4	(0.1)	1.3	(0.2)
5–10 cm	1.4	(0.1)	1.3	(0.1)	1.4	(0.1)	1.4	(0.1)
Texture (%):								
Sand	90.0	(2.2)	87.2	(1.3)	87.0	(3.1)	81.3	(3.5)
Silt	8.0	(2.0)	10.8	(1.2)	11.0	(2.3)	15.8	(3.0)
Clay	2.0	(0.8)	2.0	(0.6)	2.0	(0.8)	2.8	(0.8)
Organic carbon (%)	1.7	(0.4)	1.6	(0.5)	0.9	(0.3)	1.0	(0.2)
Microtopography (cm)	3.4	(1.3)	2.5	(0.4)	1.2	(0.8)	1.3	(0.2)
Vegetative Characteristics								
Yield (kg/ha):								
Herbaceous	18.0	(10.0)	20.9	(14.0)	23.0	(8.9)	36.4	(20.3)
Litter	96.0	(46.0)	190.5	(80.0)	86.0	(62.0)	126.2	(62.4)
Basal Cover (%):								
Herbaceous	1.0	(1.0)	3.8	(4.2)	2.3	(1.0)	2.9	(2.4)
Litter	31.0	(10.0	29.8	(10.9)	16.0	(4.0)	11.7	(8.1)
Shrub Canopy (Cover %)	50.0	(12.0)	50.8	(26.7)	0	0	0	0
	Gobernador							
	Canopy				Interspace			
	1982		1983		1982		1983	
	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)
Soil Characteristics								
Bulk density (g/cc):								
0–5 cm	1.4	(0.1)	1.0	(0.1)	1.4	(0.1)	1.3	(0.1)
5–10	1.4	(0.1)	1.3	(0.1)	1.4	(0.1)	1.3	(0.1)
Texture (%):								
Sand	75.0	(1.2)	75.0	(0.6)	75.0	(0.9)	71.7	(1.2)
Silt	22.0	(2.0)	23.2	(0.7)	22.0	(1.2)	25.3	(0.8)
Clay	3.0	(1.0)	1.8	(0.4)	3.0	(1.0)	3.0	(0.6)
Organic carbon (%)	1.3	(0.8)	2.8	(0.7)	0.6	(0.2)	0.9	(0.1)
Microtopography (cm)	2.7	(0.9)	1.8	(0.6)	1.7	(1.1)	1.3	(0.3)
Vegetative Characteristics								
Yield (kg/ha):								
Herbaceous	19.0	(7.3)	51.8	(13.0)	25.0	(7.0)	54.5	(26.0)
Litter	156.0	(63.5)	353.4	(103.3)	110.0	(165.0)	112.5	(84.3)
Basal Cover (%):								
Herbaceous	4.0	(4.0)	7.1	(4.0)	6.7	(1.1)	3.0	(2.0)
Litter	36.0	(8.9)	51.7	(9.3)	26.0	(5.1)	18.2	(8.1)
Shrub Canopy Cover (%)	45.0	(17.0)	34.2	(9.2)	0	0	0	0

Table 2 (continued)

	Aztec							
	Canopy				Interspace			
	1982		1983		1982		1983	
	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)	$\bar{x}$	(s)
Soil Characteristics								
Bulk density (g/cc):								
0–5 cm	1.2	(0.1)	1.0	(0.1)	1.3	(0.0)	1.2	(0.1)
5–10 cm	1.3	(0.1)	1.1	(0.1)	1.3	(0.1)	1.2	(0.1)
Texture (%):								
Sand	74.0	(0.8)	72.7	(0.5)	72.0	(2.0)	69.3	(2.4)
Silt	22.0	(1.9)	24.5	(0.6)	22.0	(1.2)	25.8	(2.1)
Clay	3.0	(1.0)	2.8	(0.4)	6.0	(2.0)	4.8	(0.8)
Organic carbon (%)	2.5	(0.8)	2.7	(0.6)	0.7	(0.1)	0.6	(0.3)
Microtopography (cm)	2.1	(1.0)	2.0	(0.4)	0.8	(0.3)	1.1	(0.2)
Vegetative Characteristic								
Yield (kg/ha)								
Herbaceous	17.2	(12.0)	18.8	(6.0)	6.0	(5.0)	20.7	(12.6)
Litter	270.0	(361.0)	314.9	(189.5)	82.0	(72.0)	243.5	(225.2)
Basal Cover (%):								
Herbaceous	3.0	(2.0)	0.3	(0.2)	2.0	(5.0)	1.7	(2.3)
Litter	35.0	(14.0)	55.5	(21.3)	4.0	(5.0)	12.0	(9.0)
Shrub Canopy Cover (%)	60.0	(14.0)	57.5	(26.7)	0	0	0	0

were obtained ($P \leq .05$) (Steel and Torrie 1960). Regression analyses by year were used to determine the influence of soil and vegetative characteristics on terminal infiltration, sediment concentration of runoff, and total sediment production.

Results and Discussion

Infiltration

Average terminal infiltration rates were not significantly different between sites in 1982, but were slightly higher at Aztec in 1983 compared to the Bloomfield and Gobernador study areas (Table 1). Terminal infiltration under the sagebrush canopy was consistently higher at the Aztec site than at the other 2 areas, whereas infiltration rates in the interspace were similar among the 3 sites.

Terminal infiltration rates were higher under the sagebrush canopy than in the interspace regardless of site or treatment (Table 1). Infiltration rates in the interspace were about 35% less than in the canopy zone. These data agree with Blackburn (1975) when he reported that sagebrush canopy zones have a higher infiltration rate, sometimes 3 to 4 times greater, than interspace areas. In a similar study with mesquite *(Prosopis glandulosa)*, Brock et al. (1982) reported infiltration to be about twice as high under the canopy than in the interspace. Brock et al. (1982) attributed differences in infiltration rates among strata to be largely the result of the area under the canopy having a greater amount of litter and vegetation basal cover, a higher percentage of sand particles, 2 to 3 times higher percentage of organic carbon, and lower soil bulk density. In this study, litter yield and basal cover, microtopography (microrelief standard deviation), and percentage organic carbon were consistently higher under sagebrush than in the interspace (Table 2). There was also a trend of lower soil bulk density and a higher percentage of sand particles under the canopy compared to the interspace, but these differences were not always consistent.

Infiltration rates averaged across sites and vegetation zones were not significantly different among treatments for either year sampled (Table 1). Soil characteristics remained unchanged from 1982 to 1983 and were not influenced by herbicide applications (data not shown). Leaf cover of sagebrush was reduced by 100% in the completely defoliated tebuthiuron treatments, and about 50 to 60% in the partially defoliated 2,4-D spray. However, dead standing sagebrush branches and stems remained in both herbicide treatments providing ground cover. Herbaceous vegetation yield and basal cover were generally highest in the tebuthiuron treatment, intermediate in the 2,4-D spray, and lowest in the control, especially the third growing season after treatment (1983) (data not shown). However these differences were not consistent across study areas and no significant differences were found.

Regression analyses on data combined by site, strata, and treatment for a particular year indicated the primary factors positively correlated with terminal infiltration rates were sagebrush canopy cover and weight, litter cover and weight, total basal cover, soil organic carbon, and microtopography (Table 3). Infiltration rate was negatively related to soil bulk density in 1983, and clay content in the soil both years. The effects of these soil and vegetative variables upon infiltration rate are consistent with other watershed studies conducted in the sagebrush ecosystem (Blackburn 1984).

Sediment Concentration of Runoff

Sediment concentration, measured from the runoff of each of the plots, was lower at the Bloomfield site than at the Aztec or Gobernador sites (Table 4). A combination of soil characteristics can influence sediment concentration, but suspended materials in the runoff are primarily silt and clay particles (Satterlund 1972). The higher concentrations of sediments in the runoff at the Aztec and Gobernador sites compared to the Bloomfield area may be attributed to a greater percentage of fine materials (primarily silt) at the soil surface (Table 2). Percentage of sand (negative correlation) and silt (positive correlation) were highly related to sediment concentration (Table 3). The unexpectedly high percentage of sand under the canopy may be partially due to aeolian deposition, in addition to losses of silt and clay particles in the runoff (Melton 1940). A lower average soil bulk density at Aztec and Governador also may have added to increased sediment concentrations by providing a less stable surface when exposed to the same amount of runoff as the Bloomfield site. Bulk density at both depths (0–5 cm and 5–10 cm) were negatively correlated to sediment concentration.

Sediment concentrations of runoff were not significantly different between herbicide treatments within a study site or when sites were combined (Table 4). An exception was a lower amount of sediment concentration in the 2,4-D spray compared to the other brush control treatments at the Bloomfield site. A nonsignificant trend of higher sediment concentration of runoff under the canopy zone of tebuthiuron treatments and a lower concentration within the control and 2,4-D spray canopy zones was apparent, especially the third growing season after brush control at Bloomfield and

Table 3. Simple linear correlation coefficients *(r)* between watershed parameters and selected soil and vegetative characteristics from three study sites 12 and 24 months after herbicide treatment in May 1981.

	Terminal Infiltration (cm/hr)		Sediment Concentration (g/l)		Sediment Production (kg/ha/hr)	
	1982	1983	1982	1983	1982	1983
Soil Characteristics	r		r		r	
Bulk Density (g/cc): 0–5 cm	*[1]	–.63	–.28	*	*	*
5–10 cm	*	–.31	–.23	–.23	–.22	–.31
Texture (%) sand	*	*	–.25	–.24	–.24	–.28
silt	*	*	.30	.25	.23	.28
clay	–.30	–.46	*	*	.19	.38
Organic Carbon (%)	.60	.57	.31	*	*	–.24
Microrelief Standard Deviation (cm)	.40	.49	.20	*	*	–.34
Vegetative Characteristics						
Production (kg/ha): grass	*	–.29	*	*	*	*
forb	*	*	*	*	*	*
shrub	.78	.58	.33	*	–.22	*
total vegetation	.78	.50	.33	*	–.22	–.23
litter	.52	.70	.20	*	*	–.24
Relative Basal Cover (%): grass	.21	*	*	*	*	
forb	*	*	*	*	*	*
litter	.58	.53	.22	*	*	–.36
total basal cover	.60	.59	.25	*	–.18	–.38
Sagebrush Canopy Cover (%)	.77	.77	.19	*	–.29	–.36

[1]Correlation coefficients were significant at the 99% or greater level. Values with an asterisk were not significant.

Gobernador. Greater plant biomass and ground cover have been concluded to protect areas from erosion and the sagebrush canopy does protect the soil surface by reducing the impact of raindrops (Blackburn 1973, Gifford and Hawkins 1976, Dixon 1978, Dunne and Leopold 1970). We believe longer-term research is needed to determine if sediments actually increase from the canopy area of completely defoliated sagebrush compared to untreated rangeland.

Table 4. Mean sediment concentration of runoff (g/l) canopy-interspace areas as influenced by sagebrush control treatments, from three study areas in New Mexico in 1982 and 1983.

Site[1]	Treatment	Strata	Sediment Concentration[2] 1982	1983
			g/l	
Bloomfield	2,4-D	Canopy	1.1a	1.6a
(1.9a, 3.7c)	(1.3a, 1.7a)	Interspace	1.5a	1.9a
	Tebuthiuron	Canopy	2.6a	5.7b
	(2.0a, 4.9b)	Interspace	1.5a	4.1a
	Control	Canopy	1.9a	4.9ab
	(2.3a, 4.4b)	Interspace	2.6a	3.8a
Gobernador	2,4-D	Canopy	2.1a	5.6b
(2.8b, 5.1d)	(1.9a, 4.7b)	Interspace	1.8a	3.8a
	Tebuthiuron	Canopy	4.4b	7.6c
	(3.6ab, 6.5b)	Interspace	2.8a	5.3b
	Control	Canopy	2.6a	3.9a
	(2.8a, 4.0b)	Interspace	2.9a	4.2a
Aztec	2,4-D	Canopy	4.2ab	8.7ab
(3.2b, 8.4d)	(3.1a, 8.2c)	Interspace	2.1a	7.6a
	Tebuthiuron	Canopy	3.4a	8.6ab
	(3.3a, 9.2c)	Interspace	3.3a	9.8b
	Control	Canopy	4.3a	6.7ab
	(3.1a, 7.8c)	Interspace	1.9a	8.9ab

[1]Means under site and treatment correspond to data collected in 1982 and 1983, respectively.
[2]Means under a column heading and within a study site followed by the same letter are not significantly different at the 0.05 probability level.

Total Sediment Production

Differences in total sediment production between sites when strata and treatments were combined could be, as expected, largely attributed to the same soil characteristics used to explain differences in sediment concentration of runoff. Bulk density and percentage of sand were negatively correlated to sediment production (Table 5). These 2 soil characteristics were higher at the Bloomfield site, which had the lowest total sediment production of the 3 study areas (Tables 2 and 5). Percentages of silt and clay, which were positively correlated to sediment production, were highest at the Aztec and Gobernador sites and contributed a high amount of erosion compared to the Bloomfield site.

Total sediment production was 30 to 41% higher from the interspace than from canopy when measurements from all sites and treatments were combined for 1982 and 1983, respectively (Table 5). Sagebrush canopy cover and total vegetative production and basal cover showed negative and significant correlations to total sediment production and appear to be primary factors influencing differences between the strata (Table 5). However, soil characteristics (silt and clay, positive correlation; sand, bulk density, organic carbon (1983 only), and microrelief standard deviation (1983 only), negative correlation), also were highly correlated to sediment production and were equally important in explaining differences.

There was a significant interaction of sagebrush control treatments with strata on total sediment production for both measured years. There was also an interaction for sediment loss between brush control treatments and study sites (Table 5). It was hypothesized that sediment production would be accelerated by the complete defoliation of sagebrush by tebuthiuron. In general, sediment production was higher in the canopy of tebuthiuron treated areas and was less in the canopy of untreated rangeland. Surprisingly, sediment production in the interspace area of tebuthiuron treated plots was also generally higher than untreated, interspace areas. However, these differences were not consistent and were significant at only 1 study site.

In general, our research indicates herbicide treatment alone will not change watershed values in the short-term. Our data suggest

Table 5. Mean total sediment production (kg/ha/hr) for canopy-interspace areas as influenced by sagebrush control treatments, from three study areas in New Mexico in 1982 and 1983.

Site[1]	Treatment	Strata	Sediment 1982	Sediment 1983
			----------kg/ha/hr---------	
Bloomfield	2,4-D	Canopy	201a	264a
(363a, 708c)	(282a, 410a)	Interspace	363a	556ab
	Tebuthiuron	Canopy	308a	903bc
	(326a, 1036bc)	Interspace	344a	1169c
	Control	Canopy	267a	627ab
	(483a, 893b)	Interspace	699ab	1159c
Gobernador	2,4-D	Canopy	271a	962ab
(504b, 1049d)	(291, 1031bc)	Interspace	312a	1101b
	Tebuthiuron	Canopy	759b	1309b
	(747ab, 1341c)	Interspace	735b	1375b
	Control	Canopy	381a	527a
	(475a, 775b)	Interspace	569ab	1022b
Aztec	2,4-D	Canopy	609ab	863a
(545b, 1326d)	(596ab, 1262c)	Interspace	582ab	1662ab
	Tebuthiuron	Canopy	352a	895a
	(595ab, 1421c)	Interspace	838b	1947b
	Control	Canopy	377a	655a
	(446a, 1295c)	Interspace	515ab	1934b

[1]Means under a site and treatment correspond to data collected in 1982 and 1983, respectively.
[2]Means under a column heading and within a study site followed by the same letter are not significantly different at the 0.05 probability level.

that if short-term differences in watershed conditions between herbicide treated and untreated rangeland occurs, then changes will probably be greatest in the canopy zone. In contrast, an increase in infiltration and a reduction of erosion in the interspace may be a benefit of sagebrush control only in the long term.

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Vegetation Response on Allotments Grazed under Rest-Rotation Management

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Abstract

The effects of grazing management systems on plant communities in the Great Basin are largely unknown. This study is a quantitative description of the response of vegetation from 1973 to 1983 on the Goldbanks and Pueblo Mountain cattle allotments in northern Nevada managed under a 3-pasture rest-rotation grazing system. Shrub canopy cover, basal-area cover of herbaceous species, and frequency of occurrence of all species were used to estimate change in vegetation characteristics on macroplots representing 9 community types. Forage use was heavy in all years and averaged 65% in June, 75% in July and August, and 80% in October. Sandberg bluegrass [*Poa sandbergii* Vasey] and sagebrush [*Artemisia* spp. L.] were the most responsive species. Long-term increases or decreases in frequency and cover of desirable grasses were found on very few sites. Perennial forbs increased on a number of sites. Short-term changes in frequency and cover of Sandberg bluegrass and in frequency of sagebrush seedlings and young plants were attributed to a sequence of dry and wet years and to level of competition from herbaceous species. Frequency data indicated more significant changes in species composition than did cover data. The management system, forage utilization levels imposed, and climatic conditions present maintained prestudy range condition throughout the study on most sites at Pueblo Mountain. An increase in frequency and cover of Wyoming big sagebrush [*A. tridentata wyomingensis* Beetle] and a decrease in the cover of desirable grasses at Goldbanks suggest a downward trend in range condition on some sites where either Thurber needlegrass [*Stipa thurberiana* Piper] or bluebunch wheatgrass [*Agropyron spicatum* (Pursh) Scribn. & Smith] is the potential dominant grass.

Many hectares of western rangeland presently are managed under intensive grazing systems. By 1978 for example, allotment management plans had been implemented on about 11 million ha managed by the Bureau of Land Management (BLM) (USDI 1978). About 2 million ha were under intensive management in Nevada. In addition, the "Proposed Action" in many current Environmental Impact Statements and Resource Management Plans indicates that grazing systems will be the primary means of range improvement in the future. In many cases, intensive management has come to mean deferred or rest-rotation grazing systems.

Hickey (1967) and Herbel (1971) described many kinds of grazing systems and results obtained. Hormay (1956, 1970), Hormay and Evanko (1958), and Hormay and Talbot (1961) discussed the reasons for range deterioration and developed a 5-pasture rest-rotation grazing system for improving bunchgrass range in northeastern California. Hughes (1979, 1980) reported the effects of rest-rotation management on the Arizona Strip of southern Utah and northern Arizona. Laycock and Conrad (1981) evaluated the response of vegetation and cattle to several grazing systems on mountain rangelands of eastern Utah. Johnson (1965) and Gibbens and Fisser (1975) compared different grazing systems in Wyoming. Only Hyder and Sawyer (1951) studied grazing systems in an environment and vegetation typical of the Great Basin. These authors compared rotation-deferred and season-long grazing.

