

# Journal of Range Management

Publication  
of the  
Society for  
Range Management



The Trail Boss

## **TABLE OF CONTENTS: Vol. 44, No. 1, January 1991**

### **ARTICLES**

#### *Animal Ecology*

- 2 Summer habitat use and activity patterns of domestic sheep on coniferous forest range in southern Norway** by Jerry T. Warren and Ivar Myserud

#### *Hydrology*

- 7 Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta** by M.A. Naeth, A.W. Bailey, D.J. Pluth, D.S. Chanasyk, and R.T. Hardin
- 13 Water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta** by M.A. Naeth, A.W. Bailey, D.S. Chanasyk, and D.J. Pluth
- 18 Applicability of the Kostikov equation to mixed prairie and fescue grasslands of Alberta** by M.A. Naeth, D.S. Chanasyk, and A.W. Bailey

#### *Plant/Animal Interaction*

- 22 Response of tap- and creeping-rooted alfalfas to defoliation patterns** by Abdalla O. Gdara, Richard H. Hart, and John G. Dean

#### *Plant Physiology*

- 27 Competition between cheatgrass and two native species after fire: Implications from observations and measurements of root distribution** by Graciela Melgoza and Robert S. Nowak
- 34 Substrate relations for rillscale [*Atriplex suckleyi*] on bentonite mine spoil** by M.E. Voorhees, D.W. Uresk, and M.J. Trlica

#### *Economics*

- 38 Economically optimal private land grazing strategies for the Blue Mountains of eastern Oregon** by Thomas M. Quigley, John A. Tanaka, H. Reed Sanderson, and Arthur R. Tiedemann
- 43 Economic evaluation of spotted knapweed [*Centaurea maculosa*] control using picloram** by Duane Griffith and John R. Lacey

#### *Improvements*

- 48 Blue grama response to Zn source and rates** by E.M. White
- 52 Control of honey mesquite with clopyralid, triclopyr, or clopyralid:triclopyr mixtures** by Rodney W. Bovey and Steven G. Whisenant
- 56 Late season control of honey mesquite with clopyralid** by P.W. Jacoby, R.J. Ansley, and C.H. Meadors

INDIVIDUAL SUBSCRIPTION is by membership in  
the Society for Range Management.

LIBRARY or other INSTITUTIONAL SUBSCRIP-  
TIONS on a calendar year basis are \$56.00 for the  
United States postpaid and \$66.00 for other coun-  
tries, postpaid. Payment from outside the United  
States should be remitted in US dollars by interna-  
tional money order or draft on a New York bank.

BUSINESS CORRESPONDENCE, concerning sub-  
scriptions, advertising, reprints, back issues, and  
related matters, should be addressed to the Manag-  
ing Editor, 1839 York Street, Denver, Colorado  
80206.

EDITORIAL CORRESPONDENCE, concerning manu-  
scripts or other editorial matters, should be addressed  
to the Editor, Gary Frasier, USDA-ARS, Crops  
Research Laboratory, 1701 Center Ave., 1701 Cen-  
ter Ave., Fort Collins, Colorado 80526. Page proofs  
should be returned to the Production Editor, 1839  
York Street, Denver, Colorado 80206.

INSTRUCTIONS FOR AUTHORS appear on the  
inside back cover of most issues. A Style Manual is  
also available from the Society for Range Manage-  
ment at the above address @\$2.00 for single copies;  
\$1.25 each for 2 or more.

THE JOURNAL OF RANGE MANAGEMENT (ISSN  
0022-409X) is published six times yearly for \$56.00  
per year by the Society for Range Management,  
1839 York Street, Denver, Colorado 80206.  
SECOND CLASS POSTAGE paid at Denver, Colorado.

**POSTMASTER: Return entire journal with address  
change—RETURN POSTAGE GUARANTEED—to**  
Society for Range Management, 1839 York Street,  
Denver, Colorado 80206.

#### **Managing Editor**

PETER V. JACKSON III  
1839 York Street  
Denver, Colorado 80206

#### **Editor**

GARY FRASIER  
USDA-ARS  
Crops Research Laboratory  
1701 Center Ave  
Fort Collins, Colorado 80526

#### **Production Editor**

PATRICIA G. SMITH  
Society for Range Management  
1839 York Street  
Denver, Colorado 80206  
(303) 355-7070

#### **Book Review Editor**

DAVID SCARNECCHIA  
Forestry and Range Management  
Washington State University  
Pullman, Washington 99164-6410

#### **ASSOCIATE EDITORS**

DON C. ADAMS  
University of Nebraska-Lincoln  
Institute of Agriculture and  
Natural Resources  
West Central Res. and Ext. Center  
Route 4, Box 46A  
North Platte, Nebraska 69101

WILL BLACKBURN  
N.W. Watershed Res. Center  
270 South Orchard  
Boise, Idaho 83705

CARLTON BRITTON  
Range & Wildlife Mgmt  
Texas Tech University  
Lubbock, Texas 79409

DONALD BEDUNAH  
School of Forestry  
University of Montana  
Missoula, Montana 59812

TIMOTHY E. FULBRIGHT  
College of Agriculture  
Texas A&I  
POB 156, Sta. 1  
Kingsville, Texas 78363

RODNEY HEITSCHMIDT  
USDA ARS  
Livestock & Range Research  
Rt 1 Box 3  
Miles City, Montana 59301

JERRY HOLECHEK  
Animal & Range Science  
Dept. 3-1 Box 30003  
New Mexico State University  
Las Cruces, New Mexico 88003-0003

KIRK MCDANIEL  
Dept. of Animal & Range Science  
Box 31  
New Mexico State University  
Las Cruces, New Mexico 88003-0003

BRUCE ROUNDY  
325 Biological Sciences  
East Building, Univ. Arizona  
Tucson, Arizona 85721

ROY STRANG  
British Columbia Inst. of Tech.  
3700 Willingdon Ave.  
Burnaby, British Columbia  
CANADA V5G 3H2

DAVID M. SWIFT  
Natural Resources Ecology  
Colorado State University  
Ft. Collins, Colorado 80523

PAUL TUELLER  
Range Wildlife & Forestry  
UNR 1000 Valley Road  
Reno, Nevada 89512

- 59 Willow planting success as influenced by site factors and cattle grazing in  
northeastern California** by Scott D. Conroy and Tony J. Svejcar
- 64 Biomass productivity and range condition on range sites in southern  
Arizona** by William E. Frost and E. Lamar Smith

#### *Plant Ecology*

- 68 Effects of competition on spatial distribution of roots of blue grama** by  
Debra P. Coffin and William K. Lauenroth
- 72 Seedstalk production of mountain big sagebrush enhanced through short-  
term protection from heavy browsing** by Fred J. Wagstaff and Bruce L.  
Welch
- 75 Influences of temperature and water stress on germination of plains rough  
fescue** by J.T. Romo, P.L. Grilz, C.J. Bubar, and J.A. Young
- 82 Cutting frequency and cutting height effects on rough fescue and Parry oat  
grass yields** by Walter D. Willms
- 86 Some effects of precipitation patterns on mesa dropseed phenology** by  
Robert P. Gibbens

#### TECHNICAL NOTES

- 91 A technique to determine seed location in relation to seedbed preparation  
treatments** by Von K. Winkel and Bruce A. Roundy

#### BOOK REVIEWS

- 93 *Terroirs Pastoraux et Agropastoraux en Zone Tropicale.*** J. Audru, G.  
Boudet, J. Cesar, D. Dulieu, A. Gaston, G. Mandret, P. Merlin, G.  
Rippstein, G. Roberge, and B. Toutain; *Rangelands.* edited by Bruce A.  
Buchanan; *Rangeland Management in Pakistan.* Noor  
Mohammad.



The Trail Boss ®

**President**  
**REX CLEARY**  
Box 16  
Genoa, Nevada 89411

**1st Vice-President**  
**STAN TIXIER**  
2589 North 200 East  
Ogden, Utah 84414

**2nd Vice-President**  
**JOHN L. ARTZ**  
2581 Westville Trail  
Cool, CA 95614

**Executive Vice-President**  
**PETER V. JACKSON, III**  
Society for Range Management  
1839 York Street  
Denver, Colorado 80206  
(303) 355-7070

**Directors**  
**1988-1990**  
**KENDALL L. JOHNSON**  
Dept. of Range Resources  
University of Idaho  
Moscow, Idaho 83843

**ED NELSON**  
Box 206  
Stavely, Alberta  
Canada T0L 1Z0

**1989-1991**  
**CHARLES E. JORDAN**  
P.O. Box 1530  
Rapid City, South Dakota 57709

**PHILLIP L. SIMS**  
Southern Plains Range Research Station  
USDA, ARS  
2000 18th Street  
Woodward, OK 73801

**1990-1992**  
**MURRAY L. ANDERSON**  
26 Glengarry Circle  
Sherwood Park, Alberta  
CANADA T8A 3A2

**WILL H. BLACKBURN**  
NW Watershed Research  
NSDA-ARS  
800 Park Boulevard  
Plaza 4, Suite 105  
Boise, ID 83712

The term of office of all elected officers and directors begins in February of each year during the Society's annual meeting.

**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 properly take care of the basic rangeland resources of soil, plants and water;
- 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.

---

***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. Editorial comment by an individual is also welcome and, subject to acceptance by the editor, will be published as a "Viewpoint."

---

**Contribution Policy:** The Society for Range Management may accept donations of real and/or personal property subject to limitations set forth by State and Federal law. All donations shall be subject to management by the Executive Vice President as directed by the Board of Directors and their discretion in establishing and maintaining trusts, memorials, scholarships or other types of funds. Individual endowments for designated purposes can be established according to Society policies. Gifts, bequests, legacies, devises, or donations not intended for establishing designated endowments will be deposited into the SRM Endowment Fund. Donations or requests for further information on Society policies can be directed to the Society for Range Management, Executive Vice President, 1839 York Street, Denver, CO 80206. We recommend that donors consult Tax Advisors in regard to any tax consideration that may result from any donation.

# Summer habitat use and activity patterns of domestic sheep on coniferous forest range in southern Norway

JERRY T. WARREN AND IVAR MYSTERUD

## Abstract

Eight domestic sheep (*Ovis aries* L.) ewes were fitted with radio collars and tracked during the 1985 grazing season in Trysil, Hedmark County, southern Norway. The ewes were relocated 761 times between 11 June until 13 September. All relocations were used to describe activity patterns, and 565 were plotted and used to estimate habitat use. Range use was initially concentrated on and about areas previously influenced by man (e.g., abandoned homesteads, old fields) and on adjacent stands of rich spruce/fern (*Picea abies* (L.) Karsten)/(*Dryopteris* spp.) forest. This preference was displayed especially during the day; poorer forest types were used more in the evening and at night. As the season progressed, use of the meadow/old-field habitat type declined in favor of the forest types. Activity peaks were at mid-morning and late evening. Animals camped in groups at midday and at night, always further upslope at night than during the day. Sheep were less active in cold, wet weather. Habitat selection and activity patterns observed in this study were similar to those of both wild and domestic sheep studied elsewhere.

**Key Words:** *Ovis aries* L., radiotelemetry, sheep diet, sheep grazing, forest grazing

With their ability to utilize plant biomass in areas unsuitable for cultivation, domestic sheep (*Ovis aries* L.) are economically important in many parts of the world. Their value as a source of meat and wool has led to extensive research into sheep genetics, physiology, and nutrition. However, the activity and utilization patterns of sheep grazing freely on open range and in forests have received less attention (Noble 1975). Many such studies have involved fenced, sown, and fertilized pasture (Hunter 1962, Lynch 1971, De Leeuw and Bakker 1986) and major predators have been absent (Grubb and Jewell 1974, Scott and Sutherland 1981).

In Hedmark county, in southeastern Norway, over 130,000 of the country's 2,300,000 sheep graze unattended (Bergøy 1982). In this region, vast tracts of coniferous forest provide ample forage for the many herds scattered throughout the county. Detailed knowledge of their activity patterns and habitat use in these forested areas is lacking. This lack of data comes at a time when outside interests are pressing for greater development of tourist facilities, and when current management plans call for an increase in native carnivore populations (primarily wolf (*Canis lupus* L.), brown bear (*Ursus arctos* L.), and wolverine (*Gulo gulo* L.)) (Vaag et al. 1986).

Before the impact of larger predator populations and increased human encroachment on sheep grazing can be assessed, analysis of sheep activity patterns, habitat selection, and range use is necessary.

A herd of sheep at Lutnes, Trysil, was followed intensively throughout the 1985 summer grazing season. Results of this work

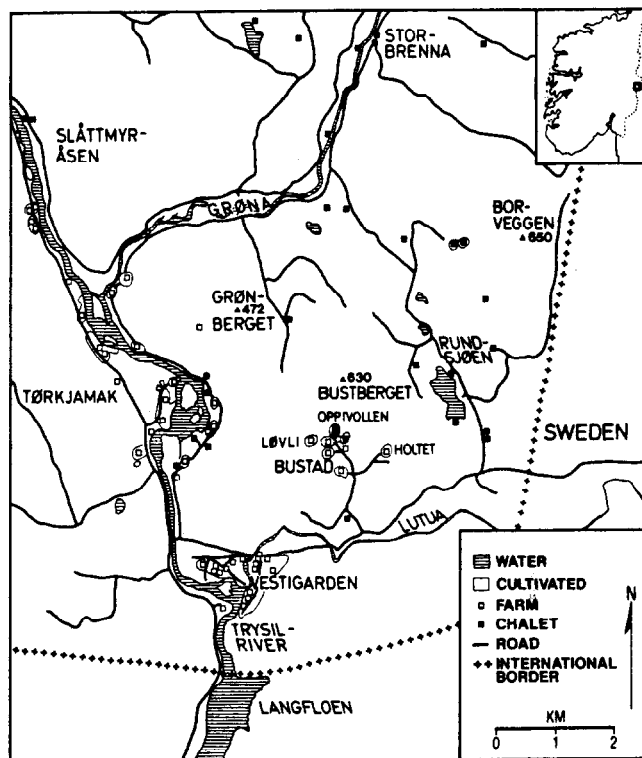


Fig. 1. Study area in Trysil, Hedmark County, Norway.

are presented here.

## Study Area

The study area of approximately 50 km<sup>2</sup> lies in the southeast corner of Trysil, in Hedmark County in southern Norway (Fig. 1). Sheep graze in the area east of the Trysil River, between the Grønå River to the north and the Lutua River to the south. Grazing in Sweden is rare because of extensive bogs just east of the border. The landscape is rolling, with rounded peaks and narrow valleys. Altitude ranges from 300 to 700 m. Topography is locally steep and rocky, with Borveggen (650 m) and Bustad (630 m) the dominant summits. A few small lakes and ponds dot the region. Forested and unforested bogs are common.

Climate in the region is classified as semi-continental with warm summers, cold winters, and no drought period (climate type D<sub>3</sub>, Nordisk ministerraad 1977). Precipitation is heaviest in summer and winter. Winter snow pack can be substantial. Average January and July temperatures at the Plassen weather station, 10 km north of the study area, are -10.1 and +14.4° C, respectively. Average annual precipitation is 716 mm, increasing with altitude (Lystad 1978). Vegetation in the region is primarily boreal coniferous forest. Norway spruce (*Picea abies* (L.) Karsten) and Scots pine (*Pinus sylvestris* L.) are the dominant tree species. Pure stands of

Authors are research assistant and assistant professor, Division of Zoology, Department of Biology, University of Oslo, Box 1050, Blindern, N-0316 Oslo 3.

Funding was provided by the Directorate for Nature Management (DN). The administrative assistance of Arne B. Vaag (DN) is appreciated.

The foreman of the Trysil Sheep and Goat Association, Frank Jacobsen; agronomist Bjarne Vaage; sheep owner Ola Bustad and family; and Koll and Solveig Granli were of great help before, during, and after the season in Trysil. Field assistance by Jon Bekken and Haakon Solvang was of great help. Larry Kirkendall's review of the manuscript was appreciated.

Manuscript accepted 26 April 1990.



spruce and of pine are found on moister, more fertile, and dryer, more infertile sites, respectively. A mixture of the 2 species is most common, however, with pine often dominating mixed stands. Birch (*Betula odorata* Bechst.) may also be well represented in these mixed stands. Other species include aspen (*Populus tremula* L.) and mountain ash (*Sorbus aucuparia* L.).

Understory vegetation varies from heather (*Calluna vulgaris* (L.) Hull)/lichen (*Cladonia* spp.) in the dry, infertile pine stands, to blueberry (*Vaccinium myrtillus* L.)/fern (*Dryopteris* spp.) in the richer spruce stands. In the mixed stands, understory vegetation is variable, consisting mainly of blueberry, heather, and hairgrass (*Deschampsia flexuosa* (L.) Trin.).

The Lutnes area along the Trysil River was first settled in the late 1600s by Finnish immigrants. Cultivation and livestock grazing were subsequently begun on the south slope of Bustberget, as this higher-lying area was less subject to early frosts. Human activity on Bustberget increased steadily for more than 200 years. By the early 1900s, 3 farms and 6 small holdings (crofts) dotted Bustberget. Today, many of these are abandoned, with just 5 houses still inhabited. None of these graze livestock, and cultivation is minimal. Timber harvesting and sheep grazing (the study herd from Vestigarden) are the only major activities on Bustberget today.

On some sites, holdings established and abandoned between 1700–1950 have been invaded by the surrounding forest. Tracts that were once open meadows and gardens are now covered with birch and spruce. Other once-cultivated areas have been reforested with spruce and pine since 1950. Regardless of the source of the prevailing overstory vegetation (by invasion or planting), the area's use from 1700–1950 is still reflected by the understory.

### Materials and Methods

On 8 June 1985, 8 ewes in the Lutnes herd were selected from a total of 112 ewes which were accompanied by 193 lambs; selection was designed to reflect roughly flock composition with regard to ewe breed and age. Each ewe was fitted with a motion-sensing radio collar (model TX-IC-2 SMA\*142, Televilt of Sweden) weighing about 150 g. The transmitters operate on a frequency of 142 MHz with a maximum output of 3 mW. A separation of 10 KHz between each transmitter allows easy identification of individuals by frequency.

The collared ewes, along with most of the remaining flock, were driven on foot from the farm Vestigarden to Løvli on Bustberget, a distance of about 4 km. The remainder of the flock, about 40 animals, were driven by truck to Borveggen, an area 5 km northeast of Løvli (Fig. 1). On Bustberget and Borveggen the sheep were left to graze freely throughout the remainder of the summer.

Radio tracking was done on foot beginning 11 June. A portable receiver (Televilt RX-81) was used with a hand-held 4 element Yagi antenna. This system was tested on sheep in Trysil in 1984 with good results (Myserud et al. 1985). Initially, animals were located every 36 hours; 1000 the first day, 2200 the second, and not at all on the third day. After about 2 weeks, experience gained with the equipment, topography, and the flock allowed tracking frequency to be increased. It also became clear that the original tracking strategy was inadequate. A realistic description of the animals' habitat use and activity patterns was not being provided by the original tracking schedule.

Four new times—0600, 1400, 1800, and 0200—in addition to the original times, 1000 and 2200, were used. Animals were located every 28 hours; 0600 the first day, 1000 the second, 1400 on the third, and so on. On the seventh day the tracking cycle began again from 0600.

Ewes were located primarily by triangulation (Cochran 1980). Several limitations associated with the triangulation procedure

have been described (Springer 1979, Garrett et al. 1986, Schober 1986). Relocation accuracy depends upon the number and accuracy of receiving stations, and the distance between the transmitter and receiver (White 1985). Animals were relocated using 2–3 bearings. Since sheep are easily approached, most bearings were taken <250 meters from the collared animals.

Direct observations of collared animals were also common. Only direct observations and locations that resulted from a triangulation angle of 35–145° (Litvaitis et al. 1986) were plotted. These observations were plotted on a 1:5000 economic map. An 8-digit UTM (Universal Transverse Mercator) coordinate was assigned each location (Østbye 1971).

Tracking ended 13 September, when the flock was herded and returned to Lutnes.

Site classification was recorded for each observation. This was read directly from the 1:5000 economic map of the study area. Readings were related to habitat type as shown in Table 1.

**Table 1. Habitat type as related to site classification. (Devised from Landskogstakseringen 1961, Fremstad and Elven 1987).**

Site classification <sup>1</sup>	Habitat types in this study	Vegetation types <sup>2</sup>
Highly productive coniferous forest	<i>Picea abies</i> / <i>Dryopteris</i> spp.	Large-herb spruce forests Small herb spruce forest Large fern spruce forest Small fern spruce forest
Middling productive coniferous forest	<i>Picea abies</i> / <i>Vaccinium myrtillus</i>	Blueberry spruce-forest Berry/shrub mixed forest
Lesser productive coniferous forest	<i>Pinus sylvestris</i> / <i>Calluna vulgaris</i> / <i>Cladonia</i> spp.	Heather-, lichen-rich pine forest
Fully/lightly cultivated land	Meadow/old-field	Cleared pasture on small fern spruce sites Abandoned meadow/old-field (calcium poor)

<sup>1</sup>From 1:5000 economic map.

<sup>2</sup>After Fremstad and Elven 1987.

Availability of habitat types was calculated by placing a 1,050-point grid over a map of the area and systematically recording habitat type at each point on the grid. This tally is assumed to give an adequate estimate of the relative proportion of the types available (Myserud 1983). A chi-square test of homogeneity was used to compare type use to type availability.

A motion switch which changed the pulse rate of the transmitter when an animal was either active or inactive was incorporated into each transmitter. An active animal is indicated by a slow pulse rate; an inactive animal by a rapid pulse rate. Collared animals were often observed directly, as well as located by telemetry. When observed, a more detailed description of their activity was recorded. Since determination of animal activity/inactivity did not depend upon accurate triangulation, all 761 relocations could be used to describe activity patterns.

The relationship of warm/cool weather to activity/inactivity was tested using a 2 × 2 contingency table.

### Results

#### Habitat Preference

The 8 sheep frequented all 4 of the study area's habitat types. Habitat use was not in proportion to habitat availability, however ( $P < 0.01$ ). Use of the richer meadow/old-field and spruce/fern types was proportionally greater than availability. The common spruce/blueberry type and the poorer pine/heather/lichen type were used proportionally less than availability (Table 2).

**Table 2. Availability and use of each habitat type in the Lutnes study area, southern Norway.**

Habitat type <sup>1</sup>	Availability (%)	Use (%)
<i>Picea abies</i> / <i>Dryopteris</i> spp.	19.1	32.8
<i>P. abies</i> / <i>Vaccinium myrtillus</i>	70.5	51.0
<i>Pinus sylvestris</i> / <i>Calluna vulgaris</i> / <i>Cladonia</i> spp.	5.8	4.5
Meadow/old-field	4.1	11.6

<sup>1</sup>Habitat types are described in Table 1.

Habitat use varied significantly with time of day ( $P < 0.01$ ). Use of meadow/old-field and spruce/fern habitat types occurred primarily during morning and early afternoon. Of a total of 255 relocations falling within these 2 types, 167 (65%) were recorded between 0600 and 1400. In contrast, 88 (35%) were recorded between 1800 and 0200.

While the richer types were preferred during the day, the more common spruce/blueberry and the poorer pine/heather/lichen types were preferred in the evening and at night. Of a total of 310 relocations falling within these 2 types, 206 (66%) were recorded between 1800 and 0200. One hundred and four (34%) were recorded between 0600 and 1400 (Table 3).

**Table 3. Number (percent)<sup>1</sup> of relocations in each habitat type by time of day (TOD) in the Lutnes study area, southern Norway.**

TOD	Habitat type <sup>2</sup>				Total
	<i>Picea abies</i> / <i>Dryopteris</i> spp.	<i>P. abies</i> / <i>Vaccinium</i> sp.	<i>Pinus sylvestris</i> / <i>Calluna</i> sp., <i>Cladonia</i> spp.	Meadow/ Old-field	
0200	6 (13.3)	29 (64.4)	8 (17.7)	2 (4.4)	45
0600	8 (16.0)	35 (70.0)	3 (6.0)	4 (8.0)	50
1000	89 (50.2)	43 (24.2)	3 (1.6)	42 (23.7)	177
1400	13 (29.5)	20 (45.4)	0 (0.0)	11 (25.0)	44
1800	19 (47.5)	17 (42.6)	2 (5.0)	2 (5.0)	40
2200	54 (25.8)	140 (66.9)	10 (4.7)	5 (2.3)	209
Total	189	284	26	66	565

<sup>1</sup>Number of relocations in habitat type *h* at TOD *t*/Total number of relocations obtained at TOD *t*.

<sup>2</sup>Habitat types are given in Table 1.

Habitat preference varied significantly as the grazing season progressed ( $P < 0.01$ ) (Table 4). Use of the meadow/old-field habitat type declined from the beginning of the season to the end. Thirty-two of the 66 relocations (48%) falling within this type were obtained during the first 1/3 of the season. Only 10 relocations (15%) fell within this type in the final 1/3 of the season. Use of the 3 forest types, which accounted for 95% of the available habitat, contrasted sharply to this. In the first 1/3 of the season they contained 70% (24) of the 106 relocations; in the final 1/3, this had increased to 96% (247 of 257 relocations).

### Activity Patterns

Sheep activity on Bustberget was rhythmic and consistent. Grazing began around sunrise and continued until midday. Activity started on and about the campsite used the previous night. From this starting point, movement was not random, but directed downslope. Sub-flocks grazed hurriedly and sporadically, often trotting or running downslope 10–50 meters only to stop suddenly and begin grazing again. Of 289 relocations obtained between 0600 and 1000, 201 (70%) were noted as active.

**Table 4. Number (percent)<sup>1</sup> of relocations in each habitat type obtained in the beginning, middle, and end of the grazing season, in the Lutnes study area, southern Norway.**

Period	Habitat type <sup>2</sup>				Total
	<i>Picea abies</i> / <i>Dryopteris</i> spp.	<i>P. abies</i> / <i>Vaccinium</i> sp.	<i>Pinus sylvestris</i> / <i>Calluna</i> sp., <i>Cladonia</i> spp.	Meadow/ Old-field	
11.06–10.07	35 (33.0)	34 (32.1)	5 (4.7)	32 (30.2)	106
11.07–10.08	51 (25.2)	121 (60.0)	6 (3.0)	24 (11.9)	202
11.08–13.09	103 (40.1)	129 (50.2)	15 (5.8)	10 (3.9)	257
Total	189	284	26	66	565

<sup>1</sup>Number of relocations in habitat *h* during period *p*/Total number of relocations obtained during period *p*.

<sup>2</sup>Habitat types are given in Table 1.

Most of the flock was inactive for 2–5 hours in the middle of the day. Sheep lay idle until mid-afternoon, often gathered in large flocks and lying tightly huddled. This time was also spent ruminating.

Grazing began again around mid-afternoon—gradually at first, with only a few individuals grazing. Within a short time all were active. A total of 60 relocations were made at 1400. Of these, 40 (67%) were recorded as active. By 1800 this had increased to 98% (49 of 50 relocations).

Movement in the afternoon was directed upslope. This movement was more gradual than that of the morning. Flocks dispersed during the course of the evening, but often gathered again in groups of 5 to 20 at the night's campsite. Here, animals grazed until just after sunset. By nightfall most of the sheep were bedded down for the night. Fifty-two percent (155 of 299) of the relocations from 2200 were recorded as active. At 0200, only 1 of 64 (<2%) relocations indicated an active animal.

Night camping was in groups, though these groups were more loosely assembled than those formed at midday. Huddling was not observed. Little night time activity was noted. This daily cycle continued throughout the season, though it was affected by both weather conditions and day length. Cold or wet weather, defined as a temperature at observation time of  $<10^{\circ}\text{C}$ , and/or rainy or foggy conditions, significantly reduced the herd's overall activity level ( $P < 0.01$ ). Under such conditions, 52% (171 of 327) of the signals received indicated an inactive animal. This is compared to 33% (144 of 434) received under dryer conditions.

After 23 June, the days became shorter. This delayed the starting point in the morning and made for earlier camping in the evening.

## Discussion

### Habitat Preference

A relatively stable diel pattern of habitat use was established early in the grazing season. Use of the culturally modified areas and the adjacent spruce/fern forest type was most common during the day, while the poorer forest types were utilized more in the evening and at night. The largest congregations of sheep were observed at midday at Løvli. However, modified areas such as Løvli, were seldom, if ever, used as a campsite at night. Similar behavior in sheep has been noted elsewhere (Hewson and Wilson 1979, Scott and Sutherland 1981). Pratt et al. (1986) observed that both cattle and ponies displayed a diel redistribution from more open grasslands during the day to denser woodland at night. They suggested this to be shelter-seeking behavior, as it was more pronounced with extreme weather conditions. Welch (1981) also reported diel movement by sheep, from richer grassland to the coarser heather.

The daily migration of sheep (and other livestock) is perhaps best described in terms of structural rather than vegetational preference. Sheep's preference for higher-lying ground at night is well documented (Bowns 1971, Arnold and Dudzinski 1978, Scott and Sutherland 1981, Welch 1981). This preference was consistently displayed in Trysil, where sheep typically camped on high, open ridges. It is doubtful that this uphill movement was in response to nutritional needs. Richer meadow vegetation and salt were located downslope from the usual campsites.

Higher altitudes may provide other advantages at night. Biting insects are more numerous in the dense, calm forest stands. Insect pests may be effectively evaded by moving to open breezy ridges. Uphill movement may also be a behavioral mechanism used for predator avoidance (Martin 1963). Though predation was not noted in this study, losses to bears in this region are prevalent (Mysterud and Warren unpublished). The open, high-lying campsites in Trysil afforded a wide view of the surrounding terrain. Evening breezes may also have provided the bedded sheep with olfactory information about their surroundings. High, open areas may therefore offer the safest bedding sites. The notion that uphill movements serve as an anti-predator strategy has been questioned (Hewson and Verkaik 1981). In Scotland, Hewson and Wilson (1979) stated that the vegetation found higher up on the hill consisted of 'birch trees and scrub [that] gave better cover to foxes.' This behavioral trait may, however, be a remnant from wild sheep. An affinity for camping and bedding sites on high, relatively inaccessible ground with good visibility is common among bighorn sheep (*Ovis canadensis* Shaw) (Woolf et al. 1970, Simmons 1980, Gionfriddo and Krausman 1986). If such behavior in modern domestic sheep is a remnant from ancestral forms, it may well conflict with present-day conditions in Scotland.

Preference for the culturally influenced meadow/old-field type was predominant in the beginning of the season. Decades of cultivation on sites chosen because of their fertility, favorable exposure, and drainage has certainly enhanced production of highly palatable forage plants. Similar observations were made in Wales by Hughes et al. (1975). Here, the highest concentrations of sheep were consistently found '... on land affected by man from an earlier period.'

Use of this habitat type declined in favor of the forest types as the season progressed. Snow retreats first from open sites, thus allowing the growing season to commence several days (or even weeks) earlier than in denser forest stands. As forage plants in the openings mature, their fiber content increases and nutritional value declines. Many of the same preferred forage species are found on the forested sites, but at an earlier stage of development. Sheep likely followed a phenological gradient, from open sites early in the season, into the denser forest as the season progressed, in order to locate preferred forage plants and maximize nutrient intake.

The increased use of the forest types as the season progressed may have been prompted by an increased avoidance of the meadow/old-field type in addition to an increased preference for the forest. The heavy use of the meadow/old-field sites at the beginning of the season led to their early contamination with excrement. Sheep are known to avoid contaminated forage (Hulet et al. 1975). At some point in the first half of the grazing season, some contamination threshold may have been reached, causing the herd to shun this previously favored type. In the chi-square calculations, the negative use of the meadow/old-field type at the end of the season was surpassed only by the strong preference of this type early in the season.

Use of the pine/heather/lichen type was also observed, but to a lesser extent than was use of the richer areas. The attraction to such areas may be related to the distribution and development of fungi. The utilization of fungi by livestock is apparently common. Bjug-

stad and Dalrymple (1968) found that cattle used otherwise non-preferred habitats in search of fungi. Syrjälä-Qvist (1986) found fungi to contain the highest percent of crude protein of all forage species tested. Crude protein in fungi was more than double that in hairgrass. Little is known about the relative importance of fungi in the sheep's diet, though they are recognized as a seasonally important component in that of deer (*Odocoileus* spp.) (Miller and Halls 1969, Crawford 1982) and cattle (Bjugsstad and Dalrymple 1968). It is possible that areas generally viewed as very poor sheep range can in fact contribute significantly to the animal's diet.

Temperature and precipitation greatly influence vegetation growth and production. The summer of 1985 was exceptionally rainy and cool. Precipitation was nearly double the normal in many parts of Trysil. The unusual weather likely affected the study area's vegetation by delaying development and preventing or delaying the drying out of exposed areas. Such weather would also favor fungi production. How habitat use deviated in 1985 from that of a "normal" year is unknown. The general patterns observed in Trysil are, however, similar to those observed elsewhere in the region (Ola Bustad per comm., Mysterud and Warren 1987).

### Activity and Movements

The cyclic activity pattern displayed by the Bustberget herd is typical for both wild and domestic sheep. From the Stone's sheep (*Ovis dalli stonei* Allen) and desert bighorn in North America, to domestic breeds in New Zealand, Australia, and Great Britain, the same daily cycle is displayed (Lynch 1971, Simmons 1980, Scott and Sutherland 1981, Welch 1981, Seip and Bunnell 1985).

In this study, it was not only the basic activity pattern that was typical. Observations made in Trysil were comparable, in detail, to studies done elsewhere. Bowns (1971), working with purebred Ramboulet, Targhee, and Columbia sheep in USA, described the same behavior as observed in Trysil. In his study, sheep travelled further, and in a shorter period of time, in the morning than in the evening; morning grazing was more sporadic. Moreover, movements from the campsite and from the midday bedding site were not random, but consistently directed downslope and upslope, respectively. Also, as observed in Trysil, Bowns' sheep 'reached the bedgrounds before they were ready to bed down. . . They spent this time feeding.'

As no predation was noted in this study, it is not known how the cyclic activity pattern may be affected by the presence of large predators. However, the predictable activity exhibited by the sheep would likely make them highly susceptible to predation, since an intelligent predator would quickly learn and take advantage of the seemingly consistent pattern.

The 8 ewes monitored in this study were less active in chilly, damp weather. With the transmitters used here, detailed description of sheep activity was not possible. More detailed time-budget studies elsewhere have shown that most "activity" is grazing (Grubb and Jewell 1974; Arnold and Dudzinski 1978, Scott and Sutherland 1981). The many direct observations made in Trysil support this. There was no basis on which to judge animal performance in this study. It is therefore impossible to say how a possible reduction in grazing time may have affected performance.

### Literature Cited

- Arnold, G.W., and M.L. Dudzinski. 1978. Ethology of free-ranging domestic animals. Elsevier Publ., Amsterdam.
- Bergøy, O. 1982. Development and Goal-setting, p. 11-35. In: O. Bergøy (ed), Sheep husbandry in the future. (In Norwegian). Landbruksforlaget, Oslo.
- Bjugsstad, A.J., and A.V. Dalrymple. 1968. Behavior of beef heifers on Ozark ranges. Missouri Agr. Exp. Sta. Bull. 870.
- Bowns, J.E. 1971. Sheep behavior under unherded conditions on mountain summer ranges. J. Range Manage. 24:105-109.

- Crawford, H.S. 1982.** Seasonal food selection and digestability by tame white-tailed deer in Central Maine. *J. Wildl. Manage.* 46:974-982.
- Cochran, W.W. 1980.** Wildlife telemetry, p. 507-520. *In:* S.D. Schemnitz (ed), *Wildlife management techniques manual*. Wildlife Society, Washington, D.C.
- De Leeuw, J., and J.P. Bakker. 1986.** Sheep grazing with different foraging efficiencies in a Dutch mixed grassland. *J. Appl. Ecol.* 23:781-793.
- Fremstad, E., and R. Elven (eds). 1987.** Units for vegetation mapping in Norway. (In Norwegian). *Økoforsk report 1987:1*. Univ. of Trondheim, Trondheim.
- Garrott, R.A., G.C. White, R.M. Bartman, and D.L. Weybright. 1986.** Reflected signal bias in biotelemetry triangulation systems. *J. Wildl. Manage.* 50:747-752.
- Gionfriddo, J.P., and P.R. Krausman. 1986.** Summer habitat use by mountain sheep. *J. Wildl. Manage.* 50:331-336.
- Grubb, P., and P.A. Jewell. 1974.** Movement, daily activity and home range of Soay Sheep, p. 160-194. *In:* P.A. Jewell, C. Milner and J.M. Boyd (eds), *Island survivors-The ecology of the Soay sheep of St. Kilda*. Athlone Press, London.
- Hewson, R., and C.J. Wilson. 1979.** Home range and movements of Scottish blackface sheep in Lochaber, NW Scotland. *J. Appl. Ecol.* 16:743-751.
- Hewson, R., and A.J. Veraik. 1981.** Body condition and ranging behaviour of blackface hill sheep in relation to lamb survival. *J. Appl. Ecol.* 18:401-415.
- Hughes, R.E., J. Dale, M.D. Mountford, and I.E. Williams. 1975.** Studies on sheep populations and environment in the mountains of north Wales. II. Contemporary distribution of sheep populations and environment. *J. Appl. Ecol.* 12:165-178.
- Hulet, C.V., G. Alexander, and E.S. Hafez. 1975.** The behaviour of sheep, p. 246-294. *In:* E.S. Hafez (ed), *The behaviour of domestic animals*. Baillière Tindall, London.
- Hunter, R.F. 1962.** Hill sheep and their pasture: a study of grazing sheep in south-east Scotland. *J. Ecol.* 50:651-680.
- Landskogstakseringen. 1961.** Appraisal of Norwegian forests, Hedmark County. (In Norwegian). E. Sem, Halden.
- Litvaitis, J.A., J.A. Sherburne, and J.A. Bissonette. 1986.** Bobcat habitat use and home range size in relation to prey density. *J. Wildl. Manage.* 50:110-117.
- Lynch, J.J. 1971.** Merino sheep: some factors affecting their distribution in very large paddocks. *Int. Union Conserv. Natur. Nat. Resour. Pub.* 2:697-707.
- Lystad, S.L. 1978.** Weather and climate, p. 49-65. *In:* S. Moren (ed), Hedmark. (In Norwegian). Gyldendal, Oslo.
- Martin, D.J. 1963.** The diet of Scottish blackface sheep. Ph.D. Thesis, Univ. of Glasgow.
- Miller, H.A., and L.K. Halls. 1969.** Fleshy fungi commonly eaten by Southern wildlife. USDA, Forest Serv. Res. Pap. SO-49.
- Mysterud, I. 1983.** Characteristics of summer beds of European brown bears in Norway. *Int. Conf. Bear Res. Manage.* 5:208-222.
- Mysterud, I., B. Vaage, F. Gyllström, and F. Jacobsen. 1985.** Radio-collaring of sheep in Hedmark. Testing of equipment 1984. (In Norwegian). Landbrukskontoret in Trysil and Biological Institute, Univ. of Oslo.
- Mysterud, I., and J.T. Warren. 1987.** Radio-collaring of sheep in Hedmark 1986. (In Norwegian) Landbrukets Utmarks kontor and Biological Institute, Univ. of Oslo.
- Noble, I.R. 1975.** Computer simulations of sheep grazing in the Arid Zone. Ph.D. Thesis, Univ. of Adelaide.
- Nordisk Ministerraad. 1977.** Natural geographic regions of the nordic countries. (In Swedish). Nordiska Ministerraad, Stockholm.
- Pratt, R.M., R.J. Putman, J.R. Ekins, and P.J. Edwards. 1986.** Use of habitat by free-ranging cattle and ponies in the New Forest, Southern England. *J. Appl. Ecol.* 23:539-557.
- Schober, F. 1986.** Radio triangulation and its limitations for wildlife research. (In German). *Z. Jagdwiss.* 32:65-75.
- Scott, D., and B.L. Sutherland. 1981.** Grazing behaviour of merinos on an undeveloped semi-arid tussock grassland block. *N.Z. J. Exp. Agr.* 9:1-9.
- Seip, D.R., and F.L. Bunnell. 1985.** Foraging behaviour and food habits of Stone's sheep. *Can. J. Zool.* 63:1638-1646.
- Simmons, N.M. 1980.** Behavior, p. 124-145. *In:* G. Monson and L. Sumner (eds), *The desert bighorn-its life history, ecology and management*. Univ. of Arizona Press, Tucson.
- Springer, J.T. 1979.** Some sources of bias and sampling error in radio triangulation. *J. Wildl. Manage.* 43:926-935.
- Syrjälä-Qvist, L. 1986.** Improvement of natural pasture utilization by sheep, p. 157-167. *In:* O. Gudmundsson (ed), *Grazing research at northern latitudes*. Plenum Press/NATO Scientific Affairs Division, New York.
- Vaag, A.B., A. Haga, and H. Granstuen. 1986.** Suggested plans for management of bear, wolverine and wolf in Norway. (In Norwegian). Viltrapport. 39. Directorate for Nature Management, Trondheim.
- Welch, D. 1981.** Diurnal movements by Scottish blackface sheep between improved grassland and a heather hill in northeast Scotland. *J. Zool.* 194:267-271.
- White, G.C. 1985.** Optimal locations of towers for triangulation studies using biotelemetry. *J. Wildl. Manage.* 49:190-196.
- Wolf, A., T. O'Shea, and D.L. Gilbert. 1970.** Movements and behavior of bighorn sheep on summer ranges in Yellowstone National Park. *J. Wildl. Manage.* 34:446-450.
- Østbye, E. 1971.** Use of the UTM system in location assignment in zoological research. (In Norwegian). *Fauna.* 24:1-9.

## SRM Election Results

The Elections Committee counted the ballots for new officers at the Society for Range Management headquarters. Elected officers are:

Second Vice President—**Gary B. Donart**  
 Directors (1991 – 1993)—**Barbara H. Allen-Diaz** and **Deen Boe**  
 Directors Allen-Diaz and Boe will replace retiring Directors Johnson and Nelson in February 1991.

Ballots and tally sheets are retained in the Denver office for one year for review. Approximately 30% of the membership voted.

# Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta

M.A. NAETH, A.W. BAILEY, D.J. PLUTH, D.S. CHANASYK, AND R.T. HARDIN

## Abstract

Impacts of long-term cattle grazing on litter and soil organic matter were assessed in mixed prairie, parkland fescue, and foothills fescue grasslands of Alberta, Canada. Grazing regimes were of light to very heavy intensities, grazed early, late, and continuously during the growing season. Litter and soil organic matter were sampled in 0.1-m<sup>2</sup> quadrats and removed as live vegetation, standing litter, fallen litter, and soil organic matter. Litter and organic matter samples were air dried and sorted by size using sieves and an automatic sieve shaker. Organic carbon content was determined by thermal oxidation. Ground cover was determined using point frames, and heights of standing litter and fallen litter were measured.

Heavy intensity and/or early season grazing had greater negative impacts on litter and soil organic matter than did light intensity and/or late season grazing. Under the former regimes there were significant reductions in heights of standing and fallen litter, decreases in live vegetative cover and organic matter mass, and increases in bare ground. More large particle-sized organic matter, particularly standing litter, occurred in controls than in grazed treatments since it would not be removed or trampled by grazing animals. More medium and small particle-sized organic matter occurred in grazed treatments than in ungrazed controls since vegetation likely decomposed more rapidly when it was trampled and broken down as animals grazed.

**Key Words:** organic carbon, ground cover, Solonetzic soils, Chernozemic soils, rough fescue

In the Canadian Northern Great Plains, accumulated litter ranges from 0.28 to 1.24 kg m<sup>-2</sup> in fescue grasslands (Johnston 1961, Willms et al. 1986) and from 0.06 to 0.09 kg m<sup>-2</sup> in mixed prairie (Smoliak 1965, Willms et al. 1986). Grazing reduces litter mass, with lowest values under very heavy grazing (Coupland et al. 1960, Johnston 1961, Johnston 1962, Johnston et al. 1971). Some researchers found grazing does not affect soil organic matter (Lodge 1954, Johnston et al. 1971, Dormaar et al. 1977). Others found heavy grazing reduces total carbon in Ah horizons in some grasslands (Smoliak et al. 1972, Dormaar et al. 1977) and increases it in other grasslands (Dormaar et al. 1984). Below ground dry matter can decrease under grazing (Coupland et al. 1960, Smoliak 1965) or increase (Johnston 1961, Smoliak et al. 1972), with the most significant changes occurring in the upper 15 cm of the soil profile.

Branson (1984) stated there may be a critical point in moist climates at which litter accumulation above 0.5 kg m<sup>-2</sup> depresses plant yields. In Canadian mixed prairie, litter accumulation is not high enough to significantly reduce herbage productivity (Willms

et al. 1986). In Canadian fescue grasslands, removal of standing dead and surface litter marginally increased yields and increased tiller density for 2 (Sinton 1980) and 3 (Willms et al. 1986) years after litter removal. There was no evidence these trends continued beyond 3 years. In most Northern Great Plains studies, litter accumulation does not generally exceed 0.27 kg m<sup>-2</sup> and does not adversely affect range condition or productivity. From a hydrologic perspective, there is considerable uncertainty about amounts of litter and vegetative cover needed to prevent excessive runoff and erosion under the diverse topography and soil conditions of grasslands (Meeuwig 1970). Litter and soil organic matter increase soil aggregation, aggregate stability, and infiltration rate, and decrease raindrop impact, runoff, erosion, and soil surface evaporation (Tomanek 1969). They provide habitats for organisms and retain nutrients (Risser 1984). Thus for hydrologic benefit on most rangelands, management for litter accumulation may be as important as management for increasing live plant cover (Branson 1984).

Since litter and soil organic matter have numerous beneficial effects on grasslands, it is important to determine how they are affected by grazing. The major objective of this study was to determine how litter and soil organic matter were affected by season and intensity of grazing in Alberta mixed prairie and fescue grassland ecosystems. It was hypothesized that both season and intensity of grazing would affect amounts of soil organic matter and litter. It was also hypothesized that proportions of litter of different particle sizes would vary with season and intensity of grazing due to trampling and breakdown during grazing. Inherently, litter of different particle sizes would decompose at different rates, affecting soil organic matter mass. Therefore a second objective was to categorize litter and soil organic matter according to particle size and to quantify categories with grazing treatments. Previous studies in Alberta rangelands had not examined total litter or soil organic matter.

## Materials and Methods

### Study Sites

Three study sites representing major rangeland ecosystems of southern and central Alberta were selected. Each site had long-term grazing treatments, ungrazed controls, grass-dominated vegetation that had never been cultivated, and slopes of less than 2% (Naeth 1988).

The mixed prairie site was located near Brooks approximately 225 km east of Calgary (51° N and 112° W). The area has a continental prairie climate and a semiarid moisture regime. Mean annual precipitation is 355 mm. Mean annual temperature is 4° C, with a July mean of 19° C and a January mean of -14° C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solonchized Solonetz and Brown Solod (Natriboroll) developed on till (Kjearsgaard et al. 1982). Vegetation is of the Blue grama-Spear grass-Wheat grass (*Bouteloua-Stipa-Agropyron*) faciation, dominated by blue grama grass (*Bouteloua gracilis* Lag.), spear grass (*Stipa comata* Trin. & Rupr.), and western and northern wheatgrasses (*Agropyron smithii* Rydb. and *dasystachyum* Hook.). Pasture sage (*Artemisia frigida* Willd.) and little club-

Authors are research associate, Department of Soil Science; professor, Department of Plant Science; professor, Department of Soil Science; professor, Department of Soil Science; and professor, Department of Animal Science, University of Alberta, Edmonton, Alta., Canada, T6G 2E3. At the time of the research, the senior author was a Ph.D. graduate student, Department of Plant Science, University of Alberta.

The authors wish to acknowledge the financial support of NOVA Corporation of Alberta. K. Ostermann, V. Naeth, J. Scott, J. McGill, G. Hoppe, and D. White are thanked for their technical assistance. The Lethbridge Research Station of Agriculture Canada, the Eastern Irrigation District, and the University of Alberta are acknowledged for the use of their long-term grazing treatments.

Manuscript accepted 10 May 1990.

moss (*Selaginella densa* Rydb.) are common forbs. A short grass disclimax dominated by blue grama is common as a result of heavy long-term grazing.

The parkland fescue site was located near Kinsella approximately 150 km southeast of Edmonton (53° N and 111° W). The climate is dry subhumid. Mean annual precipitation is 422 mm. Mean annual temperature is 2° C, with a July mean of 17° C and a January mean of -17° C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems (Cryoboroll) developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals. Plains rough fescue (*Festuca hallii* Vasey Piper) (Pavlick and Looman 1984) dominates open undisturbed grasslands, and western porcupine grass (*Stipa curtisetia* Hitchc.) co-dominates on grazed areas. Forbs are a common component of the vegetation.

The foothills fescue grassland site was located near Stavelly approximately 100 km south-southwest of Calgary (50° N and 114° W). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5° C, with a July mean of 18° C and a January mean of -10° C. Elevation averages 1,350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems (Haploboroll) developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association with rough fescue (*Festuca campestris* Rydb.) dominating in the undisturbed and lightly grazed areas. Parry's oat grass (*Danthonia parryi* Scribn.) and bluebunch fescue (*Festuca idahoensis* Elmer) are co-dominates in grazed areas. Under heavy grazing regimes, rough fescue is replaced by annual invaders and bluegrass (*Poa* L.) species.

#### Grazing Treatments

In mixed prairie, 3 grazing treatments were studied within a community pasture established in 1964: (1) early season grazing from May through July; (2) late season grazing from August through October; and (3) a control ungrazed since the late 1930s. The stocking rate was heavy at 0.9 AUM ha<sup>-1</sup> (B. Shanks, personal communication, December 1984).

In parkland fescue, 5 grazing treatments established in 1973 on the University of Alberta ranch were studied: (1) light June grazing from 1 to 30 June at 1.5 AUM ha<sup>-1</sup>; (2) heavy June grazing from 1 to 30 June at 4.4 AUM ha<sup>-1</sup>; (3) heavy autumn grazing from 15 September to 15 October at 4.4 AUM ha<sup>-1</sup>; (4) light autumn grazing from 15 September to 15 October at 1.5 AUM ha<sup>-1</sup>; and (5) a control ungrazed since 1942 (Bailey et al. 1987).

In foothills fescue, 5 grazing treatments established in 1949 on the Agriculture Canada Range Research Substation and grazed May through September were studied: (1) very heavy grazing at 4.8 AUM ha<sup>-1</sup>; (2) heavy grazing at 2.4 AUM ha<sup>-1</sup>; (3) moderate grazing at 1.6 AUM ha<sup>-1</sup>; (4) light grazing at 1.2 AUM ha<sup>-1</sup>; and (5) a control comprised of permanent exclosures in each treatment (Johnston et al. 1971).

#### Experimental Design and Statistical Analyses

The experimental design within each site had a hierarchical arrangement of grazing treatment, sample area, and subsamples (Steel and Torrie 1980). Three 0.1-ha sample areas were randomly established within each treatment.

Statistical analyses were conducted using variation among the 0.1-ha sample areas as a measure of error for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). Analysis of variance was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% probability level

(Steel and Torrie 1980).

In each year by treatment combination, variation among samples was not significantly different from subsamples and therefore, sample and subsample variation were pooled in further analyses. There were no significant differences within a treatment between study years so data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

#### Sampling and Analyses

For this study, litter refers to all dead organic material not incorporated with mineral soil and occurring above soil mineral horizons. Soil organic matter refers to the organic fraction of soil (Canada Department of Agriculture 1979).

At each site, sampling was conducted in late August 1985 and 1986 using 10 randomly located 0.1-m<sup>2</sup> quadrats in each sample area (30 per treatment). Live vegetation, including dried tips of live plants, and standing litter were removed with clippers at ground level. Fallen litter was removed from the soil surface with hand rakes. Soil organic matter was lifted as a slab, after cutting down to a mineral soil horizon where color and textural changes were used to locate the bottom of the Ah horizon. Sampling depths ranged from 5 to 8 cm in mixed prairie (no difference in depth among treatments) and 10 to 15 cm in parkland fescue (no difference in depth among treatments) and foothills fescue (very heavy treatment shallower than other treatments).

Live vegetative material was oven dried at 65° C for 24 hours, then weighed. Litter and organic matter samples were air dried then sorted by size using sieves mounted on an automatic sieve shaker as modified from Coupland (1973). Five minutes of shaking was required to sort the samples without breaking down plant material. Sieves selected on the basis of laboratory trials had openings of 2.0, 0.85, and 0.212 mm (9, 20, and 65 mesh Tyler equivalents), with a bottom pan.

The litter and soil organic matter were separated into 6 categories: (1) standing litter collected in the field; (2) coarse litter remaining in the top sieve (2 mm) and recognizable as undecomposed plant parts; (3) medium litter that was partly decomposed and collected in the second sieve (0.85 mm); and (4) fine organic matter that was relatively decomposed and collected in the third sieve (0.212 mm); (5) very fine organic matter that was decomposed and collected in the bottom pan; and (6) roots visibly greater than 0.2 mm which were removed from the above samples. Categories 4 and 5 contained most smaller roots and root hairs. The above ground category comprised standing, coarse, and medium litter, and live vegetation. The below ground category comprised roots, and fine and very fine organic matter. Total organic matter included all above categories.

To measure organic matter in each category and to separate it from mineral matter included in the total weight, organic carbon content was determined by oxidation with a Leco Carbon Determinator. In each category, 5 subsamples from each 0.1-ha area were analyzed (15 per treatment). Soil samples were ground to pass through a 0.15-mm sieve. Soil carbonates in 10 samples from each study site were determined by acid neutralization to pH 8.2 (Black 1965). Organic carbon was calculated by subtracting percent inorganic carbon from percent total carbon. Percent organic carbon was multiplied by 1.724 (organic matter is approximately 58% organic carbon) to determine percent organic matter in each category. This value was then multiplied by total mass of each category to give mass in the 0.1 m<sup>2</sup> sample. Masses were then converted to specific mass (kg m<sup>-2</sup>).

In each 0.1-ha area, 10 randomly located 10-point transects were used to determine percent bare ground, live vegetation, and dead vegetation (300 points per treatment). Standing litter, fallen litter, and standing litter heights (cm) of each major plant species or

**Table 1. Percent ground cover (bare ground, live vegetation, litter) in mixed prairie, parkland fescue, and foothills fescue grasslands.**

Site	Grazing treatment	Ground Cover Category		
		Bare ground	Live vegetation	Litter
Mixed Prairie	Early Season	7.0a	12.0a	81.0a
	Late Season	4.0ab	15.5a	80.5a
	Ungrazed Control	1.5b	17.5a	81.0a
Parkland Fescue	Light June	0.0b	35.5a	64.5a
	Heavy June	2.0a	31.5a	66.5a
	Heavy Autumn	0.5b	36.0a	63.5a
	Light Autumn	0.0b	38.5a	61.5a
	Ungrazed Control	0.0b	39.5a	60.5a
Foothills Fescue	Very Heavy	14.5a	21.0b	64.5b
	Heavy	10.5b	22.0b	67.5b
	Moderate	1.0c	30.5a	68.5b
	Light	0.5c	30.0a	69.5b
	Ungrazed Control	0.0c	12.3c	87.7a

Within ground cover category means with the same letters are not significantly different ( $P<0.05$ ).

group were measured at 30 randomly located points in each 0.1-ha area (90 per treatment).

## Results

### Mixed Prairie

Live vegetation and litter components of ground cover were not affected by grazing (Table 1). Grazing increased bare ground 2.7 to 4.7 times, with early season grazing being more detrimental than late season grazing. Fallen litter height was 6.4 times greater in the control than in grazed treatments and standing litter was 1.4 times greater (Table 2).

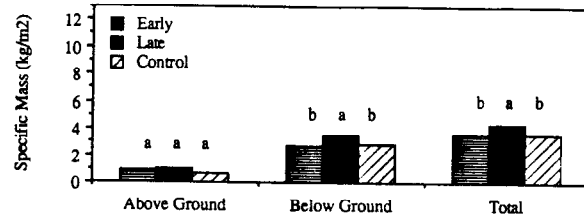
Organic carbon was higher in litter categories than in soil organic matter categories (Table 3). Season of grazing affected organic carbon with early season grazing reducing values in roots and standing litter but increasing it in coarse and medium litter. Grazing treatment had no effect on organic carbon in soil organic

**Table 2. Height (cm) of fallen and standing litter in mixed prairie, parkland fescue, and foothills fescue grasslands.**

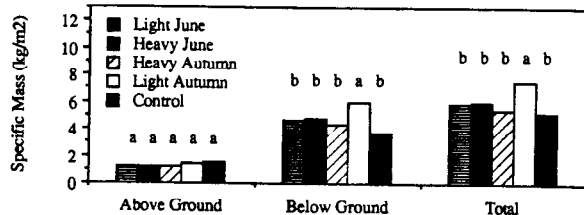
Site	Grazing treatment	Fallen litter	Standing litter
Mixed Prairie	Early Season	0.5b	15.7b
	Late Season	0.5b	16.1b
	Ungrazed Control	3.2a	21.3a
Parkland Fescue	Light June	2.8b	30.7c
	Heavy June	1.3b	29.6c
	Heavy Autumn	1.9b	25.9c
	Light Autumn	3.8b	37.3b
	Ungrazed Control	14.6a	53.9a
Foothills Fescue	Very Heavy	0.2e	36.4d
	Heavy	2.2d	48.9c
	Moderate	4.9c	55.0b
	Light	8.5b	57.3ab
	Ungrazed Control	13.4a	59.6a

Within litter category means with the same letters are not significantly different ( $P<0.05$ ).

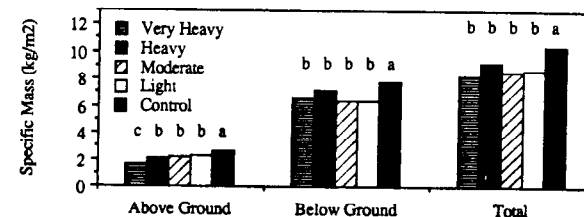
(a) Mixed Prairie



(b) Parkland Fescue



(c) Foothills Fescue



Liner And Organic Matter Category

**Fig. 1. Specific mass of above-ground, below-ground, and total litter and organic matter in (a) mixed prairie, (b) parkland fescue, and (c) foothills fescue grasslands. Within category means with the same letters are not significantly different ( $P<0.05$ ).**

matter. Above ground litter mass was not affected by grazing; below ground organic matter and total masses were highest under late season grazing (Fig. 1). Total mass was distributed approximately 75% below ground and 25% above ground. Greatest masses were in fine and very fine categories. Grazing did not have a significant effect on mass of standing litter, coarse litter, or very fine organic matter. Grazing increased medium litter and roots, and decreased live vegetation. Highest fine organic matter was under late season grazing.

### Parkland Fescue Grassland

Live vegetation and litter components of ground cover were not affected by grazing (Table 1). Bare ground increased only under heavy intensity grazing, particularly if grazed in June. Standing litter was 1.5 to 2.0 times higher and fallen litter was 4.0 to 11.0 times higher in ungrazed controls than in grazed treatments. Standing litter was higher under light autumn grazing than under any other grazed treatment (Table 2).

Organic carbon in roots and coarse litter was not affected by grazing but in standing litter it was highest in control and heavy June treatments and lowest in the heavy autumn treatment (Table 3). Organic carbon in medium litter, fine and very fine organic matter was lowest in the control, being 1.4 to 1.9 times higher in grazed treatments. Total organic matter was comprised of approximately two-thirds below ground and one-third above ground components (Fig. 1). Above ground mass was not affected by grazing. Below ground and total masses were highest in the light autumn treatment. Grazing decreased masses of standing and coarse litter and increased those of medium and very fine organic matter (Fig. 2). The highest fine organic matter mass was under



**Table 3. Organic carbon (%) in litter and soil organic matter categories in mixed prairie, parkland fescue, and foothills fescue grasslands.**

Site	Grazing treatment	Litter and Organic Matter Category					
		Roots	Standing litter	Coarse litter	Medium litter	Fine organic matter	Very fine organic matter
Mixed Prairie	Early Season	22.0b	23.2b	31.4a	14.4a	6.0a	3.9a
	Late Season	28.0a	29.1a	30.0ab	11.3b	6.0a	4.3a
	Ungrazed Control	25.0ab	25.5ab	27.0b	6.2c	4.6a	3.6a
Parkland Fescue	Light June	33.2a	31.8b	26.3a	8.8a	8.7a	8.4a
	Heavy June	34.8a	34.6a	28.8a	8.8a	8.1a	8.8a
	Heavy Autumn	30.0a	29.7c	25.9a	10.3a	9.3a	9.2a
	Light Autumn	31.3a	31.7b	29.3a	10.6a	9.5a	8.4a
	Ungrazed Control	27.6a	35.1a	27.2a	5.5b	5.7b	5.9b
Foothills Fescue	Very Heavy	40.8a	40.3a	33.9a	15.4a	16.3a	12.8a
	Heavy	38.2a	41.1a	33.3a	14.3a	13.1a	11.2a
	Moderate	36.4a	39.8a	33.2a	13.2a	13.3a	11.3a
	Light	37.8a	40.9a	34.2a	11.5a	10.7a	11.3a
	Ungrazed Control	35.2a	40.8a	31.9a	11.3a	12.8a	11.5a

Within litter and organic matter category means with the same letters are not significantly different ( $P < 0.05$ ).

light autumn grazing.