This study is a quantitative description of changes in species composition on representative plant communities in different seral stages. The study was conducted on 2 allotments in northern Nevada grazed by cattle in a 3-pasture rest-rotation management system. The study was not designed to compare rest-rotation management to any other grazing system or to compare rest-rotation grazing under management conditions different from those described.

Experimental Areas

Goldbanks Allotment

This 7771-ha allotment is located about 48 km south of Winnemucca, Nevada and is administered by the Winnemucca District, BLM. Topography consists of broad alluvial fans, hills, several drainages, and a very steep escarpment on 1 boundary. Elevation ranges from 1,500 to 2,700 m. Annual precipitation, mostly snow, averaged 26 cm for the period 1974–1983 and ranged from a low of 15 cm in 1980–81 to a high of 37 cm in 1977–78. Ecological range condition on study areas varies from early- to mid-seral. Wyoming big sagebrush [*Artemisia tridentata wyomingensis* Beetle] is present on all study sites. Decreaser grasses are Thurber needlegrass [*Stipa thurberiana* Piper], bluebunch wheatgrass [*Agropyron spicatum* (Pursh) Scribn. & Smith], and Idaho fescue [*Festuca idahoensis* Elmer]. Big sagebrush, green rabbitbrush [*Chrysothamnus viscidiflorus* (Hook.) Nutt.], bottlebrush squirreltail [*Sitanion hystrix* (Nutt.) J.G. Sm.], and Sandberg bluegrass [*Poa sandbergii* Vasey] are the principal increaser species. Common forbs are desert phlox [*Phlox austromontana* Cov.], milkvetch [*Astragalus* spp. L.], tapertip hawksbeard [*Crepis acuminata* Nutt.], tailcup lupine [*Lupinus caudatus* Kell.], and Stansbury phlox [*Phlox stansburyi* Hel.].

A 3-pasture rest-rotation management system for grazing from May through October was established in 1973. Actual use in grazed pastures has varied between 152 and 1,193 AUM's (Animal Unit Months) of cow-calf use. Average use in grazed pastures has been 633 AUM's. The grazing sequence for 1 pasture over a 3-year period is:

A. First year-graze (graze from May 1 to Oct. 31)
B. Second year-seedripe (graze from July 15, seedripe, to Oct. 31)
C. Third year-rest (rest year-long)

Pueblo Mountain Allotment

This 4,007-ha allotment is located about 160 km north, northwest of Winnemucca, Nevada and also is administered by the Winnemuca District, BLM. Topography consists of mountain slopes, small alluvial fans, and several drainages with rimrock and steep mountains forming 2 boundaries. Elevation ranges from 1,524 to 1,981 m. Annual precipitation averaged 36 cm for the period 1974–1983 and ranged from a low of 25 cm in 1976–77 to a high of 40 cm in 1981–82. Ecological range condition on study areas varies from early- to late-seral. Basin big sagebrush [*Artemisia tridentata tridentata* Nutt.] and mountain big sagebrush [*A. tridentata vaseyana* (Rybd.) Beetle] are the dominant subspecies of big sage-

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brush on fans and mountain slopes. Low sagebrush [*A. arbuscula* Nutt.] occurs on the steeper slopes on soils with a strong argillic B horizon. Antelope bitterbrush [*Purshia tridentata* (Pursh.) DC.] is a common decreaser shrub. Principal decreaser grasses are bluebunch wheatgrass and Idaho fescue. Increaser species include big and low sagebrush, green rabbitbrush, squirreltail, thickspike wheatgrass [*Agropyron dasystachyum* (Hook.) Scribn.], Thurber needlegrass, and Sandberg bluegrass. Forbs are more prevalent than on the Goldbanks Allotment. Important species are: low pussytoes [*Antennaria dimorpha* (Nutt.) T. & G.], agoseris [*Agoseris* spp. Raf.], fleabane [*Erigeron* spp. L.], crag aster [*Aster scopulorum* Gray], tailcup lupine, tapertip hawksbeard, Stansbury phlox, and milkvetch.

A 3-pasture rest-rotation management system for grazing from June through October was established in 1972. Actual use in grazed pastures has varied between 330 and 636 AUM's of cow-calf use. Average use in grazed pastures has been 491 AUM's. The grazing sequence for 1 pasture over a 3-year period is:

A. First year-graze (graze from June 1 to July 31)
B. Second year-seedripe (graze from Aug. 1, seedripe, to Oct. 31)
C. Third year-rest (rest year-long)

The grazing systems on both allotments were quite similar in spite of different periods of time indicated for cattle use in the graze pasture. At Pueblo Mountain, normal drift of cattle was followed by riding to move all animals from the graze to the seedripe pasture soon after July 31. At Goldbanks, all movement of cattle was accomplished by drift and most animals were in the seedripe pasture soon after July 15. Some animals, however, remained in the graze pasture until Oct. 31. Remaining cattle grazed the more favored areas, such as riparian sites, not the upland sites where study sites were located. Because of this, grazing impacts on the 2 allotments were similar. Management at Goldbanks has now been modified to specify removal of all cattle from the grazed pasture by riding soon after July 15.

Low stocking rates at both allotments occurred in years of below average precipitation. Fewer head were grazed in these years or animals were grazed for a shorter time. High stocking rates occurred early in the study when additional cattle numbers were authorized above the active preference (temporary non-renewable use) through 1976 at Goldbanks and through 1978 at Pueblo Mountain. This additional use was given as an incentive for ranchers to participate in the allotment management plan. The adjustment of stocking rates among favorable and unfavorable years resulted in rather uniform utilization of forage as will be discussed later.

Methods

Study sites were subjectively located in homogeneous stands of vegetation that appeared to represent ecological units of different potential. Since a synecological study of each allotment was not conducted, the ecological sites (range sites or phases of habitat types) present could not be determined absolutely. However, soil, remnant vegetation, and Ecological Site Descriptions for the Malhauer High Plateau (USDA 1965) and for the Humboldt Area (USDA 1982) were used to make inferences between present vegetation on a study site, termed community type (CT), and potential vegetation. We feel that the community types studied represent the important potential natural communities on these allotments.

On the Goldbanks Allotment, 7 study areas represented the Wyoming big sagebrush-Thurber needlegrass CT, 3 represented the Wyoming big sagebrush-bluebunch wheatgrass CT, 3 represented the Wyoming big sagebrush-Idaho fescue CT, and 1 represented the Wyoming big sagebrush-Great basin wildrye CT. On the Pueblo Mountain Allotment, 5 study areas represented the basin big sagebrush-bluebunch wheatgrass CT, 5 represented the mountain big sagebrush-bluebunch wheatgrass CT, 5 represented the mountain big sagebrush-Idaho fescue CT, 1 represented the low sagebrush-bluebunch wheatgrass CT, and 2 represented the low sagebrush-Idaho fescue CT.

Vegetation response was based on changes in species composition on a 30 × 60-m macroplot at each study site (Fig. 1). Changes were evaluated by estimates of basal-area cover of herbaceous species, canopy cover of shrubs, and frequency of occurrence of all species from 1973 to 1983. All data were collected by the same individual throughout the study. Five permanent 0.9-m^2 quadrats were selected along a transect through the center of the macroplot by restricted randomization so that at least 2 quadrats were located in the 0 to 15-m or in the 16 to 30-m segment of each macroplot. Basal area of bunchgrasses and caespitose forbs, ground area covered by mat-forming forbs, and canopy cover of shrubs rooted

Table 1. Number of macroplots on 4 community types at the Goldbanks Allotment on which shrub, grass, or forb species increased (+) or decreases (−) significantly or showed no significant change (0) in percent frequency or percent cover (canopy or basal by chart quadrat and canopy by line intercept) during the study period.[1,2] Quadrat cover is shown in parentheses. Intercept cover is shown on the second data line for each shrub species. A dash indicates that a species did not occur in the frequency or cover sample.

	Community Types: Wyoming big sagebrush/Thurber needlegrass (7)[3] and Wyoming big sagebrush/Great Basin wildrye (1)			Wyoming big sagebrush/bluebunch wheatgrass (3)			Wyoming big sagebrush/Idaho fescue (3)		
Shrub	+	−	0	+	−	0	+	−	0
Wyoming big sagebrush	4(2)	0(0)	4(4)	0(1)	0(0)	3(2)	1(0)	1(0)	1(3)
	4	2	2	2	0	1	1	1	1
Green rabbitbrush	—	—	—	0(0)	0(0)	0(2)	0(0)	0(0)	2(2)
				0	0	2	0	0	2
Grass									
Sandberg bluegrass	2(0)	0(2)	5(4)	3(1)	0(0)	0(2)	3(1)	0(0)	0(2)
Bottlebrush squirreltail	0(0)	2(1)	5(5)	0(0)	0(0)	3(3)	1(0)	0(0)	2(3)
Thurber needlegrass	0(0)	0(1)	1(2)	1(0)	0(0)	2(3)	0(0)	0(0)	1(2)
Bluebunch wheatgrass	—	—	—	0(0)	0(1)	3(2)	—	—	—
Idaho fescue	—	—	—	—	0(0)	0(1)	0(1)	0(0)	3(2)
Great Basin wildrye	0(0)	0(0)	4(2)	—	—	—	0(0)	0(0)	2(1)
Forb									
Milkvetch	2(0)	0(0)	1(0)	1(0)	0(0)	0(1)	0(0)	1(0)	1(1)
Tapertip hawksbeard	—	—	—	1(0)	0(0)	1(1)	2(0)	0(0)	0(0)
Tailcup lupine	—	—	—	1(0)	0(0)	0(1)	2(0)	0(0)	0(0)
Desert phlox	3(0)	0(2)	2(3)	0(0)	1(0)	1(2)	0(0)	0(0)	2(2)
Stansbury phlox	1(1)	1(0)	1(0)	—	—	—	1(0)	0(0)	2(1)

[1]Frequency data are compared between 1974 and 1981 or 1982. Chart-quadrat cover is compared between 1974 and 1980, 1981, or 1982. Intercept cover is compared between 1973 and 1980.
[2]Significant differences between beginning and ending frequency or cover values were determined by Duncan's multiple range test ($P \leq 0.05$).
[3]Number of sites representing the community type.

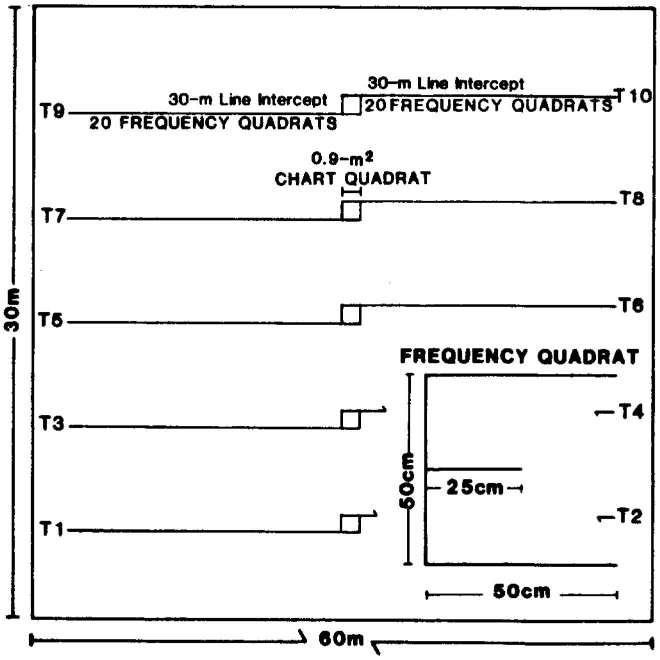

Fig. 1. *Illustration of plots and transects used to sample vegetation within a macroplot.*

in or overhanging the quadrat were charted. The quadrat was subdivided into 7.5-cm² units to facilitate charting individual plants. A dot grid was used to calculate total area of each species charted. Cover data were obtained every 3 years on the same quadrats in an ungrazed pasture. Shrub canopy cover over the entire macroplot was estimated by the line-intercept method (Canfield 1941). Measurements were made in 1973 and in 1980 on 10, 30-m lines originating from 2 opposite corners of each of the 5 randomly located chart-quadrat plots.

Frequency of occurrence (Hyder et al. 1963) was selected as the most objective and sensitive method to detect vegetation change. In addition, frequency is rather insensitive to weather fluctuations (Range Inventory Standardization Committee 1983). Rooted frequency of all species was estimated on 20 quadrats on each of 10 transects. Frequency transects originated from the same random points as did the line-intercept transects. Quadrats were divided into sub-units so that frequency of important species was between 30 and 70%. A 25-cm² quadrat was the sample size for Sandberg bluegrass at Pueblo Mountain and for Sandberg bluegrass, desert phlox, and Stansbury phlox at Goldbanks. A 50-cm² quadrat was used to sample all other species on both allotments. Frequency was estimated on the same transect lines in consecutive years from 1974 to 1979 in seedripe and rested pastures. Since 1980, these data were collected every 3 years in a rested pasture.

Forage utilization was estimated on the 5 chart-quadrat plots on each macroplot by the Key Forage Plant Methods (USDI nd). From 1974 to 1976 utilization was estimated at the end of the grazing season. From 1977 to 1983 utilization estimates were made at least once during the growing season as well as at the end of the grazing season.

Individual chart quadrats, intercept lines, and frequency transects were at least 4 m apart in the macroplot. Therefore, we assumed that these samples were independent and that sample size was the number of independent plots and transects in each macro-

Table 2. Number of macroplots on 5 community types at the Pueblo Mountain Allotment on which shrub, grass, or forb species increased (+) or decreased significantly or showed no significant change (0) in present frequency or percent cover (canopy or basal by chart quadrat and canopy by line intecept) during the period.[1,2] Quadrat cover is shown in parentheses. Intercept cover is shown in the second data line for each shrub species. A dash indicates that a species did not occur in the frequency or cover sample.

	Community Types								
	Basin (5)[3] and mountain (5) big sagebrush/bluebunch wheatgrass			Mountain big sagebrush/Idaho fescue (5)			Low sagebrush/bluebunch wheatgrass (1) and low sagebrush/Idaho fescue (2)		
	+	–	0	+	–	0	+	–	0
Shrub									
Basin big sagebrush	2(0)	0(0)	3(5)	—	—	—	—	—	—
	0	0	5						
Mountain big sagebrush	2(1)	0(0)	3(4)	3(0)	0(0)	2(5)	—	—	—
	0	1	4	0	1	4			
Low sagebrush	—	—	—	—	—	—	3(2)	0(0)	0(1)
							1	0	2
Bitterbrush	0(0)	0(0)	2(3)	0(0)	0(0)	1(1)	—	—	—
	0	1	3	0	0	3			
Green rabbitbrush	1(0)	0(0)	2(4)	2(0)	0(0)	1(5)	0(0)	0(0)	2(1)
	0	0	5	0	0	4	0	0	2
Grass									
Sandberg bluegrass	3(2)	0(2)	7(6)	4(0)	0(0)	1(5)	3(3)	0(0)	0(0)
Bottlebrush squirreltail	0(0)	2(0)	6(6)	0(0)	0(0)	3(3)	1(0)	0(0)	2(3)
Thurber needlegrass	1(1)	0(1)	9(6)	1(0)	0(0)	4(5)	0(0)	0(1)	1(0)
Bluebunch wheatgrass	2(1)	0(0)	5(8)	0(1)	0(0)	5(4)	0(0)	0(0)	3(3)
Thickspike wheatgrass	1(0)	0(0)	4(4)	1(0)	0(0)	0(0)	—	—	—
Idaho fescue	0(0)	0(0)	1(1)	1(0)	0(0)	4(5)	0(0)	0(0)	2(2)
Great Basin wildrye	0(0)	0(0)	3(0)	0(0)	0(0)	1(1)	—	—	—
Forb									
Milkvetch	1(0)	0(0)	1(3)	0(0)	0(0)	4(3)	3(1)	0(0)	0(2)
Tapertip hawksbeard	2(0)	0(0)	1(0)	0(0)	0(0)	2(1)	0(0)	0(0)	3(0)
Tailcup lupine	6(2)	0(0)	2(6)	4(1)	0(0)	0(4)	2(1)	0(0)	1(0)
Desert phlox	—	—	—	—	—	—	1(0)	0(0)	0(1)
Stansbury phlox	1(1)	0(0)	6(7)	0(1)	0(0)	2(1)	1(1)	0(0)	2(1)

[1]Frequency data are compared between 1974 and 1981, 1982, or 1983. Chart-quadrat cover is compared between 1974 and 1980 or 1983; between 1975 and 1981; and between 1976 and 1979 or 1982. Intercept cover is compared between 1973 and 1980.
[2]Significant differences between beginning and ending frequency or cover values were determined by Duncan's multiple range test ($P \leq 0.05$).
[3]Number of macroplots representing the community type.

plot. This assumption is subject to further research to test the relation between the independence of data from adjacent plots and the distance between those plots. The sample size for quadrat cover was 1 observation for each species on each of the 5 chart-quadrat plots. The sample size for line-intercept cover and frequency was 1 observation, composed of the transect mean for each species estimate, for each of the 10 transects.

A repeated-measures analysis (Winer 1971) was used in this study because data were collected periodically from the same plots or transects. A Hartley F-max test performed on percent frequency data showed that a transformation was needed. The variance was stabilized by the arcsin squareroot technique. A 1-way analysis of variance with repeated measures was conducted on transformed data. If a significant ($P \leq 0.05$) F value was obtained, a Duncan's multiple range test was used to determine significant means for frequency or cover measured at the start and end of the study, or at any point during a management cycle. Although analyses were performed on transformed data, untransformed means and standard errors are presented in this paper.

Results

Macroplot data are presented for 2 time intervals: long term, based on frequency and cover data collected at the start of the study, and again at, or near, the end of the study; and short term, based on frequency and cover data collected every 1 to 3 years during the study. The number of macroplots with a significant increase or decrease or no significant change in percent frequency or cover is given for the Goldbanks Allotment (Table 1) and for the Pueblo Mountain Allotment (Table 2). Examples of changes in percent frequency and cover, with standard errors, on 4 macroplots are shown in Tables 3–6 (frequency and cover data for all 32 macroplots are available from the authors). Frequency and cover data presented in the text are average values based on the number of sites with a significant change.