#### Foothills Fescue Grassland

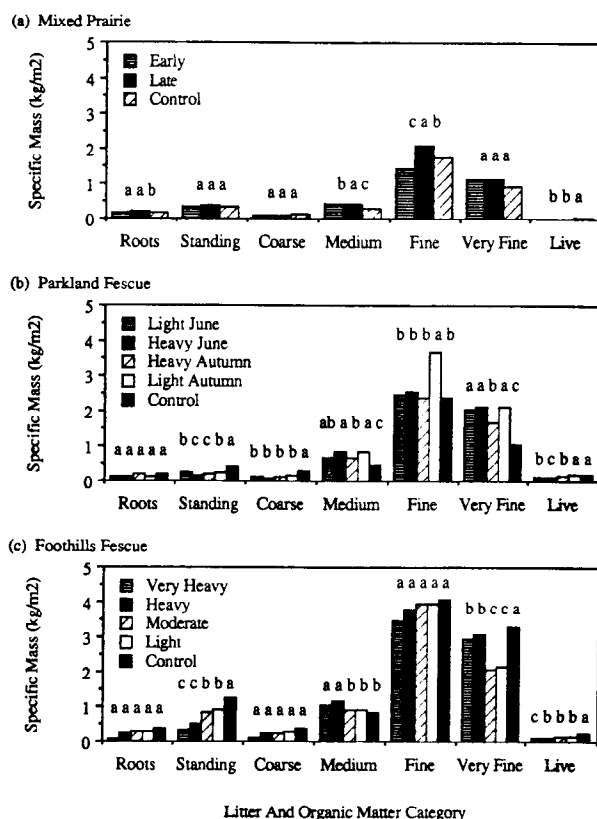
Bare ground increased under moderate, heavy, and very heavy grazing (Table 1). Live vegetative cover was highest under light and moderate grazing, intermediate under heavy and very heavy grazing, and lowest in the control. Litter cover was highest in the control but did not vary among grazed treatments. Standing and fallen litter height decreased with increased grazing intensity (Table 2). Standing litter was 1 to 1.6 times higher in the control than in grazed treatments and fallen litter was 1.6 to 6.7 times higher.

In all litter and organic matter categories, organic carbon was not affected by grazing treatment (Table 3). Total organic matter was comprised of approximately two-thirds below ground and one-third above ground components (Fig. 1). Above ground, below ground, and total masses were lower in grazed treatments than in the control. Above ground mass was lower in the very heavy treatment than in other grazed treatments. Root, coarse litter, and fine organic matter masses were not affected by grazing (Fig. 2). Grazing decreased standing litter and live vegetation and increased medium litter. Masses of very fine organic matter were higher in control, heavy, and very heavy treatments than in light and moderate treatments.

#### Discussion

##### Grazing Effects

As hypothesized, both season and intensity of grazing affected amounts of litter and soil organic matter. Although ecosystem characteristics varied considerably, there were general grazing trends. Bare ground increased while standing and fallen litter, and live vegetative cover and mass decreased with increasing grazing intensity. Early season grazing was more detrimental than late season grazing. Litter depth and height were reduced with treading through breakage and compaction (Naeth et al. 1990). Since sampling occurred late in the growing season, there was little live vegetation. In ungrazed foothills fescue, live cover was low since most vegetation was dormant when sampled, whereas in grazed treatments some autumn forb growth occurred. Also as hypothesized, proportions of different particle-sized litter varied with grazing season and intensity although masses were affected more con-



**Fig. 2. Specific mass of litter and organic matter categories in (a) mixed prairie, (b) parkland fescue, and (c) foothills fescue grasslands. Within category means with the same letters are not significantly different ( $P < 0.05$ ).**

sistently by intensity than season of grazing. All categories except medium litter decreased with increased grazing intensity. With grazing, standing and coarse litter would be trampled, broken into smaller pieces, and thus categorized as medium litter. Soil organic matter levels would reflect changes in total litter.

Early season heavy intensity grazing reduced litter and organic



matter more than late season heavy intensity grazing or light intensity grazing either late or early in the growing season. Early in the growing season when plant growth is rapid and carbohydrate reserves are low, vegetation is more susceptible to grazing damage. Heavy intensity grazing removes more vegetation with less regrowth and litter accumulation. Data from early season grazing in mixed prairie and heavy June grazing in parkland fescue support this. Foothills fescue treatments also start early in the growing season, but only under heavy intensities did bare ground increase. The late season mixed prairie treatment was heavy, but grazing when plants were dormant reduced the impact. The less negative effects of light intensity and/or late season grazing were supported by higher organic matter masses under late season grazing in mixed prairie, light autumn grazing in parkland fescue, and light or moderate grazing in foothills fescue. Although grazing had not yet occurred at sampling time in autumn treatments in parkland fescue, standing litter was higher under light than heavy grazing intensities.

Plant species changes due to grazing affected amounts and kinds of litter and organic matter. Litter cover in mixed prairie was high for heavy long-term grazing because little club-moss, which comprised an average 58% of the basal area (Naeth 1985), was dormant when sampled and therefore classed as litter, comprising a major portion of that category. Litter mass similarities between control and grazed treatments were also related to little club-moss in grazed treatments that sorted into coarse and medium litter categories. Reduced litter height under very heavy grazing compared to heavy grazing in foothills fescue was due to reduction or elimination of taller plant species under very heavy grazing and replacement by lower growing grasses and forbs. These shallow rooted species in heavier grazed treatments (Johnston 1962), rooting in the upper 20 cm of the soil profile (Coupland 1979), can account for higher values in organic matter categories that included small roots.

Grazing can affect litter decomposition rate, which affects organic matter mass. Trampling can reduce litter particle size and create better litter-soil contact, facilitating more rapid decomposition by soil microorganisms (McCalla 1943, Dyksterhuis and Schmutz 1947) in some grazed treatments than in controls. This is evidenced by lower below ground and total organic matter masses in the controls than in the light autumn treatment in parkland fescue and the late season treatment in mixed prairie, and higher very fine masses in very heavy and heavy treatments than in light and moderate treatments in foothills fescue. In mixed prairie, forbs and shrubs were more prominent under early season grazing and grasses more prominent under late season grazing (Naeth 1985). Grasses contain less lignin than shrubs and forbs and decompose more rapidly (Norman 1933), increasing fine organic matter under late season grazing.

Reduced standing litter with long-term grazing was in agreement with most North American grassland studies (Coupland 1979). Litter masses were higher than those for other Alberta mixed prairie studies (Smoliak 1965, Smoliak et al. 1972, Willms et al. 1986); it is not known whether little club-moss was included in litter samples for these studies. Standing and coarse litter values were similar to those of Coupland (1973) for Saskatchewan mixed prairie but coarse, fine, and very fine values are not comparable to those in this study due to differences in sieve size and sampling depth. Rough fescue above ground litter values were higher than others from Alberta (Smoliak et al. 1985, Willms et al. 1986, Bailey et al. 1987), again due to sampling differences. Crider (1955) reported partial or complete defoliation reduces plant root mass. Although mass of roots greater than 0.2 mm was not affected by grazing in this study, there were treatment differences in fine

and/or very fine organic matter masses which comprised smaller roots.

### Organic Carbon

Higher organic carbon in roots, standing litter, and coarse litter compared to medium litter, fine and very fine organic matter reflected the larger ratio of mineral soil to plant material in the latter categories. Organic carbon in litter of different particle sizes may be affected by CO<sub>2</sub> losses during decomposition. For fescue and spear grass species, 28 to 33% of the original carbon in roots and residue may be lost within 47 weeks of incubation (Herman 1974). Plant species differ in chemical composition and significant differences in dominant species within grazing treatments may affect total carbon in the organic matter. Results from this study are in agreement with those of Dormaar et al. (1977), who reported total carbon does not change with grazing intensity. Dormaar et al. (1984) also found higher amounts of total carbon in a heavy grazed site compared to an ungrazed one in mixed prairie at Manyberries, Alberta. Large amounts of little club-moss may have contributed to these higher values.

### Management Implications

The increases in bare ground in mixed prairie and parkland fescue under grazing are of little practical significance because both % bare ground and the increases were so small. However the increases in foothills fescue under heavy and very heavy grazing are of practical significance since hydrologic changes such as reduced infiltration and increased runoff occur in this ecosystem when bare ground is approximately 15% (Johnston 1962, Naeth 1988).

Naeth et al. (1991) found the amount of large particle-sized relative to small particle-sized litter and organic matter was a critical factor in determining magnitude of water holding capacity (WHC) of litter and the soil surface in a given rangeland. They found WHC increased with increasing particle-size, being higher for roots and standing and fallen litter than for soil organic matter categories. WHC decreased with heavy intensity early season grazing through species composition changes and trampling. Thus, grazing regimes facilitating accumulation of litter in larger particle-sized categories would increase overall hydrologic condition. For example, although the heavy and very heavy treatments in foothills fescue have high fine and very fine organic matter, there were significant reductions in the high WHC categories such as standing litter, coarse litter, and roots. Thus these treatments would have an overall lower hydrologic condition than the light and moderate treatments in that ecosystem.

When considering the importance of a good ground cover and litter accumulation, several management implications are evident. For heavy intensity grazing in mixed prairie, late season grazing after July is better than early season grazing. For grazing during the growing season, a moderate intensity is advised. In parkland fescue grassland, reducing June or early season grazing in favor of autumn grazing would maintain the most litter and organic matter. Grazing foothills fescue grasslands at a moderate or light season-long regime appears to be best and may be an alternative to rotational or deferred grazing which is often economically difficult on large foothills ranches. Certainly from a hydrologic perspective, the above grazing regimes are the best for maintaining critical levels of litter and organic matter for good hydrologic condition (Naeth 1988).

### Conclusions

Both season and intensity of grazing affected amounts of litter and soil organic matter, with heavy intensity and/or early season grazing having a greater negative effect than light intensity and/or late season grazing. Bare ground increased while standing and fallen litter, and live vegetative cover and mass decreased with

increasing grazing intensity. Bare ground values were only practically significant in the foothills fescue grassland where they were high enough to affect hydrologic condition.

Proportions of different particle-sized litter varied with grazing season and intensity. Litter masses were affected more consistently by intensity than season of grazing, with heavy intensity and/or early season regimes having the greatest negative effect. All categories except medium litter decreased with increased grazing intensity. Higher litter and organic matter in grazed treatments than in controls in some medium and small particle-sized categories was probably due to more rapid decomposition when vegetation was trampled and broken down into smaller particle sizes. More larger particle-sized organic matter in controls than grazed treatments was due to lack of treading and removal by grazing.

## References

- Bailey, A.W., M.G. Willoughby, and B.D. Irving. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Proj. 84-0335.
- Black, C.A. 1965. Methods of soil analysis. Part I: Physical and mineralogical properties, including statistics of measurement and sampling. Agronomy Ser. 9. Amer. Soc. Agron.
- Branson, F.A. 1984. Evaluation of "Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses". pp. 985-1000. In: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London.
- Canada Department of Agriculture. 1979. Glossary of terms in soil science. Can. Dep. Agr. Pub. 1459.
- Coupland, R.T. 1973. I. Dynamics of aboveground standing crop. Tech. Report 27. Canadian Comm. for the Internat. Biol. Prog. Saskatoon, Sask.
- Coupland, R.T. 1979. Grassland ecosystems of the world: analysis of grasslands and their uses. Cambridge Univ. Press. Cambridge, Engl. IBP 18.
- Coupland, R.T., N.A. Skoglund, and A.J. Heard. 1960. Effects of grazing in the Canadian mixed prairie. Proc. Eighth Internat. Grassl. Congr. pp. 212-215.
- Crider, F.J. 1955. Root growth stoppage resulting from defoliation of grass. Tech. Bull. USDA No. 1102:2-23.
- Dormaar, J.F., A. Johnston, and S. Smoliak. 1977. Seasonal variations in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. J. Range Manage. 30:195-198.
- Dormaar, J.F., A. Johnston, and S. Smoliak. 1984. Seasonal changes in carbon content, dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31-37.
- Dyksterhuis, E.J., and L.M. Schmutz. 1947. Natural mulches or 'litter' of grassland with kinds and amounts on a southern prairie. Ecology 28:163-179.
- Herman, W.A. 1974. Chemical composition of roots and decomposing root residues from three grass species. M.Sc. Thesis. Dept. Soil Sci. Univ. Alberta, Edmonton.
- Howitt, R.W. 1988. Soil survey of the County of Beaver. Alberta Soil Survey Report 47. Alberta Res. Council. Open File Report 1987-4.
- Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.
- Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15:79-87.
- Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.
- Kjearsgaard, A.A., T.W. Peters, and W.W. Pettapiece. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41.
- Lodge, R.W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.
- McCalla, T.M. 1943. Microbiological studies of the effect of straw used as a mulch. Trans. Kansas Acad. Sci. 43:52-56.
- Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:183-188.
- Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonchets native rangeland in southern Alberta. M.Sc. Thesis. Univ. Alberta. Edmonton.
- Naeth, M.A. 1988. The impact of grazing on litter and hydrology in mixed prairie and fescue grassland ecosystems of Alberta. Ph.D. Thesis. Univ. Alberta. Edmonton.
- Naeth, M.A., D.J. Pluth, D.S. Chanasyk, A.W. Bailey, and A.W. Fedkenheuer. 1990. Soil compacting impacts of grazing in mixed prairie and fescue grassland ecosystems of Alberta. Can. J. Soil Sci. 70:157-167.
- Naeth, M.A., A.W. Bailey, D.S. Chanasyk, and D.J. Pluth. 1991. Water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. J. Range Manage. 44:13-17.
- Norman, A.G. 1933. The natural decomposition of plant materials. Sci. Prog. 27:470-485.
- Pavlick, L.E., and J. Looman. 1984. Taxonomy and nomenclature of rough fescues, *Festuca albaica*, *Festuca campestris* (F. *Scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.
- Risser, P.G. 1984. Methods for inventory and monitoring of vegetation, litter, and soil surface condition. pp. 647-690. In: Developing strategies for range management. NRC/NAS. Western Press/Boulder and London.
- Shapiro, S.S., and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.
- Sinton, H.M.M. 1980. Effect of burning and mowing on *Festuca hallii* (Vasey) Piper, *Festuca scabrella* Torr. M.Sc. Thesis. Dept. Plant Sci., Univ. Alberta. Edmonton.
- Smoliak, S. 1965. A comparison of ungrazed and lightly grazed *Stipa-Bouteloua* prairie in southeastern Alberta. Can. J. Plant Sci. 45:270-275.
- Smoliak, S., J.F. Dormaar, and A. Johnston. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. 25:246-250.
- Smoliak, S., B.W. Adams, B.G. Schuler, R.A. Wroe, S.G. Klumph, and W.D. Willms. 1985. Forage production on selected native prairie sites in southern Alberta. Res. Branch, Agr. Can. Lethbridge Res. Sta. Cont. 5.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York.
- Tomanek, G.W. 1969. Dynamics of mulch layer in grassland ecosystems. In: Dix, R.L. and Beidleman, R.G. (eds.). The grassland ecosystem, a preliminary synthesis. Range Sci. Dep. Series No. 2:225-240. Colorado State Univ. Fort Collins.
- Willms, W.D., S. Smoliak, and A.W. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-540.

# Water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta

M.A. NAETH, A.W. BAILEY, D.S. CHANASYK, AND D.J. PLUTH

## Abstract

Litter and organic matter accumulations can reduce soil water through interception of precipitation and subsequent evaporation of absorbed water. Interception varies with mass and water holding capacity (WHC) of litter and organic matter, and is highest from small precipitation events. WHC varies with vegetation type, which is affected by grazing regime. Thus long-term grazing could affect WHC of litter and organic matter and would be important in the hydrologic assessment of rangelands subjected to many small precipitation events throughout the growing season.

The study was conducted in mixed prairie, parkland fescue, and foothills fescue grasslands in Alberta, Canada. Grazing regimes were of light to very heavy intensities, grazed early, late, and continuously during the growing season. Litter and organic matter were sorted by sieving into various sized categories. Litter-soil cores were also evaluated.

WHC of litter and organic matter was lower in mixed prairie than in fescue grasslands. WHC increased with increased particle size, being higher for roots and standing and fallen litter than for organic matter. WHC of large particle-sized material decreased with heavy intensity and/or early season grazing. WHC was affected more by intensity than season of grazing. Grazing affected WHC through species composition changes, since species have different WHC, and through trampling which affected particle size. It was concluded that litter and organic matter WHC were important in rangeland hydrologic assessments.

**Key Words:** interception, grazing intensity, field capacity, rangeland hydrology

Litter can reduce the amount of water reaching the soil surface through interception of precipitation and subsequent evaporation of absorbed water. Interception losses from small storms are generally high while those from larger storms are under 10% (Corbett and Crouse 1968, Couturier and Ripley 1973). Interception in grasslands varies with plant species. Interception losses by big bluestem (*Andropogon gerardi* Vitman) range from 57 to 84% of simulated precipitation applied for 30 minutes at 3 to 25 mm and interception losses by buffalograss (*Buchloe dactyloides* Nutt. Engelm.) were 17 to 74% of simulated rainfall at 3 to 13 mm for 30 minutes (Clark 1940). Percent of annual precipitation lost through interception by grasses was 56% by Kentucky bluegrass (*Poa pratensis* L.) (Haynes 1940), 13 to 19% by a South African veld dominated by *Themeda* spp. and *Cymbopogon* spp. (Beard 1956), 26% by California grassland composed of *Avena*, *Stipa*, *Lolium*, and *Bromus* species (Kittredge 1948), 10.8% by curlymesquite (*Hilaria belangeri* Steud.), and 18.1% by sideoats grama (*Bouteloua curtipendula* Torr.) (Thurow et al. 1987). Couturier and

Ripley (1973) calculated net interception losses by mixed prairie grasses at 14 to 24%. The amount of water subsequently evaporated is governed primarily by the mass of accumulated litter (Helvey and Patric 1965), water holding capacity (WHC) of litter, and evaporation potential before and after the precipitation event (Corbett and Crouse 1968). WHC of litter varies with vegetation type, with that of litter in grasslands ranging from 0.5 to 8.4 mm (Flory 1936, Weaver and Rowland 1952, Burgy and Pomeroy 1958, Corbett and Crouse 1968). Thurow et al. (1987) reported WHC of 114% for curlymesquite and 81% for sideoats grama in Texas.

Grazing regimes facilitating accumulation of litter and organic matter could reduce mineral soil water due to retention of precipitation above-ground and subsequent evaporative loss. However the increased infiltration capacity and reduced evaporation from the soil surface from such accumulations and the reductions in evapotranspiration due to defoliation from grazing will generally more than offset this (Lowdermilk 1930, Weaver and Rowland 1952). In rangelands of the Northern Great Plains where many small precipitation events occur throughout the growing season, precipitation not contributing to soil water because it was intercepted and evaporated could be significant. It was hypothesized that WHC of litter and organic matter would be affected by its particle size distribution and thus grazing regimes facilitating accumulation of litter or organic matter of sizes which had high water holding capacities would reduce soil water the most. It was further hypothesized that overall water holding capacity would differ with ecosystem as affected by plant species composition.

If long-term grazing affects WHC of litter and organic matter and leads to reductions in soil water, these reductions will be important in the hydrologic assessment of rangelands subjected to many small precipitation events throughout the growing season and should be considered in management and modelling. Thus a study was initiated in mixed prairie and fescue grasslands of Alberta, Canada, with the objectives (1) to determine whether WHC of litter and organic matter is affected by ecosystem, (2) to determine whether particle size of litter and organic matter affected WHC, and (3) to determine the effect of season and intensity of grazing on WHC of litter and organic matter.

## Materials and Methods

### Study Sites

Three study sites representing major rangeland ecosystems of southern and central Alberta were selected. Each site had long-term grazing treatments, ungrazed controls, grass-dominated vegetation that had never been cultivated, and slopes of less than 2% (Naeth 1988).

The mixed prairie site was located near Brooks approximately 225 km east of Calgary (51° N and 112° W). The area has a continental prairie climate and a semiarid moisture regime. Mean annual precipitation is 355 mm. Mean annual temperature is 4° C, with a July mean of 19° C and a January mean of -14° C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod (Natriboroll) deve-

Authors are research associate, Department of Soil Science; professor, Department of Plant Science; professor, Department of Soil Science; and professor, Department of Soil Science, University of Alberta, Edmonton, Alta., Canada, T6G 2E3. At the time of the research, the senior author was a Ph.D. graduate student, Department of Plant Science, University of Alberta.

The authors wish to acknowledge the financial support of NOVA Corporation of Alberta. K. Ostermann, V. Naeth, J. Quinn, J. McGill, G. Hoppe, and D. White are thanked for their technical assistance. The Lethbridge Research Station of Agriculture Canada, the Eastern Irrigation District, and the University of Alberta are acknowledged for the use of their long-term grazing treatments.

Manuscript accepted 10 May 1990.

loped on till (Kjearsgaard et al. 1982). Vegetation is of the Blue grama-Spear grass-Wheat grass (*Bouteloua-Stipa-Agropyron*) faciation, dominated by blue grama grass (*Bouteloua gracilis* Lag.), spear grass (*Stipa comata* Trin. & Rupr.), and western and northern wheatgrasses (*Agropyron smithii* Rydb. and *dasystachyum* Hook.). Pasture sage (*Artemisia frigida* Willd.) and little clubmoss (*Selaginella densa* Rydb.) are common forbs. A short grass disclimax dominated by blue grama is common as a result of heavy long-term grazing.

The parkland fescue site was located near Kinsella approximately 150 km southeast of Edmonton (53° N and 111° W). The climate is dry subhumid. Mean annual precipitation is 422 mm. Mean annual temperature is 2° C with a July mean of 17° C and a January mean of -17° C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems (Cryoboroll) developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals. Rough fescue (*Festuca hallii* Vasey Piper) (Pavlick and Looman 1984) dominates open undisturbed grasslands and western porcupine grass (*Stipa curtisetia* Hitchc.) co-dominates on grazed areas. Forbs are a common component of the vegetation.

The foothills fescue grassland site was located near Stavelly approximately 100 km south-southwest of Calgary (50° N and 114° W). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5° C, with a July mean of 18° C and a January mean of -10° C. Elevation averages 1,350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems (Haploboroll) developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association with rough fescue (*Festuca campestris* Rydb.) dominating in the undisturbed and lightly grazed areas. Parry's oat grass (*Danthonia parryi* Scribn.) and bluebunch fescue (*Festuca idahoensis* Elmer) are co-dominants in grazed areas. Under heavy grazing regimes, rough fescue is replaced by annual invaders and bluegrass (*Poa* L.) species.

### Grazing Treatments

In mixed prairie, 3 grazing treatments were studied within a community pasture established in 1964: (1) early season grazing from May through July; (2) late season grazing from August through October; and (3) a control ungrazed since the late 1930s. The stocking rate was heavy at 0.9 AUM ha<sup>-1</sup>.

In parkland fescue, 5 grazing treatments established in 1973 on the University of Alberta ranch were studied: (1) light June grazing from 1 to 30 June at 1.5 AUM ha<sup>-1</sup>; (2) heavy June grazing from 1 to 30 June at 4.4 AUM ha<sup>-1</sup>; (3) heavy autumn grazing from 15 September to 15 October at 4.4 AUM ha<sup>-1</sup>; (4) light autumn grazing from 15 September to 15 October at 1.5 AUM ha<sup>-1</sup>; and (5) a control ungrazed since 1942 (Bailey et al. 1987).

In foothills fescue, 5 grazing treatments established in 1949 on the Agriculture Canada Range Research Substation and grazed May through September were studied: (1) very heavy grazing at 4.8 AUM ha<sup>-1</sup>; (2) heavy grazing at 2.4 AUM ha<sup>-1</sup>; (3) moderate grazing at 1.6 AUM ha<sup>-1</sup>; (4) light grazing at 1.2 AUM ha<sup>-1</sup>; and (5) a control comprised of permanent exclosures in each treatment (Johnston et al. 1971).

### Experimental Design and Statistical Analyses

The experimental design within each site had a hierarchical arrangement of grazing treatment, sample area, and subsamples (Steel and Torrie 1980). Three 0.1-ha sample areas were randomly established within each treatment.

Statistical analyses were conducted using variation among the 0.1-ha sample areas as a measure of error for testing the significance of treatments. Data were tested for homogeneity of variance using

Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). Analysis of variance was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% probability level (Steel and Torrie 1980).

In each year by treatment combination, variation among samples was not significantly different from subsamples and, therefore, sample and subsample variation were pooled in further analyses. There was no significant difference within a treatment between study years so data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

### Sampling and Analyses

For this study, litter refers to all dead organic material not incorporated with mineral soil and occurring above soil mineral horizons. Soil organic matter refers to the organic fraction of soil (Canada Department of Agriculture 1979).

At each site, sampling was conducted in late August 1985 and 1986 using 10 randomly located 0.1-m<sup>2</sup> quadrats in each sample area (30 per treatment). Live vegetation, including dried tips of live plants, and standing litter were removed with clippers at ground level. Fallen litter was removed from the soil surface with hand rakes. Soil organic matter was lifted as a slab, after cutting down to a mineral soil horizon where color and textural changes were used to locate the bottom of the Ah horizon. Sampling depths averaged 5 to 8 cm in mixed prairie (no difference in depth among treatments) and 10 to 15 cm in parkland fescue (no difference in depth among treatments) and foothills fescue (very heavy treatment shallower than other treatments).

Live vegetative material was oven dried at 65° C for 24 hours, then weighed. Litter and organic matter samples were air dried then sorted by size using sieves mounted on an automatic sieve shaker as modified from Coupland (1973). Five minutes of shaking was required to sort the samples without breaking down plant material. Sieves selected on the basis of laboratory trials had openings of 2.0, 0.85, and 0.212 mm (9, 20, and 65 mesh Tyler equivalents), with a bottom pan.

The litter and soil organic matter were separated into 6 categories: (1) standing litter collected in the field; (2) coarse litter remaining in the top sieve (2 mm) and recognizable as undecomposed plant parts; (3) medium litter that was partly decomposed and collected in the second sieve (0.85 mm); (4) fine organic matter that was relatively decomposed and collected in the third sieve (0.212 mm); (5) very fine organic matter that was decomposed and collected in the bottom pan; and (6) roots visibly greater than 0.2 mm which were removed from the above samples. Categories 4 and 5 contained most smaller roots and root hairs. Above-ground organic matter comprised standing, coarse, and medium litter, and live vegetation. Below-ground organic matter comprised roots, and fine and very fine organic matter. Total organic matter included all above categories.

In 1985 and 1986, 9 soil and litter samples to a depth of 76 mm were taken from each treatment with a 76 mm diameter Uhland core sampler. The top of the core corresponded to the top of the fallen litter layer. These cores were used to determine WHC of litter and organic matter in a relatively undisturbed state and thus a truer reflection of treatment effect.

### Determination of Water Holding Capacity

Water holding capacity (WHC) of litter and soil organic matter was determined with modifications to methods outlined by Kittridge (1955) and Bernard (1963). After sorting of the samples collected each year, 5 randomly selected samples from each litter and soil organic matter category from each 0.1-ha sample area was

used to fill 7 cm high by 7 cm diameter plastic cylinders to a standard weight (15 per treatment). Cotton fabric secured with a rubber band was used to cover the cylinder bottom. Cylinders were saturated for 48 hours in a sink and then placed on a tray of damp sand to drain for 48 hours.

The sand mixture used for drainage was 11% gravel, 23% very coarse sand, 38% coarse sand, 22% medium sand, and 6% fine and very fine sand as determined by dry sieving (McKeague 1978). Prior to samples being placed on it, the sand was put in a large plastic tray with a drainage spout for water, saturated with water and drained for 48 hours. Water content of sand at the time litter and organic matter samples were placed on it was 10.8% (SD 2.1%). After the cylinders drained for 48 hours, water content of the sand was 14.0% (SD 2.4%). Laboratory temperature was maintained at approximately 18° C and relative humidity at approximately 35%. Trays were covered with plastic to prevent evaporation and create a stable microenvironment.

After draining on the sand, the samples were weighed and oven dried at 105° C for 48 hours then re-weighed. Water holding capacity for each sample was determined by subtracting oven dry mass of its cylinder contents from its drained mass, dividing by oven mass, and multiplying by 100 ( $\text{g water/g litter (o.d.w.)} \times 100 = \% \text{ WHC}$ ). Upland core samples were treated in the same manner.

## Results

Within a treatment, WHC of litter and soil organic matter did not generally differ significantly with year, and plotted data are means of years. At all 3 sites, WHC of roots, standing litter, and coarse organic matter were higher than that of medium, fine, and very fine organic matter (Figs. 1, 2, and 3). WHC was generally

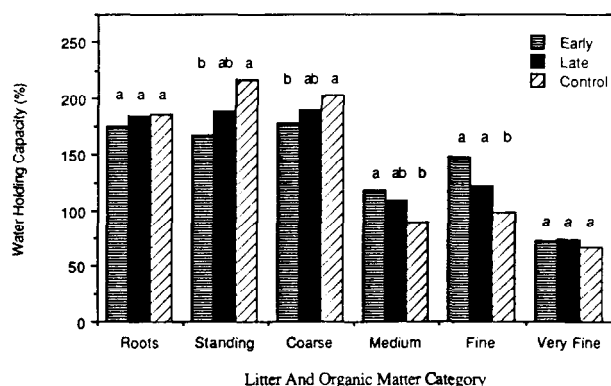


Fig. 1. Water holding capacity of roots, litter, and organic matter in mixed prairie. Within category, means with the same letters are not significantly different ( $P < 0.05$ ).

higher in fine than in medium or very fine organic matter.