Utilization

Forage use was heavy in each year on macroplots in all grazed pastures of both allotments with no significant differences among years for each grazing period. Utilization during the grazing season averaged 65% in June, 75% in July and August, and 80% in October. Utilization after seedripe averaged 80% in October. Heavy use throughout the grazing season is probably related to the stocking rate established when the management plan was initiated. In each case, allowable cattle numbers for the allotment as a whole were not reduced, but in some cases were temporarily increased. Under a 3-pasture rest-rotation system, therefore, two-thirds of each allotment had to support the same number of cattle, or more, each year that previously had grazed over the entire allotment prior to implementation of the management system.

Long-Term Changes

Intercept-Shrub Cover

Changes in the canopy cover of sagebrush varied with community type, species of sagebrush, and subspecies of big sagebrush (Tables 1–6). On the Goldbanks Allotment in the Wyoming big sagebrush-Thurber needlegrass CT, big sagebrush cover increased on 4 of 7 sites from a mean of 15.4% in 1973 to 30.8% in 1980. In the same CT, sagebrush cover decreased from 9.8 to 4.4% on 1 site, and remained unchanged on 2 sites. Cover of sagebrush in the Wyoming big sagebrush-bluebunch wheatgrass CT increased on 2 of 3 sites from a mean of 12.3% in 1973 to 23.4% in 1980 and remained unchanged on 1 site. Cover of sagebrush in the Wyoming big sagebrush-Idaho fescue CT decreased on 1 of 3 sites, from 7.7 to 2.2% and remained unchanged on 2 sites. On 1 Wyoming big sagebrush-Great Basin wildrye CT, sagebrush cover decreased from 24.7% to 9.8%. Rabbitbrush cover was unchanged on the 4 sites where it occurred.

On the Pueblo Mountain Allotment, big sagebrush cover did not increase on any site in any community type. Cover was unchanged on all 5 sites in the basin big sagebrush-bluebunch wheatgrass CT. In the mountain big sagebrush-bluebunch wheatgrass CT, big sagebrush cover decreased on 1 of 5 sites from 53.5% in 1973 to 34.7% in 1980 and was unchanged on 4 sites. In the mountain big sagebrush-Idaho fescue CT, big sagebrush cover decreased on 1 of 5 sites from 29.3% in 1973 to 19.1% in 1980 and was unchanged on 4 sites. Cover of low sagebrush increased from 26.2 to 29.4% on 1 of 2 sites in the low sagebrush-Idaho fescue CT. Cover of bitterbrush decreased from 23.3 to 12.6% on 1 of 4 sites in the mountain big sagebrush-bluebunch wheatgrass CT. Rabbitbrush cover was unchanged on all 11 sites where it occurred.

Table 3. Frequency (%), basal cover of herbaceous species (% by chart quadrat), and canopy cover of shrubs (% by line intercept and chart quadrat) with standard errors on a macroplot representing a Wyoming big sagebrush-Thurber needlegrass community type in the Panther Canyon Pasture of the Goldbanks Allotment. The 2 entries in the frequency change column are the values at the beginning (1974) and at the end (1982) of data collection. The 2 quadrat-cover entries in the cover-change column are the values at the beginning (1974) and at the end (1980) of data collection. The 2 intercept-cover entries are data collected in 1973 and 1980.

	Frequency		Cover[1]	
Species	Change	Standard error	Change	Standard error
Shrub				
Wyoming big sagebrush	37–60*[2]	3.8	15.8–23.3*	1.8
			0.7–1.5*	0.3
Grass				
Sandberg bluegrass	60–73	4.9	2.6–1.2	0.4
Bottlebrush squirreltail	42–29*	3.2	0.3–0.04	0.1
Thurber needlegrass	0[3]		0.1–0.2	0.04
Great Basin wildrye	8–11	0.3	0	
Forb				
Milkvetch	0		0	
Tapertip hawksbeard	0		0	
Tailcup lupine	0		0	
Desert phlox	32–48	5.8	0.4–0.2	0.1
Stansbury phlox	0		0	

[1]For shrubs, intercept cover is listed first, followed by quadrat cover.
[2]Significant differences between beginning and ending frequency and cover values are indicated by an asterisk and were determined by Duncan's multiple range test at $P \leq 0.05$.
[3]Species did not occur in the frequency or cover sample.

Frequency and Quadrat Cover

On macroplots at Goldbanks, the increaser species Wyoming big sagebrush and Sandberg bluegrass, and perennial forbs were the most responsive (Table 1). An example of the direction and magnitude of significant and nonsignificant changes for 1 study site in the Wyoming big sagebrush-Thurber needlegrass CT is shown in Table 3. On sites with Thurber needlegrass the potential dominant grass, frequency of big sagebrush increased on 4 of 7 sites from 29 to 47% and quadrat cover increased on 2 of 7 sites from 2.4 to 4.0%. Frequency of sagebrush decreased from 12 to 4% on only 1 site, that in the community type with Idaho fescue the potential dominant grass. An increase in the frequency (57 to 79%) and cover (2.5 to 5.8%) of bluegrass and in the frequency of milkvetch (11 to 26%), of hawksbeard (10 to 41%), and of lupine (10 to 21%) occurred on macroplots in the more moist community types and those in mid-seral range condition. These community types have bluebunch wheatgrass or Idaho fescue as the potential dominant grass. Decreases in frequency (46 to 30%) and cover (0.5 to 0.02%) of squirreltail and cover (4.2 to 12.%) of bluegrass occurred on sites with Thurber needlegrass the potential dominant grass. Also, on the same sites, an increase in frequency (28 to 48%) of desert phlox accompanied by a decrease in cover (4.4 to 1.0%) suggest that the large plants of this species with a mat-like growth form are breaking into many, small plants.

At Goldbanks the frequency and cover of most decreaser grasses on most sites did not change during the study (Table 1). Cover of Thurber needlegrass decreased (1.9 to 0.5%) on 1 of 3 sites where this species was present in the sample and where it is the potential dominant grass. In this case, needlegrass responded as a decreaser species. Frequency of needlegrass increased (10 to 30%) on 1 of 3 sites where bluebunch wheatgrass is the potential dominant grass. In this instance, needlegrass responded as an increaser species. In the Wyoming big sagebrush-bluebunch wheatgrass CT, basal area of bluebunch wheatgrass decreased on 1 of 3 study sites from 8.1% in 1974 to 0.4% in 1982. The concurrent decrease in frequency (39 to 30%) was not significant. Cover of Idaho fescue increased (1.4 to 2.8%) on 1 of 3 sites where this species is the potential dominant grass.

The trend in species frequency and cover on macroplots at Pueblo Mountain was similar to that at Goldbanks (Table 2). The major difference was that decreaser grasses and perennial forbs had significant increases in frequency and cover on a few more sites. This difference would be expected because of greater precipitation, more productive soils, and generally higher ecological range condition at Pueblo Mountain than at Goldbanks. Examples of the direction and magnitude of significant and nonsignificant changes for the mountain big sagebrush-bluebunch wheatgrass CT, the mountain big sagebrush-Idaho fescue CT, and the low sagebrush-Idaho fescue CT are shown in Tables 4, 5, and 6, respectively.

Basin and mountain big sagebrush and low sagebrush were the most responsive shrubs at Pueblo Mountain (Table 2). The mean increase in frequency of basin big sagebrush was from 10 to 28% on 2 of 5 sites, for mountain big sagebrush from 10 to 37% on 5 of 10 sites, and for low sagebrush from 59 to 82% on all sites where this species was the dominant shrub. No species or subspecies of sagebrush decreased in frequency or cover. Quadrat cover of basin big sagebrush did not increase on any of the 5 sites where it is the dominant shrub. Cover of mountain big sagebrush increased on only 1 of 10 sites where it is the dominant shrub. Quadrat cover of low sagebrush increased from 11.3 to 15.6% on both sites with Idaho fescue the potential dominant grass.

Table 4. Frequency (%), basal cover of herbaceous species (% by chart quadrat), and canopy cover of shrubs (% by line intercept and chart quadrat) with standard errors on a macroplot representing a mountain big sagebrush-bluebunch wheatgrass community type in the Albertson Basin Pasture of the Pueblo Mountain Allotment. The 2 entries in the frequency-change column are the values at the beginning (1974) and at the end (1982) of data collection. The 2 quadrat-cover entries in the cover-change column are the values at the beginning (1976) and at the end (1982) of data collection. The 2 intercept-cover entries are data collected in 1973 and 1980.

Species	Frequency		Cover[1]	
	Change	Standard error	Change	Standard error
Shrub				
Mountain big sagebrush	14-28*[2]	2.9	15.9-19.2	2.9
			5.0-11.3*	2.7
Bitterbrush	0[3]		—[4]	
			0.0-1.8	1.0
Grass				
Sandberg bluegrass	14-17	2.5	0.3-0.1	0.08
Bottlebrush squirreltail	0		0	
Thurber needlegrass	40-45	3.0	1.0-0.5	0.2
Bluebunch wheatgrass	52-60	3.9	7.6-10.1*	1.1
Forb				
Milkvetch	0		0	
Tapertip harksbeard	1-4*	0.9	0	
Tailcup lupine	21-30*	2.7	0.00-0.04	0.07
Desert phlox	0		0	
Stansbury phlox	0		0	

[1]For shrubs, intercept cover is listed first, followed by quadrat cover.
[2]Significant differences between beginning and ending frequency and cover values are indicated by an asterisk and were determined by Duncan's multiple range test at $P \leq 0.05$.
[3]Species did not occur in the frequency or cover sample.
[4]Cover to sparse to calculate a valid mean and standard error.

Table 5. Frequency (%), basal cover of herbaceous species (% by chart quadrat), and canopy cover of shrubs (% by line intercept and chart quadrat) with standard errors on a macroplot representing a mountain big sagebrush-Idaho fescue community type in the Denio Basin Pasture of the Pueblo Mountain Allotment. The 2 entries in the frequency-change column are the values at the beginning (1974) and at the end (1981) of data collection. The 2 quadrat-cover entries in the cover-change column are the values at the beginning (1975) and at the end (1981) of data collection. The 2 intercept-cover entries and data collected in 1973 and 1980.

Species	Frequency		Cover[1]	
	Change	Standard error	Change	Standard error
Shrub				
Mountain big sagebrush	20-30*[2]	3.2	16.4-11.2	2.3
			2.7-7.6	2.0
Green rabbitbrush	14-25*	2.6	4.0-6.7	1.5
			0.3-3.1	1.7
Bitterbrush	6-12	2.3	8.2-7.0	3.4
			0	
Grass				
Sandberg bluegrass	23-38*	3.5	0.6-0.7	0.1
Bottlebrush squirreltail	10-8	1.8	0.1-0.2	3.2
Thurber needlegrass	9-10	2.2	0.3-0.4	0.05
Idaho fescue	59-72*	3.4	1.6-2.7	0.4
Bluebunch wheatgrass	24-31	3.6	0.1-0.4	0.2
Forb				
Milkvetch	7-10	1.8	0.02-0.1	0.08
Tapertip hawksbeard	14-24	2.9	0	
Tailcup lupine	51-70*	3.2	2.8-2.2	0.6
Desert phlox	0[3]		0	
Stansbury phlox	0		0	

[1]For shrubs, intercept cover is listed first, followed by quadrat cover.
[2]Significant differences between beginning and ending frequency and cover values are indicated by an asterisk and were determined by Duncan's multiple range test at $P \leq 0.05$.
[3]Species did not occur in the frequency or cover sample.

Sandberg bluegrass was the most responsive grass. Frequency increased from 20 to 34% on 4 of 5 sites in the mountain big sagebrush-Idaho fescue CT and from 32 to 70% on all sites with low sagebrush the dominant shrub. Cover of bluegrass increased on only 2 of 15 sites where either basin or mountain big sagebrush was the dominant shrub and bluebunch wheatgrass the potential dominant grass. Bluegrass cover increased (1.0 to 3.0%) on all sites with low sagebrush the dominant shrub. An increase in frequency (21 to 40%) and cover (1.8 to 4.5%) of Thurber needlegrass and in frequency (16 to 24%) of thickspike wheatgrass occurred on sites where either bluebunch wheatgrass or Idaho fescue is the potential dominant grass. In these instances needlegrass and thickspike wheatgrass appeared to respond as increaser species.

Frequency (6 to 15%) and cover (7.6 to 10.1%) of bluebunch wheatgrass increased on 2 sites and frequency (59 to 72%) of Idaho fescue increased on 1 site where these species are the potential dominant grass. On these same sites frequency and cover of the more desirable forbs, milkvetch and hawksbeard, and of the less desirable forb, tailcup lupine, also increased.

Most grasses and perennial forbs with a significant long-term change in frequency or quadrat cover showed a trend either to consistently increase or to consistently decrease in that attribute throughout the study. For example, of 219 frequency comparisons on both allotments, only 14 showed a significant increase during the course of the study followed by a significant decrease in that attribute by the end of the study. Similarly, of 215 cover comparisons only 6 showed a significant increase followed by a significant decrease in that attribute. Neither frequency or cover decreased significantly then increased significantly during the study.

Total Quadrat Cover

Total canopy cover of shrubs and total basal cover of herbaceous species at the start and end of data collection were calculated from estimated cover of individual species on chart quadrats on each macroplot. Total shrub cover did not decrease significantly on any study sites at either allotment. At Goldbanks, mean total shrub cover increased on 4 of 12 sites from 1.8 to 3.7%. Only Wyoming big sagebrush accounted for the increase in total shrub cover in community types with either Thurber needlegrass or bluebunch wheatgrass the potential dominant grass. Both Wyoming big sagebrush and green rabbitbrush accounted for the increase in total shrub cover in the community type with Idaho fescue the potential dominant grass. Total cover of herbaceous species increased from 6.7 to 9.1% on 1 site in the Wyoming big sagebrush-Idaho fescue community type due mainly to an increase in the cover of Sandberg bluegrass. Total herbaceous cover decreased from 11.6 to 6.5% due to a decrease in basal cover of bluebunch wheatgrass and Thurber needlegrass on 1 site in the Wyoming big sagebrush-bluebunch wheatgrass CT in mid-seral range condition. The decrease in total basal cover would have been greater had the basal area of bluegrass not increased from 2.3 to 5.6%. Total herbaceous cover also decreased from 9.6 to 5.2% due to a decrease in basal cover of Sandberg bluegrass, Thurber needlegrass, squirreltail, and desert phlox on 2 sites in the Wyoming big sagebrush-Thurber needlegrass CT in early-seral range condition. Total herbaceous cover did not change significantly on 10 of 14 study sites.

Table 6. Frequency (%), basal cover of herbaceous species (% by chart quadrat), and canopy cover of shrubs (% by line intercept and chart quadrat) with standard errors on a macroplot representing a low sagebrush-Idaho fescue community type in the Pueblo Pasture of the Pueblo Mountain Allotment. The 2 entries in the frequency-change column are the values at the beginning (1974) and at the end (1982) of data collection. The 2 quadrat-cover entries in the cover-change column are the values at the beginning (1974) and at the end (1980) of data collection. The 2 intercept-cover entries are data collected in 1973 and 1980.

	Frequency		Cover[1]	
Species	Change	Standard error	Change	Standard error
Shrub				
Low sagebrush	50–88*[2]	3.3	26.2–29.4*	3.0
			11.3–15.6*	0.9
Green rabbitbrush	4–8	2.4	—[4]	
			0.4–0.4	0.01
Grass				
Sandberg bluegrass	42–86*	3.1	1.0–3.8*	0.2
Bottlebrush squirreltail	18–22	2.4	0.04–0.2	0.05
Thurber needlegrass	0[3]		0	
Idaho fescue	52–58	3.6	1.3–1.2	0.2
Bluebunch wheatgrass	8–6	1.3	0.1–0.04	0.03
Forb				
Milkvetch	40–64*	4.3	0.3–1.1*	0.3
Tapertip hawksbeard	2–2	1.0	0	
Tailcup lupine	1–2	1.0	0	
Desert phlox	0		0	
Stansbury phlox	6–12	2.7	0.0–0.8*	0.01

[1]For shrubs, intercept cover is listed first, followed by quadrat cover.
[2]Significant differences between beginning and ending frequency and cover values are indicated by an asterisk and were determined by Duncan's multiple range test at $P \leq 0.05$.
[3]Species did not occur in the frequency or cover sample.
[4]Cover too sparse to calculate a valid mean and standard error.

At Pueblo Mountain, total shrub cover increased on 4 of 15 sites in community types with basin (1 site) or mountain (3 sites) big sagebrush the dominant shrub and either bluebunch wheatgrass (2 sites) or Idaho fescue (2 sites) the potential dominant grass. The average increase was from 5.0 to 10.5% with both big sagebrush and green rabbitbrush contributing to the change in total shrub cover. Total shrub cover, mostly low sagebrush, increased (7.9% to 11.0%) in the low sagebrush-Idaho fescue CT. Total herbaceous cover increased (6.2% to 12.6%) on 4 of 15 sites in community types with either basin or mountain big sagebrush the dominant shrub and either bluebunch wheatgrass (1 site) or Idaho fescue (3 sites) the potential dominant grass. Total herbaceous cover increased (5.4 to 11.1%) on 1 of 2 sites in the low sagebrush-Idaho fescue CT. Species contributing to the increase in total herbaceous cover in these community types were Sandberg bluegrass, Thurber needlegrass, bluebunch wheatgrass, Idaho fescue, lupine, Stansbury phlox, low pussytoes, and crag aster. Total herbaceous cover did not decrease significantly on any study site in this allotment.

Short-Term Changes

Data in Tables 1 through 6 represent changes in frequency and cover of individual species on macroplots over a 7- to 10-year period. However, the direction, magnitude, and perhaps the permanence of these long-term changes can be influenced by species response during the intervening years. We used species frequency to quantify these changes because frequency data were collected more often than were cover data. Changes in cover, however, support the conclusions reached from frequency data.

Subspecies of big sagebrush, low sagebrush, and Sandberg bluegrass were also the most responsive species over the short term. The general trend on macroplots at both allotments was an increase in the frequency and cover of bluegrass from 1974 to 1977 with little change in frequency of sagebrush. Drought conditions in 1976–77, 18 and 25 cm precipitation at Goldbanks and Pueblo Mountain, respectively, resulted in a significant decrease in frequency and cover of bluegrass. Frequency and cover of desirable grasses or perennial forbs did not decrease on any site on either allotment during this dry year. This very dry year was followed by a very wet year in 1977–78, 37 cm at Goldbanks and 39 cm at Pueblo Mountain. In the 2 years following this sequence of low and high precipitation, frequency of sagebrush seedlings increased significantly on all 14 study sites at Goldbanks and on 9 of 18 sites at Pueblo Mountain. A reduction in bluegrass competition followed by a year of high precipitation probably account for good seed germination and seedling emergence of sagebrush. Most of the decreases in bluegrass frequency and increases in sagebrush frequency were on study sites in the Wyoming big sagebrush-Thurber needlegrass CT at Goldbanks and in the basin big sagebrush-bluebunch wheatgrass, mountain big sagebrush-bluebunch wheatgrass, and low sagebrush-Idaho fescue CT's at Pueblo Mountain.

After 1978, the frequency of bluegrass continued to increase at Goldbanks and by the early 1980's was higher than predrought levels on 7 of 14 sites by an average of 21%. Six of these sites were in the more moist community types with either bluebunch wheatgrass or Idaho fescue the potential dominant grass. After 1978, bluegrass frequency increased on 4 of 18 sites at Pueblo Mountain by an average of 30%. By the early 1980's bluegrass frequency was equal to pre-drought levels on all 5 sites in the basin big sagebrush-bluebunch wheatgrass CT and on both sites in the low sagebrush-Idaho fescue CT, was greater by 19% on the 1 site in the low sagebrush-bluebunch wheatgrass CT, was less on 2 of 5 sites in the mountain big sagebrush-bluebunch wheatgrass CT by an average of 22%, and was less on 3 of 5 sites in the mountain big sagebrush-Idaho fesuce CT by an average of 21%.

After 1978, the frequency of big and low sagebrush decreased to pre-increase levels on many sites on both allotments. In the early 1980's, however, 3 sites at Goldbanks, 2 of which were the Wyoming big sagebrush-Thurber needlegrass CT, had frequencies of Wyoming big sagebrush that were higher than pre-increase levels by an average of 14%. At Pueblo Mountain, frequency of sagebrush on 3 sites was higher than pre-increase level: by 15% on 2 of 5 sites in the basin big sagebrush-bluebunch wheatgrass CT, by 10% on 2 of 5 sites in the mountain big sagebrush-bluebunch wheatgrass CT, and by 12% on both sites in the low sagebrush-Idaho fescue CT.

Discussion

Significant reductions in intercept cover and frequency of big sagebrush occurred on only a few sites and probably were due to local disturbances rather than to the grazing system. For example, reductions in cover of Wyoming big sagebrush in 3 community types at Goldbanks were attributed to damage by the sagebrush moth [*Aroga websteri* Clark]. Reductions in the cover of mountain big sagebrush on 2 sites and of bitterbrush on 1 site at Pueblo Mountain may have been caused by insect or rodent damage, by waterlogged soils following a very wet winter, or by winter-induced physiological drought during a very dry winter as described by Hanson et al. (1982). All of these perturbations occurred in northern Nevada during certain years of the study.

Significant increases in the cover and frequency of Wyoming big sagebrush at Goldbanks occurred on sites in early-seral range condition and on sites with a reduction in the basal area of decreaser grasses. The negative response of decreaser grasses may have been due to heavy utilization during the study. In both cases little competitive understory vegetation was present to restrict growth and reproduction of sagebrush. Significant increases in the frequency of basin and mountain big sagebrush and low sagebrush at Pueblo Mountain occurred on those sites where shrub reproduction has survived for several years in existing stands of vegetation under conditions of reduced bluegrass competition and favorable precipitation. Heavy grazing also may have reduced the competitive level of decreaser grasses enough to permit survival of these sagebrush seedlings. If these plants establish and grow, secondary succession may be slowed or prevented by additional brush competition. The localized nature of the factors responsible for increases or decreases in shrub cover and frequency may explain some of the variability in these parameters encountered among macroplots during the study.

Significant decreases in the cover of Thurber needlegrass and bluebunch wheatgrass on 2 sites at Goldbanks suggest at least a beginning of a downward trend in range condition on community types where these 2 species are the potential dominant grass. An increase in cover of Idaho fescue on 1 site was the only example of a favorable response of a decreaser grass to the management system, utilization level, and climate at Goldbanks during the study. At Pueblo Mountain, increased cover and frequency of bluebunch wheatgrass and frequency of Idaho fescue on a few sites where these species are the potential dominant grass suggest at least a beginning of an upward trend in range condition. An accompanying increase in the frequency of desirable forbs on the same sites supports this contention.

Variability in the response of herbaceous species among macroplots within a community type can be attributed to several factors. (1) The study period may have been too short to show a positive or negative response to grazing management on a majority of sites. The results obtained may just be starting to show a change in vegetation composition. (2) Variation in sagebrush cover described previously can produce different levels of competition that may be responsible for the varied response of understory species. For example, sagebrush canopy cover on 14 macroplots on Goldbanks ranged from 4.3 to 29.8% in 1980. On 18 macroplots at Pueblo Mountain sagebrush canopy cover ranged from 8.4 to 34.7%. Although considerable variation in sagebrush cover occurred among macroplots within a community type, the small number of significant changes in the cover and frequency of decreaser species in response to this variation resulted in a sample too small to test for a relation between brush cover and species response. (3) Differences in species abundance on macroplots within a community type create variability in the competitive status of the community and, therefore, in the seed production potential and in the space available for growth of existing plants and for establishment of new plants from seed. Our ability to obtain an adequate estimate of species frequency or cover by the sampling techniques used also is dependent on the abundance of that species. Therefore, data from a macroplot with sparse cover and frequency of a decreaser grass may indicate no significant change in that species, where change actually occurred, because of an inadequate sample. In comparison, data from a macroplot with more of a decreaser grass may correctly indicate a significant change in composition because our sample was adequate. (4) Different kinds of soils, as identified at the Family level of soil taxonomy (USDA 1975), are associated with macroplots representing each community type. At Goldbanks, 6 different soils were associated with the 7 macroplots representing the Wyoming big sagebrush-Thurber needlegrass CT, 2 soils were associated with the 3 macroplots representing the Wyoming big sagebrush-bluebunch wheatgrass CT, and 3 soils were associated with the 3 macroplots representing the Wyoming big sagebrush-Idaho fescue CT. At Pueblo Mountain, 4 soils were associated with each of the 5 macroplots representing either the basin big sagebrush-bluebunch wheatgrass, mountain big sagebrush-bluebunch wheatgrass, or mountain big sagebrush-Idaho fescue CT's. The effects of individual and integrated soil profile features on species response to grazing management were not determined. Therefore, we are unable to discuss the cause and effect for differential species responses due to specific soil differences. These effects should be the subject of future research. Research should also identify those soil profile features, not now considered in soil classification, that may affect plant response to various perturbations.

The *variability* in species response among macroplots within a community type indicates the difficulty of obtaining an estimate of change in species composition on a key management area based on data from 1 or a small number of macroplots. If an estimate of change is based on data from only 1 macroplot, that estimate will not likely be accepted as representative of the "true change" on the management area! If an estimate of change is based on data from several macroplots with different responses, which composite statistic will be selected to represent the "true change" on the management area?

Based on the information obtained in this study, several suggestions can be made to decrease this variability and to increase the value of interpretations made from the data obtained. (1) Consult with a statistician who is familiar with finite sampling theory and field sampling techniques. (2) Stratify vegetation into units of similar potential and select, in cooperation with all interested parties, at least 1 area and 1 species in each stratum to be the "key area" and "key species" on which management decisions will be made. (3) Sample the key area or areas by locating several macroplots according to accepted field-sampling procedures. Macroplots should be located on the same or very similar soil, elevation, slope, and exposure and should have enough of the key species to ensure that the sampling techniques used will give an adequate estimate of the character of that species. (4) Plan on a long-term sampling program to allow time for all possible changes to occur.

Interpretation and Management Implications

Statistical inference is restricted to results obtained from individual macroplots representing certain community types. We believe, however, that trends based on macroplot data allow us to make subjective statements about vegetation response on unsampled but similar community types managed under similar grazing systems and utilization intensity and with similar climatic conditions. The authors are responsible for these interpretations.

Many claims have been made for the efficacy of a grazing system to improve vegetation. In this study, frequency and cover of decreaser grasses were unchanged on a majority of sites after 7 to 10 years of rest-rotation grazing management under the climatic conditions present and the utilization levels imposed. We attributed this lack of response to 3 factors: (1) Heavy utilization that maintained low plant vigor and restricted basal-area growth and seed production; (2) sagebrush competition that reduced the environmental potential for plant growth, seed production, and seedling establishment; (3) ecological range condition when management was initiated that determined the potential for "openings" in the stand and the availability of seed of desirable species.

Grasses and desirable forbs in pastures grazed during the growing season or after seedripe were heavily utilized. Damage done by heavy grazing, particularly during the growing season, may exceed the benefits gained from subsequent, supposedly better, management (Robertson et al. 1970), Heady 1975, Mueggler 1975). Heavy use is sometimes recommended as a means of reducing competition between palatable and unpalatable species. Heady (1975) stated that most evidence, however, favors the view that heavy defoliation reduces the vigor of desirable species more than it helps them by lessening competition from undesirable species. Hickey (1967) and Hyder and Bement (1977) concluded that no management system is entirely satisfactory if that system requires overgrazing during the growing season in order to obtain rest or deferment from grazing at other times during the grazing season.

Logic suggests that rest-rotation management should have a better chance of success on grasslands, where all species are fairly palatable, than on ranges where unpalatable species, such as sagebrush, are important components in stands of palatable species (Mueggler 1972). In this case, brush can respond to reduced competition due to defoliation of herbaceous species and become more competitive with desirable species. Bullock (1975) theorized that in areas of low growing-season precipitation even moderate use of perennial grasses places them at a severe competitive disadvantage with nonpalatable and well-adapted shrubs. In mixed stands of forage plants and brush, anything approaching full forage use inevitably leads to an increase in brush (Day 1979). Brush competition also reduces the establishment of seedlings of desirable herbaceous species. Many authors have shown the futility of seeding semiarid rangelands without adequate weed control, even when species with excellent seedling vigor are used. In grazing management, the problem of seedling establishment is compounded because seed is not properly planted, most native herbaceous species have low seedling vigor, and resident brush is very competitive with seedlings for soil water and nutrients.

We speculate that an upward trend in ecological range condition, as indicated by an increase in the composition of desirable species and a decrease in the composition of undesirable species, is strongly influenced by ecological range condition at the time management is initiated. This concept is in agreement with observations made on a BLM allotment in Idaho after about 10 years of rest-rotation management (Blaisdell et al. 1982). An upward trend on rangelands in early-seral condition will be extremely slow, or will not occur at all, because grazing pressure continues on the few remaining desirable plants, little or no seed is produced by these species, and competition from sagebrush prevents establishment of seedlings of desirable species. On sites in late-seral condition, upward trend also will be slow because competition within the community prevents recruitment of new individuals of desirable species except on rare occasions. The best opportunity to obtain an upward trend may be on sites in mid-seral condition. Under proper management, vigor, growth, and seed production of desirable species is enhanced. Then as the less desirable, short-lived herbaceous perennials become senescent and die, the major seed source is that of desirable species. At this time the chance for recruitment of new individuals of desirable species is enhanced provided conditions for seed production and seedling establishment are favorable over a sequence of years. A downward trend can be measured at all levels of range condition by a decrease in the composition of desirable species and an increase in the composition of undesirable species. If this speculation is correct, land management agencies should select trend plot locations on key management areas with vegetation in mid-seral condition. In this way, both upward and downward trend can be measured on the same site.

Results of the study showed that both frequency and quadrat cover data detected change in understory vegetation. For the more responsive species, frequency and cover data tended to support the same conclusions, although frequency data indicated significant changes on more sites than did cover data. At Goldbanks, frequency data indicated 35 significant differences, cover data 14. At Pueblo Mountain, frequency data indicated 54 significant differences compared to 23 for cover data. Others (Hyder et al. 1963, Tueller et al. 1972, and Range Inventory Standardization Committee 1983) have stated that frequency data are easy to obtain, objective, statistically reliable, and cost efficient. In this study, for example, the time required per macroplot to obtain an estimate of frequency of occurrence was 1 man-day compared with 5 to 10 man-days for estimating cover on 5 chart quadrats. An adequate sample of shrub crown cover by this technique would be too expensive for large-scale monitoring purposes. We suggest that the line-intercept method be used to estimate growth of desirable and undesirable shrubs and to aid in interpretation of changes in understory vegetation.

If rest-rotation grazing will maintain vegetation in late-seral condition and improve vegetation in mid-seral condition, it is a valuable management tool. If rest-rotation grazing can only maintain early-seral vegetation in an unimproved condition, then these areas are candidates for range improvement practices.

This research should continue through additional grazing cycles to further evaluate vegetation response. Based on results to date, however, land managers perhaps can consider modifications of the grazing plans on these 2 allotments that may retard increases in the composition of undesirable species and stimulate increases in the composition of desirable species.

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Assessment of Spring Defoliation to Improve Fall Forage Quality of Bluebunch Wheatgrass (*Agropyron spicatum*)

MICHAEL D. PITT

Abstract

Bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith) was clipped at 4 phenological stages to compare forage quality of subsequent regrowth relative to nondefoliated plants. Following 2 years of treatment, plants clipped at boot, emergence, flowering, and seed formation produced lower levels of ADF and higher values of CP and P than control plants at equivalent phenological stages. Clipping at boot and emergence for 2 years delayed flowering by 16 and 15 days, respectively, while subsequent flowering of plants clipped at flowering and seed formation occurred only sporadically. These delays in plant phenology altered forage quality on 26 October compared to nondefoliated plants. Clipping at boot, emergence, flowering, and seed formation reduced percent foliar ADF, while increasing relative proportions of CP, Ca, and P compared to untreated herbage. Crude protein in plants clipped for 2 years at emergence, flowering, and seed formation averaged 11.9%, 12.5%, and 13.7%, respectively. Phosphorus in regrowth foliage of plants clipped at flowering and seed formation equalled 0.22% and 0.26%, respectively, on 26 October. These values exceed maintenance requirements of cattle and elk, indicating that judicious grazing management can improve nutritive values of bunchgrass vegetation.

Controlled livestock grazing has been recommended to improve or maintain both the quantity and quality of range forage (Stoddard 1946, Hyder and Sneva 1963, Hormay 1970, Hyder 1971, Jensen et al. 1972, Malachek et al. 1978). Anderson and Scherzinger (1975) summarized a grazing management plan for bluebunch wheatgrass/Idaho fescue (*Agropyron spicatum* (Pursh) Scribn. & Smith/*Festuca idahoensis* Torr.) ranges of central Oregon which controls the intensity and season of livestock grazing in order to improve forage quality for wintering elk. This grazing management plan was based upon the theoretical assumption that spring grazing by livestock delayed plant phenology, such that nutrients were retained in the foliar portions of bunchgrasses rather than being translocated to the roots prior to the onset of summer aestivation (Anderson and Scherzinger 1975).

Many grazing management plans in British Columbia have been developed in response to the recommendations of Anderson and Scherzinger (1975), who cautioned, however, that their conclusions were predicated primarily upon biological principles combined with field observations. Although bluebunch wheatgrass has been studied intensively (Hanson and Stoddard 1940, McIlvanie 1942, Stoddart 1946, Blaisdell and Pechanec 1949, Heady 1959, Mueggler 1975, Rickard et al. 1975, Uresk and Cline 1976, McLean and Wikeem 1985) virtually no quantitative data are available which describe the functional relationships among spring grazing, delays in plant phenology and resultant fall or winter forage quality. The objectives of this investigation were to document such relationships in order to assess the recommendations of Anderson and Schezinger (1975), particularly in relation to the most judicious phenological stage at which bluebunch wheatgrass should be grazed by cattle in order to improve fall forage quality for wildlife.

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Materials and Methods

The research was conducted during 1978 and 1979 at the University of British Columbia in Vancouver. Experimental plots occurred at an elevation of 93 m on soils classified as Humo Ferric Podzols (Canada Soil Survey Committee 1978). The maritime climate is characterized by warm summers and cool winters, with average annual precipitation equal to 102 cm and an average frost free period of 210 days (Harry and Wright 1967).

Two hundred seeds of bluebunch wheatgrass were germinated in the greenhouse and transplanted to the experimental plots, at 1-meter centers, in August of 1976. In 1978 surviving plants were randomly assigned to each of 5 clipping treatments: control, plus herbage removal at boot, emergence, flowering, and seed formation stages of development. Moderate grazing was simulated by clipping plants to a 15-cm stubble height.

Forty-five plants were allocated as control, so that 5 replicates were available for sampling at 9 phenological stages identified by Metcalfe (1973): vegetative, boot, emergence, flowering, seed formation, ripe seed, seed shatter, stem-cured, and weathered. Similarly, at each treatment stage of herbage removal, a sufficient number of plants were clipped so that 5 replicates could be harvested for chemical analysis at each subsequent stage of phenological development. This experimental approach permitted assessment of forage quality in regrowth herbage relative to forage quality in unclipped plants at comparable phenological stages. These procedures were repeated in 1979.

Forage samples were dried at 65°C for 24 hours, and then ground in a Wiley Mill through a 40-mesh screen. Chemical analyses were conducted according to the procedures outlined by the Association of Official Analytical Chemists (1975). Forage digestibility was evaluated with acid detergent fiber (ADF), while nitrogen (N), calcium (Ca), and phosphorus (P) were measured as assessments of forage quality. All chemical determinations were expressed as a percentage of dry matter. Percent crude protein (CP) was derived by multiplying percent nitrogen by 6.25.

Differences in forage quality at equivalent phenological stages were determined with analysis of variance followed by a studentized Newman-Keuhls multiple range test at the 5% level of significance (Steele and Torrie 1980). These analyses are presented for comparison with previous research on bluebunch wheatgrass, which typically reports forage quality at specific phenological stages.

The primary objective of the current study, to assess the potential of spring cattle grazing for improving forage quality, requires that comparisons also be made with respect to calendar date. Because of variabilities in plant maturity rates, differences in forage quality at phenological stages are not identical to differences in forage quality at specific calendar dates. Consequently, polynomial regressions were used to predict forage quality means for nine 25-day intervals beginning with 9 April and ending on 26 October. Regression equations were based upon forage quality measurements within each clipping treatment at each phenological stage. The predictor variable was measured as the number of days elapsed between 1 January and date of forage quality sampling.