WHC of mixed prairie roots, standing litter, and coarse organic matter ranged from 172 to 216% and that of fine, medium, and very fine organic matter from 68 to 148% of oven dry weight (Fig. 1). In parkland fescue, WHC of roots, standing litter, and coarse organic matter ranged from 180 to 258% and that of medium, fine, and very fine organic matter ranged from 78 to 148% (Fig. 2). In foothills fescue, WHC of roots, standing litter, coarse, and fine organic matter ranged from 200 to 254%, while that of medium and very fine organic matter ranged from 107 to 139% (Fig. 3).

WHC of undisturbed cores was affected more by intensity of grazing than by season of grazing (Table 1). In both fescue grasslands, WHC of cores was lower in heavy and very heavy treatments than in control or moderate treatments. In mixed prairie WHC did not differ significantly with treatment. WHC was highest in foothills fescue and lowest in mixed prairie.

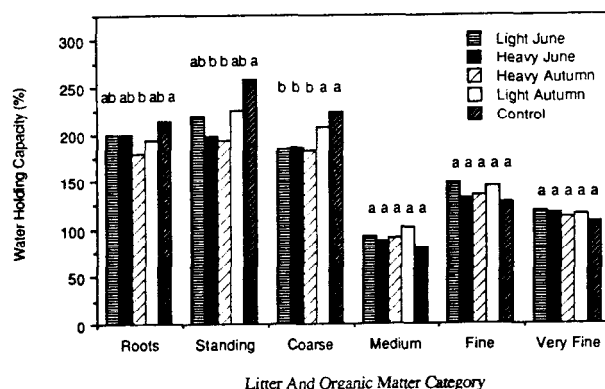


Fig. 2. Water holding capacity of roots, litter, and organic matter in parkland fescue. Within category, means with the same letters are not significantly different ( $P < 0.05$ ).

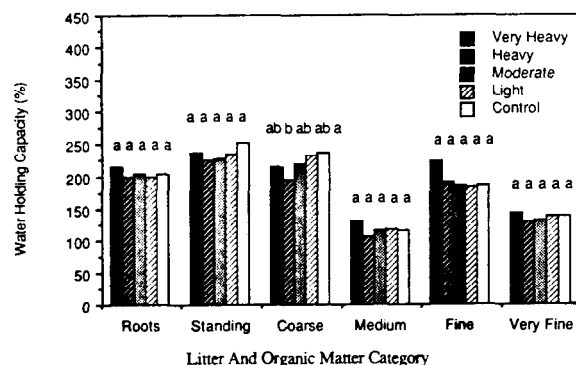


Fig. 3. Water holding capacity of roots, litter, and organic matter in foothills fescue. Within category, means with the same letters are not significantly different ( $P < 0.05$ ).

Grazing effects on WHC of litter and organic matter varied with site. At all 3 sites, coarse organic matter tended to have higher WHC in controls and light intensity and/or late season treatments such as light autumn in parkland fescue. WHC of coarse organic matter was lowest in heavy intensity and/or early season treatments. WHC of standing organic matter was affected by grazing treatment being highest in controls and lowest in early season and/or heavy intensity treatments.

Although not tested in this study, there was visual evidence of

Table 1. Water holding capacity of undisturbed litter and soil core samples (76 mm diameter and depth) at the study sites.

Site	Grazing Treatment	Water Holding Capacity (%)
Mixed Prairie	Early Season	42a
	Late Season	35a
	Control	43a
Parkland Fescue	Light June	69ab
	Heavy June	61b
	Heavy Autumn	64b
	Light Autumn	74ab
	Control	84a
Foothills Fescue	Moderate	133a
	Heavy	130b
	Very Heavy	124c

Within site, treatment means with the same letters are not significantly different ( $P < 0.05$ ).

hydrophobicity when wetting the litter and organic matter. Organic substances adsorbed on mineral particles were reported to confer hydrophobic properties on mineral soils (Debano and Letey 1969), reducing WHC.

## Discussion

WHC of roots, standing litter, and coarse organic matter were higher than those of medium, fine, and very fine organic matter because of larger amounts of material in a relatively undecomposed state in these former fractions. This is best explained by the work of Farmer (1978), who reported that soil organic matter occurs in 2 forms: discrete, largely organic particles and a molecular form on mineral surfaces. At saturation, the large organic particles with a wide range of pores hold up to twice as much water per volume as mineral soils. More highly decomposed organic matter of the molecular form would hold less water due to less pore space and adhesion in molecular form. Although very fine organic particles would have a greater surface area than larger particles and therefore hold more water, the higher porosity of the larger particles tends to offset this. The higher WHC of fine organic matter compared to medium and very fine organic matter is also related to particle size. The fine organic matter category contains the majority of small roots and root hairs and is thus largely in a relatively undecomposed state, capable of holding more water than the largely molecular organic matter in the medium and very fine categories.

Grazing treatment effects on WHC reflect changes in species composition caused by grazing and the effect of treading on litter decomposition rate. Soil characteristics had less effect since there were no significant within-site soil textural differences (Naeth 1988). There were no significant differences in soil bulk density among cores in mixed prairie (Naeth 1988). Significant differences did occur in both fescue grasslands. However, resulting differences in soil porosity contributed only a small fraction to the resultant WHC compared to differences attributable to litter. WHC of litter varies with grassland vegetation (Flory 1936, Weaver and Rowland 1952, Burgoyne and Pomeroy 1958, Corbett and Crouse 1968) and there were major vegetation changes due to grazing in mixed prairie (Naeth 1985), parkland fescue (Bailey et al. 1987), and foothills fescue (Johnston 1961, Johnston et al. 1971). Since grazing effects on WHC occurred where the greatest species composition differences were found—the control and early season grazing in mixed prairie, the control and heavy grazing in parkland fescue, and the control and light grazing compared to heavy grazing in foothills fescue—it can be stated that grazing affects WHC of litter and organic matter. This is partly explained by different cellulose and lignin contents of different species resulting in different decomposition rates (Norman 1933). Higher WHC of organic matter in the control is in part due to the absence of trampling which can break litter into smaller pieces, create better litter-soil contact, and facilitate more rapid decomposition (McCalla 1943). Thus there will be more large particle-sized litter in the control contributing to higher WHC. Zeller (1963) also found higher amounts of decomposed litter than fresh litter in grazed grasslands.

WHC in this study represents maximum available storage and the upper limits for precipitation held in organic matter mass. Although some differences in WHC of individual litter and organic matter categories occurred among grazing treatments, the overall effect of grazing on WHC of litter and organic matter in mixed prairie is likely small, since differences in WHC of whole cores were not detected in any treatment. In the fescue grasslands, whole core values show WHC of organic matter generally declines with heavy intensity grazing. From a soil conservation perspective this may be contradictory in that light grazing, which improves overall hydrologic condition (Naeth 1988), can lead to accumulation of organic

matter with higher WHC. However, the more beneficial effects of holding water as opposed to its running off the soil surface would tend to negate the higher WHC. Similar conclusions have been made by Lowdermilk (1930) and Weaver and Rowland (1952). The lack of significant grazing treatment effects on WHC of organic matter would indicate grazing treatment would not affect overall below-ground WHC. However, the higher WHC in the coarse litter in parkland fescue under light autumn grazing and in the control, and in the heavy grazing treatment in foothills fescue would indicate the above-ground litter would have the greatest effect on overall WHC. This is evidenced by the often lower surface soil water contents in the controls than in the grazed treatments for the study sites (Naeth 1988).

McCalla (1944) found decreases in dry weight and volume of litter were accompanied by increases in wetting speed in initial decomposition stages, which combined with higher WHC of larger sized organic matter, would mean greater absorption of precipitation. Greater masses of large sized organic matter per unit land area and higher ground cover in control and light intensity grazing treatments (Naeth 1988) could lead to higher interception and retention than in heavy intensity grazing treatments.

Biomass and cover have also been identified as sources of variation in interception by Clark (1940) and Thurow et al. (1987). Thurow et al. (1987) hypothesized that pilose blades and horizontal growth form of curlymesquite aided water retention, compared to the relatively vertical smooth blades of sideoats grama, but this was offset by a lower standing crop production potential. Thus interception storage capacity was greater for sideoats grama-dominated grasslands than for curlymesquite dominated grasslands. Similarly such biomass and growth forms may affect actual field interception and WHC of litter and organic matter in grasslands from this study, with that of mixed prairie vegetation being lower than that of the 2 fescue grasslands.

## Conclusions

- (1) WHC of litter and organic matter differed with ecosystem, being lower in mixed prairie than in fescue grasslands.
- (2) WHC differed with particle size of litter and organic matter. WHC of large particle-sized litter and organic matter was higher than that of small particle-sized litter and organic matter.
- (3) Grazing affected WHC of litter and organic matter with WHC in large particle-sized organic matter decreasing with heavy intensity and/or early season grazing, and WHC of small particle-sized organic matter being less affected by grazing treatment. WHC of undisturbed cores was affected more by intensity than season of grazing.
- (4) WHC of litter and organic matter, plant species composition, and amounts and kinds of organic matter are all key factors in determining the overall WHC of litter and soil organic matter layers in individual grasslands. WHC must be considered in hydrologic assessments and modelling of rangelands where small storms are a common form of precipitation since they may affect soil water especially in the near surface zone. The amount of large particle-sized organic matter relative to small particle-sized organic matter is a critical factor in determining the magnitude of WHC in the 3 grassland ecosystems examined.

## References

- Bailey, A.W., M.G. Willoughby, and B.D. Irving. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Proj. 84-0335.
- Beard, J.S. 1956. Results of the mountain home rainfall interception and infiltration project on black wattle, 1953-1954. J. So. Afr. Forest. 27:72-85.
- Bernard, J.M. 1963. Forest floor moisture capacity of the New Jersey pine barrens. Ecology 44:574-576.

- Burgy, R.H., and C.R. Pomeroy. 1958. Interception losses in grassy vegetation. *Trans. Amer. Geophys. Union.* 39:1095-1100.
- Canada Department of Agriculture. 1979. Glossary of terms in Soil Science. Can. Dep. Agr. Pub. 1459.
- Clark, O.R. 1940. Interception of rainfall by prairie grasses, weeds, and certain crop plants. *Ecol. Monog.* 10:243-277.
- Corbett, E.S., and R.P. Crouse. 1968. Rainfall interception by annual grass and chapparal. USDA Forest Serv. Res. Pap. PSW-48.
- Coupland, R.T. 1973. I Dynamics of aboveground standing crop. Tech. Rep. 27. Canadian Comm. for the International Biological Program. Saskatoon, Sask.
- Couturier, D.E., and E.A. Ripley. 1973. Rainfall interception in mixed grass prairie. *Can. J. Plant Sci.* 53:659-663.
- Debano, J.F., and J. Letey (eds.). 1969. Water-repellent soils. *Proc. of the Symp. on water-repellent soils.* Univ. of California. Riverside.
- Farmer, V.C. 1978. Water on particle surfaces. pp. 405-448. *In: The chemistry of soil constituents.* Greenland, D.J. and Hayes, M.H.B. (eds.). John Wiley and Sons. Chichester.
- Flory, E.L. 1936. Comparison of the environment and some physiological responses of prairie vegetation and cultured maize. *Ecology* 17:67-103.
- Haynes, J.L. 1940. Ground rainfall under vegetation canopy of crops. *J. Amer. Soc. Agron.* 32:176-184.
- Helvey, J.D., and J.H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of Eastern United States. *Water Resour. Res.* 1:193-206.
- Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Rep. 1987-4.
- Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. *Can. J. Plant Sci.* 41:615-622.
- Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on fescue grassland. *J. Range Manage.* 24:185-188.
- Kittredge, J. 1948. Forest influences. McGraw-Hill Book Co., New York, N.Y.
- Kittredge, J. 1955. Litter and forest floor of the chapparal in parts of the San Dimas Experimental Forest. *Hilgardia* 23:563-596.
- Kjearsgaard, A.A., W. Peters, and W.W. Pettapiece. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Rep. S-82-41.
- Lowdermilk, W.C. 1930. The influence of litter on run-off, percolation, and erosion. *J. Forest.* 28:474-491.
- McCalla, T.M. 1943. Microbiological studies of the effect of straw used as a mulch. *Trans. Kansas Acad. Sci.* 43:52-56.
- McCalla, T.M. 1944. Changes in the physical properties of straw during the early stages of decomposition. *Soil Sci. Soc. Amer. Proc.* 8:258-262.
- McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. Can. Soc. Soil Sci.
- Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. M.Sc. Thesis. Univ. of Alberta. Edmonton.
- Naeth, M.A. 1988. The impact of grazing on litter and hydrology in mixed prairie and fescue grassland ecosystems of Alberta. Ph.D. Diss. Univ. of Alberta, Edmonton.
- Norman, A.G. 1933. The natural decomposition of plant materials. *Sci. Prog.* 27:470-485.
- Pavlick, L.E., and J. Looman. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica*, *Festuca campestris* (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. *Can. J. Bot.* 62:1739-1749.
- Shapiro, S.S., and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52:591-611.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York.
- Thurrow, T.L., W.H. Blackburn, S.D. Warren, and C.A. Taylor Jr. 1987. Rainfall interception by midgrass, shortgrass, and live oak mottes. *J. Range Manage.* 40:455-460.
- Weaver, J.E., and N.W. Rowland. 1952. Effects of excessive natural mulch on development, yield, and structure of native grassland. *Bot. Gaz.* 114:1-19.
- Zeller, D.H. 1963. Certain mulch and soil characteristics in major range sites in western North Dakota as related to range condition. M.Sc. Thesis. North Dakota State Univ. Fargo.



# Applicability of the Kostiakov equation to mixed prairie and fescue grasslands of Alberta

M.A. NAETH, D.S. CHANASYK, AND A.W. BAILEY

## Abstract

The Kostiakov equation is of interest in rangeland hydrology because it is a simple 2 parameter equation with values of constants easy to determine from measured infiltration data, and because of its reasonable fit to infiltration data for many soils over short time periods. There is, however, some controversy in the literature regarding its applicability to rangelands.

The Kostiakov infiltration equation was examined to determine its suitability to characterize infiltration on mixed prairie and fescue grassland ecosystems in Alberta, Canada. The infiltration data from double ring infiltrometers fit the Kostiakov equation very well. Of 26 regressions, 10 had an  $R^2$  over 0.95 while another 8 had an  $R^2$  over 0.90. The average  $R^2$  for all data at a site was 0.931 for mixed prairie, 0.857 for parkland fescue, and 0.938 for foothills fescue grassland.

Changes in antecedent soil water and different grazing regimes altered the 2 equation parameters. Intercepts consistently declined with intensity and earliness in the growing season of grazing, although there were no consistent treatment trends with grazing. The Kostiakov equation is considered a good equation for infiltration in the 3 grassland ecosystems studied. Although parameter  $m$  had a narrow range of values for all 3 ecosystems and an average value from this study could be used, parameter  $a$  limits the equation and field testing is required for its determination.

**Key Words:** infiltration equation, infiltrometer, rangeland, hydrology

Infiltration is a key hydrologic process partitioning precipitation into soil water and runoff. The ability to model the impacts of grazing on the hydrologic regime is essential for efficient management of rangeland resources. Hydrologic models which can be used in making management decisions require accurate equations for infiltration. Several equations of the infiltration process are available, including Green-Ampt, Horton, Holtan, Philip, and Kostiakov.

The Kostiakov equation is a simple 2 parameter empirical equation (Kostiakov 1932). It relates infiltration to time as a power function:  $f = at^m$  where  $f$  = infiltration capacity;  $t$  = time elapsed since the start of infiltration; and  $a$  and  $m$  are coefficients. In logarithmic form the equation can be written as:  $\log f = \log a + m \log t$ . If  $\log f$  is plotted against  $\log t$ , a straight line should result if Kostiakov's equation applies. The intercept of the equation (infiltration rate at time  $t = 1$ ) is  $a$  and the slope is  $m$ . The lower the value of  $m$ , the flatter the slope and thus the lower the rate of decline of infiltration. The greater the value of  $a$ , the greater the initial infiltration value.

Interest in the Kostiakov equation stems from its simplicity, ease of determining values of the 2 constants from measured infiltration data, and its reasonable fit to infiltration data for many soils over

short time periods (Clemmens 1983). However at long elapsed times, resulting calculated infiltration rates approach zero while actual infiltration rates generally approach a steady value. Kostiakov (1932) indicated that the equation is no longer applicable once the characteristic steady infiltration rate has been attained. This limitation has been circumvented by development of the Kostiakov Branch equation which is useful for analyzing distribution uniformity, although determining constants becomes more difficult than with the simple Kostiakov formulation (Clemmens 1983). Another modification is to add constant infiltration rate to that calculated at all times.

Clemmens (1983) found the Kostiakov equation significantly better than the theoretical equations of Philip and Green-Ampt for border irrigation infiltration data. The  $r^2$  values were 0.950 for cumulative infiltration data sets, 0.856 for cumulative infiltration data sets from infiltration rings, and 0.727 for infiltration rate data from infiltration rings. Clemmens (1983) concluded that for most situations the simple Kostiakov equation was adequate to describe infiltration and when not adequate he recommended the Modified or Branch Kostiakov models which can account for a constant final infiltration rate.

Gifford (1976) found the Kostiakov equation did not fit infiltrometer data collected from semiarid rangelands in Australia or the United States.  $R^2$  values ranged from 0.48 for data from Australia to 0.13 for data from southern Utah. He found no consistent influence of antecedent moisture conditions on  $R^2$  values. Gifford (1978) concluded coefficients in Kostiakov's equation were related more to vegetation factors than to soil factors based on infiltrometer data run with soils pre-wet to field capacity prior to the infiltration test. Haverkamp et al. (1987) stated that although the Kostiakov equation showed a high level of precision up to the time limit, its application to predictive use becomes highly erroneous because of the reduction in precision with time, especially in coarse-textured soils.

The objective of this study was to investigate the suitability of the Kostiakov equation for characterizing infiltration data from double ring infiltrometers in mixed prairie and fescue grassland ecosystems of Alberta. The Kostiakov equation was chosen because of simplicity and the controversy in the literature surrounding its use in rangelands. In grassland ecosystems of Alberta, ponded infiltration conditions are believed to suitably represent natural conditions of generally low rainfall intensities and snowmelt. Vegetative cover and litter are generally high enough (Naeth 1988) to minimize the detrimental effects of raindrop impact on infiltration.

## Materials and Methods

### Study Sites

Three study sites representing major rangeland ecosystems of southern and central Alberta were selected. Each site had long-term grazing treatments, ungrazed controls, grass-dominated vegetation that had never been cultivated, and slopes of less than 2% (Naeth 1988).

The mixed prairie site was located near Brooks approximately 225 km east of Calgary (51° N and 112° W). The area has a

Authors are research associate, Department of Soil Science; professor, Department of Soil Science; and professor, Department of Plant Science, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3. At the time of the research, the senior author was a Ph.D. graduate student, Department of Plant Science, University of Alberta.

The authors wish to acknowledge the financial support of NOVA Corporation of Alberta. The Lethbridge Research Station of Agriculture Canada, the Eastern Irrigation District, and the University of Alberta are acknowledged for the use of their long-term grazing treatments.

Manuscript accepted 10 May 1990.



continental prairie climate and a semiarid moisture regime. Mean annual precipitation is 355 mm. Mean annual temperature is 4° C, with a July mean of 19° C and a January mean of -14° C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod (Natriboroll) developed on till (Kjearsgaard et al. 1982). Soil was loam textured in the uppermost 30 cm and clay loam below. Vegetation is of the Blue grama-Spear grass-Wheat grass (*Bouteloua-Stipa-Agropyron*) faciation, dominated by blue grama grass (*Bouteloua gracilis* Lag.), spear grass (*Stipa comata* Trin. & Rupr.), and western and northern wheat grasses (*Agropyron smithii* Rydb. and *dasystachyum* Hook.). Pasture sage (*Artemisia frigida* Willd.) and little clubmoss (*Selaginella densa* Rydb.) are common forbs. A short grass disclimax dominated by blue grama is common as a result of heavy long-term grazing.

The parkland fescue site was located near Kinsella approximately 150 km southeast of Edmonton (53° N and 111° W). The climate is dry subhumid. Mean annual precipitation is 422 mm. Mean annual temperature is 2° C, with a July mean of 17° C and a January mean of -17° C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems (Cryoboroll) developed on till. Soil was sandy clay loam textured in the uppermost 5 cm and loam to sandy loam below. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals. Rough fescue (*Festuca hallii* Vasey Piper) (Pavlick and Looman 1984) dominates open undisturbed grasslands and western porcupine grass (*Stipa curtisetia* Hitchc.) co-dominates on grazed areas. Forbs are a common component of the vegetation.

The foothills fescue grassland site was located near Stavely approximately 100 km south-southwest of Calgary (50° N and 114° W). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5° C, with a July mean of 18° C and a January mean of -10° C. Elevation averages 1,350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems (Haploboroll) developed on till (Johnston et al. 1971). Soils were clay loam textured in the uppermost 30 cm and loam to clay loam below (Naeth 1988). Vegetation is of the fescue grassland association with rough fescue (*Festuca campestris* Rydb.) dominating in the undisturbed and lightly grazed areas. Parry's oat grass (*Danthonia parryi* Scribn.) and bluebunch fescue (*Festuca idahoensis* Elmer) are co-dominants in grazed areas. Under heavy grazing regimes, rough fescue is replaced by annual invaders and bluegrass (*Poa* L.) species.

#### Grazing Treatments

In mixed prairie, 3 grazing treatments were studied within a community pasture established in 1964: (1) early season grazing from May through July; (2) late season grazing from August through October; and (3) a control ungrazed since the late 1930s. The stocking rate was heavy at 0.9 AUM ha<sup>-1</sup>. There was 7.0% bare ground under early season grazing, 4.0% under late season grazing, and 1.5% in the control.

In parkland fescue, 5 grazing treatments established in 1973 on the University of Alberta ranch were studied: (1) light June grazing from June 1 to 30 at 1.5 AUM ha<sup>-1</sup>; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha<sup>-1</sup>; (3) heavy autumn grazing from 15 September to 15 October at 4.4 AUM ha<sup>-1</sup>; (4) light autumn grazing from 15 September to 15 October at 1.5 AUM ha<sup>-1</sup>; and (5) a control ungrazed since 1942 (Bailey et al. 1987). There was 0.0% bare ground under light June grazing, light autumn grazing, and the control, 2.0% under heavy June grazing, and 0.5% under heavy autumn grazing.

In foothills fescue, 5 grazing treatments established in 1949 on the Agriculture Canada Range Research Substation and grazed

May through September were studied: (1) very heavy grazing at 4.8 AUM ha<sup>-1</sup>; (2) heavy grazing at 2.4 AUM ha<sup>-1</sup>; (3) moderate grazing at 1.6 AUM ha<sup>-1</sup>; (4) light grazing at 1.2 AUM ha<sup>-1</sup>; and (5) a control comprised of permanent exclosures in each treatment (Johnston et al. 1971). There was 14.5% bare ground under very heavy grazing, 10.5% under heavy grazing, 1.0% under moderate grazing, 0.5% under light grazing, and 0.0% in the control.

#### Infiltration Tests

Infiltration data were collected in late July 1985 and 1986 using double ring infiltrometers with outside diameters of approximately 63 cm and inside ring diameters of approximately 33 cm. Water was added to the rings to maintain a head of 5 to 8 cm. Float readings were started the first minute after the rings were filled. Subsequent readings were taken every minute in the first 5 minutes, at 7 minutes, at 10 minutes, and every 5 minutes thereafter until a steady rate was achieved. The tests were usually terminated after 1 hour. Six infiltration tests in 1985 and 9 in 1986 were conducted in each treatment at each site, except in the Stavely control in 1986 when 12 tests were conducted.

Soil water and bulk density for the uppermost 7.5 cm were measured immediately adjacent to the rings at the time of the infiltration tests using a surface/moisture density gauge. Degree of saturation (%) at the time of infiltration was calculated using bulk density and soil water, assuming a particle density of 2.65 Mg m<sup>-3</sup>. A best fit regression line for the averaged data was fit for log infiltration rate versus log time, up to an elapsed time of 40 min, and slope intercept of the regression lines were determined.

#### Results and Discussion

Near-surface soil bulk densities in parkland fescue and foothills fescue were less than 1.00 Mg m<sup>-3</sup>, with soil porosities of 60 to 70%. Bulk densities in mixed prairie were slightly higher, averaging 1.10 Mg m<sup>-3</sup>, with porosities of 56 to 61%. Degrees of soil saturation at the time of the infiltration tests were higher in 1986 than in 1985 (Table 1).

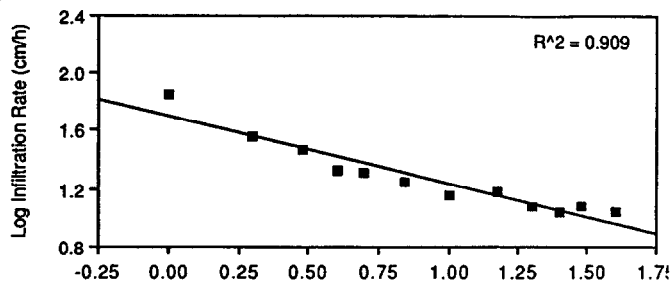
Table 1. Degree of saturation (%) at time of infiltration tests.

Site	Grazing Treatment	Year	
		1985	1986
Mixed Prairie	Early Season	18.5	24.0
	Late Season	16.0	28.1
	Control	22.4	26.3
Parkland Fescue	Light June	48.9	67.0
	Heavy June	50.5	66.2
	Heavy Autumn	44.3	61.6
	Light Autumn	26.0	58.1
	Control	27.4	46.5
Foothills Fescue	Very Heavy	24.9	26.0
	Heavy	24.7	31.0
	Moderate	22.7	29.0
	Light	23.0	33.1
	Control	21.8	28.9

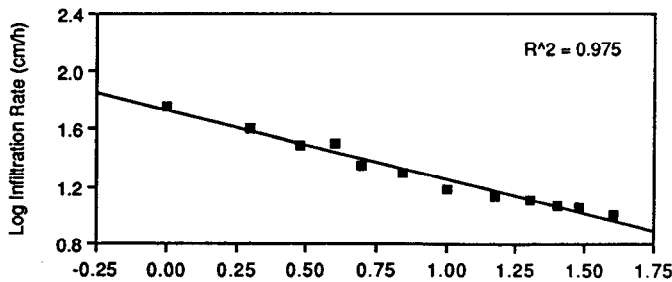
The Kostikov equation fit double ring infiltration data from the 3 ecosystems very well (Fig. 1). Of 26 regressions, 10 had an  $R^2$  over 0.95 while another 8 had an  $R^2$  over 0.90. The average  $R^2$  for all data at a site was 0.931 for mixed prairie, 0.857 for parkland fescue, and 0.938 for foothills fescue. The lower  $R^2$  values for parkland fescue are likely due to soil profile heterogeneity caused by a gravelly layer at a depth of approximately 10 cm.

Infiltration capacity generally decreases with increased grazing intensity and reduced range condition (Blackburn 1984). In the 3

(a) Mixed Prairie



(b) Parkland Fescue



(c) Foothills Fescue

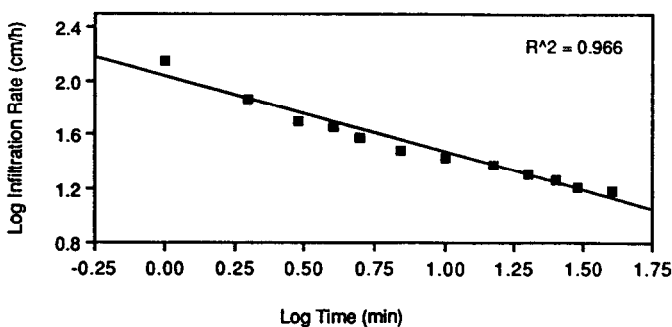


Fig. 1. Best fit infiltration line for averaged data from the ungrazed controls in (a) mixed prairie, (b) parkland fescue, and (c) foothills fescue in 1985.

study sites, infiltration capacity was affected by grazing intensity and season of grazing, being lower under early season and/or heavy intensity treatments than under late season and/or light intensity treatments (Naeth 1988). The Kostiakov equation was sensitive to these changes in infiltration capacity brought about through grazing treatments. Both intercepts and slopes in all 3 grasslands were affected by grazing treatment and antecedent soil water. In mixed prairie the lowest slopes were in the control, with the lowest intercepts in the early season grazed treatment (Table 2). In parkland fescue the lowest slopes were in the heavy June grazed treatment and the lowest intercepts were in the light June or heavy

Table 2. Infiltration equation parameters and  $R^2$  values for mixed prairie.

Year	Parameter	Early Season Grazed	Late Season Grazed	Control (Ungrazed)
1985	slope (m)	-0.495	-0.573	-0.437
	intercept (a)	36.3	46.3	43.7
	$R^2$	0.952	0.951	0.869
1986	slope (m)	-0.522	-0.531	-0.447
	intercept (a)	37.7	47.0	49.0
	$R^2$	0.951	0.951	0.910

June grazed treatments (Table 3). In foothills fescue the lowest slopes were in the light grazed treatment and the lowest intercept was in the very heavy grazed treatment (Table 4). Intercept consistently declined with intensity and earliness in the growing season of grazing for all 3 ecosystems. There were no consistent treatment trends for slopes.

Table 3. Infiltration equation parameters  $R^2$  values for parkland fescue.

Year	Parameter	Light June Grazed	Heavy June Grazed	Heavy Autumn Grazed	Light Autumn Grazed	Control (Ungrazed)
1985	slope (m)	-0.655	-0.364	-0.537	-0.476	-0.496
	intercept (a)	43.8	27.7	49.1	51.9	55.2
	$R^2$	0.907	0.803	0.879	0.892	0.974
1986	slope (m)	-0.494	-0.189	-0.309	-0.354	-0.316
	intercept (a)	13.4	13.6	18.5	23.8	22.9
	$R^2$	0.843	0.680	0.850	0.934	0.804

The influence of increasing soil water on both slope and intercept is dramatically shown for parkland fescue. The average reduction in slope was 35% and average reduction in intercept was 59% for an increase in average degree of soil saturation from 39.4 to 60.0% (Table 3). Greatest year-to-year soil water differences at the time of the infiltration tests were in the light autumn treatment in parkland fescue (Table 1). The 227% increase in soil water reduced the intercept by 54% and the slope by 25% (Fig. 2 and Table 3).