The form of polynomial regressions varied among treatment means, and was selected to yield the highest coefficient of determination for each regression equation. Predicted means are presented only for significant ($p<0.05$) polynomial regressions at calendar dates when plants were sampled within each clipping treatment. Comparisons within calendar dates are indicated with 95% confidence intervals for each predicted mean.

Results

All clipping treatments delayed phenological development during both years of study. Plants defoliated at boot flowered an average of 9 and 16 days later than control plants in 1978 and 1979, respectively. Equivalent delays occurred for plants clipped at emergence, which flowered approximately 15 days later than untreated plants in both 1978 and 1979. Subsequent flowering for plants clipped at flowering occurred sporadically, and averaged 73 and 194 days later than unclipped plants in 1978 and 1979, respectively. Flowering of plants clipped during seed formation averaged 95 and 142 days later than nondefoliated plants in 1978 and 1979, respectively. During both years of study, clipped plants failed to reach the weathered stage of plant maturity.

These defoliation-induced delays in plant phenology form the basis for Anderson and Scherzinger's (1975) recommendation to utilize spring cattle grazing to enhance fall forage quality. For example, plants clipped at boot, emergence, and flowering in 1978 showed initial reductions in percent ADF in subsequent stages of plant phenology compared to unclipped plants (Table 1). These increases in digestibility generally failed to persist, however, although plants clipped at seed formation displayed significantly lower ADF (37.9%) compared to untreated plants (43.2%) at the stem-cured stage of plant maturity. Crude protein in plants clipped at boot and emergence in 1978 produced no statistically significant changes in percent crude protein at subsequent phenological stages compared to untreated plants (Table 2). Clipping at flowering and seed formation, however, increased CP to 11.9% and 13.4% respectively at the stem-cured stage compared to only 8.9% for unclipped plants.

Table 1. Acid detergent fiber (%) in regrowth of bluebunch wheatgrass.

Phenological stage	Clipping treatment: Control	Boot	Emergence	Flowering	Seed formation
Vegetative					
1978	24.0				
1979	33.8				
Boot					
1978	32.6				
1979	34.2				
Emergence					
1978	37.4a[1]	34.6a			
1979	38.1a	30.7b			
Flowering					
1978	38.4ab	39.5b	34.8a		
1979	39.3a	33.9b	33.8b		
Seed Formation					
1978	41.7a	34.8b	35.7b	38.6ab	
1979	41.4a	34.2b	37.5b	39.0b	
Ripe Seed					
1978	42.1a	38.3b	38.2b	41.3ab	39.8ab
1979	46.2a	37.8b	37.0b	35.8b	
Seed Shatter					
1978	46.9a	43.6a	43.5a	39.8b	38.6b
1979	47.3a	42.4ab	43.5ab	36.4ab	35.6b
Stem-cured					
1978	43.2a	44.6a	41.3ab	42.5a	37.9b
1979	49.8a	43.3b	38.1c	42.4b	38.9c
Weathered					
1978					
1979	52.0				

[1]Means within rows followed by different letters are significantly different at $p<0.05$.

Table 2. Crude protein (%) in regrowth of bluebunch wheatgrass.

Phenological stage	Clipping treatment: Control	Boot	Emergence	Flowering	Seed formation
Vegetative					
1978	26.8				
1979	16.6				
Boot					
1978	18.1				
1979	14.1				
Emergence					
1978	14.3a[1]	17.2a			
1979	10.8a	15.6b			
Flowering					
1978	11.8a	11.5a	14.0a		
1979	7.3a	11.7b	12.7b		
Seed Formation					
1978	10.0a	11.2a	10.5a	11.0a	
1979	5.3a	8.8b	8.6b	10.3b	
Ripe Seed					
1978	8.2a	9.0a	8.9a	8.5a	12.4b
1979	3.6a	7.1b	8.9b	15.8c	
Seed Shatter					
1978	7.3a	7.8a	9.8a	12.7b	12.9b
1979	5.0a	8.1b	9.3b	13.2c	15.2c
Stem-cured					
1978	8.9a	9.3a	10.6ab	11.9bc	13.4c
1979	4.6a	7.6b	8.7b	9.6bc	12.3c
Weathered					
1978					
1979	6.1				

[1]Means within rows followed by different letters are significantly different at $p<0.05$.

In contrast to ADF and CP, the initial year of clipping in 1978 produced no statistical differences in percent Ca at comparable stages of plant phenology (Table 3). Percent foliar P of plants clipped in 1978 generally increased initially compared to nondefoliated plants (Table 4). As the foliage matured, however, these differences diminished, such that no differences in phosphorus among treatments existed by the ripe seed stage of plant phenology.

A second year of defoliation in 1979 produced more notable and persistent changes in forage quality of regrowth herbage. Plants clipped at boot, emergence, flowering, and seed formation all provided lower ADF than control plants. These reductions occurred in phenological stages immediately following defoliation, and were still evident at the stem-cured stage of plant development (Table 1). Repeated clipping in 1979 similarly promoted additional increases in percent CP, as all defoliation treatments showed higher CP percentages relative to unclipped plants at comparable stages of plant phenology. Percent CP at the stem-cured stage of plant phenology was enhanced by progressively later clipping treatments, as plants defoliated at boot, emergence, flowering and seed formation averaged 7.6, 8.7, 9.6, and 12.3%, respectively, compared to only 4.6% CP for untreated plants (Table 2).

In contrast to 1978, all clipping treatments in 1979 increased Ca and P relative to untreated plants at equivalent stages of plant phenology. Percent Ca at the stem-cured stage of maturity was most pronounced in plants clipped at boot (0.66%) and emergence (0.67%), declining successively with later clipping treatments at flowering (0.42%) and seed formation (0.40%) (Table 3). Increased foliar P, however, became more evident with successively later clipping treatments, as nondefoliated plants averaged only 0.07% P at the stem-cured stage of development, while plants clipped at boot, emergence, flowering, and seed formation equalled 0.13, 0.14,

Table 3. Calcium (%) in regrowth of bluebunch wheatgrass.

Phenological stage	Clipping treatment: Control	Boot	Emergence	Flowering	Seed formation
Vegetative					
1978	0.54				
1979	0.40				
Boot					
1978	0.26				
1979	0.20				
Emergence					
1978	0.26a[1]	0.26a			
1979	0.18a	0.36b			
Flowering					
1978	0.36a	0.32a	0.28a		
1979	0.17a	0.32b	0.24b		
Seed Formation					
1978	0.38a	0.42a	0.35a	0.39a	
1979	0.24a	0.45b	0.41b	0.58c	
Ripe Seed					
1978	0.34a	0.45a	0.43a	0.47a	0.43a
1979	0.19a	0.54b	0.45b	0.82c	
Seed Shatter					
1978	0.37a	0.38a	0.49a	0.45a	0.48a
1979	0.30a	0.57b	0.43ab	0.58b	0.64b
Stem-cured					
1978	0.39a	0.43a	0.44a	0.37a	0.50a
1979	0.22a	0.66b	0.67b	0.42c	0.40c
Weathered					
1978					
1979	0.25				

[1]Means within rows followed by different letters are significantly different at $p<0.05$.

Table 4. Phosphorus (%) in regrowth of bluebunch wheatgrass.

Phenological stage	Clipping treatment: Control	Boot	Emergence	Flowering	Seed formation
Vegetative					
1978	0.43				
1979	0.24				
Boot					
1978	0.28				
1979	0.22				
Emergence					
1978	0.27a[1]	0.34b			
1979	0.16a	0.23b			
Flowering					
1978	0.21a	0.20a	0.23b		
1979	0.14a	0.18a	0.23a		
Seed Formation					
1978	0.20a	0.22a	0.20a	0.18b	
1979	0.10a	0.15ab	0.20bc	0.19c	
Ripe Seed					
1978	0.15a	0.19a	0.16a	0.16a	0.18a
1979	0.08a	0.16b	0.18b	0.31c	
Seed Shatter					
1978	0.15a	0.15a	0.18a	0.20a	0.21a
1979	0.09a	0.16b	0.18b	0.22c	0.26c
Stem-cured					
1978	0.15a	0.18a	0.20a	0.19a	0.21a
1979	0.07a	0.13b	0.14b	0.18b	0.25c
Weathered					
1978					
1979	0.09				

[1]Means within rows followed by different letters are significantly different at $p<0.05$.

0.18, and 0.25% P respectively (Table 4).

Effect of Spring Defoliation on Fall Forage Quality

These altered nutrient values at comparable phenological stages tended to correspond with improved forage quality for grazing animals and likely resulted from a combination of stimulated tillering following clipping, plus removal of mature herbage during the initial year of clipping. The potential for improved forage quality resulting from spring defoliation, however, must be assessed ultimately by comparisons at calendar dates rather than equivalent phenological stages. For example, ADF for unclipped plants averaged 42.7% on 6 September 1978, which did not differ significantly from plants clipped either at boot (43.8%), emergence, (41.3%) flowering (39.8%), or seed formation (40.0%). Following a second defoliation in 1979, however, all clipping treatments significantly reduced ADF concentrations, indicating greater forage digestibility compared to unclipped plants. These reductions in ADF appeared immediately following clipping and persisted throughout the growing season. Nondefoliated plants on 26 October 1979 averaged 52.3% ADF, while plants clipped at emergence, flowering, and seed formation equalled only 41.7, 38.7, and 37.3% ADF, respectively (Table 5).

Crude protein in nondefoliated plants declined from 23.2% on 9 April to 9.4% on 6 September 1978. Clipping at the boot stage of plant phenology produced an initial increase on 29 May from 12.8 to 18.0% CP, which then declined rapidly, such that no differences with control plants existed by 23 June. Clipping at emergence in 1978 produced similar initial increases in CP compared to control plants, followed by a subsequent decline to levels of CP similar to foliage in unclipped plants. Only those plants clipped at seed formation provided foliar CP (12.5%) on 6 September that exceeded statistically the 9.4% CP in unclipped plants. These higher levels persisted at least until 26 October when foliage clipped at flowering and seed formation in 1978 averaged 15.4 and 13.3% CP, respectively, compared to only 9.4% for nondefoliated plants on 6 September (Table 6).

Following repeated clipping in 1979, all treated plants produced statisticly significant increases in percent CP compared to unclipped plants, which averaged only 5.6% on 26 October. Increases in CP were enhanced by successively later clipping regimes, as plants clipped at emergence, flowering, and seed formation averaged 11.9, 12.5, and 13.7% CP, respectively, on 26 October 1979. Plants clipped at boot in 1979 initially provided increased levels of CP, but failed to retain such increases, compared to control plants, beyond 6 September (Table 6).

Clipping in 1978 failed to produce statistically significant increases in calcium compared to untreated plants, which averaged 0.36% Ca on 6 September. In 1979, however, foliar regrowth of clipped plants contained significantly more Ca than untreated plants. Predicted average Ca for control plants equalled only 0.19% on 26 October compared to 0.80, 0.57 and 0.52% for plants harvested initially at emergence, flowering, and seed formation, respectively (Table 7).

Percent phosphorus in clipped herbage displayed trends similar to those provided by calcium. Although clipping at boot in 1978 increased P initially, from 0.24% to 0.36% on 29 May, no significant differences remained by 23 June. On 6 September, no treated plants differed statistically from control plants, which averaged 0.17% P (Table 8).

Following a second application of treatments in 1979, percent foliar P in regrowth of all clipped plants exceeded P contained in unclipped plants. Such differences persisted until 26 October when unclipped plants (0.09%) contained significantly less P than plants clipped at emergence (0.14%), flowering (0.22%) or seed formation (0.26%) (Table 8).

Table 5. Predicted means and 95% confidence intervals for acid detergent fiber (%) in regrowth of bluebunch wheatgrass.

		Clipping treatment			
	Control	Boot	Emergence	Flowering	Seed formation
April 9					
1978	23.8 ± 3.3				
1979	34.2 ± 1.5				
May 5					
1978	33.7 ± 1.0				
1979	36.5 ± 1.2				
May 29					
1978	39.0 ± 1.1	34.1 ± 3.0			
1979	38.7 ± 1.0	30.3 ± 1.5			
June 23					
1978	39.8 ± 1.0	37.4 ± 1.6	33.1 ± 1.9		
1979		41.0 ± 0.9	33.0 ± 1.1		32.8 ± 2.3
July 18					
1978	41.3 ± 1.0	34.3 ± 2.2	35.8 ± 1.3		39.9 ± 0.9
1979	43.3 ± 0.8	35.9 ± 0.8	37.5 ± 2.2		
August 12					
1978	45.4 ± 1.1	41.7 ± 1.6	38.6 ± 1.0	39.8 ± 1.7	40.4 ± 1.2
1979	45.5 ± 0.9	38.6 ± 0.8	38.6 ± 1.8		
September 6					
1978	42.7 ± 1.7	43.8 ± 2.0	41.3 ± 1.4	39.8 ± 4.1	40.0 ± 0.9
1979	47.8 ± 1.1	41.4 ± 1.0	38.1 ± 1.2		
October 1					
1978			44.0 ± 2.1	42.5 ± 8.6	38.9 ± 0.5
1979	50.1 ± 1.3	44.2 ± 1.4	38.4 ± 1.9		
October 26					
1978					36.9 ± 1.4
1979	52.3 ± 1.6		41.7 ± 2.3	38.7 ± 5.6	37.3 ± 3.4

Table 6. Predicted means and 95% confidence intervals for crude protein (%) in regrowth of bluebunch wheatgrass.

		Clipping treatment			
	Control	Boot	Emergence	Flowering	Seed formation
April 9					
1978	23.2 ± 2.3				
1979	15.3 ± 1.1				
May 5					
1978	16.7 ± 0.7				
1979	11.5 ± 0.7				
May 29					
1978	12.8 ± 0.7	18.0 ± 2.2			
1979	7.9 ± 0.4	20.5 ± 2.4			
June 23					
1978	11.0 ± 0.6	10.7 ± 1.3	14.8 ± 1.7		
1979	5.2 ± 0.6	11.8 ± 0.9	11.0 ± 1.3		
July 18					
1978	9.4 ± 0.6	10.9 ± 1.2	10.7 ± 1.1		11.7 ± 1.0
1979	3.9 ± 0.6	7.8 ± 0.9	8.9 ± 0.8		
August 12					
1978	7.4 ± 0.8	9.1 ± 1.2	8.9 ± 1.2	9.0 ± 1.8	12.1 ± 0.7
1979	3.7 ± 0.5	7.0 ± 0.7	8.0 ± 1.1		
September 6					
1978	9.4 ± 1.1	8.4 ± 1.3	9.3 ± 1.2	11.2 ± 0.9	12.5 ± 0.6
1979	4.5 ± 1.1	7.6 ± 0.6	8.2 ± 1.0		
October 1					
1978			12.1 ± 2.9	13.3 ± 1.9	12.9 ± 0.7
1979	5.5 ± 1.4	7.8 ± 1.9	9.5 ± 0.8		
October 26					
1978				15.4 ± 3.5	13.3 ± 0.9
1979	5.6 ± 0.9		11.9 ± 1.8	12.5 ± 3.0	13.7 ± 3.1

Table 7. Predicted means and 95% confidence intervals for calcium (%) in regrowth of bluebunch wheatgrass.

	Control	Clipping treatment			
		Boot	Emergence	Flowering	Seed formation
April 9					
1978	0.33 ± .05				
1979	0.38 ± .08				
May 5					
1978	0.26 ± .03				
1979	0.25 ± .03				
May 29					
1978	0.27 ± .02	0.25 ± .04			
1979	0.16 ± .03	0.30 ± .08			
June 23					
1978	0.31 ± .03	0.35 ± .03	0.29 ± .06		
1979	0.17 ± .03	0.37 ± .05	0.21 ± .10		
July 18					
1978	0.37 ± .03	0.41 ± .03	0.35 ± .04		
1979	0.23 ± .03	0.44 ± .04	0.40 ± .08		
August 12					
1978	0.39 ± .03	0.43 ± .03	0.41 ± .03	0.43 ± .06	
1979	0.27 ± .03	0.51 ± .04	0.20 ± .17		
September 6					
1978	0.36 ± .06	0.41 ± .04	0.46 ± .05	0.45 ± 0.7	
1979	0.23 ± .04	0.59 ± .05	0.40 ± .12		
October 1					
1978			0.52 ± .07	0.37 ± .07	0.49 ± .13
1979	0.14 ± .09	0.66 ± .07	0.80 ± .02		
October 26					
1978					
1979	0.19 ± .05		0.80 ± .14	0.57 ± .17	0.52 ± .16

Table 8. Predicted means and 95% confidence intervals for phosphorus (%) in regrowth of bluebunch wheatgrass.

	Control	Clipping treatment			
		Boot	Emergence	Flowering	Seed formation
April 9					
1978	0.33 ± .02				
1979	0.24 ± .02				
May 5					
1978	0.28 ± .01				
1979	0.19 ± .01				
May 29					
1978	0.24 ± .01	0.36 ± .04			
1979	0.15 ± .01	0.19 ± .03			
June 23					
1978	0.21 ± .01	0.20 ± .03	0.22 ± .02		
1979	0.12 ± .01	0.18 ± .02			
July 18					
1978	0.17 ± .01	0.22 ± .02	0.17 ± .02		
1979	0.10 ± .01	0.17 ± .02	0.23 ± .18		
August 12					
1978	0.15 ± .01	0.18 ± .02	0.16 ± .02	0.17 ± .02	
1979	0.08 ± .01	0.16 ± .01	0.20 ± .06		
September 6					
1978	0.17 ± .02	0.16 ± .02	0.19 ± .01	0.20 ± .03	
1979	0.08 ± .01	0.15 ± .02	0.18 ± .02		
October 1					
1978			0.26 ± .05	0.19 ± .05	0.21 ± .02
1979	0.08 ± .02	0.14 ± .03	0.18 ± .02		
October 26					
1978					
1979	0.09 ± .02		0.14 ± .02	0.22 ± .07	0.26 ± .06

Discussion

Two years of clipping at boot, emergence, flowering, and seed formation produced significant reductions in ADF, plus increases in CP, Ca, and P on 26 October compared to nondefoliated plants. Other than for Ca, these altered herbage constituents represent improved forage quality available for fall grazing. These results support the theoretical potential to improve fall forage quality with cattle grazing during spring, which delays plant phenology of subsequent regrowth. This regrowth provides higher forage quality not only because of younger photosynthetic tissue, but also because of increased availability due to the removal of old growth (Laycock and Price 1970). Moreoever, the magnitude of improved forage quality is sufficient to warrant considerable interest for grazing management planning.

The National Research Council (1976) recommended minimum levels of 5.9% CP, plus 0.18% for P and Ca for mature pregnant cows during fall and winter. Nelson and Leege (1982) utilizing data from Thorne et al. (1976) reported a similar requirement of 5.5% CP for winter maintenance of pregnant elk body weights under feedlot conditions. Presumably elk also share requirements for Ca and P similar to cattle. Tables 6 and 8 indicate that CP and P of unclipped foliage on 26 October 1979 equalled or fell below these winter requirements respectively, while CP of plants clipped at emergence, flowering and seed formation all exceeded maintenance levels. Foliar P of plants clipped at flowering and seed formation similarly exceeded maintenance values for cattle and elk on 26 October 1979 (Table 8).

Based upon these experimental plots, fall forage quality improves with successively later clipping treatments, particularly at emergence, flowering, and seed formation. Regrowth of foliage in plants clipped at boot tended to be lower in nutritive quality than with later clipping treatments, even when compared at equivalent phenological stages. These results suggest that plants defoliated during the boot stage of development still retained a sufficient portion of the growing season to respond similarly to undefoliated plants.

Such generalizations, however, should be extrapolated to other sites with caution. Specifically, the extent of regrowth depends upon availability of soil moisture, with response becoming less pronounced as soil moisture declines. For example, Hedrick et al. (1969) found that vegetative regrowth following grazing by yearling heifers occurred only in 2 of 5 years under the prevailing weather patterns of fall-winter-spring precipitation in eastern Oregon. Similarly, the duration of any improved forage quality may not persist into a second growing season. Uresk and Cline (1976) found no differences in nutritive content of bluebunch wheatgrass at seed development 1 year subsequent to 2 years of moderate spring grazing by cattle.

Moreover, intensity and timing of grazing relative to elevation of apical meristems also influences subsequent forage quality. Hyder and Sneva (1963) reported that complete removal of crested wheatgrass (*Agropyron desertorum)* (Fisch.) Schult.) growing points produced a higher quality forage with increased proportions of vegetative tillers relative to reproductive culms. Bedell (1973) also illustrated that clipping of crested wheatgrass in June removed a substantial proportion of apical meristems, such that summer and fall regrowth contained nearly 50% more protein than plants clipped in May, where regrowth herbage consisted of both vegetative tillers and reproductive culms.

Anderson and Scherzinger (1975) postulated that spring grazing can produce increased nutrients per unit area for fall utilization relative to ungrazed forage. Demarchi (1973) provided inferential data to support this hypothesis, as moderately grazed bluebunch wheatgrass sites, dominated by needleandthread (*Stipa comata* Trin. & Rupr.), yielded greater crude protein per unit area than did lightly grazed bluebunch wheatgrass sites in excellent range condition. Alternatively, McIlvanie (1942) reported that total nitrogen in bluebunch wheatgrass declined 53% when clipped biweekly, while Aldous (1930) concluded that observed increases in forage value of frequently clipped prairie grasses may not compensate for decreased yield and density of the vegetative cover. Similarly, Blaisdell et al. (1952) reported that total quantities of crude protein and phosphorus were greater in unclipped bluebunch wheatgrass because herbage yield exceeded that of unclipped plants.

The value of spring grazing to improve quality of fall forage depends upon total available forage as well as grazing ungulate demand for fall forage. Consequently, even if total nutrients per unit area are decreased relative to ungrazed sites, spring grazing may still be beneficial if sufficient forage quantity remains to satisfy fall forage biomass requirements of wintering ungulates. Moreover, because of spring grazing-induced phenological delays, forage quality of the remaining available forage will be improved relative to that of ungrazed sites.

Recommendations for specific management plans utilizing spring grazing to improve fall forage quality must assess carefully the physiological impacts of defoliation at alternative phenological stages. Daer and Willard (1981) cautioned that herbage removal of bluebunch wheatgrass late in the growing season may reduce carbohydrate reserves more than defoliation early in the growing season. McLean and Wikeem (1985a) reported that successively later clipping treatments prior to cessation of leaf growth corresponded with increased mortality, reduced leaf length and depressed forage yields. Plant mortality in the current study similarly increased with later defoliation, while the number of flowering stems/plant was severely reduced by clipping at emergence in 2 successive years (Table 9). Consequently, although fall forage quality is enhanced most by grazing at successively later phenological stages, such improvements occur at the expense of plant health and reproductive potential. Optimum management recommendations must therefore consider all costs and benefits associated with specific grazing management alternatives.

Table 9. Response of bluebunch wheatgrass to two years of defoliation, measured in May, 1980.

	Clipping treatment				
	Control	Boot	Emergence	Flowering	Seed formation
Basal Area (cm)	101a[1]	103a	109a	109a	103a
Stem Weight (g/plant)	584a	649a	739a	656a	772a
Flowering Stems (#/plant)	89a	10b	4b	23c	14c
Flowers (#/basal area)	1.02a	0.12b	0.10b	0.19b	0.13b
Mortality (%)	13	20	52	60	60
(#/n)	(6/45)	(6/30)	(13/25)	(13/20)	(9/15)

[1]Means within rows followed by different letters are significantly different at $p<0.05$.

Such benefits must necessarily include increased utilization of the improved forage during fall and winter, with subsequent gains in animal production. Willms et al. (1979) reported increased deer utilization in spring of pastures grazed heavily by cattle during the previous fall. Alternatively, Skovlin et al. (1983) reported no increased utilization by elk during winter of forage theoretically improved by spring cattle grazing. Indeed, elk use actually declined 28% following cattle grazing in 1 of 3 years of study. Although the recommendation of Anderson and Scherzinger (1975) was considered plausible by Skovlin et al. (1983), they recommended that light cattle use in spring could be maintained primarily when forage supplies exceeded the winter needs of elk. Smith et al. (1979) identified an additional ecological complexity when they reported that although mule deer diets on winter range grazed the previous fall by domestic sheep contained higher proportions of preferred forage species, the nutritive quality of this forage remained unaffected by sheep grazing activities. Such inconsistencies in research results clearly indicate the need for site-specific management recommendations.

The current study verifies the hypothesis of Anderson and Scherzinger (1975) that spring defoliation can increase fall forage quality of bluebunch wheatgrass. These nutritional benefits, however, are best enhanced by defoliation during stages when the plant is most susceptible to grazing damage. For example, Mueggler (1975) observed that bluebunch wheatgrass required more than 5 years to recover in vigor from a single defoliation of 50% just prior to flower stalk formation. Consequently, Anderson and Scherzinger's (1975) recommendation must be implemented judiciously, and is best applied within a rotation that permits rest from grazing every second or third year (McLean and Wikeem 1985b).

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Cattle Weight Gains in Relation to Stocking Rate on Rough Fescue Grassland

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Abstract

The effects of 4 stocking rates (1.2, 1.6, 2.4, and 4.8 AUM/ha) on cattle production were examined, over a 35-year period, on a Rough Fescue (*Festuca scabrella* Torr.) Grassland. Forage productivity was reduced at the higher stocking rates. This resulted in a shortened grazing season in the field stocked at 4.8 AUM/ha. Although individual animals' weights decreased with increased stocking rate, cattle gains per unit area increased. Average daily gain of cows was greatest in May but declined to become a loss in September. Calves showed maximum gains from June to July and never lost weight. Stocking rate affected the relative magnitude of average daily gain as well as the trend over the grazing season.

The native grasslands of western Canada are managed primarily for cattle using a system of continuous grazing. In implementing this system, the major decision is to set the stocking rate that will be used. Financial considerations often dictate a high stocking rate that may eventually result in a reduced carrying capacity of the range. Sustained heavy grazing may reduce the productivity of the grassland by lowering plant vigor and, over many years, by modifying the species composition to a cover dominated by less productive species.

Numerous grazing experiments have been reported (Sarvis 1941, Clarke et al. 1947, Woolfolk and Knapp 1949, Johnson 1953, Peters 1955, Lewis et al. 1956, Launchbaugh 1957, Klipple and Costello 1960, Beetle et al. 1961, Reed and Peterson 1961, Houston and Woodward 1966, Bement 1969, Smoliak 1974) that examine the effects of stocking rate on weight gain. However, none have been reported for the Rough Fescue (*Festuca scabrella* Torr.) Grasslands found in southwestern Alberta and few experiments have extended beyond the time required for the plant community to reach equilibrium with the grazing regime imposed on it. Consequently, this paper reports on the findings, over a 35-year period, of a study that began in 1949 with the objectives of determining the effects of fixed stocking rates on cattle weight gains over the grazing season, the weight gains of cattle over the grazing season on Rough Fescue Grassland, and the relationship between cattle gains and available forage. The effects of fixed stocking rates on the species composition of the Rough Fescue Grassland are reported in a separate paper (Willms et al. 1985).

Site Description

The study area was in the foothills of southwestern Alberta, 80 km northwest of Lethbridge at the Agriculture Canada Research Substation near Stavely. Geologic and climatic conditions were described by Willms et al. (1985).

Rough fescue was the dominant species in the study area and Parry oat grass (*Danthonia parryi* Scribn.) was co-dominant. Vegetation was representative of the Rough Fescue Association (Moss and Campbell 1947).

Historical grazing of the study area was described by Johnston (1961). The area was moderately stocked for summer grazing with cattle from 1884 to 1908 and with horses from 1908 to 1920. From 1920 to 1943, the area was again stocked with cattle for summer grazing. Use was heavy during the 1930's drought. The area was used lightly for winter pasture from 1944 to 1949.

Methods

The study was begun in 1949 and terminated in 1983. Four fields were fenced to enclose areas of 65, 48, 32, and 16 ha and stocked with 13 cows and their calves from approximately mid-May to mid-November. This resulted in 4 stocking rates: light (L), 1.2 AUM/ha; moderate (M), 1.6 AUM/ha; heavy (H), 2.4 AUM/ha; and very heavy (VH), 2.5–4.8 AUM/ha. The stocking rate on field VH was 4.8 AUM/ha from 1949 to 1958 but was adjusted yearly after 1959 to avoid animal losses. The cattle were removed from the field when they first lost weight. This resulted in stocking rates that varied from 2.5 to 4.8 AUM/ha and averaged 3.2 AUM/ha for the period from 1960 to 1983. The recommended stocking rate for range in good condition in the area was 1.6 AUM/ha (Wroe et al. 1981).

Cows and calves were obtained from a nearby rancher. From 1949 to 1978, the cattle used were Hereford, Angus, and Hereford × Angus crosses with Hereford being dominant. From 1979 to 1983, the cattle also included Simmental, Charolais, and their crosses with Hereford.

The cattle were introduced into the experimental area in early May of each year. In mid-May they were weighed and partitioned into 4 groups of equal numbers. One group was randomly assigned to each of the 4 fields for the duration of the grazing season.

All cattle were weighed at monthly intervals. Food and water were withheld from the animals 1 day prior to weighing. Cows were weighed individually but calves were weighed in lots of 2 to 5 animals within a grazing group. Weighing calves in groups reduced errors since the scale was not accurate for small weights.

Water was provided from dugouts fed by springs and run-off. Cobalt salt and mineral blocks were made available *ad libitum* to cattle in all fields.

Available forage was estimated by harvesting 10 to 30 plots that had been protected by temporary exclosures within each field. A paired grazed plot was harvested near each exclosure to provide estimates of residual forage and to enable estimates of utilization by subtracting residual from available forage. Estimates of residual forage were made from 1967 to 1981 but available forage was estimated from 1972 to 1981. Plot area ranged from 0.5 to 1.6 m^2. Forage was harvested, near ground level, in early October to avoid snowfall.

Cattle weight gains were analyzed separately for cows and calves. Average daily gains (ADG) were calculated for each interval between weighings (periods (P) 1 to 6: P1, 15 May to 14 June; P2, 15 June to 14 July; P3, 15 July to 14 August; P4, 15 August to 14 September, P5, 15 September to 14 October; P6, 15 October to 14 November).

Orthogonal polynomials were used in 2 different ways in the analysis of these data. Since ADG's for all periods in a grazing season formed a set of repeated measurements from each animal, the trend of ADG change over the grazing season was investigated by calculating linear and quadratic polynomial contrasts of ADG over periods for each cow (or group of calves) and applying analysis of variance to these contrasts as in Rowell and Walters (1976). To investigate the effects of stocking rates on the ADG trends of the animals, stocking rate was used as a factor in the analysis of variance and sums of squares of the contrasts due to stocking rates (logarithmic scale) were partitioned into orthogonal polynomial

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Table 1. Available forage and utilization (estimated in October) from 1972–81 and residual forage after grazing from 1967–81 in fields stocked at four rates.

	Stocking Rate				SEM	Effect of stocking rate
	L	M	H	VH		
Available forage (kg/ha)	2199	2171	1865	1170	93	*
Utilization (%)	26	36	47	81	4	*
Residual forage (kg/ha)	1748	1557	1102	280	64	*

*Significant ($P<0.05$).

components (Steel and Torrie 1980). These tests were performed (1) to evaluate the signifiance of the ADG-time period contrasts averaged over the stocking rates, and (2) to assess trends in the ADG-time period contrasts due to stocking rates.

Analysis of variance was also used to test: the effects of stocking rate on individual ADG's for each period; cattle weights prior to the grazing season; total changes in cattle weights over the grazing season; and estimates of forage yield and percent utilization. In all analyses of variance, the two-way model without interaction was used, with years and stocking rates as the main effects. The validity of the analysis depends on the assumptions that the years were independent of each other and that the geographical effects confounded with the stocking rates were negligible.

Forage production was correlated with stocking rate and precipitation, for the period preceding and during the growing season representing the winter period (November to March) and individual months from April to August, using a stepwise regression procedure that maximized R^2 (SAS Institute Inc. 1982).

Several methods were then used to relate weight gain of cattle to available forage. One method was to determine available forage per animal unit (AF/AU). This estimate was related to weight gain of cows and calves using several models including the polynomial and plateau. However, the best fit was obtained with an asymptotic model using the Mitscherlich equation (Mitscherlich 1930 in Mead and Pike 1975): $Y = M(1 - e^{A-BX})$, where M is the asymptote, A is the Y-intercept (set at zero), B is the rate coefficient, and X (kg) is the AF/AU. The dependent variable was, in different analyses, net wet gain (kg) in cows, net weight gain (kg) in calves, and maximum weight gain (kg) in cows. The best fit (asymptote and rate coefficient) was obtained by iteration (SAS Institute Inc. 1982). Data from all fields were included in this analysis. Correlations were also made of net and maximum weight gains on total available forage in each field.

In other analyses, ADG in the final grazing period was related to residual forage, measured in that period, using linear and quadratic polynomial equations. This approach assumed a relationship between residual forage and grazing pressure and eliminated forage quality as a factor influencing weight gain. Data for this analysis were available from 1967 to 1981 and the analysis was repeated with and without the data from field VH.

Results

Available forage was similar at the 2 lowest stocking rates over the years in which they were measured (Table 1). Availability declined substantially as stocking rate was increased. Forage utilization in October ranged from 26% in field L to 81% in field VH (Table 1). When utilization was extrapolated to the end of the grazing season, on the basis of average daily use prior to harvesting, then the estimates for fields L, M, H, and VH were 28, 41, 53, and 84%, respectively. Residual forage in October was 1,748 kg/ha in field L and 280 kg/ha in field VH (Table 1).

Cattle weights at the start of the grazing season were similar in each field (Table 2). Total individual weight gains over the grazing season declined significantly ($P<0.05$) with increased stocking rate, (Table 2). However, weight gains per unit area increased with an increase in stocking rate. Cattle gains per hectare over the grazing season were 17, 23, 27, and 49 kg for cows, and 28, 39, 55, and 83 kg for calves in fields L, M, H, and VH, respectively.

Table 2. Initial cattle weights (kg) at the beginning of the grazing season and weight gains (kg) over a six-month grazing period, from 1949 to 1983, in fields stocked at four rates.

	Initial weights		Weight gains	
Stocking rate	Cows	Calves	Cows	Calves
L	409.8	63.4	85.5	138.4
M	419.1	64.2	85.4	144.7
H	415.2	62.7	67.5	137.1
VH[1]	421.2	61.7	61.1	102.9
Standard error of mean	8.1	6.0	15.8	13.1
Effect of stocking rate				
Overall	NS[2]	NS	*	*
Linear			*	*
Quadratic			NS	*

[1]Length of grazing season in field VH adjusted annually, after 1959, in relation to available forage.
[2]Effect of stocking rate on the relationship of weight gain to stocking rate is not significant ($P>0.05$).
*Effect of stocking rate on the relationship of weight gain to stocking rate is significant ($P<0.05$).

The weight gains of cows declined linearly with an increase in stocking rate when measured as total gain or as ADG within a period (Table 3). Only in period 2 was the effect not noticeable.

Table 3. Effect of stocking rate on ADG (kg/animal) during individual periods throughout the grazing season.

Cattle type	Period	ADG	SEM	Relationship of ADG to stocking rate: Linear	Quadratic
Cows	1	0.91	0.21	*	NS[1]
	2	0.95	0.14	NS	NS
	3	0.73	0.14	*	NS
	4	0.50	0.14	*	NS
	5	−0.11	0.17	*	NS
	6	−0.64	0.21	*	NS
Calves	1	0.82	0.12	NS	NS
	2	0.82	0.08	NS	*
	3	0.95	0.11	*	NS
	4	1.00	0.16	NS	*
	5	0.73	0.12	*	NS
	6	0.41	0.18	*	NS

[1]Linear or quadratic regression coefficients are not significantly ($P>0.05$) different from zero.
*Linear or quadratic regression coefficients are significantly ($P<0.05$) different from zero.

The ADG of cows declined over the grazing season and became negative in period 5 (Fig. 1). ADG increased from periods 1 to 2 only in fields H and VH. The ranking of stocking rates was generally maintained throughout the grazing season (Fig. 1). However, the relationship between linear contrasts of ADG over time and stocking rates was linear (Table 4), indicating divergence of ADG's toward the end of the season.