In 1985, degree of soil saturation in foothills fescue at the time of the infiltration tests was similar for all treatments (Table 1).  $R^2$  of 0.973, 0.916, and 0.942 were obtained for the fit of the Kostiakov equation in the very heavy grazed, light grazed, and control treatments, respectively (Fig. 3). Slopes were not dramatically different among treatments, but the intercepts declined from 105.7 to 48.4  $\text{cm h}^{-1}$  as grazing intensity increased (Table 4). Data for the very heavy grazed treatment in foothills fescue for the 2 study years can be used to indicate possible year-to-year variation in equation parameters (15% for slope and 16% for intercept) since degree of soil saturation for this treatment in both years was similar (24.9% versus 26.0%).  $R^2$  were identical for both years (Table 4).

The range of values for  $m$  for all 3 ecosystems was narrow (Tables 2, 3, and 4). From a modelling perspective this is important in that an average value for  $m$  obtained from this study could be

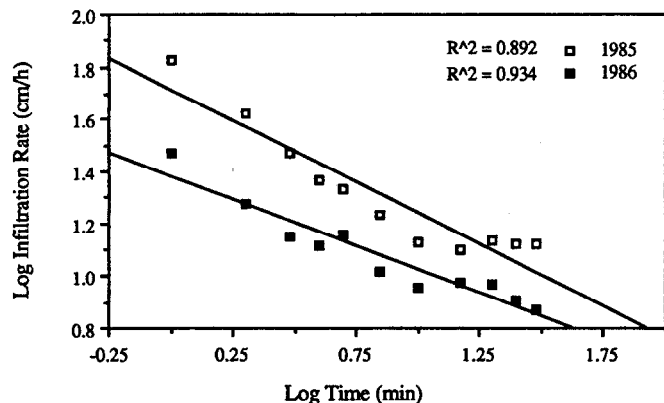


Fig. 2. Infiltration under light autumn grazing in parkland fescue in 1985 and 1986.

**Table 4. Infiltration equation parameters  $R^2$  values for foothills fescue.**

Year	Parameter	Very Heavy Grazed	Heavy Grazed	Moderate Grazed	Light Grazed	Control (ungrazed)
1985	slope (m)	-0.453	-0.598	-0.497	-0.436	-0.561
	intercept (a)	48.4	61.1	71.3	73.8	105.7
	$R^2$	0.973	0.935	0.921	0.916	0.942
1986	slope (m)	-0.519	-0.624	-0.575	-0.444	-0.493
	intercept (a)	40.8	54.6	56.4	58.3	84.3
	$R^2$	0.974	0.942	0.960	0.927	0.925

used. However, this not true for a since this parameter varies quite dramatically with soil water and intensity and season of grazing. As a result parameter a becomes the limiting parameter and field testing is required for its determination.

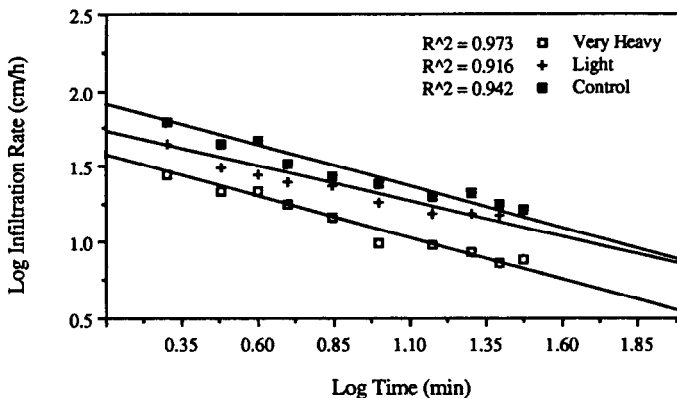
These results do not support the work of Gifford (1976), who found the Kostiakov equation did not fit infiltration data for the United States and Australian rangelands. This discrepancy may be due to the differences in the ecosystems or to the fact that data from double ring infiltrometers were evaluated in this study, whereas Gifford used data obtained from rainfall simulators. Differences in pre-treatment strategies may also have contributed to the discrepancy. Some of Gifford's tests were pre-wet and others were not. All tests in this study were run at field water contents to reflect field conditions. Also in this study, infiltration rates were determined directly; in Gifford's study infiltration rates were calculated by difference.

### Conclusions

The infiltration data from mixed prairie and fescue grassland ecosystems of Alberta fit the Kostiakov equation quite well. Changes in antecedent soil water and intensity and season of grazing affected the intercept much more than the slope. Intercepts consistently declined with intensity and earliness in the growing season of grazing, although there were no consistent treatment trends for slopes.

### References

Bailey, A.W., M.G. Willoughby, and B.D. Irving. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Rep Proj. 84-0335.



**Fig. 3. Infiltration in foothills fescue in 1985 in the very heavy grazed, light grazed, and control treatments.**

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses. P. 927-983 *In*: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London.

Clemmens, A.J. 1983. Infiltration equations for border irrigation models. P. 266-274. *In*: Advances in infiltration. Proc. Nat. Conf. on Advances in Infiltration. Dec. 12-13, 1983. Chicago, Ill. ASAE Pub. 11-83. St. Joseph Mo.

Gifford, G.F. 1976. Applicability of some infiltration formulae to rangeland infiltrometer data. J. Hydrol. 28:1-11.

Gifford, G.F. 1978. Use of infiltration equation coefficients as an aid in defining hydrologic impacts of range management schemes. J. Range Manage. 31:115-117.

Haverkamp, R., L. Rendon, G. Vachaud. 1987. Infiltration equations and their applicability for predictive use. P. 142-152. *In*: Infiltration development and application. Proc. Internat. Conf. Infiltration Development and Application. Yu-SI Fok (ed.). Jan. 6-9, 1987. Honolulu, Hawaii.

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Rep. 47. Alberta Research Council Open File Rep. 1987-4.

Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on fescue grassland. J. Range Manage. 24:185-188.

Kjearsgaard, A.A., W. Peters, and W.W. Pettapiece. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Rep. S-82-41.

Kostiakov, A.N. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. *In*: Trans. 6th Comm. Int. Soc. Soil Sci. Russian Part A:17-21.

Naeth, M.A. 1988. The impact of grazing on litter and hydrology in mixed prairie and fescue grassland ecosystems of Alberta. Ph.D. thesis. Univ. Alberta, Edmonton.

Pavlick, L.E., and J. Looman. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica*, *Festuca campestris* (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

# Response of tap- and creeping-rooted alfalfas to defoliation patterns

ABDALLA O. GDARA, RICHARD H. HART, AND JOHN G. DEAN

## Abstract

Under grazing, creeping-rooted alfalfa (*Medicago sativa* L.) cultivars have been reported to be more productive and have higher survival than tap-rooted cultivars. To determine if differences in persistence could be related to response to defoliation patterns, we clipped 3 tap- and 3 creeping-rooted alfalfa cultivars. Different fractions of the total number of stems were clipped to different stubble heights every 21 days. Both tap- and creeping-rooted cultivars responded similarly to defoliation. Maximum forage production was obtained when one-third of the stems on a plant were cut back to 5 cm above the ground at each harvest. The lowest forage production was obtained when all stems on a plant were cut back to 5 cm. The most lenient defoliation (one-third of the height of one-third of the stems removed at each harvest) maximized total herbage production (forage plus stubble) but only 32% of the herbage was harvested as forage, leaving 68% as unharvested stubble. Severe defoliation every 21 days decreased the concentration of total nonstructural carbohydrate in the roots and reduced total root biomass. Thirteen alfalfa cultivars responded similarly to grazing when seeded in dense stands. The greater persistence of creeping-rooted alfalfa cultivars under grazing does not appear to be a result of greater intrinsic productivity or more rapid recovery from defoliation. The lateral spread of individual creeping-rooted plants in open stands may increase the probability that some stems will escape defoliation at each grazing; these stems then contribute to rapid recovery from grazing and to plant survival.

**Key Words:** *Medicago sativa* L., grazing, clipping, root reserves, survival, forage production

Alfalfa (*Medicago sativa* L.) has been grazed for many years in different areas of the world with varying degrees of success. However, stand deterioration is common when alfalfa is grazed. Alfalfa cultivars differ in type of root or crown, stem number, stem height, extent of axillary branching, and site and activity of regrowth; all these characteristics may influence their response to grazing.

Newly developed cultivars of rhizomatous or creeping-rooted alfalfas have been reported to survive longer and produce more forage under grazing than tap-rooted alfalfas (Clark 1960, Kilcher and Heinrichs 1966, Ashford and Heinrichs 1967, Daday 1968, Rumbaugh and Pedersen 1979, Counce et al. 1984, Heinrichs and Bolton 1985, Berdahl et al. 1989, Smith et al. 1989). In contrast, Leach (1969) reported that creeping-rooted alfalfa cultivars had no advantage in either production or survival when grazed in Australia. He also pointed out that the effect of grazing on alfalfa depended on the time, intensity, and frequency of defoliation.

Our objectives were to evaluate the forage production of creeping-rooted and tap-rooted alfalfas under lenient to severe clipping, and to relate the survival of cultivars under actual grazing to their responses to grazing simulated by clipping.

Authors are former research assistant, Range Science Dept., Colorado State University, Fort Collins 80523; and range scientist and agronomist (deceased), USDA, Agricultural Research Service, High Plains Grasslands Research Station, Cheyenne, Wyo. 82009. Gdara's current address is 18565A East Colima Road, Rowland Heights, Calif. 91748.

Manuscript accepted 21 April 1990.

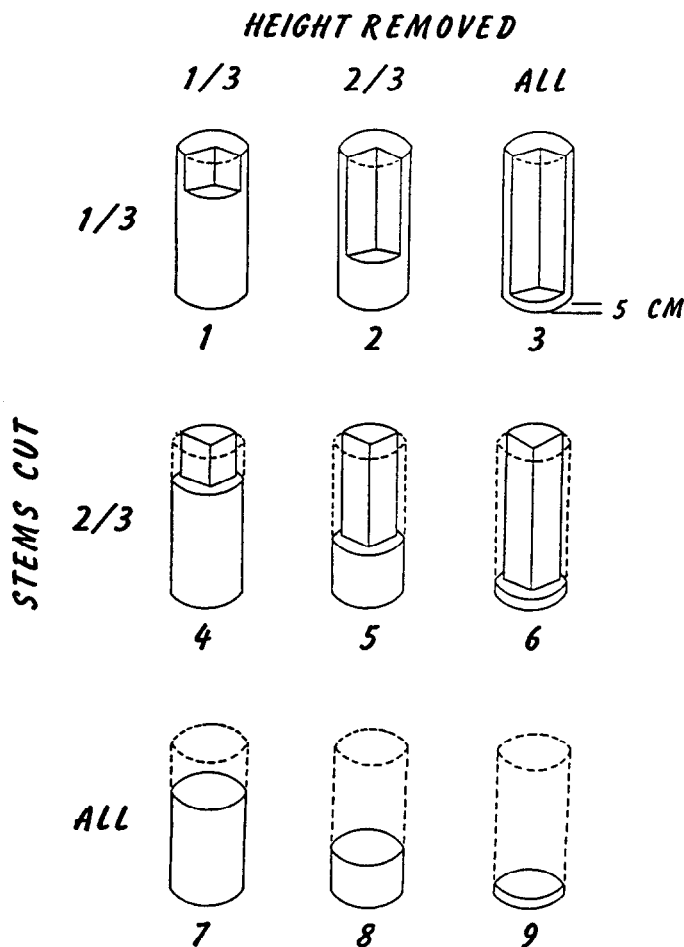


Fig. 1. Clipping treatments: dotted lines indicate portions removed.

## Materials and Methods

Two studies were conducted at the USDA-ARS High Plains Grasslands Research Station near Cheyenne, Wyoming (latitude 41° 11' N, longitude 104° 54' W) during 1978–1980. Elevation of the study area is 1,885 m. Mean annual temperature is 9° C, with January having the lowest mean monthly temperature (–3° C) and July the highest (20° C). Length of frost-free growing season is approximately 127 days per year, but considerable alfalfa growth may occur before the last frost of spring and after the first frost of fall. April–September precipitation averages 272 mm; April–September precipitation was 276 mm in 1978, 339 mm in 1979, and 200 mm in 1980.

The experiments were established on irrigated Archerson sandy clay loam (Aridic Argiustoll). Analysis of the soil from the 0–15 cm depth showed 230 kg N ha<sup>–1</sup>; 60 kg P ha<sup>–1</sup>; 140 kg K ha<sup>–1</sup>; 1,070 kg Ca ha<sup>–1</sup>; 80 kg Mg ha<sup>–1</sup>; and a pH of 7.5

The 13 alfalfa cultivars tested were: 'Drylander', 'NC-Cr1', 'Roamer', 'Travois', and 'Victoria' with creeping roots and the

**Table 1. Total dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars under 9 cutting treatments during 1979 (3 cuts).**

Cultivar	Treatment number								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1/3 of stems cut			2/3 of stems cut			All stems cut		
	Fraction of height (above 5 cm) removed								
	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All
g/plant									
Creeping-rooted									
Drylander	34a	82ab	149ab	52a	77a	69a	41a	37a	28a
Roamer	50a	123a	169a	71a	69a	61a	52a	32a	34a
Travois	40a	61b	102b	79a	71a	71a	52a	40a	45a
Tap-rooted									
Agate	43a	63b	107b	45a	61a	72a	43a	43a	34a
Vernal	36a	90ab	119ab	40a	63a	88a	51a	38a	42a
WL 307	21a	45b	129a	48a	74a	71a	47a	41a	32a
Mean	36D	77B	127A	56BCD	69BC	72B	48CD	39D	36D

a, A Cultivar × treatment means in the same column followed by the same lower-case letter and cutting treatment or cultivar means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test).

ability to produce stems on these creeping or laterally spreading roots: 'Teton' with rhizomes; and 'Agate', 'Baker', 'Kanza', 'Ramsey', 'Riley', 'Vernal', and 'WL307' with taproot systems.

#### The Clipping Experiment

Six alfalfa cultivars (Drylander, Roamer, Travois, Agate, Vernal, and WL307) were seeded in the greenhouse on 10 June 1978 in sandy loam soil in clay pots 15 cm across and 15 cm deep. The seeds were scarified and inoculated with *Rhizobium* immediately before planting 1 seed per pot. Forty-five days after seeding, the plants were transplanted to the field. Each plot of 1 m<sup>2</sup> consisted of 2 plants spaced 30 cm apart. A randomized complete block design with 4 replications was used. Each replication contained 54 plots (6 cultivars × 9 treatments).

Clipping treatments were classified according to the fraction of the total number of stems that were clipped (1/3, 2/3, or all) and the fraction of the height above 5 cm that was removed from the clipped stems (1/3, 2/3, or all). Combinations of number of stems clipped and height of clipping produced 9 cutting treatments (Fig. 1).

Plants were clipped 4 June, 28 June, and 19 July in 1979; a severe hailstorm 31 July removed all top growth to ground level and precluded further clipping. In 1980, plants were clipped 28 May, 18 June, 9 and 30 July, and 19 August, and the aftermath remaining after the last clipping was harvested to ground level on 3 Sep-

tember. Clipped forage was dried 48 hr at 70° C, and the dry weight was recorded.

In both years, the alfalfa plants were first clipped at 10% bloom; Smith (1972) concluded grazing should be delayed until this stage to maintain productive stands. The optimum interval between defoliations is 35–45 days (Smith 1972, Irvine and McElgunn 1982), but the 21-day interval was chosen to increase defoliation stress and accelerate the response to clipping.

Crowns on each plant under treatments 1 through 6 were divided into 3 equal sectors. Under treatments 1, 2, and 3, we clipped all stems from sector 1 at the first clipping, sector 2 at the second clipping, sector 3 at the third, sector 1 at the fourth, and sector 2 at the fifth. Under treatments 4, 5, and 6, we clipped all stems from sectors 1 and 2 at the first clipping, sectors 3 and 1 at the second clipping, sectors 2 and 3 at the third, etc. Under treatments, 7, 8, and 9 all stems were clipped at each clipping.

At the end of the experiment, on 10 September 1980, main crowns and tap roots to a depth of 30 cm were collected from all tap-rooted plants. Samples of creeping roots were randomly selected on creeping-rooted plants. The samples were dried and analysed for total nonstructural carbohydrate (TNC) by a modification of the method of Smith (1969). Amylglucodiase enzyme was used to hydrolyse starch and a colorimetric procedure was used to determine reducing power.

**Table 2. Total dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars under 9 cutting treatments during 1980 (5 cuts).**

Cultivar	Treatment number									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	1/3 of stems cut			2/3 of stems cut			All stems cut			
	Fraction of height (above 5 cm) removed									
	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All	Mean
	g/plant									
Creeping-rooted										
Drylander	220	306	382	256	272	231	256	85	66	230
Roamer	171	354	494	306	244	208	269	86	76	245
Travois	156	362	341	319	268	251	180	79	92	228
Tap-rooted										
Agate	209	242	423	203	278	285	166	120	83	232
Vernal	158	381	349	244	226	206	279	134	85	229
WL 307	152	205	377	233	256	342	236	72	58	215
Mean	178C	308B	394A	260B	257B	254BC	231BC	96D	77D	

A, B Cutting treatment means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test). Cultivar and cultivar × treatment means are not significantly different.

Table 3. Aftermath dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars following 5 cuts under 9 cutting treatments in 1980.

Cultivar	Treatment number									Mean
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	1/3 of stems cut			2/3 of stems cut			All stems cut			
	Fraction of height (above 5 cm) removed									
	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All	
g/plant										
Creeping-rooted										
Drylander	473	179	124	206	103	64	173	36	18	153
Roamer	333	199	123	272	67	48	150	35	19	139
Travois	265	181	72	229	84	65	76	39	18	114
Tap-rooted										
Agate	453	111	80	196	83	60	118	28	15	129
Vernal	169	212	77	169	63	35	206	32	17	142
WL 307	314	96	75	187	56	58	157	14	15	108
Mean	368A	163B	92BC	210B	76C	55C	147B	31C	17C	

A,B Cutting treatment means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test). Cultivar and cultivar  $\times$  treatment means are not significantly different.

### The Grazing Study

All 13 alfalfa cultivars were used in this study. They were drill-seeded in June 1978 in the field at 7 kg/ha of pure live seed. Plots consisted of 5 rows 8 m long and 25 cm apart, in a randomized complete block design with 5 replications. Ranger alfalfa was seeded around the outside of the plot area to create a total area of alfalfa of 0.3 ha.

This area was grazed by 3 ewes on 25–29 June, and 2–7 and 9–14 July 1979; all remaining forage was clipped with a rotary mower 16 July and the area was grazed again 8–29 August. In 1980, the area was grazed by 5 ewes 27 May–14 June, 7–25 July, and 18–31 August. Stocking rates were equivalent to 11 animal-months/ha during the 1979 growing season and 26 animal-months/ha during the 1980 growing season. Ewes weighed 55 to 70 kg each. The percentage of row covered by plant crowns (basal cover) was estimated visually on 4 permanent 1-m plots in each of the 3 center rows of each plot on 18 September 1978, 16 June and 22 September 1979, and 22 May and 20 September 1980.

### Data Analysis

Analyses of variance and F-tests were performed on the forage dry matter yields of 1979, 1980, and both years together; on aftermath yields of 1980; on row cover; and on the TNC data. Tukey's test at the 0.05 level was used to separate means.

Row cover at the end of the 1980 grazing season was analyzed by covariance, using 1978 row cover as the covariate. Adjusted means were separated by Tukey's test at the 0.05 level.

## Results

### Yield, Survival, and Root TNC Concentration under Clipping

In 1979 treatment 3, in which one-third of the stems of each plant were cut at 5 cm above ground level while the other two-thirds were left uncut at each of the 3 clipping dates, produced the greatest forage dry matter (DM) yield (Table 1). Production was significantly reduced below treatment 3 when only two-thirds of the height was removed from one-third of the stems at each harvest (treatment 2). Cutting two-thirds of the stems at each harvest (treatments 4, 5, and 6) produced the same amount of forage DM as treatment 2, regardless of the fraction of height removed. Cutting all stems at each harvest (treatments 7, 8, and 9) produced no more forage DM, again regardless of height, than removing only one-third of the height of one-third of the stems at each harvest (treatment 1).

No significant differences were found among cultivar means. The only significant interaction found was among cultivars and treatments 2 and 3. Under both treatments, Roamer produced

more forage than Agate or Travois, but under treatment 2 Roamer also produced more than WL 307.

In 1980, clipping effects on yield (Table 2) were similar to those in 1979. Treatment 3 again produced the highest forage yield, followed by treatments 2, 4, 5, and 6, which were not significantly different. But in 1980, removing one-third of the height of all stems on each plant (treatment 7) produced as much forage as any treatment except treatment 3 and more forage than removing two-thirds or all of the height from all the stems (treatments 8 and 9). Differences among cultivars and the cultivar  $\times$  treatment interaction were not significant.

All 6 cultivars under all treatments produced higher forage DM yields from the first 3 cuttings in 1980 than in 1979 when only 3 cuttings were taken. Mean yields from 3 cuts were 142 and 62 g/plant, respectively. Plants were a year older in 1980 and capable of much higher yields. All plants established in 1978 survived through 1980, regardless of clipping treatment.

The most lenient cutting treatment, treatment 1, was also the least productive treatment in 1979, and in 1980 produced more forage than only treatments 8 and 9. Most of the production under treatment 1 remained in the uncut stubble, which contained more DM than that of any other treatment at the end of the season (Table 3). Less DM remained in stubble when two-thirds or all of the height of cut stems was removed than when only one third was removed, and when two-thirds or all of the stems were harvested rather than only one-third. No significant differences were found among stubble yields of the 6 cultivars.

Cultivars and the cultivar  $\times$  treatment interaction had no effect on total nonstructural carbohydrate (TNC) concentrations in roots. Roots from treatment 1 had the highest TNC concentration of 42.5%, followed by treatment 7 with 42.2%; 2, 41.8%; 4, 41.4%; 3, 40.8%; 5, 39.9%; 6, 38.9%; 8, 35.1%; and 9, 33.6%. Concentrations of TNC under treatments 8 and 9, the most severe cutting treatments, were significantly less than concentrations under other treatments.

Although roots of adjacent plants were so intermingled that an accurate root weight could not be obtainable, field observations indicated that root systems of all alfalfa cultivars tested became much smaller under more intensive clipping. Cutting alfalfa every 3 weeks not only reduced the rate of regrowth and decreased the yield, but also decreased the TNC concentration and reduced root growth which together reduced the total amount of TNC in the roots.

### Cover under Grazing

Data collected in 1978 on stand establishment indicated significant differences among alfalfa cultivars. Crowns of WL 307 pro-

duced the highest percentage of basal cover in the row, Riley the least, and Ramsey, Vernal, NC-Cr1, Roamer, Agate, Victoria, Travois, Kanza, Drylander, Baker, and Teton intermediate, with no differences among them (Table 4).

**Table 4. Proportion of row covered by crowns of 6 creeping-rooted and 7 tap-rooted alfalfa cultivars, 1978–1980.**

Cultivar	---- 1979 ----		----- 1980 -----			
	1978	Pre- grazing	Post- grazing	Pre- grazing	- Post-grazing - Actual	Adjusted <sup>1</sup>
----- % Row cover -----						
<b>Creeping-rooted</b>						
Drylander	62bc	47	47	50	48	48b
NC-Cr1	69b	47	51	59	50	51ab
Roamer	68b	47	51	61	48	50ab
Teton	61bc	56	56	66	53	50ab
Travois	63bc	64	59	72	55	48b
Victoria	64bc	53	47	54	43	48b
<b>Tap-rooted</b>						
Agate	63bc	50	48	59	53	50ab
Baker	61bc	36	37	44	38	48b
Kanza	63bc	38	44	50	46	52ab
Ramsey	70b	51	63	62	55	52ab
Riley	57c	34	37	41	36	48b
Vernal	69b	52	54	64	56	51ab
WL 307	83a	70	69	75	67	56a

<sup>1</sup>Adjusted for initial differences in row cover.

a, b Means or adjusted means in the same column followed by the same letter are not significantly different (0.05 level, Tukey's Test). Unadjusted means in 1979 and 1980 were not analysed.

During the 1979 growing season, when the study area was grazed at a stocking rate of 11 animal-months/ha, sheep grazed primarily on leaves and branches; thick stems were left ungrazed and were removed by clipping. Sheep were observed to prefer Drylander and Travois first; Agate, Kanza and WL 307 last; and other cultivars in between. This result seems to be related to the thinner stems of Drylander and Travois, which are creeping-rooted cultivars, compared to the thick stems of Agate, Kanza and WL 307, which are tap-rooted cultivars.

During the 1980 growing season, when the study area was grazed at 26 animal-months/ha, sheep grazed the alfalfa plants more heavily than in 1979. Although they grazed on leaves and branches first, stems also were grazed. No appreciable amount of stubble was left at the end of each grazing period in 1980, although some stubble had been left after grazing and before clipping in 1979.

After 2 years of grazing, WL-307 (tap-rooted) had maintained more basal cover in the row (adjusted for 1978 levels) than Drylander, Travois, Victoria (all creeping-rooted), Baker, or Riley (both tap-rooted). All other cultivars were intermediate, with no differences among them.

## Discussion and Conclusions

Folkens et al. (1961) reported that the yield of creeping-rooted Rhizoma was not significantly different from that of tap-rooted 'Grimm' over 5 years. Irvine and McElgunn (1982) reported that yields of tap-rooted 'Beaver' alfalfa were not significantly different from yields of creeping-rooted Roamer. On the other hand, Langille et al. (1965) found that Rhizoma yielded more than tap-rooted 'DuPuits' when the first cut was taken at a pre-bud stage followed by 2 cuts at the 50% flowering stage. Among tap-rooted cultivars, Kehr et al. (1963) found that adapted narrow-crowned alfalfa cultivars generally produced higher yields than did broad-crowned or creeping-rooted cultivars. Broad-crowned alfalfa cultivars were found to persist better than narrow-crowned cultivars under shorter intervals between harvests (Jung et al. 1969; Jones 1971). Yields

of alfalfa cultivars may show a strong cultivar × defoliation frequency interaction, particularly if cultivars vary in their adaptation to the area where they are tested.

As expected, forage production declined as intensity of defoliation increased (Graber et al. 1927, Smith 1972, Irvine and McElgunn 1982). But all cultivars, tap- or creeping-rooted, responded the same.

Again as expected, TNC concentrations in roots decreased as the intensity of defoliation increased (Graber et al. 1927, Smith 1972, Chatterton et al. 1974). TNC reserves in the roots of alfalfa plants are used to produce new top growth, and the decrease in TNC concentration continues until the plant has produced about 15 to 20 cm of new top growth (Smith 1972). Frequent or prolonged grazing does not permit enough top growth to persist for long enough to restore root carbohydrates, slowing recovery from defoliation and reducing forage production and plant survival. These effects can persist into the following year (Allen et al. 1986a and 1986b). But we found no differences among individual cultivars or between tap- and creeping-rooted cultivars.

Our study revealed no significant differences in forage production, survival, or root TNC concentrations between creeping- and tap-rooted alfalfas. Yet survival of the creeping-rooted cultivars 'Nomad' and 'Rhizoma,' after 7 years of grazing at Grouse Creek, Utah, was much better than that of 'Ladak,' the only tap-rooted *M. sativa* cultivar to survive (Rumbaugh and Pedersen 1979). Twice as many plants of Rhizoma and 5 times as many plants of Nomad survived as plants of Ladak. Survival of the creeping-rooted Travois was as great as that of any tap-rooted cultivar, and better than that of 7 of the 21 tap-rooted cultivars, after 2 years of grazing (Counce et al. 1984). Berdahl et al. (1989) included several of the cultivars in our study in their study of 17-year-old alfalfa stands near Mandan, North Dakota. Mean survival of creeping-rooted Drylander, Roamer, and Travois was 6.0 plants/m<sup>2</sup>, vs a mean of 2.0 plants/m<sup>2</sup> for Baker, Kanza, Ramsey, and Riley. Smith et al. (1989) reported that, after 3 years of grazing in Georgia, 6–9 plants/m<sup>2</sup> of tap-rooted hay-type alfalfas (Apollo and Florida 77) survived, vs 40–48 plants/m<sup>2</sup> of creeping-rooted grazing type alfalfas (Travois, Spredor II, and GA-GC).

Greater survival of creeping-rooted alfalfas may be related less to an intrinsic capacity to recover from grazing than to the probability of escaping complete defoliation. In the clipping study, creeping-rooted cultivars produced stems as far as 2 m from the original plant. Under range conditions, plants may be widely spaced; Rumbaugh and Pedersen (1979) and Rosenstock and Stevens (1989) reported stands of 1.6 to 3.8 and 0.5 to 2.5 plants/m<sup>2</sup> respectively, comparable to our spacing of 2 plants/m<sup>2</sup>. In such an open stand, the probability that some stems on each plant would remain ungrazed at each grazing event would be increased, although other stems might be completely removed. This is the defoliation pattern imposed in treatments 1 through 6, which produced higher yields and TNC concentrations than treatments 7 through 9 in which all stems were defoliated simultaneously. Treatments 7, 8, and 9 resemble the way in which narrow-crowned, tap-rooted alfalfas are defoliated under grazing.

Pitelka and Ashmun (1985) concluded that formation of spreading clones via rhizomes or stolons favored higher rates of survival and more rapid recovery after defoliation in many species of perennial plants, including grasses, legumes, and other forbs. Cook (1985) stated "Sources of mortality that are intense but local in space would favor clonal reproduction. The effects of herbivores ... might operate in this way." Jeffries (1984) concluded that the probability of damage to a plant from grazing decreases as the number of stems or tillers increase. Gosse et al. (1988) suggested that competition among alfalfa stems for light may limit growth when stem densities are high; this is more likely to happen with

tap-rooted than with creeping-rooted cultivars.

Thus the reported superiority of creeping-rooted cultivars, in view of the similar response of all cultivars to the treatments, may be caused by their ability to evade complete grazing and inter-tiller competition, rather than from any special ability to resist or recover rapidly from grazing. Rosenstock and Stevens (1989) also concluded that the survival of creeping-rooted alfalfas was related to their ability to evade complete defoliation, and cited the earlier work of Gdara (1985) in support. They and Berdahl et al. (1986) questioned whether rapid regrowth after defoliation was conducive to alfalfa survival in semiarid conditions. However, the proliferation of roots of creeping-rooted alfalfas under moderate defoliation (Carlson et al. 1964) may increase chances of survival.