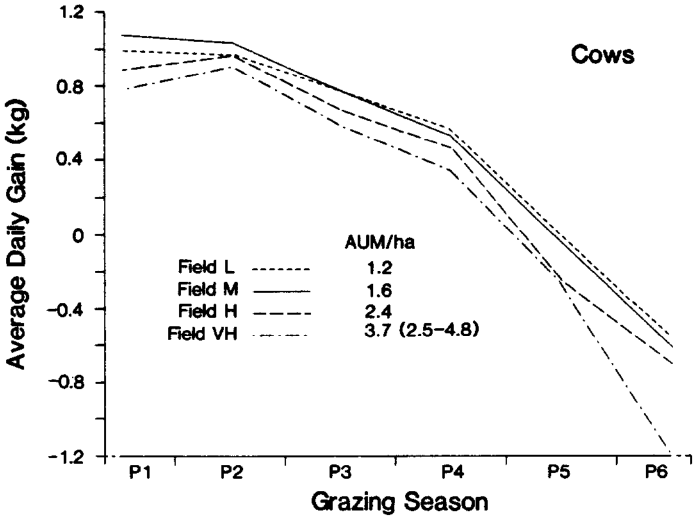

Fig. 1. *Average daily gain of cows in relation to stocking rate over the grazing season (P1, 15 May to 14 June; P2, 15 June to 14 July; P3, 15 July to 14 Aug.; P4, 15 Aug. to 14 Sept.; P5, Sept. to 14 Oct.; P6, 15 Oct. to 14 Nov.).*

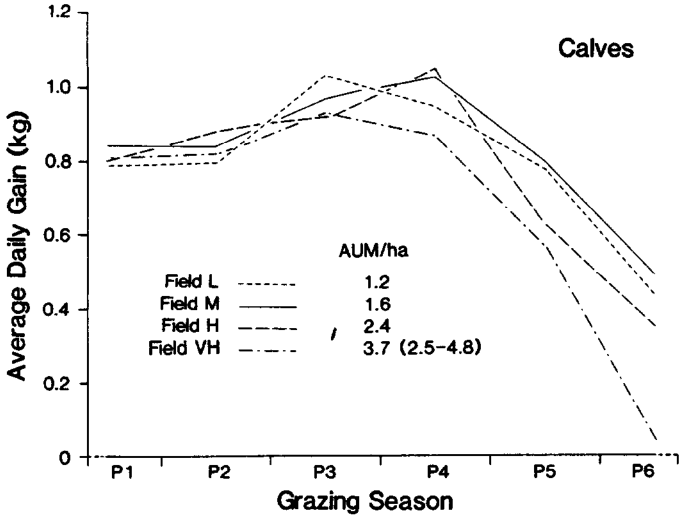

Fig. 2. *Average daily gain of calves in relation to stocking rate over the grazing season (P1, 15 May to 14 June; P2, 15 June to 14 July; P3, 15 July to 14 Aug.; P4, 15 Aug. to 14 Sept.; P5, 15 Sept. to 14 Oct.; P6, 15 Oct. to 14 Nov.).*

Table 4. A test of the average trend of ADG over time and of the effect of stocking rate on the trend (demonstrated in Figures 1 and 2).

Cattle type	Trend of ADG over time	Significance of trend	Significance of effect of stocking rate on trend[1] Linear	Quadratic
Cows	Linear	*	*	NS[2]
	Quadratic	*	*	NS
Calves	Linear	*	*	NS
	Quadratic	*	NS	NS

[1]A test for parallelism in trends among stocking rates.
[2]The effect of stocking rate on the trend is not significant ($P>0.05$).
*The trend or the effect of stocking rate on the trend is significant ($P<0.05$).

Stocking rate had a significant ($P<0.05$) effect on the weight gain of calves over the grazing season (Table 2). Calf weight gains increased as stocking rates increased from fields L to M but then declined with further increase in stocking rates. This relationship was evident from the quadratic trend of ADG's over stocking rates which was significant ($P<0.05$) over the whole grazing season (Table 2) and in periods 2 and 4 of the grazing season (Table 3).

In spite of significant trends, however, the ADG's of calves for all stocking rates were similar during the first half of the grazing season (Fig. 2) and the rankings of the stocking rates were inconsistent. However, from periods 4 to 6, the rankings were more consistent and the differences were greater. The ADG in field VH was smallest during this time. As in the cow data, the linear contrasts for ADG of calves over time showed a significant linear trend (Table 4) over stocking rates, indicating a gradual divergence in ADG between stocking rates. The ADG of calves was maximum in periods 3 or 4 and never became negative (Fig. 2).

The ADG's in periods 5 and 6, of field VH, could be determined in each year before 1960 but only for those years when grazing was continued after 1959, because of the policy of removing animals in the summer when they began losing weight. As such, the ADG of periods 5 and 6 does not consider the weight loss as a function of limited forage and is probably too high.

Forage production (FP, kg/ha) was best correlated in a 4-variable equation with stocking rate (SR, AUM/ha) and precipitation (mm) in May (MY), June (JE), and July (JY): FP = –170 – 25.8 SR + 12.7 MY + 13.2 JE + 10.0 JY (R^2 = 0.84, $P < 0.01$ for each variable). Precipitation in April was negatively correlated while precipitation in winter had no effect ($P>0.05$).

The asymptote of weight gain was 151.5 kg for calves and 111.5 kg for cows (Fig. 3). Ninety-nine percent of these weights were achieved with 5,000 and 6,000 kg forage, per AU, for calves and cows, respectively. Unit forage weights in the data set ranged from 700 to 16,000 kg.

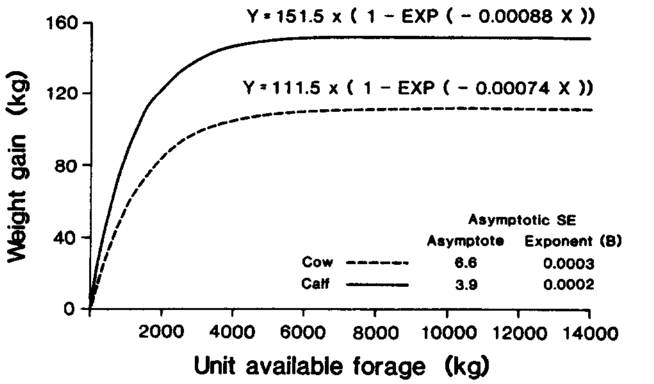

Fig. 3. *The relationship of weight gain (Y) over the grazing season to unit available forage (AF/AU, X) on fields stocked at 4 rates.*

Average daily gains of cows and calves in the final 2 periods of the grazing season were not related to residual forage which varied from 600 to 2,400 kg/ha in fields L, M, and H. Neither the linear nor quadratic polynomial equations were significant ($P>0.10$). The inclusion of ADG obtained in the last grazing period, from field VH, did not improve the regression even though the estimate of residual forage extended the range to near zero.

Cow weight gains, both net (CWn) and maximum (CWm), were significantly ($P<0.05$) correlated with total available forage (AF, kg/ha) only in field VH: CWn = 22.8 + 0.036 AF (R^2 = 0.9, n = 8); CWm = 36.1 + 0.032 AF (R^2 = 0.6, n = 8); CWm = 36.1 + 0.032 AF (R^2 = 0.6, n = 9). Calf weight gains in any field were not significantly ($P>0.05$) correlated with total available forage.

Table 5. Predicted forage yields, forage requirements, and calf gains in relation to set stocking rates over the long term and short term (nested in the former) calculated for 1 ha.

Long-term effects at set stocking rates					Short-term effects at set stocking rates			
Stocking rate		Forage (kg)		Available forage (kg)[4]	Stocking rate	Forage required	Animal gain (kg)	
AUM	AU[1]	MIG[2]	DR[3]		AUM	DR	Individual[5]	Area
1.2	0.20	1000	396	2000[6]	1.2	396	152	30
					2.4	792	152	61
					4.8	1584	135	108
1.6	0.27	1350	534	1886[6]	1.2	396	152	30
					2.4	792	149	60
					4.8	1584	132	106
2.4	0.40	2000	792	1658[6]	1.2	396	151	30
					2.4	792	149	60
					4.8	1584	132	106
4.8	0.80	4000	1584	974[7]	1.2	396	149	30
					2.4	792	134	53
					4.8	1584	100	80

[1]6-month grazing period.
[2]Maximum individual gain based on 5,000 kg/AU (Fig. 3).
[3]Daily requirement based on 11 kg/day/AU.
[4]Relative yield after long-term stocking at fixed rates.
[5]Calculated for calves from Figure 3.
[6]Capable of supporting 1.2 to 4.8 AUM on short term.
[7]Capable of supporting 1.2 to 2.4, but not 4.8, AUM on short term.

Discussion

Forage production was related to precipitation and past historical use. Productivity may decline, over a short term, because of a loss in plant vigor or, over a long term, because of a change in species composition to one that is less productive. In a study made concurrently on the same area, we found that persistent heavy grazing of Rough Fescue Grassland favored an increase in the proportion of unproductive forbs and grasses and a reduction in the proportion of rough fescue (Willms et al. 1985). The net effect was a decline in range condition and a reduction in the recommended carrying capacity (Wroe et al. 1981).

The equation relating forage production with precipitation and previous stocking rate suggests a decrease in forage of about 258 kg/ha for each additional AUM with which the range was stocked. As a variable in a prediction equation, this has little value unless it can be related to the plant community which it represents. For the fescue grassland in this study, the plant communities in fields L, M, H, and VH were, respectively, rough fescue-Parry oat grass, rough fescue-Parry oat grass, Parry oat grass-rough fescue, and Parry oat grass-Idaho fescue (*Festuca idahoensis* Elmer) (Willms et al. 1985).

July precipitation was most important in determining total forage production in the current year. Lack of response from early spring or winter precipitation suggests that moisture during that time was not limiting in the years for which data were available. In other work, forage production was best correlated with precipitation occurring before August on the Mixed Prairie (Smoliak 1986 and before September in the Mountain Grasslands of western Montana (Mueggler 1983).

The greater cattle gains per unit area on heavily stocked ranges were similar to results reported by others (Sarvis 1941, Clarke et al. 1947, Launchbaugh 1957, Klipple and Costello 1960, Beetle et al. 1961), and seem to indicate that most benefit could be derived from a heavy stocking rate. Bement (1969) suggested that maximum profits could be realized when yields per unit area were near maximum on a short grass prairie. However, in the present study, the grazing season in field VH was shortened by about 57 days after 1959. The loss of flexibility in grazing management, the cost of additional feed to the end of the grazing season, and the condition of the animals at market are only 3 of many factors to be considered when assessing the benefits of producing maximum gains per unit area.

Only field M was stocked at the recommended carrying capacity of 1.6 AUM/ha (Wroe et al. 1981) for range in good condition. Field L was understocked while fields H and VH were overstocked. Despite a loss in forage productivity, field H was able to support cattle for the entire grazing season in every year of the study.

Field VH supported from 3 to 4 times the recommended carrying capacity in the first 11 years of the study. The subsequent loss in carrying capacity forced the removal of cattle before the end of the grazing season and a reduction of stocking rate from 4.8 AUM/ha to an average of 3.2 AUM/ha. The revised stocking rate was still about 3.5 times the recommended rate for a grassland in poor condition.

The heaviest stocking rate resulted in a 46% decrease in forage availability but almost triple the cattle weight gain per unit area. These results were achieved well after the plant communities had adjusted to the grazing influence but at the cost of early removal of cattle. Keeping the animals in field VH for the same length of time as in the other fields would have resulted in considerable loss of cattle gains and a further decrease in forage productivity. It would appear that the readjusted stocking rate of 3.2 AUM/ha, modified yearly in relation to available forage, can be sustained, while stocking at 4.8 AUM/ha could result in complete destruction of range productivity. However, managing for maximum gains on a unit area basis introduces considerable risk which may be untenable to most livestock operations.

Individual animals gained most weight at light or moderate stocking rates (Table 2). The greater ADG of calves in field M than of those in field L was consistent in all periods throughout the grazing season, except in period 3 (Fig. 2). Cows also gained more in field M in periods 1 and 2. An apparent increase in weight gain, with a small increase in stocking rate, has been reported elsewhere (Peters 1955). Powell et al. (1982) showed that calves on poor range produced better gains than did calves on good range. Evidently, native range in Nebraska that was in good condition offered forage that was less digestible than forage from range in poor condition.

Near maximum individual cattle gains were achieved with 5,000 kg AF/AU. Fields L, M, H, and VH produced, on average, 11,000, 8,100, 4,600, and 1,450 kg AF/AU, respectively. This indicates that field H was managed most efficiently since field L and M produced in excess of the required forage while field VH was considerably deficient. Evidently, forage was not limiting towards the end of the grazing season in either fields L, M, or H since ADG in the final grazing period was not related to residual forage.

The relationships defined in this study may be used to predict available forage and, in turn, the stocking rate for optimum sustained beef production. This may be done by using long-term weather records to determine probable forage yield. This estimate, combined with estimates of weight gain in relation to available forage (Fig. 3) and length of grazing season can be combined to develop an appropriate grazing strategy as illustrated in Table 5. The information, with animal gain calculated for the calf component of the AU, shows that range in good condition could support a heavy stocking rate on a short term but, as the range deteriorates, the carrying capacity will also be reduced. This information identifies stocking at 2.4 AUM/ha as the most efficient (of the rates examined) since it was sustained over a long term, it produced near maximum individual gains, and yields per unit area were maximum. The management strategy that may be tempting would be to stock the range heavily for several years before reducing to an acceptable level. This may be possible but at the risk of prolonged loss of forage and cattle production.

Restrictions on nutrient intake were apparent throughout the grazing season in field VH for cows, but only after period 3 for calves (Figs. 1 and 2). Presumably, calves relied primarily on milk in the first 3 periods of the grazing season.

In periods 5 and 6, cows lost weight while calves reduced their weight gain. Similar results were reported by Launchbaugh (1957) for cows on the shortgrass prairie. Since forage quantity was abundant in fields L and M, the weight loss may be attributed to loss of forage digestibility which may lead to a reduction of forage intake (van Soest 1965). Bezeau and Johnston (1962) reported a reduction of about 50% in the digestibility and nutritive value of native grasses from spring to early summer.

The model used to assess the effect of stocking rate on ADG at various periods throughout the grazing season was similar to that proposed by Hart (1978) (i.e., linear after stocking rate transformed to their logarithms indicating a concave trend above the critical rate) but without the plateau. Evidence for a plateau would be indicated by a significant quadratic polynomial on a test of the transformed stocking rates.

However, the exponential model gave the best fit of total gain to AF/AU. This was identical to the model proposed by Mott (1960) but apparently invalidated by subsequent evidence (Peterson et al. 1965, Jones and Sandland 1974). The exponential model should be the correct one under the management conditions of this study where the animals were removed before losing weight but after having consumed most of available forage. Evidently, the critical stocking rate, the point at which weight gain would decline in relation to forage, occurred between 2.4 and 4.8 AUM/ha but the exact rate varied with productivity in the current year.

Differences between the trends of ADG to stocking rate and animal gain to AF/AU are probably accounted for by the type of data explained and by the variability included. In the first trend, the model describes weight gain over stocking rate with the among-year variability removed while in the second trend, the model describes weight gain in relation to available forage with the among-year variability included.

Very heavy stocking resulted in a loss of flexibility in managing cattle. The duration that cattle were kept in field VH, in any year, depended on available forage which was related to precipitation during that year. In effect, the forage in field VH was utilized as an annual crop without the benefit of potentially high productivity that such crops offer.

Although an economic and ecological impact assessment was not included in this study, it was evident that stocking at 2.4 AUM/ha (field H) produced satisfactory yields without loss of management flexibility when beef production was the only resource being managed. However, stocking at this rate resulted in a substantial reduction in the cover of rough fescue and an increase in the cover of shorter, less productive, grasses. Therefore, a stocking rate of approximately 1.6 AUM/ha should be used to maintain a productive vegetative resource as well as to sustain a habitat for wildlife in the Rough Fescue Grassland zone.

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Technical Notes:

Reference Unit-based Estimates of Winterfat Browse Weights

DIEGO R. CABRAL AND NEIL E. WEST

Abstract

Precise and accurate plant weight data are important to range managers, but difficult and expensive to obtain. Indirect and nondestructive estimates are especially desirable where vegetation is sparse and slow-growing on permanent plots. A new indirect, nondestructive approach developed in Australia, the reference unit method, was quantitatively related to clipped weights of winterfat *(Ceratoides lanata)* browse in Curlew Valley, Utah. The reference unit method was quite precise, accurate, and efficient in predicting browse weights even though size and form of the shrubs differed greatly. The only major disadvantage was mental fatigue created by the requirement of greater sustained concentration.

Plant weight or phytomass is a variable most range managers would choose to estimate because it relates more directly to forage availability, and thus animal carrying capacity, than alternatives such as cover, density, or frequency (West 1983). However, phytomass data have not been gathered as often as desired because of notoriously high variation from small samples and the great cost and tedium in obtaining statistically adequate sample numbers via clipping approaches. These difficulties encouraged the development of numerous double sampling estimation techniques (Reese et al. 1979, Ahmed et al. 1983). These, however, require relatively large samples from clipped plots for validation and thus are expensive to do.

Australian range scientists have for several decades used a double sampling approach that combines some of the advantages of visual estimation with the curve-fitting of the newer quantitative techniques (Andrew et al. 1979). Relatively few plants have to be sacrificed to establish the quantitative relationships and these can be harvested outside permanent plots. The worker can define whatever portion of aboveground phytomass he chooses. Andrew et al. (1981) reported a very favorable comparison of the accuracy, precision and efficiency of this approach against dimensional and capacitance methods. Since only data from large, unbrowsed Australian chenopod shrubs had been presented, we thought it worthwhile to test the reference unit approach on a smaller American half-shrub under different historic levels of herbivory.

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Study Area

The study area in which we chose to make this comparison was in pure winterfat [*Ceratoides lanata* (Moq.) J.T. Howell] communities located in Curlew Valley, Utah (41°, 52′N, 113° 5′W, 1,350 m elev.) Bjerregaard et al. (1984) give details of the soils here. Details of the climate of this study area can be found in Caldwell et al. (1977) and West and Gasto (1978). The mean annual temperature is 7.1°C; yet during summer months, average daily temperatures are high (up to 32°C). Average total annual precipitation is 244 mm with most of the precipitation coming during the winter and early spring. The precipitation for the 12 months prior to our investigation was 171% of the long-term average (Cabral 1983).