This conclusion is not contradicted by the fact that all cultivars reacted similarly to grazing. In the grazing study, the alfalfa was planted at a heavy seeding rate; there was little opportunity for plants to spread (Kilcher and Heinrichs 1969, Daday et al. 1974) and creeping-rooted cultivars had little opportunity to evade complete grazing as they might have in a more open stand on rangeland. Hartnett (1989) found defoliation was equally damaging to switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) in dense stands, but was much less damaging to the rhizomatous switchgrass than to bluestem in open stands.

### Literature Cited

- Allen, V.G., D.D. Wolf, J.P. Fontenot, J. Cardina, and D.R. Notter. 1986a. Yield and regrowth characteristics of alfalfa grazed with sheep. I. Spring grazing. *Agron. J.* 78:974-979.
- Allen, V.G., L.A. Hamilton, D.D. Wolf, J.P. Fontenot, T.H. Terrill, and D.R. Notter. 1986b. Yield and regrowth characteristics of alfalfa grazed with sheep. II. Summer grazing. *Agron. J.* 78:979-985.
- Ashford, R., and D.H. Heinrichs. 1967. Grazing of alfalfa varieties and observations of bloat. *J. Range Manage.* 20:152-153.
- Berdahl, J.D., A.C. Wilson, and A.B. Frank. 1989. Survival and agronomic performance of 25 alfalfa cultivars and strains interseeded into rangeland. *J. Range Manage.* 42:312-316.
- Carlson, G.E., V.G. Sprague, and J.B. Washko. 1964. Effects of temperature, daylength, and defoliation on the creeping-rooted habit of alfalfa. *Crop Sci.* 14:284-286.
- Chatterton, N.J., G.E. Carlson, R.H. Hart, and W.E. Hungerford. 1974. Tillering, nonstructural carbohydrates, and survival relationships in alfalfa. *Crop Sci.* 14:783-787.
- Clark, K.W. 1960. Persistence of 'Rambler' alfalfa under grazing. Rep. 17th Alfalfa Imp. Conf., p. 99-106.
- Cook, R.E. 1985. Growth and development in clonal plant populations. p. 259-296. In: Jackson, J.B.C., L.W. Buss, and R.E. Cook (eds.) *Population biology and evolution of clonal organisms*. Yale University Press, New Haven.
- Counce, P.A., J.H. Bouton, and R.H. Brown. 1984. Screening and characterizing alfalfa for persistence under mowing and continuous grazing. *Crop Sci.* 24:282-285.
- Daday, H. 1968. Heritability and genotypic and environmental correlations of creeping root and persistency in *Medicago sativa* L. *Aust. J. Agr. Res.* 19:27-34.
- Daday, H., A. Grassia, and J. Peak. 1974. Effect of plant density on the expression of the creeping-rooted character and forage yield of the lucerne (*Medicago sativa*) cultivar Cancreep. *Aust. J. Exp. Agr. Anim. Husb.* 14:735-741.
- Folkins, L.P., J.E.R. Greenshields, and F.S. Nowosad. 1961. Effect of date and frequency of defoliation on yield and quality of alfalfa. *Can. J. Plant Sci.* 41:188-194.
- Gdara, A.O. 1985. The effect of grazing and various intensities of clipping on the regrowth and survival of several alfalfa cultivars. Ph.D. Diss., Colorado State University, Ft. Collins. Diss. Abstr. Int. 46:1777-1778B.
- Gosse, G., C. Lemaire, M. Charlier, and F. Balfourier. 1988. Structure of a lucerne population (*Medicago sativa* L.) and dynamics of stem competition for light during regrowth. *J. Appl. Ecol.* 25:609-617.
- Graber, L.F., N.T. Nelson, W.A. Luekel, and W.B. Albert. 1927. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. *Wisconsin Agr. Exp. Sta. Res. Bull.* 80.
- Hartnett, D.C. 1989. Density- and growth stage-dependent responses to defoliation in two rhizomatous grasses. *Oecologia* 80:414-420.
- Heinrichs, D.H., and J.L. Bolton. 1985. 'Rambler' alfalfa. *Canada Dep. Agr. Pub.* 1030.
- Irvine, R.B., and J.D. McElgunn. 1982. Effect of eight three-cut harvesting schedules on production of alfalfa forage under irrigation in southwestern Saskatchewan. *Can. J. Plant Sci.* 62:107-110.
- Jeffries, R.L. 1984. The phenotype: its development, physiological constraints and environmental signals. p. 347-358. In: R. Dirzo and J. Sarukhan (eds.) *Perspectives on plant population ecology*. Sinauer Assoc., Inc., Sunderland, Mass.
- Jones, E.R. 1971. Carbohydrate reserves in alfalfa (*Medicago sativa* L.) as influenced by several management factors. PhD Diss., Univ. of Saskatchewan, Saskatoon. Diss. Abstr. Int. 30:4878B.
- Jung, G.A., D. Smith, and J.A. Balasko. 1969. Studies on yield, management, persistence and nutritive value of alfalfa in West Virginia. *West Virginia Agr. Exp. Sta. Bull.* 581T.
- Kehr, W.R., E.C. Conard, M.A. Alexander, and F.C. Owen. 1963. Performance of alfalfa under five management systems. *Nebraska Agr. Exp. Sta. Res. Bull.* 211.
- Kilcher, M.R., and D.H. Heinrichs. 1966. Persistence of alfalfas in mixture with grasses in a semiarid region. *Can. J. Plant Sci.* 46:163-167.
- Kilcher, M.R., and D.H. Heinrichs. 1969. Influence of row spacing on yield and creeping root development of 'Rambler' alfalfa in a semiarid region. *Can. J. Plant Sci.* 49:307-311.
- Langille, J.E., L.B. MacLeod, and F.S. Warren. 1965. Influence of harvesting management on yield, carbohydrate reserves, etiolated regrowth and potassium utilization of alfalfa. *Can. J. Plant Sci.* 45:383-388.
- Leach, G.J. 1969. Shoot numbers, shoot size, and yield of regrowth in three lucerne cultivars. *Aust. J. Agr. Res.* 20:425-434.
- Pitelka, L.F., and J.W. Ashmun. 1985. Physiology and integration of ramets in clonal plants. p. 399-435. In: Jackson, J.B.C., L.W. Buss, and R.E. Cook (eds.) *Population biology and evolution of clonal organisms*. Yale University Press, New Haven.
- Rosenstock, S.S., and R. Stevens. 1989. Herbivore effects on seeded alfalfa at four pinyon-juniper sites in central Utah. *J. Range Manage.* 42:483-490.
- Rumbaugh, M.D., and M.W. Pedersen. 1979. Survival of alfalfa in five semiarid range seedings. *J. Range Manage.* 32:48-51.
- Smith, D. 1969. Removing and analysing total nonstructural carbohydrates from plant tissue. *Wisconsin Agr. Exp. Sta. Res. Rep.* 41.
- Smith, D. 1972. Cutting schedules and maintaining pure stands in alfalfa. In: C.H. Hanson (ed.) *Alfalfa science and technology*. *Agron.* 15:481-496.
- Smith, S.R. Jr., J.H. Bouton, and C.S. Hoveland. 1989. Alfalfa persistence and regrowth potential under continuous grazing. *Agron. J.* 81:960-965.



# Competition between cheatgrass and two native species after fire: Implications from observations and measurements of root distribution

GRACIELA MELGOZA AND ROBERT S. NOWAK

## Abstract

During 1987 and 1988, a study was conducted in northern Nevada to examine root growth of cheatgrass (*Bromus tectorum* L.) and 2 native species, needle-and-thread grass (*Stipa comata* Trin. & Rupr.) and rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.), after fire. Profile wall maps were used to determine the distribution of roots in the soil profile for the 2 native species. Root morphology differed between the 2 species: needle-and-thread grass had a flabelliform root system, whereas rabbitbrush had a main tap root with 2–4 major lateral roots. Although total root biomass differed between the species, more than half the root biomass was in the top 0.2 m of soil for both needle-and-thread grass and rabbitbrush. Measurements of root length density were used to evaluate the interaction between root systems of cheatgrass and the native species. Root production of plots with only the native species was not significantly different from that of plots with both the native species and cheatgrass for the first 2 years after fire. Furthermore, root production of plots in a recently burned area was also not significantly different from that in an area burned 12 years prior to our study. Thus, root systems of these species rapidly occupied the belowground space and competed for soil resources after fire, and the presence of cheatgrass partially reduced the root systems of the native species.

**Key Words:** *Chrysothamnus viscidiflorus*, rabbitbrush, *Stipa comata*, needle-and-thread grass, root length density, root biomass

Roots are the primary structures that plants have to utilize belowground resources, but very little is known about how root growth responds after fires. Fire affects the availability of soil resources (Britton and Ralphs 1979). Burning converts plant biomass into ash, which releases nutrients (Raison 1979, Wright and Bailey 1982). Soil water is influenced by fire (Daubenmire 1968, Wright and Bailey 1982), increasing or decreasing the amount of water present in the soil (Anderson et al. 1970). Soil resources are also freed by the loss of fire-intolerant plants. Root growth and density are coupled to uptake of nutrients (Silberbush and Barber 1985, Caldwell and Richards 1986) and water (Caldwell 1976, Lascano and van Bavel 1984). Thus, root growth after fire may influence how plants exploit newly available nutrients and acquire sufficient moisture for enhanced shoot growth (Raison 1979, Hadley and Kieckhefer 1963).

Cheatgrass (*Bromus tectorum* L.) is well adapted to frequent fire and often dominates plant communities after fire (Young et al. 1969). The success of cheatgrass after fire has often been attributed to its capability to rapidly occupy the open spaces created by the

removal of fire-intolerant plants (Stewart and Hull 1949, Klemmedson and Smith 1964, Young et al. 1969, Young and Evans 1973, Thill et al. 1984). Recently, we found that cheatgrass also successfully competes for soil water with native species that survive the fire (Melgoza et al. 1990). This capability of cheatgrass to successfully compete with its neighbors may be related to differences in their capacities to extend root systems after fire. However, how roots of cheatgrass and established adult perennials compete for and exploit the soil resources available after fire in sagebrush (*Artemisia tridentata* Nutt.) ecosystems is unknown.

This study describes the distribution of roots for 2 native species: needle-and-thread grass (*Stipa comata* Trin. & Rupr.) and rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.). It also investigates the spatial distribution of roots after fire for these 2 species and how competition with cheatgrass affects rooting characteristics. Finally, because results from a 2-year study after fire may not accurately predict changes that occur during extended periods of time after fire, we compared root production of a recently burned area with that from an area that burned 12 years prior to our study.

## Methods

### Study Area

The study plots were located in 2 adjacent areas: a 1-ha area that was naturally burned during late-summer 1986 and a 0.7-ha area that had not burned for at least 12 years. The recently burned study area probably resulted from an isolated lightning strike that was quickly extinguished because of accompanying rain and low fuel load. The second study area served as a "long-term reference" to compare rooting characteristics after an extended post-fire period of time with those during the first 2 years after a fire. Both areas were fenced to exclude grazing.

Soil characteristics of the recently burned and long-term reference areas were similar. We dug 2 soil pits, one in each study area. Soils were classified as coarse-loamy, mixed, mesic, Xerollic Haplargids. Soils were very deep (depth to bedrock exceeded 2 m) and well drained with 15–25% surficial coarse fragments. The study areas were on a remnant summit of a fan piedmont, and parent material was alluvium from nearby granitic mountains. Average slope was 2% with a west-southwest aspect. Soils also have been mapped to the same unit, which belongs to the Bedell series (Baumer 1983).

Vegetative characteristics of the adjacent study areas were also similar. Both areas were in the middle of a sagebrush-bunchgrass community. Sagebrush, rabbitbrush, needle-and-thread, horsebrush (*Tetradymia canescens* DC.), squirreltail (*Sitanion hystrix* (Nutt.) J.G. Smith), and the introduced species cheatgrass were the dominant species in the community. Average precipitation was estimated to be 250 mm (Evans and Young 1977). Measurements were taken during 1987 and 1988, which had 95% and 50% of estimated normal precipitation, respectively. The study areas (39°51'N, 119°48'W) were 35 km north of Reno, Nevada at 1,570 m elevation.

Authors are range scientist, Rancho Experimental La Campana, Chihuahua, Chihuahua, Mexico 31000; and assistant professor, Department of Range Wildlife and Forestry, University of Nevada Reno, 1000 Valley Road, Reno, Nevada 89512. At the time of the research, the senior author was a graduate research assistant, Department of Range, Wildlife, and Forestry, University of Nevada Reno. The authors wish to thank E. Blake, S. Leonard, R. Miles, and F. Peterson for their help in soil and vegetation classification and 2 anonymous reviewers for their helpful comments on the statistical analyses.

Please address reprint requests to R.S. Nowak.

This research was funded by the Nevada Agricultural Experiment Station.

Manuscript accepted 17 May 1990.

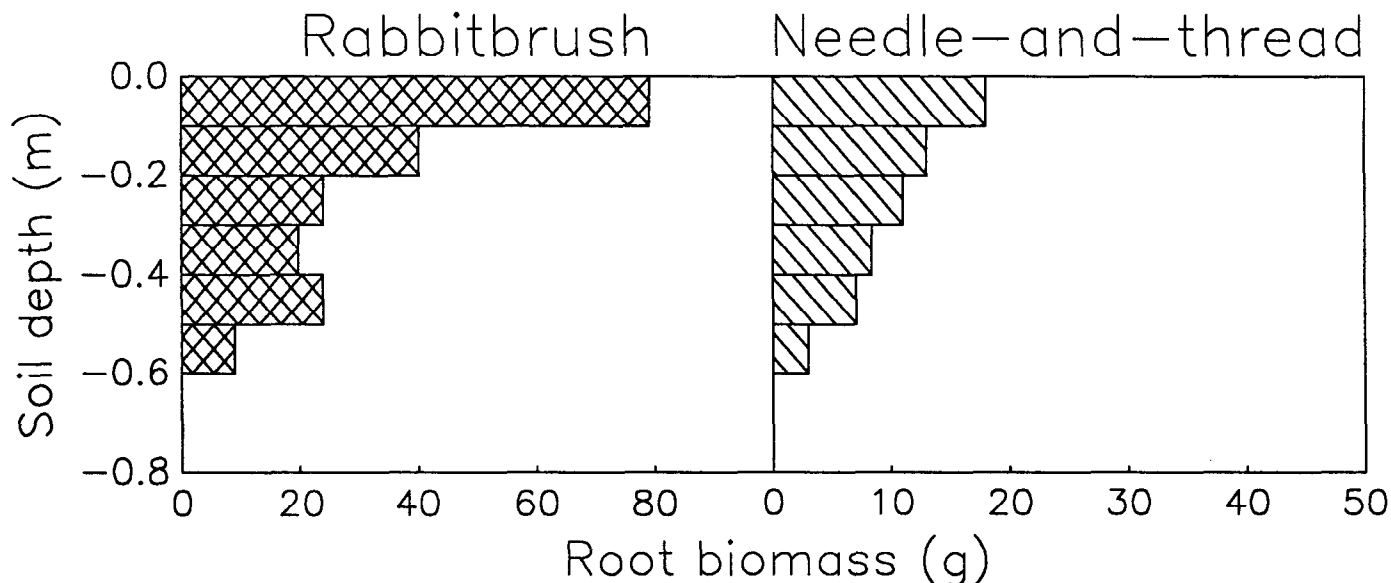


Fig. 1. Root biomass distribution for 2 rabbitbrush plants (left frame) and 2 needle-and-thread grass plants (right frame). Root systems were excavated by hand from a trench dug 0.2 m away from each individual. Note the different x-axis scales for the 2 species.

### Target Species

Two native species that are relatively resistant to fires in late summer, rabbitbrush, and needle-and-thread grass (Young 1983), were selected to determine the effects of fire and cheatgrass competition on root growth and density. Rabbitbrush is a perennial, undesirable shrub and needle-and-thread grass is a perennial, desirable bunchgrass. At the beginning of the study, we selected plants that were similar in size based upon measurements of basal area. Sixteen target individuals of each species in the recently burned area were selected with stratified random technique to assure adequate size and spatial interspersed (Hurlbert 1984). Eight target individuals of each species in the long-term reference area were selected using the same technique. These target individuals were the same ones used for soil water measurements in Melgoza et al. (1990).

In order to determine the short-term effects of cheatgrass competition on root growth after fire, we established plots with and without cheatgrass. All plants within a 1.0-m radius around target individuals in the recently burned area (plots without cheatgrass) were removed with a hoe during fall 1986. Many of the plants removed from the burned area appeared to be dead, but were removed to insure a uniform competitive environment among plots. During the next 2 years, cheatgrass as well as seedlings of other plants were removed as needed from the plots. Plots of target individuals with cheatgrass were established in an analogous manner: all plants except cheatgrass were removed during fall 1986 and as needed during the next 2 years.

The long-term reference area provided information on what may occur at 12 years after fire. Vegetation in the long-term reference area was not altered. Thus, these plots served as an extended time reference for rooting characteristics in a competitive environment many years after fire rather than as a strict experimental control for the treatments in the recently burned area.

### Root Observations

Direct root observations of the 2 native species were made during 1987. Trenches about 2-m deep and 5-m long were dug about 0.2 m from 2 individuals of each target species to provide access for root excavation. The soil in the trench wall was carefully removed by hand to uncover the root systems of individual rabbitbrush and needle-and-thread plants. Although fine roots were lost in the process, profile wall maps of the root systems provided

information about root form and underground distribution of biomass of larger roots. Root form and distribution was recorded to 0.6-m soil depth, and root biomass at 0.1-m depth increments was clipped, oven-dried, and weighed.

### Root Growth and Density

Root length density was determined by destructive sampling. Soil cores were taken with a 35-mm diameter auger at 2 locations: the edge of the target plant canopy and 0.5 m away from the edge. We made 2 assumptions when we selected these locations. First, the volume of soil below the canopy of the plant represents soil that is probably dominated by the plant (Caldwell and Richards 1986, Manning and Barbour 1988). Second, the volume of soil at 0.5-m distance represents a soil resource that was probably dominated by another plant but became available after the removal of that other plant by fire. These assumptions were verified by our profile wall maps.

Soil cores were taken from each plot at the end of each growing season (July 1987 and August 1988). Root cores were taken at the following depth increments: 0.0–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, 0.9–1.1, and 1.1–1.4 m depth. Samples were washed free from soils using a hydropneumatic root washer (Gillison's Variety Fabrication Inc., Benzonia, Michigan) (Smucker et al. 1982). Organic material was manually removed from samples. Live and dead roots were differentiated by a staining technique (Ward et al. 1978). Root length was measured with a Comair root length scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Australia).

Although we could differentiate between live and dead roots, we could not reliably differentiate among species. Thus, we assumed that roots were from the plants that were present in the 1-m diameter plots. For example, live roots in soil cores from plots without cheatgrass in the recently burned area were undoubtedly from the target individual of that plot. For soil cores from plots with cheatgrass, roots were from both the target individual and cheatgrass.

### Statistical Analyses

Data were analyzed using split-plot types of analysis of variance (ANOVA). We had 2 dependent variables: root length density at each depth increment and root length density for the 1.4-m deep soil profile. Whole-plot treatments had 3 levels: recently burned area without cheatgrass, recently burned area with cheatgrass,

**Table 1. Split-split-split plot analysis of variance (ANOVA) for root density data from individual depth increments.**

Source <sup>1</sup>	d.f. <sup>2</sup>	P values	
		Chvi plots <sup>3</sup>	Stco plots <sup>4</sup>
Treatment	2	0.355	0.478
Treatment*Plot (error)	21		
Year	1	0.000	0.001
Treatment*Year	2	0.629	0.656
Treatment*Year*Plot (error)	21		
Location	1	0.024	0.454
Treatment*Location	2	0.777	0.655
Year*Location	1	0.001	0.756
Treatment*Year*Location	2	0.569	0.778
Treatment*Year*Location*Plot (error)	42		
Depth	5	0.000	0.000
Treatment*Depth	10	0.800	0.069
Year*Depth	5	0.000	0.032
Location*Depth	5	0.001	0.059
Treatment*Year*Depth	10	0.931	0.061
Treatment*Location*Depth	10	0.966	0.590
Year*Location*Depth	5	0.112	0.750
Treatment*Year*Location*Depth	10	0.398	0.411
Treatment*Year*Location*Depth*Plot (error)	420		
Total	575		

<sup>1</sup>Sources of variation are: Treatment = whole-plot treatments of presence/absence of cheatgrass in recently-burned area and long-term reference; Year = 1987/1988; Location = edge of canopy/0.5 m from edge; Depth = soil depth increments of 0.0–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, 0.9–1.1, 1.1–1.4; Plot = experimental unit.

<sup>2</sup>Degrees of freedom

<sup>3</sup>ANOVA from plots with rabbitbrush as the target individual

<sup>4</sup>ANOVA from plots with needle-and-thread grass as the target individual.

and long-term reference area. Year (2 levels) and location (i.e., lateral distance from the target individual, 2 levels) were subplot factors for both dependent variables, and depth (6 levels) was an additional subplot factor for root length density at each depth increment. Our experimental unit, the individual plots of target plants, had 8 replications. Each species was analyzed separately. Because only the cheatgrass removal, whole-plot treatment factor was randomly applied to experimental units and because only 1 recently burned area was sampled, the assumption that whole-plot treatments were applied randomly to all experimental units (Winer 1971, Steel and Torrie 1980) was compromised. Nonetheless, a split-plot ANOVA was a reasonable method for statistical analysis, especially because data were taken on an individual plant basis, which were a stratified-random sample of the available population. However, extrapolation of our results to other burned areas cannot be justified on a statistical basis.

The level of significance was  $P < 0.05$ . First, we determined which interaction terms from the ANOVA were significant, then grouped means for these significant interaction terms using L.S.D. techniques (Steel and Torrie 1980:381). Next, we determined which whole-plot or subplot factors were significant, and again grouped means using L.S.D. mean comparisons. Although the L.S.D. test is less conservative than other mean comparisons, we agreed with Snedecor and Cochran (1967:275): "For routine purposes, thoughtful use of either the L.S.D. or the Newman-Keuls method should be satisfactory."

## Results

### Root Observations

The root system of rabbitbrush was characterized by a main tap root at least 0.6 m deep, with some major, secondary roots extended laterally over 0.6 m and many fine roots. Needle-and-thread grass had a flabelliform root system, about 0.5-m wide.

Excavations for root observations were stopped when the silica-cemented horizon was reached (at about 0.6 m depth) because it became very difficult to track roots. Below 0.6 m, roots were few and very fragile. More than 50% of the total root biomass for both species was distributed in the upper 0.2 m of soil depth (Fig. 1).

### Root Length Density

Three interaction terms and 3 subplot factors were significant from the split-split-split plot ANOVA of root length density data for individual depth increments from plots with rabbitbrush plants as the target individual (Table 1). From the mean comparisons for the Location\*Depth interaction term, root length densities near the edge of the target plant's canopy were significantly greater than those 0.5 m away from the edge only for the 0.0–0.3 m depth increments (Table 2a). Root length densities for the 5 depth increments below 0.3 m were not significantly different between loca-

**Table 2. Mean comparisons for root length density (cm cm<sup>-3</sup>) from individual depth increments for plots with rabbitbrush as the target individual.**

----- (a) Locations by depth (Location*Depth interaction term) -----						
Depth increment	Canopy edge	0.5 m from edge				
0.0-0.3 m	15.0a <sup>1</sup>	8.2b				
0.3-0.5 m	8.2a	6.4a				
0.5-0.7 m	5.1a	3.8a				
0.7-0.9 m	5.4a	4.6a				
0.9-1.1 m	4.4a	3.6a				
1.1-1.4 m	3.3a	3.5a				
----- (b) Depths by year (Year * Depth interaction term) -----						
	Depth increment					
Year	0.0-0.3 m	0.3-0.5 m	0.5-0.7 m	0.7-0.9 m	0.9-1.1 m	1.1-1.4 m
1987	6.0b	3.2a	2.2a	3.1a	1.7a	2.8a
1988	17.2d	11.3c	6.6b	6.8b	6.2ab	4.0a
----- (c) Locations by year (Year*Location interaction term) -----						
	Canopy edge	0.5 m from edge				
Year						
1987	2.7a	3.7a				
1988	11.0b	3.4a				
----- (d) Depth increment subplot factor -----						
0.0-0.3 m	0.3-0.5 m	0.5-0.7 m	0.7-0.9 m	0.9-1.1 m	1.1-1.4 m	
11.6c	7.3b	5.0a	4.4a	4.0a	3.4a	
----- (e) Location subplot factor -----						
Canopy edge		0.5 m from edge				
6.9b		5.0a				
----- (f) Year subplot factor -----						
1987		1988				
3.2a		8.7b				

<sup>1</sup>Mean comparisons were made with an L.S.D. test; means within a row that have the same letter did not differ significantly ( $P > 0.05$ ).

tions. The Year\*Depth interaction term was also significant: individual depth increments overlapped to a greater extent in 1987 than in 1988 (Table 2b). For example, the 0.3–0.5 depth increment was significantly greater than the 0.5–0.7 increment in 1988, but not in 1987. Mean comparisons for the Year\*Location interaction term showed that locations were significantly different in 1988, but not in 1987 (Table 2c). Thus, 2 of the significant subplot factors, Depth and Location (Tables 1, 2d, 2e) are moderately confounded by the significant interaction terms. However, the significant Year subplot factor (Table 2f) is more consistent: root length density in 1988 is almost always greater than that in 1987.

The ANOVA for root length density data from individual depth increments for plots with needle-and-thread grass at target individuals had fewer significant terms than that for rabbitbrush plots.

**Table 3. Mean comparisons for root length density ( $\text{cm cm}^{-3}$ ) from individual depth increments for plants with needle-and-thread grass as the target individual.**

----- (a) Depths by year (Year*Depth interaction term) -----						
Year	Depth increment					
	0.0-0.3 m	0.3-0.5 m	0.5-0.7 m	0.7-0.9 m	0.9-1.1 m	1.1-1.4 m
1987	7.1c <sup>1</sup>	3.5b	3.2b	2.2ab	1.7ab	0.6a
1988	13.8d	10.6c	6.7b	6.1ab	8.0b	4.4a
----- (b) Depth increment subplot factor -----						
	0.0-0.3 m	0.3-0.5 m	0.5-0.7 m	0.7-0.9 m	0.9-1.1 m	1.1-1.4 m
	10.5d	7.0c	4.9b	4.9b	4.1b	2.5a
----- (c) Year subplot factor -----						
	1987	1988				
	3.0a	8.3b				

<sup>1</sup>Mean comparisons were made with an L. S. D. test; means within a row that have the same letter did not differ significantly ( $P>0.05$ ).

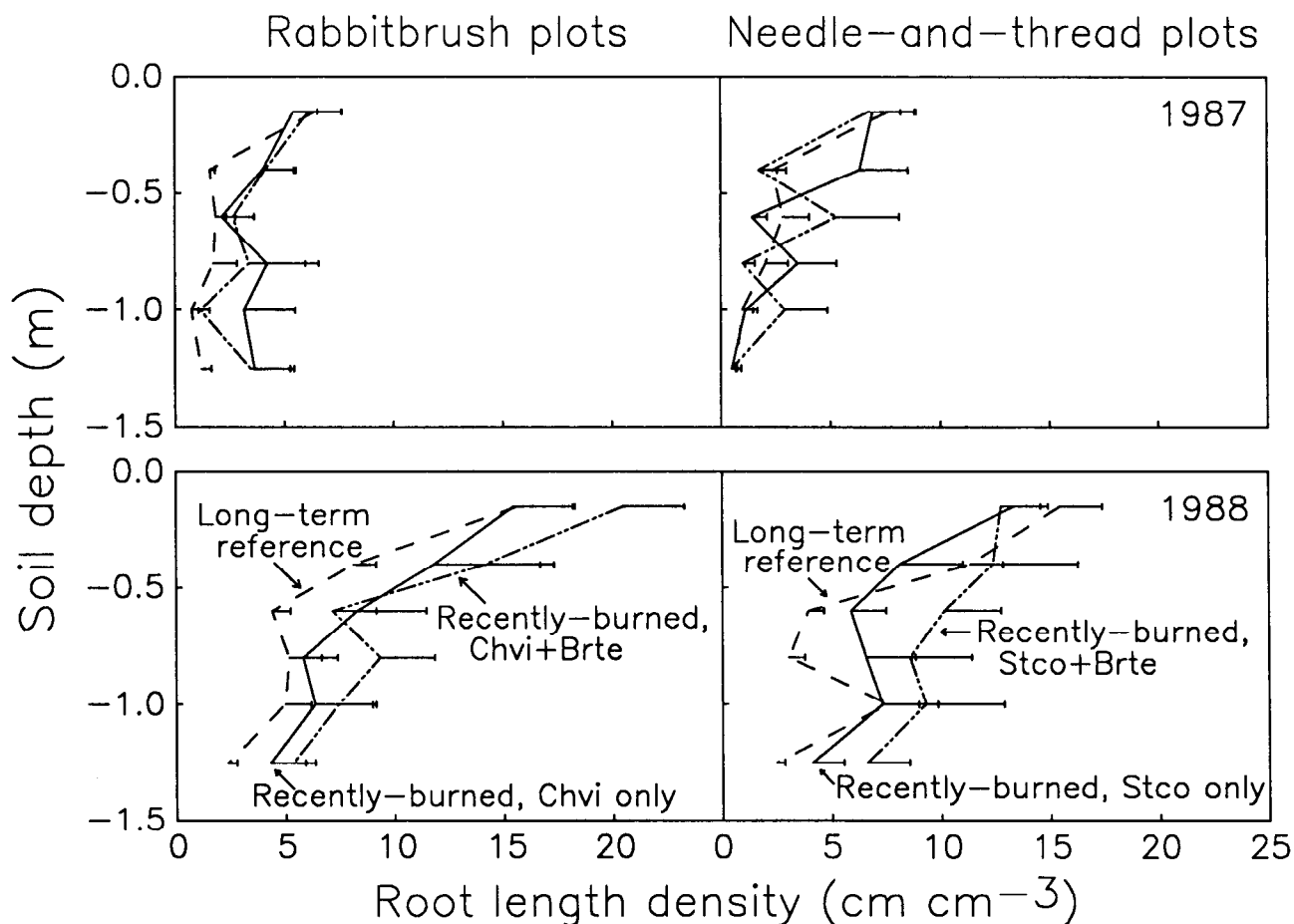
Only 1 interaction term and 2 subplot factors were significant (Table 1). As with rabbitbrush plots, the significant Year\*Depth interaction term (Table 3a) confounded the significant Depth subplot factor (Table 3b): the grouping of means for individual depth increments differed between years. Root length density in 1988 was significantly greater than that in 1987 (Table 3c).

The most important aspect of these ANOVA's was the lack of significance for any term involving the whole-plot Treatment fac-

tor (Table 1). Because the root measurements for plots with cheatgrass included roots of both the target individual and cheatgrass, we expected that treatment to have significantly greater root length density. Root length densities for individual depth increments within each treatment overlapped for both species throughout the soil profile, especially in 1987 (Fig. 2). Although differences among treatments in 1988 were larger than those in 1987, especially for plots with needle-and-thread grass as target individuals, the 3-way interaction term Treatment\*Year\*Depth was not significant for plots with either species at target individuals (Table 1).

Because the P value for the Treatment\*Year\*Depth from the ANOVA for needle-and-thread grass plots was low, we computed root length density for the entire 1.4-m-deep soil profile in order to integrate the 6 depth increments. Data were analyzed with a split-split plot ANOVA (Table 4a). For plots with rabbitbrush plants as target individuals, the Year\*Location interaction term (Table 4b) confounded the significant Location subplot factor (Table 4c). Locations were not significantly different in 1987, but were significantly different in 1988. For plots with either native species as target individuals, the root length density for the soil profile in 1987 was significantly less than that in 1988 (Table 4d). However, all ANOVA terms that involved the whole-plot Treatment factor were not significant, even though mean root length density for the soil profile of plots with cheatgrass in the recently burned area tended to be slightly greater than that of other plots in 1988 (Fig. 3).

In order to focus only on the plots from the recently burned area, we reran the ANOVA's without data from the long-term



**Fig. 2. Root length density at different depth increments for plots with rabbitbrush (Chvi) as the target individual (left frames) and plots with needle-and-thread grass (Stco) as the target individual (right frames). Upper frames are means from 1987, and lower frames are means from 1988. Solid lines are plots in the recently burned area without competition; dash-dot-dot lines are plots in the recently burned area with cheatgrass competition; and dashed lines are plots in the long-term reference area. Error bars are standard errors of the mean. At any 1 depth, treatment means within any 1 frame were not significantly different (see Table 1a).**

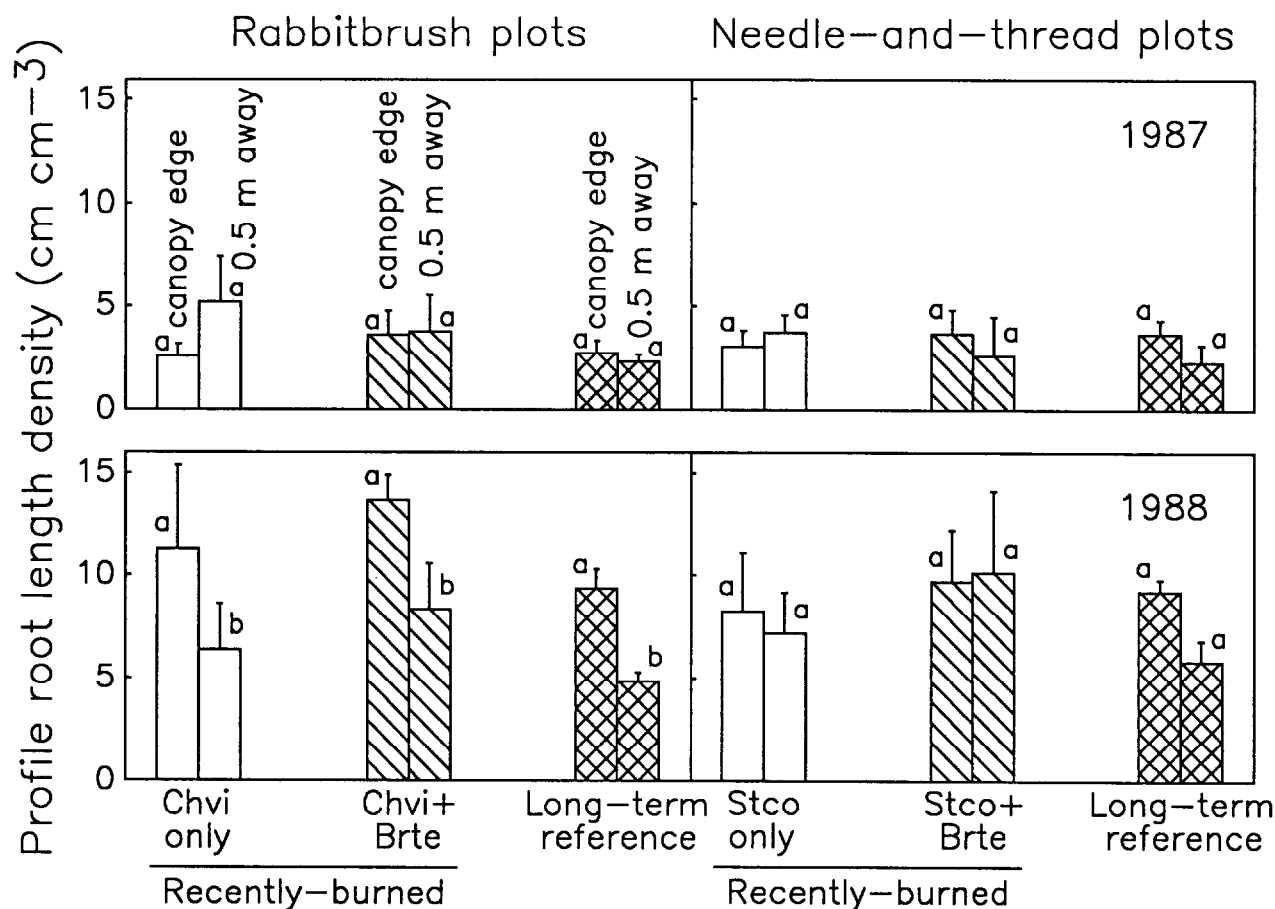


Fig. 3. Root length density for the entire soil profile from rabbitbrush (Chvi) plots (left frames) and needle-and-thread grass (Stco) plots (right frames) in 1987 (upper frames) and 1988 (lower frames). Open bars are plots in the recently burned area without competition; diagonal bars are plots in the recently burned area with cheatgrass competition; and crosshatch bars are plots in the long-term reference area. For each pair of bars, the left bar is mean root length density for soil cores taken at the edge of the target individual, and the right bar is that taken 0.5 m away from the edge of the canopy. Error bars are standard errors of the mean. With the exception of a significant Location effect in 1988 for rabbitbrush, means within a frame were not significantly different (see Table 2a).

reference area. Most of the significant terms in Tables 1 and 4a were again significant, and all the terms involving Treatment were, again, not significant (results not shown). We next removed the 1987 measurements from our data set and analyzed the data with split-plot types of ANOVA's, but all the ANOVA terms involving Treatment were still not significant.

### Discussion

The roots system of cheatgrass and the native species compete. Evidence to support this statement is based upon the lack of statistical significance for any ANOVA terms that involved the whole-plot Treatment factor. If cheatgrass roots were not affecting root growth of the established perennial plants after fire, then the combined root length densities of the target species plus cheatgrass in plots with both species should have been greater than the root length densities of plots with only the target species. We also expected that this would be especially striking at 0.5 m from the edge of the target individuals. However, root length density of plots in the recently-burned area with only the target species were nearly identical to the combined root length density of plots with both the target species and cheatgrass in 1987 (Figs. 2 and 3). Small differences in mean root length density existed in 1988, but were not significant. We cannot unequivocally conclude from our data whether cheatgrass or the native species is the better competitor: we have evidence that cheatgrass reduces root length densities of

the native species (relative to monocultures of the native species), but we do not know to what extent the native species reduce root length densities of cheatgrass (relative to cheatgrass monocultures). None-the-less, productivity and water status of both rabbitbrush and needle-and-thread grass were also adversely affected by cheatgrass (Melgoza et al. 1990). Because plants depend on their root systems to exploit the soil space around them, the results from our 2 studies suggest that the root system of cheatgrass utilized soil resources that otherwise would have been used by the native plants. Similar results were noted for competition between bluebunch wheatgrass and cheatgrass in growth chamber studies (Harris 1967).

Distribution of roots in the belowground space is important because root length density is closely related to uptake of water (Caldwell 1976, Lascano and van Bavel 1984) and nutrients (Silberbush and Baker 1985, Caldwell and Richards 1986). Water is the limiting factor in desert communities (Fowler 1986, Smith and Nowak 1990), and frequently water is present in limited amounts and space. Species growing together can avoid competition to some extent by having active roots at different depths, but root length density of all species in our study was greatest in the upper 0.5 m of soil, suggesting considerable root competition. Cheatgrass is very effective in removing soil water from the upper levels early in the spring (Cline et al. 1977, Melgoza et al. 1990), and competition between cheatgrass and native species in the upper soil layers

**Table 4. Split-split plot analysis of variance (ANOVA) and mean comparisons for root length density (cm cm<sup>-3</sup>) for the 1.4 m deep soil profile.**

----- (a) ANOVA table -----			
Source <sup>1</sup>	d.f. <sup>2</sup>	P values	
		Chvi plots <sup>3</sup>	Stco plots <sup>4</sup>
Treatment	2	0.343	0.526
Treatment*Plot (error)	21		
Year	1	0.000	0.000
Treatment*Year	2	0.589	0.677
Treatment*Year*Plot (error)	21		
Location	1	0.010	0.373
Treatment*Location	2	0.703	0.650
Year*Location	1	0.001	0.733
Treatment*Year*Location	2	0.652	0.757
Treatment*Year*Location*Plot (error)	42		
Total	95		

----- (b) Mean comparisons for locations by year ----- (Year*Location interaction term) -----			
Chvi plots:	Canopy edge	0.5 m from edge	
Year			
1987	3.0a <sup>5</sup>	3.8a	
1988	11.4b	6.5a	

----- (c) Mean comparisons for Location subplot factor -----			
Chvi plots:	Canopy edge	0.5 m from edge	
	7.2b	5.1a	

----- (d) Mean comparisons for Year subplot factor -----			
	1987	1988	
Chvi plots:	3.4a	9.0b	
Stco plots:	3.2a	8.4b	

<sup>1</sup>Sources of variation are: Treatment = whole-plot treatments of presence/absence of cheatgrass in recently-burned area and long-term reference; Year = 1987/1988; Location = edge of canopy/0.5 m from edge; Plot = experimental unit.

<sup>2</sup>Degrees of freedom

<sup>3</sup>ANOVA from plots with rabbitbrush (Chvi) as the target individual

<sup>4</sup>ANOVA from plots with needle-and-thread grass (Stco) as the target individual

<sup>5</sup>Mean comparisons were made with a L.S.D. test; means within a row that have the same letter did not differ significantly ( $P>0.05$ ).

would be intense if both draw simultaneously upon a limited supply of soil resources. Whether competition between perennial plant roots and cheatgrass roots was restricted to the upper soil profile or also occurred in lower portions of the soil profile cannot be definitively determined from our results and would require a technique to positively differentiate roots of each species.

Fire did not have any short-term effects on root production. Mean root length densities of both treatments from the recently-burned area were not significantly different from means for the long-term reference area in either 1987 or 1988. Plant survival after fire has been related more to the capacity to rapidly utilize available soil water during the early stages of regrowth after fire, rather than to direct effects of fire (R. Robberecht, personal communication). Our results are consistent with this hypothesis: all species in our study area are relatively tolerant of late-summer fires, and their root systems appeared to explore the soil profile after fire to the same extent as plants that were not recently burned. Whether short-term root production of needle-and-thread grass burned in mid-summer, when it is more susceptible to damage (Wright and Klemmedson 1965), is reduced is not known, but would be a good test of this hypothesis.

Results from this study enhance our understanding of the belowground competitive interactions of native species and cheatgrass after fire. Rapid root development and an extensive fibrous

root system have been implicated as characteristics that make cheatgrass a vigorous colonizer (Harris 1977) and enhance its ability to rapidly occupy the open spaces created by the removal of fire-intolerant plants on sagebrush sites (Thill et al. 1984, Young et al. 1969). Our studies also indicate that cheatgrass successfully competes with established native perennials (Melgoza et al. 1990) and partially reduces the root systems of native species. Competition from cheatgrass has important long-term implications. If stands of cheatgrass become established in sagebrush communities after fire, the cheatgrass stands may not only resist invasion by perennials (Harris 1967), but may also partially displace the perennial plants that survive the fire.

## Literature Cited

- Anderson, K.L., E.F. Smith, and C.E. Owensby. 1970. Burning bluestem range. *J. Range Manage.* 23:81-92.
- Baumer, O.W. 1983. Soil survey of Washoe County, Nevada, South Part. USDA. SCS.
- Britton, C.M., and M.H. Ralphs. 1979. Use of fire as a management tool in sagebrush ecosystems. p. 101-109. *In: The Sagebrush Ecosystem: A Symposium.* Utah State University, Logan.
- Caldwell, M.M. 1976. Root extension and water absorption. p. 63-85. *In: O.L. Lange, L. Kappen, and E.D. Schulze (eds.). Ecological Studies Vol. 19 Water and Plant Life.* Springer-Verlag, Berlin.
- Caldwell, M.M., and J.H. Richards. 1986. Competing root systems: morphology and models of absorption. p. 251-273. *In: T.J. Givnish (ed.). On the Economy of Plant Form and Function.* Cambridge University Press, Cambridge.
- Cline, J.F., D.W. Uresk, and W.H. Richard. 1977. Comparison of soil water used by a sagebrush-bunchgrass and a cheatgrass community. *J. Range Manage.* 30:199-201.
- Daubenmire, R. 1968. Ecology of fire in grasslands. *Adv. Ecol. Res.* 5:209-266.
- Evans, R.A., and J.A. Young. 1977. Weed control-revegetation systems for big sagebrush-downy brome rangelands. *J. Range Manage.* 30:331-336.
- Fowler, N. 1986. The role of competition in plant communities in arid and semiarid regions. *Annu. Rev. Ecol. Syst.* 17:89-110.
- Hadley, E.B., and B.J. Kieckhefer. 1963. Productivity of two prairie grasses in relation to fire frequency. *Ecology* 44:389-395.
- Harris, G.A. 1967. Some competitive relationships between *Agropyron spicatum* and *Bromus tectorum*. *Ecol. Monogr.* 37:89-111.
- Harris, G.A. 1977. Root phenology as a factor of competition among grass seedlings. *J. Range Manage.* 30:172-177.
- Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecol. Monogr.* 54:187-211.
- Klemmedson, J.O., and J.G. Smith. 1964. Cheatgrass (*Bromus tectorum* L.). *Bot. Rev.* 30:226-262.
- Lascano, R.J., and C.H.M. van Bavel. 1984. Root water uptake and soil water distributions: Tests of an availability concept. *Soil Sci. Soc. Amer. J.* 48:233-237.
- Manning, S.J., and M.G. Barbour. 1988. Root systems, spatial patterns, and competition for soil moisture between two desert shrubs. *Amer. J. Bot.* 75:885-893.
- Melgoza, G., R.S. Nowak, and R.J. Tausch. 1990. Soil water exploitation after fire: Competition between *Bromus tectorum* (cheatgrass) and two native species. *Oecologia* (in press).
- Raison, R.J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: A review. *Plant Soil* 51:73-108.
- Silberbush, M., and S.A. Barber. 1985. Root growth, nutrient uptake and yield of soybean cultivars grown in the field. *Comm. Soil Sci. Plant Anal.* 16:119-127.
- Smith, S.D., and R.S. Nowak. 1990. Physiological ecology of plants in the intermountain lowlands. *In: Ecological Studies Vol. 79 Plant Biology of the Basin and Range.* C.B. Osmond, L.F. Pitelka, and G. Hidy (eds.). (In press).
- Smucker, A.J.M., S.L. McBurney, and A.K. Srivastava. 1982. Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. *Agron. J.* 74:500-503.
- Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods, Sixth Edition. Iowa State Univ. Press, Ames.

**Steel, R.G.D., and J.H. Torrie. 1980.** Principles and procedures of statistics: A biometrical approach (2nd Edition). McGraw-Hill Book Company, New York.

**Stewart, G., and A.C. Hull. 1949.** Cheatgrass (*Bromus tectorum* L.)-An ecological intruder in southern Idaho. *Ecology* 30:58-74.

**Thill, D.C., K.G. Beck, and R.H. Callihan. 1984.** The biology of downy brome (*Bromus tectorum*). *Weed Sci.* 32:7-12.

**Ward, K.J., B. Klepper, R.W. Rickman, and R.R. Allmaras. 1978.** Quantitative estimation of living wheat-root lengths in soil cores. *Agron. J.* 70:675-677.

**Winer, B.J. 1971.** Statistical principles in experimental design. Second Edition. McGraw-Hill Book Co., New York.

**Wright, H.A., and A.W. Bailey. 1982.** Fire ecology. United States and Southern Canada. Wiley and Sons, New York.

**Wright, H.A., and J.O. Klemmedson. 1965.** Effect of fire on bunchgrasses of the sagebrush-grass region in southern Idaho. *Ecology* 46:680-688.

**Young, J.A., and R.A. Evans. 1973.** Downy brome-Intruder in the plant succession of big sagebrush communities in the Great Basin. *J. Range Manage.* 26:410-415.

**Young, J.A., R.A. Evans, and R.E. Eckert Jr. 1969.** Population dynamics of downy brome. *Weed Sci.* 17:20-26.

**Young, R.P. 1983.** Fire as a vegetation management tool in rangelands of the intermountain region. p. 18-31. *In:* S.B. Monsen and N. Shaw (compilers). *Managing Intermountain Rangeland: Improvements of Range and Wildlife Habitats.* USDA Gen. Tech. Rep. INT-157.

## CALL FOR SPECIAL SESSIONS

1992 ANNUAL MEETING  
FEBRUARY 9-14, 1992  
SPOKANE, WASHINGTON

To better accommodate diverse program needs at annual meetings, meeting organizers have been directed to conduct a call for special sessions (symposia, workshops, or others) similar to the call for volunteer papers.

Proposals should include:

- Session title and type ( symposium, workshop etc...)
- Statement of objectives and intended audience
- Number of hours required
- Number of attendees anticipated
- Name, address and phone number of organizer
- Sponsoring group (if applicable)

Submit to:

- Linda H. Hardesty
- Program Co-chair
- Department of Natural Resource Sciences
- Washington State University
- Pullman, WA 99164-6410

**Proposal deadline is April 1, 1991**

# Substrate relations for rillscale [*Atriplex suckleyi*] on bentonite mine spoil

M.E. VOORHEES, D.W. URESK, AND M.J. TRLICA

## Abstract

Rillscale (*Atriplex suckleyi*), the dominant native invader of bentonite mine spoil in northern Wyoming, is apparently uniquely adapted to this extremely harsh plant growth substrate. The objective of this study was to determine which chemical properties of spoil influence growth of rillscale. Plant production, foliar and spoil chemistry on spoils were treated as a factorial arrangement of treatments, each of 3 spoil amendments (gypsum, fertilizer, sawdust). Regression analyses with analysis of covariance and factorial analysis of variance model were used to control for effects of amendments on plant production. Calcium and nitrogen were growth-limiting nutrients for this plant. The species was very sensitive to an increase in the level of spoil molybdenum and in the ratio of copper to molybdenum, but was very tolerant of high levels of soluble sodium. Rillscale acted as a molybdenum accumulator.

**Key Words:** minerals, reclamation, forage, amendments

The bentonite clay mining industry ranks high among major land-disturbance operations in the 3-state region of Montana, South Dakota, and Wyoming, where most of the world's sodic-type bentonite is found. Bentonite mine spoil is difficult to revegetate because it poses several problems for plant growth including, salinity, sodicity, high percentages of expansive clays, and possible elemental deficiencies and toxicities (Bjugstad et al. 1981).

*Atriplex suckleyi* (Torrey) Rydb., commonly called rillscale, is a spreading, annual chenopod limited in range to the northern High Plains. It occurs on clayey, saline lands to which few species are adapted (Frankton and Bassett 1970) and is the dominant native invader of bentonite mine spoil (Sieg et al. 1983). Morphology and apparent vigor of the species vary considerably from site to site, and studies have shown that growth and vigor of the species are greatly improved by organic amendments (Smith et al. 1985, Voorhees et al. 1987).

This study was part of a larger project to evaluate suitability of rillscale for use in revegetation of bentonite mine spoil. Other papers from the project have been published elsewhere and describe studies of the effects of amendments on spoil chemistry (Voorhees and Uresk, 1990), infiltration rate (Voorhees 1986), standing crop of rillscale (Voorhees et al. 1987), and foliar chemistry (Voorhees 1990).

## Method

The study was conducted on an area west of the central Black Hills on the Mowry Shale formation, approximately 2 km northwest of Upton, Wyoming. Sites in this region have been mined at various times during a period of more than 30 years. Elevation at the study area was approximately 1,290 m, and average annual precipitation was about 370 mm (NOAA 1983). Undisturbed vegetation is characteristically big sagebrush (*Artemisia tridentata*) grassland interspersed with stands of ponderosa pine (*Pinus ponderosa*). The area provides forage for livestock and habitat for

many species of wildlife.

A topographically uniform area was selected on unreclaimed bentonite mine spoil that had been mined sometime before 1968. Topography on and around the site insured minimal runoff and runoff. Data from the Upton weather station were used as an estimate of precipitation during the study period.

The study site was rototilled to a depth of approximately 5 cm. The experimental design was a 2<sup>3</sup> factorial arrangement of treatments with each of 3 spoil amendments (gypsum, fertilizer, and sawdust with nitrogen) at 2 levels—with and without amendment. This design contained a total of 8 treatments: a control, each of 3 amendments used alone, and all possible combinations of the 3 amendments. The 8 treatments were replicated twice to give a total of 16 plots, 60 cm × 150 cm each.

The gypsum amendment (CaSO<sub>4</sub>) was applied at the rate of 31 Mg ha<sup>-1</sup>. The fertilizer amendment added nitrogen (N), phosphorus (P), and potassium (K) at rates of 114 kg, 23 kg, and 50 kg per hectare, respectively. This P and K fertilization rate was considered to be moderate for dryland soils that support rapidly growing forbs. The nitrogen rate was high because of low spoil organic matter and nitrogen. Nitrogen and phosphorus were added as ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) and diammonium phosphate ((NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub>) and potassium chloride (KCl).

The third amendment was sawdust with nitrogen, added at the ratio of 1 part sawdust to 2 parts spoil (by volume) to the 5-cm spoil depth. Depth of tillage was limited so that use of heavy equipment could be avoided, and thus efficacy of much less expensive treatments could be evaluated. Use of heavy equipment is prohibitively expensive in reclamation of these spoils on an experimental basis. Inorganic nitrogen (NH<sub>4</sub>NO<sub>3</sub>) corresponding to 0.6% of sawdust by weight (6 kg N Mg<sup>-1</sup> sawdust) was added to the sawdust before its application to prevent a large increase in the carbon-to-nitrogen ratio and subsequent tie-up of spoil nitrogen by microorganisms (Allison 1965).

Introduction of calcium ions (Ca<sup>++</sup>) in the form of CaSO<sub>4</sub> was intended to facilitate exchange with monovalent sodium, to encourage flocculation and water penetration (Brady 1974), and to discourage surface crust formation. The sawdust amendment was intended to increase permeability. Organic matter additions greatly increase the stability of the substrate where organic matter is less than 2% (Marshall and Holmes 1979) as in bentonite mine spoil (Uresk and Yamamoto 1986).

Gypsum and sawdust amendments were manually incorporated into tilled spoil, whereas the fertilizer was surface-broadcast. Plots were tilled, amended, and seeded in April 1982 and sampled for 2 growing seasons. The seed had been obtained from sites along the Montana-Wyoming border during late summer of 1980. Each plot was seeded at the rate of 3 live seeds per cm<sup>2</sup>. Seeds were surface-broadcast and raked into the spoil.

Estimates of aboveground biomass (production) for rillscale were obtained by harvesting different halves of each plot at estimated peak in standing crop for 2 consecutive years. All harvested biomass was oven-dried at 55° C, weighed, ground to pass through a 20-mesh screen, and stored for chemical analysis. Biomass samples were not washed to remove surface contamination; therefore, elemental analysis of these samples represents what herbivores would ingest. Spoil samples were collected at a depth of 0–10 cm immediately after the biomass harvest, air-dried, and stored for chemical analysis. This sampling depth was selected to characterize

Research was conducted by USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, South Dakota School of Mines, Rapid City 57701; and Department of Range Science, Colorado State University, Fort Collins 80523.

Voorhees is research scientist, and Uresk is supervisory research biologist, USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta.; Trlica is professor, Department of Range Science, Colorado State Univ.

Manuscript accepted 5 May 1990.



the observed rooting zone of rillscale.

### Spoil and Foliage Analysis

Determinations of concentrations of elements in spoil (As, B, Cd, Cu, Fe, Pb, Mn, Mo, Ni, P, K, Se, Na, and Zn) were made on an ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) extract (Soltanpour and Schwab 1977) using inductively coupled plasma atomic emission spectrometry (ICP-AES) (Jones 1977).

Saturated paste extracts were difficult to prepare because of the extremely high and variable saturation percentage of spoil. Therefore, the sodium adsorption ratio (SAR) of a 1:5 spoil:water extract was measured using ICP-AES. Electrical conductivities (EC's) and levels of soluble Ca, Mg, and Na were also measured on the 1:5 extracts.

Sulfate content of spoil was measured using a turbidimetric method (Rhoades 1982a). Nitrogen percentages were estimated using the salicylic acid modification of the semimicro-Kjeldahl method to include nitrates (Bremner and Mulvaney 1982). The pH was measured on a 1:5 spoil extract. Cation exchange capacity (CEC) was determined using the sodium acetate method (Rhoades 1982b).

Plant tissue analyses included total nitrogen by conventional micro-Kjeldahl (Church and Pond 1978) and elemental concentrations of nitric acid-extractable, Al, As, Ba, B, Cd, Ca, Cr, Cu, Fe, Mg, Mn, Mo, Ni, P, K, Se, Na, Sr, Ti, and Zn. Elemental concentrations of nitric acid extracts were measured using ICP-AES on the nitric digest (Gestring and Soltanpour 1984, Havlin and Soltanpour 1980). The ICP-AES method operates at temperatures between 5700 and 9700° C (Fassel and Knisely 1974), and organic molecules or complexes in solution would be effectively atomized (Havlin and Soltanpour 1980).

### Statistical Analysis

An element or property was considered limiting to growth if it met these 2 criteria (Bannister 1976): (1) a positive correlation between concentrations of the element in spoil and production estimates, and (2) a positive correlation between concentrations of the element in foliage and concentrations of the element in spoil. Spoil properties that could not be measured in foliage (EC, CEC, pH, saturation percentage, SAR) were subjected to the first criterion only.

The 2 criteria were individually examined using 2 separate regression analyses on 16 data points. The first regression analysis determined the strength and significance of the correlation between production of rillscale and each spoil characteristic, after treatment effects associated with a full factorial analysis of variance model had been entered into the equation as dummy variables. Terms for each of the 3 spoil amendments and all associated interactions (see 2<sup>3</sup> factorial design) were included in the analysis of variance model. Entering the analysis of variance model terms first allowed the analysis to focus on the relationships between production and spoil characteristics after linear correlations between production and spoil amendments had first been removed (i.e., focus on the partial correlation between production and spoil characteristics adjusting for spoil amendments and their interactions). Partial correlation plots of production against each spoil characteristic were examined to detect any nonlinear relationships. No nonlinear trends were observed.

This study was exploratory work on bentonite spoils. Therefore, the omission of possibly significant relationships between spoil and vegetative parameters was considered more detrimental than possible misclassification of a relationship as significant. To protect against this Type II error, levels of an element in spoil were considered significantly related with production estimates if  $p \leq 0.20$  (Hayne 1976, Carmer 1976). This was not meant to indicate a conclusive result, but to point the way to needs of further study.

**Table 1. Chemical properties of bentonite mine spoil. The mean and range were computed across controls, all amendments, and amendment combinations.**

Property (units)	Mean	Range
N (%)	0.07	0.03 - 0.10
P (μg/g)	10.0	6.0 - 15.0
K (μg/g)	218.0	177.0 - 270.0
Zn (μg/g)	4.9	3.0 - 8.0
Fe (μg/g)	35.0	11.2 - 84.6
Mn (μg/g)	16.0	8.2 - 33.8
Cu (μg/g)	4.2	1.8 - 8.3
Ni (μg/g)	2.2	0.5 - 4.1
Mo (μg/g)	0.38	0.08 - 0.87
Na (μg/g)	5626.0	4610.0 - 6620.0
B (μg/g)	0.2	0.1 - 0.3
Soluble Ca (meq/l)	7.5	0.9 - 23.0
Soluble Mg (meq/l)	2.4	0.6 - 8.5
Soluble Na (meq/l)	37.3	18.5 - 48.7
SO <sub>4</sub> (μg/g)	3471.0	643.0 - 6000.0
Pb (μg/g)	2.2	0.9 - 4.1
Cd (μg/g)	0.15	0.05 - 0.25
As (μg/g) <sup>1</sup>	<0.2	-
Se (μg/g) <sup>1</sup>	<0.2	-
CEC (meq/100g)	50.3	39.8 - 69.6
pH	7.4	5.9 - 9.0
Saturation percentage	238.0	98.0 - 404.0
EC (S m <sup>-1</sup> )	0.44	0.23 - 0.62
SAR	18.8	8.0 - 26.1

<sup>1</sup>Below detection limits for ICP-AES.

The second regression analysis characterized the relationship between foliage levels and spoil levels of the element, again after treatment effects on foliage levels had been entered into the equation as dummy variables as discussed above. Partial correlation plots of foliage levels of each element against levels of the same element in spoil were examined to detect nonlinear relationships. No nonlinear trends were observed.

## Results and Discussion

### Production

Production of rillscale on amended plots averaged 1,464 kg dry matter/ha (range 267–2,913 kg dry matter/ha). Variability in production occurred as a result of differences in spoil amendments (treatments) (Voorhees et al. 1987) and differences in the properties of unamended spoil.