In order to test methods under differing densities and forms of the shrubs due to grazing, we selected for sampling 3 portions of the winterfat community type that had been bounded by different kinds and ages of fencing, and thus differing grazing histories. These differences are detailed in Cabral (1983).

Methods

A visually homogeneous 3 × 50 m macroplot was chosen in each of the 3 sample areas. Care was taken to choose as pure a stand of *Ceratoides* as possible and thus simplify the testing of the method to predict browse weights. Plots were also located so as to avoid patches of bare ground around ant (*Pogonomyrmex* sp.) hills and badger *(Taxidea taxus)* mounds and thus not confound the issue with associated increases in shrub growth around such bared spots (Wight and Nichols 1968). The plots were also distant from invading taller shrubs so as to avoid possible influences of snow shadows (West and Caldwell 1983).

The macroplots were divided into 150 microplots each 1 × 1 m in size. Previous work (West and Baasher 1968) had shown that 1-m^2 plots were more than adequate to estimate shrub densities. The proper plot size was unknown for phytomass data. The nested sampling design allowed for aggregation of data into larger plots of 3, 9, and 15 m^2, if necessary. Graphical plots of running mean densities and phytomass were used to select appropriate plot size and numbers (Mueller-Dombois and Ellenberg 1974).

Densities of shrubs with more than half their root crown within each plot were estimated. Shrub cover and volume were estimated for all these micro-plots via dimensional approaches detailed in Cabral (1983). Means and standard errors derived from these data, along with other descriptors of vegetation differences between

Table 1. Selected vegetational characteristics of three samples areas. Means of the variable are followed by the standard errors of the mean within parentheses.

	Numbers of plots per area	Sampled Area: Rabbit Free		Livestock Free		Bureau of Land Mgt.	
Cover (%)	150	15.6	(3.59)	8.3	(2.33)	8.4	(2.95)
Mean Plant Cover (cm^2)	150	143.1	(22.7)	78.1	(12.5)	69.2	(17.2)
Mean Plant Volume (cm^3)	150	1084.9	(176.9)	461.1	(127.8)	336.8	(78.4)
Mean Plant Density ($\#/m^2$)	150	10.9	(0.4)	10.7	(0.5)	12.1	(0.5)
Mean Plant Weight (g)	3–4	9.3	(1.7)	5.4	(1.0)	3.4	(0.4)
Weight/Volume (g/cm^3)	3–4	0.008	(0.0018)	0.011	(0.0013)	0.010	(0.0014)

Table 2. Numerical values of components of regression lines used to adjust phytomass estimations. RF = rabbit free, LF = livestock free. BLM = open to both rabbit and livestock use.

Area sampled	Reference unit #	# plants harvested	y = a + bx: a	b	r^2	CV[1]	y = bx: b	CV[2]
RF	1	31	0.518	0.874	91.4	63.3	0.90	67.8
LF	2	23	2.34	0.933	92.0	58.1	1.11	67.7
BLM	3	41	0.833	0.861	97.9	60.7	0.91	67.6
RF	4	38	−1.29	0.864	99.3	63.2	0.83	67.8
LF	5	29	1.89	0.86	95.5	53.5	1.00	67.7
BLM	6	37	0.180	1.44	89.2	51.8	1.43	64.2
RF	7	40	0.74	1.05	88.3	69.2	1.23	76.5
LF	8	27	0.024	1.60	88.9	61.2	1.60	67.3
BLM	9	42	1.45	1.45	83.9	56.6	1.75	64.7
LF	10	27	0.75	0.95	91.6	62.8	0.73	68.9

[1]CV = coefficient of variation of a set of clipping weights used to obtain the model y = a + bx.
[2]CV = coefficient of variation after adjusting regression line through the origin.

Table 3. Mean live phytomass (oven dry weight of "live" growth = browse) per plant estimated via the reference unit method compared with values derived directly via clipping ands stripping of "live" growth. (To obtain g/m^2, multiply means by densities from Table 1).

Area	Sample size n	Plant Reference Unit Estimated: Mean	St. Dev.	t	Relative Difference[1]	Clipped and Stripped: Mean	St. Dev.
RF	109	9.0	9.91	0.09	−0.013	9.12	10.25
LF	106	5.40	2.91	1.0	−0.082	5.88	4.95
BLM	120	3.58	2.68	0.1	+0.026	3.49	2.75

[1]Relative differences = estimated − clipped/clipped mean plant weights.

plots, are presented in Table 1.

Ten 1-m^2 microplots, divided among 3 areas (Table 2), were randomly selected for comparison of reference unit based and direct harvest based estimates of browsed weights. The results of the direct harvest were considered the "true," actual or control values. A shrub branch (reference unit) of approximately 30–100% of the total aboveground weight of an average shrub was clipped close by the outer perimeter of the macroplots. The live tissue of each shrub within the plot was then ocularly estimated to the nearest 1% of its relative weight compared to the reference unit.

One-third of the microplots in each area were sampled in sequence before second and third rounds of the areas were completed. This was done so as to minimize the possibility that there was any growth of plants during the intervening period.

All field sampling was done during the month of August 1982, after all aboveground growth for the season had occurred and the majority of the ephemeral leaves had been lost (West and Gasto 1978). There is thus little possibility of growth having occurred within the sampling period.

Foliage wilting that occurs with hand-held samples during summer may introduce bias, thus reference units were replaced regularly and sampling took place only during short periods in early morning and late afternoon. Sampling during mid-day hours was avoided to minimize wilting effects on the reference unit.

Following the estimation of reference units, every shrub with more than one-half of its root crown within the plot was cut at ground level, labelled, individually bagged and oven-dried at 75°C for 72 hours. What had been live tissues (mainly leaves and twigs) were separated in the lab from woody and presumed dead and nonbrowse portions of the 335 plants included in the total sample.

Least squares linear regression fits of the relationship of estimated (y) to actual weights (x) were calculated using the formula:

$$y = a + bx$$

where both unconstrained values are allowed to emerge and where a = 0; that is, a zero intercept was forced. The latter was done because negative weight estimates make no biological sense.

The assumption of homogeneity of the variances between the 3 areas and normality of density and phytomass data were checked by the Bartlett and Chi-square tests, respectively.

Results and Discussion

The anticipated differences in mean plant density, average canopy volume, and weight, among the 3 areas were confirmed (Table 1). Although plant densities were quite similar, the BLM area had the most plants; but they were much smaller, as reflected in lower average volume, cover, and weight, on both a per plant and per unit area basis (Table 1). Mean plant volume for the RF exclosure was more than 3 times larger than the mean plant volume for the BLM area (Table 1). Mean plant weight was almost 3 times as great on the RF compared to the BLM area. Intermediate values for most variables were found in the LF area (Table 1).

Variance smoothed out after 22 plots had been included in the calculations of running mean density. A total of 10 1-m^2 plots yielded smooth running means of either clipped or reference unit-based estimates of phytomass.

Log-transformed values of individual live plant phytomass were quite close to normal and variance in log-transformed weights of plot totals were homogeneous among sample areas (Cabral 1983).

The reference unit method took marginally less time [field time 0.6 (0.2 standard error of mean) minutes per plant] than clipping [field time 0.7 (0.1 standard error of mean) min.]. But, to this must be added the greater total time to strip live growth from the plants on an entire plot as contrasted to the few plants needed as reference units. It took a mean of 2.4 min (0.2 standard error of mean) to separate the live portions from a shrub.

We noted some tendency of the reference unit method to overestimate the weight of smaller plants; however, the high r^2 values in Table 2 indicate how consistent the estimates were, even without being forced through the origin.

Use of r^2 is not legitimate in the case of regressions forced through the origin (Ahmed et al. 1983). Accordingly, coefficients of variation are required to compare the reliability of the 2 forms of the regression equation. As expected, variation was always somewhat higher when the line is forced through the origin (Table 2). The increase is, however, not excessive and avoidance of predicting negative phytomass values for small plants is biologically more rational.

Estimates of the mean browse weight per plant using the reference unit and clipping methods were compared (Table 3). No significant differences (α=0.05) between mean browse weights per plant obtained by clipping or reference unit estimates were noted within areas. This was presumably because quite precise and accurate phytomass estimates were obtained from the reference unit method (Table 3). We also noted only slight differences in the magnitude of the relative differences in plots with differing grazing histories (Table 3). Thus, with respect to precision, accuracy and efficiency, the reference unit method was very acceptable. The only major shortcoming is the mental fatigue which can occur after several hours of making reference unit estimates. We have found in subsequent use of this method that the wilting phenomenon can be overcome by wrapping the base of the reference unit with wet paper surrounded by polyethylene wrap. This allows readings to be made throughout the day without wilting or need to change reference units.

By use of hand-held scales, a field worker could quickly validate the accuracy and precision of his estimates of fresh weights. If a reasonably constant conversion factor for wet to dry weight exists (Sharif and West 1968), total phytomass could be rather easily and reliably estimated on rangelands dominated by one or a few species. One, of course could also use this method to estimate the browse on any selected portion of a key species in a mixed stand. If no confidence limits are required, and linear fits occur, or are forced through zero, then raw data can be accumulated in the field and converted to forage weight directly.

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Book Reviews

Wildlife Ecology and Management. William L. Robinson and Eric G. Bolin. 1984. Macmillan Publishing Company, 866 Third Avenue, New York, NY 10022. 487 p. $23.95 (cloth)

Robinson and Bolin claim, "The purpose of this book is to introduce students to the science of wildlife management. We hope our audience includes nonmajors as well as students beginning a formal curriculum in wildlife management." The authors have covered the entire range of wildlife topics and "linked principles of ecology with their application toward managing wildlife populations and their habitats." There are more than 1,600 references to the wildlife literature listed at the end of the book.

Several of the figures poorly illustrate the material described in the caption. Figure 18-6 (page 369) is a full page illustration of the breeding and winter range of the kirtland's warbler. These attributes are only poorly defined, and the nesting area is almost invisible.

There are also statements of questionable validity. For example, on page 231 the authors state, "The botfly larvae mature and leave their hosts as fully winged adults." From the information I located, the mature larvae drop to the ground and pupate before developing into fully winged adults. Other similar errors are quite common.

Some statements are not substantiated by citations and some border on anthropomorphizing. There are some punctuation problems—mostly omissions of punctuation needed for clarity. Finally, there are several printing or spelling errors. These technical errors may appear to be relatively minor. But, the question they raise is: How many other errors exist? Such errors taint the overall accuracy of a text that was especially prepared to introduce students to the science of wildlife management.

Further, I believe the authors failed in their objective to make each chapter an independent unit. There are several cross-references to related chapters, which makes them difficult to locate.

Being a range scientist, I was most interested in Chapter 10, "Wildlife and Rangelands." But the discussion of rangelands, especially grazing and plant physiology, grazing systems, and the significance and measurement of residual vegetation following grazing, is confusing and misleading. Rangelands are treated primarily as wildlife habitat without considering that range management activities are a dynamic force directed at producing livestock and not necessarily wildlife. This approach placed the wildlife biologist in an adversary position when he should be seeking a compromise that will benefit wildlife. Unfortunately, Robinson and Bolin also placed wildlife habitat management in a conflict role with farming and forestry.

The cumbersome writing style, technical errors, and oversights detract from the educational value of the text.—**H. Reed Sanderson**, Range Scientist and Certified Wildlife Biologist, USDA Forest Service, Forestry and Range Sciences Laboratory, La Grande, Oregon.

Soil Erosion and Conservation. Edited by S.A. El-swaify, W.C. Moldenhauer, and Andrew Lo. 1985. Published by the Soil Conservation Society of America, Ankeny, Iowa 50021. 793 pages, illustrated.

This volume is based on the third International Conference on soil erosion and conservation held January 16–22, 1983, in Honolulu, Hawaii. It is a follow up of the first two conferences held at Ghent, Belgium, in 1978 and Silsoe, England, in 1980.

The 125 papers are grouped under four emphasized themes:

1. Delineating sediment sources and their magnitude (erosion inventory).
2. Determining the impacts of sedimentation on productivity and the environment (erosion impacts).
3. Establishing values for erosion causing parameters (erosion prediction and control).
4. Creating networks for implementing soil and water conservation programs.

About half the papers, 62, were presented by representatives from 17 U.S. States and Canada, the remainder from 25 other countries. India, Indiana, Australia, and Hawaii were each represented by seven or more articles.

Soil erosion is finally being recognized as a world-wide problem on all continents, from wind erosion in dry areas to rainfall in the tropics and soil losses under irrigation. Soil and water losses are well documented under widely differing soil, climatic, and cropping conditions.

Many discussions include the extended uses as well as the strengths and weaknesses of the universal soil loss equation (USLE). It was described as, "a most useful intellectual coat hanger for erosion factors." It is being adopted for use in situations different from those under which it was developed.

Some interesting attempts are made to assess long term productivity losses due to soil erosion including a model for simulating erosion, crop production, and related processes.

Modelling is also adapted to incentive payments for soil conservations, sediment yield, splash detachment, etc.

Each chapter concludes with an adequate list of references and two final papers given an excellent summary of the conference.

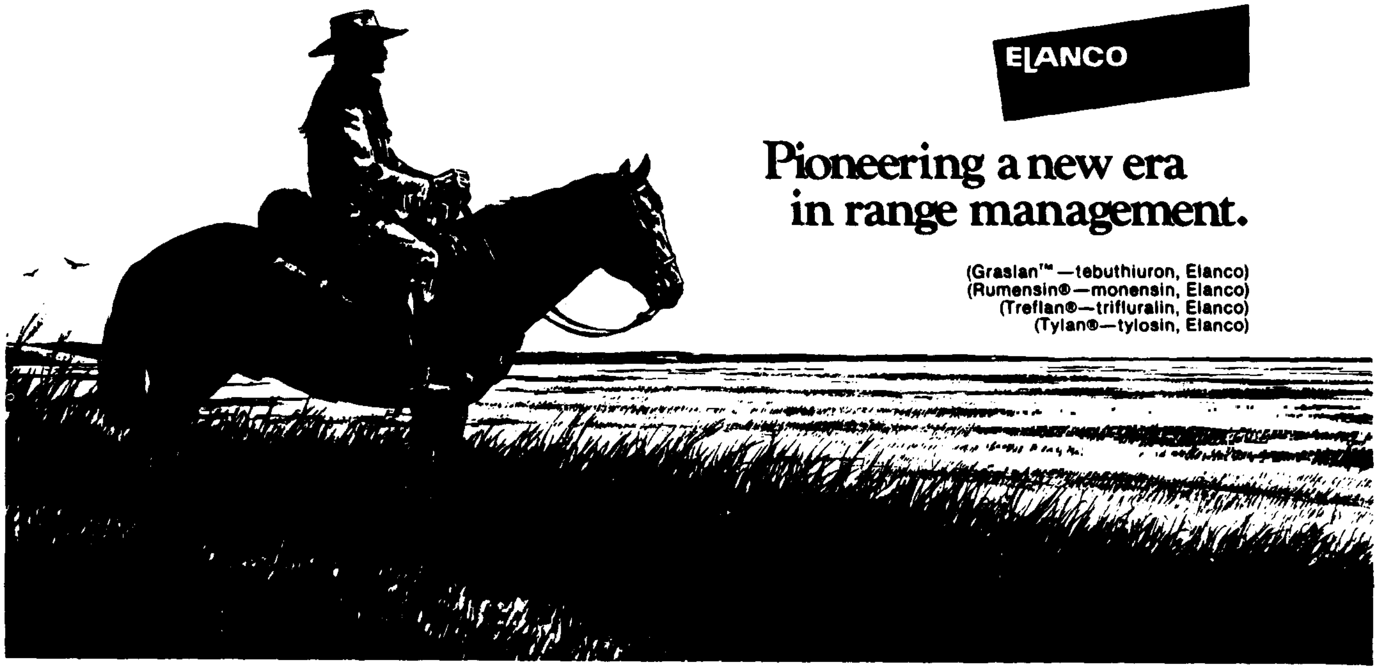
Plans were made to hold the next conference of the International Soil Conservation Organization at Maracay, Venezuela, in 1985.

This conference report will be most useful as a reference for soil conservationists interested in keeping informed on world-wide progress practices and policies.—**John L. Schwendiman**, Pullman, Washington.

Plants of the Kimberly Region of Western Australia. 1985 (in U.S.) R.V. Patheram & B. Kok. Photography E. Bartlett-Torr. University of Western Australia Press (U.S.-International Scholarly Book Service, P.O. Box 1632, Beaverton, OR 97075) 556p. $35 paper.

This might be considered a modernized version of the old (1937) U.S. Range Plant Handbook, for plants of northwestern Australia. Excellent full page color photographs are presented for each species, along with general description, occurrence, and forage, or other value. Species are arranged as forbs, shrubs, and trees (i.e. ground storey, middle storey, upper storey). Botanical and common names are provided with each of the 242 color plates. Lists of common names paired with appropriate taxonomic nomenclature are given at the beginning of each section. Photo insets of inflorescences are provided for many of the species. A brief description of the physical and biological features and range management principles precedes the body of photographs. Five appendices cover (1) basis for species selection, (2) photographic specifications and suggestions, (3) references, (4) floral parts and arrangements, and (5) glossary.

The book is written to be comprehended by the layman, but is technically accurate and is a useful source of information for interested persons at all levels.—**Ed.**



First call for Papers
1987 SRM Convention
Boise, Idaho

Titles are now being solicited for papers to be presented at the 40th Annual Meeting of the Society for Range Management, February 9-12, 1987. Please complete the following form (one form per title) and **submit to the program Chairman by June 1:**

Proposed title: ____________________

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Author(s): ____________________

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Brief summary ____________________

____

____

____

____

Type of presentation: Traditional Poster

Author who will handle correspondence:

Name ____________________

Mailing address ____________________

Telephone ____________________

Mail your completed proposal form to Dr. H.F. Mayland, USDA - ARS, Kimberly, ID 83341. Once your proposal is accepted, we will send forms and instructions for preparing your abstract. DEADLINE FOR ABSTRACTS IS AUGUST 1, 1986. Authors will be notified of acceptance or rejection by mid—September.

Presentations must be planned to conform to 12 minutes in duration. Visuals must be standard 2 × 2 slides. The presenting author is expected to be a paid-up member of SRM. Others may present papers/posters but will be charged an extra nonmember, registration fee.

Remember! Deadline for titles is June 1, 1986!