### Spoil Chemistry

The chemical analysis of spoil at the study site (Table 1) revealed several properties that could be limiting to plant growth. Nitrogen percentages of spoil were low (0.03–0.10%) as compared with soil nitrogen (4%) of cool, arid shrublands (Charley 1977). Phosphorus and potassium content of spoil appeared high (6.0 to 15.0 μg/g and 177 to 270 μg/g, respectively) as compared with similar data for soils of native and improved range grasslands (Soltanpour et al. 1979). The value of phosphorus was comparable to levels in spoils reported by other researchers (Bjugstad et al. 1981, Dollhopf and Bauman 1981, Smith 1984). Zinc, copper, and manganese concentrations appeared sufficient for plant needs (Soltanpour et al. 1979). Spoil iron levels were quite high (Soltanpour et al. 1979). Boron levels were low but not deficient.

The pH values ranged from slightly acidic to moderately basic and was considered acceptable for most plants (Table 1). In the presence of large amounts of sodium, these pH levels indicated a high content of neutral soluble salts (Buol et al. 1980). Because of the high concentration of sulfate salts present, soluble salt content is likely to vary with the soil:water ratio. Therefore, the conductivities of the 1:5 extracts were not used to estimate soil salinity.

The high concentration of sulfates in spoil was a result of the

**Table 2.** Chemical properties of foliage of rillscale grown on bentonite mine spoil. The mean and range were computed across controls, all amendments, and amendment combinations.

Property (units)	Mean	Range
Kjeldahl N (%)	1.78	1.51 – 2.18
P (%)	0.18	0.14 – 0.22
K (%)	1.11	0.94 – 1.30
Zn (μg/g)	64.0	0.0 – 99.0
Fe (μg/g)	9056.0	3110.0 – 18600.0
Mn (μg/g)	396.0	150.0 – 1020.0
Cu (μg/g)	6.0	4.0 – 8.0
Ni (μg/g)	7.0	5.0 – 12.0
Mo (μg/g)	17.0	3.0 – 52.0
Na (%)	8.37	7.64 – 9.21
B (μg/g)	38.0	32.0 – 48.0
Ca (%)	0.45	0.37 – 0.54
Mg (%)	0.95	0.68 – 1.08
Al (μg/g)	1151.0	620.0 – 1670.0
Cr (μg/g)	4.0	3.0 – 6.0
Ti (μg/g)	9.0	6.0 – 12.0
Cd (μg/g) <sup>1</sup>	1.0	–
As (μg/g) <sup>2</sup>	–	–
Se (μg/g) <sup>2</sup>	–	–
Sr (μg/g)	70.0	39.0 – 123.0
Ba (μg/g)	34.0	12.0 – 58.0
Cu:Mo	0.7	0.1 – 2.3

<sup>1</sup>Below detection limits for ICP-AES.

<sup>2</sup>High iron and aluminum caused severe spectral interferences for arsenic and selenium, making it impossible to determine these elements.

accumulation of salts, especially Na<sub>2</sub>SO<sub>4</sub> (Mengel and Kirkby 1982) or the oxidation of naturally occurring iron, nickel, and copper sulfides, which are common in soils with restricted drainage (Brady 1974) (Table 1). Jarosite, a hydrous potassium iron sulfate that has been shown to be present in bentonite mine spoil (Smith 1984, Smith et al. 1985) accounted for some of the sulfate content.

The CEC of spoil was variable but quite high on the average at 50 meq/100 g, a value intermediate between those that might be expected for montmorillonite and illite clay minerals (Brady 1974) (Table 1). Mineralogical analysis has shown both of these clay types as well as kaolinite to be present in bentonite mine spoil (Uresk and Yamamoto 1986). The saturation percentage of spoil was extremely high.

### Foliage Chemistry

Nitrogen, phosphorus, potassium, zinc, copper, boron, and magnesium in tissue of rillscale were at levels within the range considered normal for most plants (Epstein 1972, Larcher 1980, Mengel and Kirkby 1982). The extremely high iron content of 9,000 μg/g is more than 9 times the normal range for most plants (Larcher 1980) but is probably partially due to presence of spoil on unwashed foliage (Table 2). The concentration of aluminum in foliage was also very high at 1,151 μg/g: the usual amount found in the tissues of higher plants is about 200 μg/g (Mengel and Kirkby 1982). Average manganese levels were near the high end of the normal range (300 μg/g). Levels of nickel, chromium, molybdenum, and sodium were higher than normal but were not considered to be toxic for plants. The copper to molybdenum ratio was low at 0.7, which could lead to molybdenum induced copper deficiency in cattle and could limit the use of rillscale as forage. Calcium levels in foliage were marginally low (Larcher 1980).

### Production and Spoil Chemistry

Spoil molybdenum was the most significant ( $p \leq 0.018$ ) spoil parameter for predicting production of rillscale (Table 3). Although concentrations in spoil molybdenum did not appear excessive, high levels of available molybdenum were associated with low growth of rillscale ( $r = -0.76$ ). Demonstrations of plant yield decrease caused by excessive molybdenum are rare (Murphy and

**Table 3.** Partial linear correlation coefficients ( $r$ ), probability levels ( $p$ ), and regression coefficients ( $b$ ) between A) production of rillscale grown on bentonite mine spoil and each spoil chemical property, and B) elemental level in foliage of rillscale and spoil level of each element. Correlation coefficients were estimated after adjusting for the effects of treatment. Spoil properties that are not listed were not significantly ( $p < 0.20$ ) related to production of rillscale grown on spoil.

Spoil Chemical Property	Production (A)			Foliage concentration (B)		
	$r$	$p$	$b$	$r$	$p$	$b$
Extractable Mo	-0.76	(0.018)	-1961.0	+0.57	(0.11)	+29.9
Extractable Ni	+0.69	(0.041)	+395.6	-0.30	(0.435)	-0.5
Soluble Ca	+0.38	(0.048)	65.09	0.42	(0.106)	-0.002
Extractable Cd <sup>1</sup>	+0.67	(0.047)	+6945.4	—	—	—
Saturation percentage	-0.67	(0.048)	-4.5	—	—	—
Extractable Na	-0.64	(0.061)	-0.7	-0.55	(0.126)	-0.0
Cu:Mo <sup>2</sup>	+0.64	(0.062)	+14.8	+0.61	(0.081)	+0.0
Extractable Cu	+0.63	(0.069)	+216.5	-0.18	(0.646)	-0.7
Extractable Pb <sup>2</sup>	-0.61	(0.084)	-443.9	—	—	—
Extractable K	+0.57	(0.110)	+25.0	-0.49	(0.183)	-0.0
pH <sup>2</sup>	-0.54	(0.132)	-350.7	—	—	—
SAR <sup>2</sup>	-0.32	(0.147)	-53.00	—	—	—
Extractable Mg	+0.52	(0.156)	+49.4	-0.14	(0.717)	-4.6
Total N	+0.51	(0.156)	+18707.8	+0.34	(0.365)	+2.8

<sup>1</sup>Below ICP-AES detection levels in foliage (1.0 μg/g).

<sup>2</sup>Not analyzed for plant tissue.

Walsh 1972). Standing crop decrease with increased spoil molybdenum may have been associated with increased pH. Molybdenum availability is very dependent on and increase with pH (Brady 1974).

Wood residue amendment has been associated with decreased spoil Mo and with increased standing crop (Voorhees et al. 1987, Voorhees and Uresk 1990). Foliage levels of molybdenum increased as molybdenum levels of spoil increased ( $r = 0.57$ ). This indicated that rillscale was a molybdenum accumulator, which may limit its use as forage on areas with high levels of available molybdenum.

Plant accumulation of molybdenum and the apparent negative effects of molybdenum on growth might be mitigated by the addition of copper to spoil containing high levels of molybdenum (Table 3). Increases in the copper to molybdenum ratio of spoil were associated with increased production ( $r = 0.64$ ) and an increase in the copper to molybdenum ratio of foliage ( $r = 0.61$ ). A decrease in pH of spoil would increase availability of Ca and decrease availability of Mo.

Increases in the extractable amounts of several divalent cations (Ni, Cd, Cu, Mn) were associated ( $p \leq 0.20$ ) with increases in yield of rillscale. Increased amounts of potassium in spoil were also associated with increased growth ( $p \leq 0.11$ ) although potassium levels in spoil were high (Table 1). Foliage concentrations of these elements were generally not correlated with spoil concentrations (cadmium was below ICP-AES detection levels in foliage) (Table 3). Rillscale production was negatively correlated with levels of extractable spoil sodium and spoil saturation percentage. These relations indicate that these bivalent ions were not limiting as nutrients, but reflected improved spoil structure for the benefit of plant growth because of their (1) presence on exchange sites in lieu of sodium, (2) presence in solution as salts, or (3) relationship to increased organic matter content or decreased pH of spoil.

Although production of rillscale was positively correlated ( $p = .048$ ) with levels of soluble calcium in spoil ( $r = 0.38$ ), foliage concentrations of calcium were negatively correlated ( $p = 0.106$ ) with levels of soluble calcium (Table 3). Foliage calcium levels in this study were low, and calcium in foliage is generally not affected by levels in the nutrient medium when the calcium supply in the substrate is adequate (Loneragan and Snowball 1969). Therefore

the decrease in foliage calcium associated with increases in soluble calcium in spoil appeared to be a dilution effect (Larcher 1980, Mengel and Kirkby 1982). The dilution of calcium in plant tissues apparently occurs as a result of increased production caused by greater availability of calcium and by improvement of spoil structure as the amount of exchangeable calcium increases. Increases in the levels of soluble calcium also increase the salt tolerance of plants (La Haye and Epstein 1969). Gypsum amendment has been associated with increases in soluble Ca in spoil and with increased plant standing crop, when used in combination with an amendment that increased permeability of spoil (Voorhees et al. 1987, Voorhees 1986).

Increases in levels of extractable lead were associated with decreased production of rillscale ( $p = 0.08$ ) although lead content of spoil was not excessive. Wood residue amendment has been associated with a decrease in extractable lead in spoil and with an increase in standing crop (Voorhees et al. 1987, Voorhees and Uresk 1990).

The negative association between production and saturation percent ( $r = -0.67$ ) reflects differences in growth caused by differential permeability of spoil. A high saturation percentage indicates high water-holding capacity but also indicates limits on hydraulic conductivity, because absorbed water is held near the spoil surface and is not readily available to many plant roots. A high saturation percentage can result in damage to root systems by limiting air flow when the substrate is wet. Differences in the saturation percentage of spoil probably resulted from spatial variability in the proportion of the mixture of shale and bentonite clay in spoil or from degree of saturation of the exchange complex with Na.

Decreases in production were associated with increases in the levels of extractable sodium in spoil ( $r = -0.64$ ) and with increases in SAR ( $r = -0.32$ ) (Table 3). This indicated that sodium was probably detrimental to growth when present on exchange sites. Gypsum amendment has been associated with a decrease in SAR and with an increase in standing crop when used in combination with an amendment that increased permeability of spoil (Voorhees et al. 1987, Voorhees 1986). Extractable sodium was negatively correlated ( $r = -0.55$ ) with foliar sodium. Therefore, extractable sodium was either not available to plants or uptake of sodium by plants was limited because of its effects on spoil structure.

Plant growth was positively associated with decreases in pH ( $p = 0.13$ ) and with increases in total nitrogen ( $p = 0.16$ ) (Table 3). This was not surprising when the mean and range of these properties in spoil were considered.

Spoil characteristics were not adjusted for the effect of amendments. The statistical design may have been less sensitive to growth-limiting effects of characteristics that were affected by amendments. Spoil characteristics not found to be growth-limiting in this study and previously shown to be affected by the amendments used in this study include the sodium adsorption ratio, sulfate, manganese, soluble sodium, phosphorus, potassium, zinc, boron, and cation exchange capacity (Voorhees et al. 1987).

The lack of correlation between rillscale production and spoil levels of some elements, or between foliage levels and spoil levels of some elements, may reflect the inadequacies of the AB-DTPA procedure for evaluating plant-available levels of these elements. Spoil or foliage concentrations were below ICP-AES detection limits for some elements (As, Se, and Cd), and spectral interferences prevented determination of arsenic and selenium in plant tissue. Assessment of the relationships between foliage and spoil concentrations of these elements was, therefore, not possible. In some cases the range in chemical composition of spoil may not have been wide enough for significant differences in plant growth to become evident.

### Conclusions

Calcium was the only nutrient that was deficient for growth of

rillscale, although nitrogen was also implicated. Chemical limitations to the growth of rillscale on bentonite mine spoil generally appeared to be effects of toxicities or imbalances in elemental composition, or indicators of structural characteristics of spoil. This species appeared to be very sensitive to an increase in the level of spoil molybdenum and in the ratio of copper to molybdenum, but was tolerant of high levels of soluble salts and sodium.

### Literature Cited

- Allison, F.E. 1965. Decomposition of wood and bark sawdusts in soil, nitrogen requirements, and effects on plants. USDA-ARS. Tech. Bull. 1332.
- Bannister, P. 1976. Physiological ecology and plant nutrition. p. 229-295. In: S.B. Chapman (ed.), *Methods in plant ecology*. John Wiley and Sons, New York.
- Bjugstad, A.J., T. Yamamoto, and D.W. Uresk. 1981. Shrub establishment on coal and bentonite clay mine spoils. p. 104-122. In: *Shrub establishment on disturbed arid and semi-arid lands. Symposium proceedings*. Dec. 1980. Laramie, Wyo. Wyoming Fish and Game Dep., Cheyenne.
- Brady, N.C. 1974. The nature and properties of soils. 8th ed. Macmillan Pub. Co. Inc., New York.
- Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-total. p. 595-624. In: A.L. Page (ed), *Methods of soil analysis. Part 2: Chemical and microbiological properties*. 2nd ed. Monogr. 9 (Pt. 2) in the Agronomy Series. Amer. Soc. Agron. Inc., Madison, Wisc.
- Buol, S.W., F.D. Hole, and R.J. McCracken. 1980. Soil genesis and classification. 2nd ed. Iowa State Univ. Press. Ames.
- Carmer, S.G. 1976. Optimal significance levels for application of the least significant difference in crop performance trials. *Crop Sci.* 16:95-99.
- Charley, J.L. 1977. Mineral cycling in rangeland ecosystems. p. 215-256. In: R.E. Sosebee (ed), *Rangeland plant physiology*. Soc. Range Manage. Denver, Colo.
- Church, D.C., and W.G. Pond. 1978. Basic animal nutrition and feeding. Oxford Press, Portland, Ore.
- Dollhopf, D.J., and B.J. Bauman. 1981. Bentonite mine land reclamation in the northern great plains. Montana Agr. Exp. Sta. Res. Rep. 179. Montana State Univ., Bozeman.
- Epstein, E. 1972. Mineral nutrition of plants: Principles and perspectives. John Wiley and Sons Inc., New York.
- Fassel, V.A., and R.N. Knisely. 1974. ICP—Optical emission spectroscopy. *Anal. Chem.* 46:1110A.
- Frankton, C., and I.J. Bassett. 1970. The genus *Atriplex* (Chenopodiaceae) in Canada. II. Four native western annuals: *A. argentea*, *A. truncata*, *A. powellii*, and *A. dioica*. *Can. J. Bot.* 48:981-989.
- Gestring, W.D., and P.N. Soltanpour. 1984. Evaluation of the ammonium bicarbonate-DTPA soil test for assessing boron availability to alfalfa. *Soil Sci. Soc. Amer. J.* 48:96-100.
- Hayne, D.W. 1976. Experimental designs and statistical analyses in small mammal population studies. p. 3-13. In: *Populations of small mammals under natural conditions*. Pymatuning Laboratory of Ecology. Spec. Publ. Series Vol. 5. Univ. of Pittsburgh.
- Havlin, J.L., and P.N. Soltanpour. 1980. A nitric acid plant tissue digest method for use with inductively coupled plasma spectrometry. *Commun. Soil Sci. Plant Anal.* 11:969-980.
- Jones, J.B., Jr. 1977. Elemental analysis of soil extracts and plant tissue ash by plasma emission spectroscopy. *Commun. Soil Sci. Plant Anal.* 8:349-365.
- La Haye, P.A., and E. Epstein. 1969. Salt tolerance by plants: enhancement with calcium. *Science* 166:395-396.
- Larcher, W. 1980. *Physiological plant ecology*. 2nd ed. Springer-Verlag, New York.
- Loneragan, J.F., and K. Snowball. 1969. Calcium requirements of plants. *Aust. J. Agr. Res.* 20:465-478.
- Marshall, T.J., and J.W. Holmes. 1979. *Soil physics*. Cambridge Univ. Press, New York.
- Mengel, K., and E.A. Kirkby. 1982. *Principles of plant nutrition*. 3rd ed. Internat. Potash Instit., Worblaufen-Bern, Switzerland. 655 p.
- Murphy, L.S., and L.M. Walsh. 1972. Correction of micronutrient deficiencies with fertilizers. p. 347-387. In: J.J. Mortvedt, P.M. Giordano, and W.L. Lindsay (eds), *Micronutrients in agriculture. Symp. Proc.*, April 1971. Muscle Shoals, Ala. Soil Sci. Soc. Amer. Inc., Madison, Wisc.
- National Oceanic and Atmospheric Administration. 1983. Wyoming climatological data: Annual summary. Environmental Data and Information Center, Nat. Climatic Center, Asheville, N.C.

- Rhoades, J.D. 1982a.** Soluble salts. p. 167-179. *In*: A.L. Page (ed), Methods of soil analysis. Part 2: Chemical and microbiological properties. 2nd ed. Monograph No. 9 (Pt. 2) in the Agronomy Series. Amer. Soc. Agron. Madison, Wisc.
- Rhoades, J.D. 1982b.** Cation exchange capacity. p. 149-157. *In*: A.L. Page (ed), Methods of soil analysis. Part 2: Chemical and microbiological properties. 2nd ed. Monogr. 9 (Pt. 2) in the Agronomy Series. Amer. Soc. Agron. Madison, Wisc.
- Sieg, C.H., D.W. Uresk, and R.M. Hansen. 1983.** Plant-soil relationships on bentonite mine spoils and sagebrush-grassland in the northern High Plains. *J. Range Manage.* 37:289-294.
- Smith, J.A. 1984.** Wood residue and fertilizer amendments for reclamation of orphan bentonite mine spoils. M.S. Thesis. Univ. Wyoming, Laramie.
- Smith, J.A., G.E. Schuman, E.J. Deput, and T.A. Sedbrook. 1985.** Wood residue and fertilizer amendment of bentonite mine spoils: I spoil and general vegetation responses. *J. Envir. Quality* 14:575-580.
- Soltanpour, P.N., A.E. Ludwick, and J.O. Reuss. 1979.** Guide to fertilizer recommendations in Colorado. 2nd ed. Coop. Ext. Serv., Colorado State Univ., Fort Collins.
- Soltanpour, P.N., and A.P. Schwab. 1977.** Use of inductively coupled plasma spectrometry for the simultaneous determination of macro- and micronutrients in  $\text{NH}_4\text{CO}_3$ -DTPA extracts of soils. *Soil Sci. Soc. Amer. J.* 43:75-78.
- Uresk, D.W., and T. Yamamoto. 1986.** Growth of forbs, shrubs and trees on bentonite mine spoil under greenhouse conditions. *J. Range Manage.* 39:113-117.
- Voorhees, M.E. 1990.** Forage quality of rillscale (*Atriplex suckleyi*) grown on amended bentonite mine spoil. *Great Basin Natur.* 50:57-62.
- Voorhees, M.E. M.J. Trlica, and D.W. Uresk. 1987.** Growth of rillscale on bentonite mine spoil as influenced by amendments. *J. Envir. Quality* 16:411-416.
- Voorhees, M.E. 1986.** Infiltration rate of bentonite mine spoil as affected by amendments of gypsum, sawdust and inorganic fertilizer. *Reclam. Reveg. Res.* 5:483-490.
- Voorhees, M.E., and D.W. Uresk. 1990.** Effect of amendments on chemical properties of bentonite mine spoil. *Soil Sci.* 150:663-670.

# Economically optimal private land grazing strategies for the Blue Mountains of eastern Oregon

THOMAS M. QUIGLEY, JOHN A. TANAKA, H. REED SANDERSON, AND ARTHUR R. TIEDEMANN

## Abstract

The Oregon Range Evaluation Project implemented 3 levels of grazing management intensities (strategies) on private land pastures in the Blue Mountains of northeastern Oregon. Prior to implementing each management strategy, a coordinated resource plan was prepared and a benefit-cost analysis on each practice and pasture was performed. The goal was to achieve the largest economic return from grazing for each strategy implemented. Returns above variable costs were used to select the optimal grazing strategy for the ecosystems represented. The commodity production strategy was found to be optimal in all ecosystems over a wide range of interest rates, management costs, and beef prices.

**Key Words:** economics, grazing management, commodity production

Land management decisions have been influenced by economic processes since the settlement of the West. Economic decisions in range management occur at the practice level, the pasture level, and the ranch or allotment level. Choices at the pasture level include selection of practices to be implemented (how many miles of fence to construct, how many acres to seed, and which water developments to install). At the ranch and allotment level, decisions are made with respect to the number and size of pastures and respond to national or regional policies, coordination with national programs, price supports, and establishment of fees. Ranches and allotments combined comprise the production system of a region or nation.

Broad policy decisions directly affect the economics of practice implementation. Economic decisions of investments are related to the economic well being of regions and nations. These types of economic decisions are interdependent. A recent review of the range economics literature shows many studies at the practice and

ranch level, but few at the pasture level (Wagstaff 1986). The objectives of this study were to determine costs and revenues of managing ecosystems at different intensities and to determine the most economic grazing strategies for ecosystems of the Blue Mountains in eastern Oregon on private lands.

## Study Area and Methods

The Oregon Range and Related Resources Evaluation Area Project (EVAL) was started, in part, to determine the costs and benefits associated with different intensity levels of range management. The overall study has examined forage, water quantity and quality, storm runoff, and associated impacts of range management on resources (Sanderson et al. 1988). The EVAL area is about 485,000 hectares (1.2 million acres) of private and public land (the northern half of Grant County, Ore.). Private ranchers had to apply to be included in the EVAL study. Coordinated plans were developed for selected ranches. The planning process was led by the USDA Forest Service and included all Federal, State, and private lands associated with the selected ranches. Beginning in 1976 and ending in 1986, coordinated plans were developed and implemented for over 137,500 hectares (340,000 acres) of private and public rangelands in the Blue Mountains of eastern Oregon. Only private land management will be considered in this paper.

Range management strategies were planned and implemented on 140 pastures (21 ranches). Cost share arrangements were made to partially finance improvements on private land. All practices were monitored for compliance with standards specified by the EVAL team, an interagency group with leadership responsibilities for the EVAL project. Physical specifications were the same on all land ownerships and were developed with private landowners, agency planners, and the county committee for the Agricultural Stabilization and Conservation Service.

The coordinated resource planning process followed that outlined by Sanderson et al. (1988). An interdisciplinary team developed a management plan for all rangelands that included an

Authors are range scientist, Pacific Northwest Research Station, La Grande, Oregon 97850; assistant professor, Department of Agriculture and Resource Economics, Oregon State University Agriculture Program, Eastern Oregon State College, La Grande, Oregon 97850; and range scientist and principal range scientist, Pacific Northwest Research Station, La Grande, Oregon 97850.

Manuscript accepted 21 April 1990.

assessment of the improvement potential for each pasture. A management intensity (grazing strategy) was selected for each pasture with guidance from the private landowner. Specific practices for the management strategy were selected and scheduled for implementation. Each individual practice was subjected to standard investment analysis (benefit-cost or net present value) prior to being included in the strategy. Practices were implemented between 1976 and 1981. Gathering and monitoring of data continued through September 1984.

A benefit-cost approach was used in the analysis. Benefits were estimated as beef production and were converted to monetary values using an average price for beef. Costs were estimated for improvements, maintenance of improvements, and management of livestock. Benefits and costs were annualized (amortized) and the difference, net revenue, determined. The optimal strategies were defined to be those with the largest net revenue.

### Management Strategies

Range management intensity within a pasture was defined by management strategies (Sanderson et al. 1988). Strategies (Table 1)

**Table 1. Range management strategy definitions.**

Strategy	Definition
A	Environmental management without livestock
B	Environmental management with livestock Goal—livestock control Typical management practice—fencing
C	Extensive management of livestock and environment without cultural practices Goal—uniform livestock distribution Typical management practices—fencing, water developments, access trails
D	Intensive management of livestock and environment with cultural practices Goal—enhancing forage production and uniform livestock distribution Typical management practices—fencing, water developments, access trails, thinning, seeding, fertilization, brush control, irrigation
E	Maximize commodity production with no degradation of base resources and no constraining multiple use consideration on private land Goal—enhancing commodity production and uniform livestock distribution Typical management practices—fencing, water developments, access trails, thinning, seeding, fertilization, brush control, irrigation

were defined to provide a practical management perspective. Management intensity progresses from excluding livestock (strategy A) to commodity production with no environmental constraints (strategy E). Practices compatible with a strategy at a lower level are also consistent with higher level strategies; however, some practices at a higher level may not be consistent with strategies at lower levels.

The objective of strategy implementation was to achieve the largest economic returns possible. Expected costs and expected benefits were considered before implementation of practices, rather than implementing large-scale practices and analyzing the costs and benefits after implementation. Decisions were based on the expected increase in net revenues of the projects to be implemented. This objective differs from other studies of range improvement (for example, Heady and Bartlome 1977, Pope and Wagstaff 1987) where both low and high productive areas were treated and

included in the analysis. If a large proportion of the area were in low productive status, there would be a bias in the analysis toward a poor benefit-cost ratio. Areas where forage could have been increased through treatment were generally excluded from treatment in this study when costs exceeded benefits. Exceptions included treatments where all benefits could not be quantified in economic terms yet were important to the EVAL team and manager or owner. At all strategy levels, basic soil and water resource values were protected.

### Cost Determination

Cost accounting procedures were implemented to track the resources used to install the range practices. This included labor, equipment, and materials; for example, miles driven, hours and type of equipment used, number of fence posts, rolls of barbed wire, amount of seed applied, and so on for all resources. These were converted into dollar amounts in 1978 costs (FOB John Day, Ore.). Cost information was separated by skilled labor, unskilled labor, equipment, and material expenses for each practice type (Quigley et al. 1989, Quigley and Sanderson 1989). More than 800 individual practices were monitored.

### Direct and Fixed Costs

All direct costs of implementation and maintenance of the practices were assessed to the grazing strategy. When costs were incurred for purposes other than grazing, the separable costs-remaining benefit approach (Gittinger 1982) was used to assign only those costs of the practices that provided range benefits to the grazing strategy. An additional cost allocation process was necessary to provide costs on an ecosystem basis because most pastures included more than 1 ecosystem. Benefits from a practice occurring in only 1 ecosystem may spread to the entire pasture. For example, a pasture with 3 ecosystems each having one-third of the area could have only 1 water development in the pasture. The cost associated with constructing, maintaining, and managing the single development was allocated proportionally to all 3 ecosystems contributing to grazing capacity. We totaled all grazing costs in a pasture and proportionally allocated them to the ecosystems in the pasture based on their contribution to the total grazing capacity of the pasture.

Fixed costs were neither measured nor estimated in this study. Fixed costs are those that do not vary with changing levels of production; they are important in the decision to produce or not to produce but not in the level of production (Workman 1986). It was assumed in the analysis that the physical plant (e.g., land area, facilities) was constant over the life of the analysis. Research in North Dakota shows that implementation of short-duration graz-

**Table 2. Numbers of ecosystem and pasture combinations by strategy.**

Total number of pastures	139
Number of pastures with	
Strategy C	37
Strategy D	27
Strategy E	75
Number of pastures with ecosystem	
Douglas-fir	17
Ponderosa pine	39
Larch <sup>1</sup>	6
Sagebrush	51
Juniper	56
Mountain grassland	88
Mountain meadow	28
Total number of ecosystem-pasture cells	285

<sup>1</sup>Excluded from analysis. Not enough observations across strategies.

ing systems on ranches increases fixed costs an average of 5% (Mack 1985). Implementing EVAL strategies involved fewer improvements than typically occur with short-duration grazing systems and would likely result in a small increase in fixed costs. Therefore, the potential bias associated with excluding fixed costs should have little effect on the economically optimal strategies of the EVAL program.

### Management Costs

Costs for livestock management were estimated on an AUM basis following the Oregon data reported by Obermiller and Lambert (1984). The costs included expenses for turn-out, round-up, movement, routine management, salting, feeding, veterinary services, meetings, death loss, fees, and rent. Multiplying the costs per AUM by the number of AUM's in a given ecosystem resulted in an estimate of the cost of livestock management for the ecosystems within the pasture.

### Annualized Costs

All costs were adjusted to 1978 dollars by using the prices-paid index (USDA Statistical Reporting Service 1987). Costs were annualized over a 50-year planning horizon at interest rates of 4, 7, and 10% to determine the annual amount of money required to implement and maintain the given management strategy for 50 years and pay interest at the selected rate. All developments and improvements were assumed to have a useful life of 25 years. Each practice was considered as replaced once during the planning period. At year 25, we assumed the maintenance costs exceeded the costs of replacement and had therefore reached the end of its economic life. The selected interest rates represented estimates of the long-term real cost of capital (opportunity cost plus risk, but without inflation).

### Benefit Determination

Although management of rangelands can result in many market and nonmarket benefits, we chose to consider only marketable beef benefits for this analysis. Practices implemented through EVAL had more than a single purpose with benefits accruing to other resources such as wildlife, soil, and water. Although these were important considerations in implementing practices, the selection of grazing strategies at the pasture level was made on the basis of marketable beef. The procedure required estimates of grazing capacity (AUM's) and marketable beef by ecosystems within pastures.

### AUM Allocation

AUM allocation refers to the process of allocating the total

estimated AUM capacity in a pasture to the ecosystems within that pasture. Records of actual use were obtained and forage utilization maps drawn for each pasture in the study at the end of each grazing season. The Soil Conservation Service personnel were responsible for gathering and interpreting this information. The SCS made recommendations on next year's stocking rate and the management plan was based, in part, on this information.

The AUM allocation process used ecosystem and forage utilization maps, actual-use records, personal knowledge of practices and management, and the personal experience of the team members. The total number of AUM's for each pasture was estimated and then allocated to the ecosystems represented in the pasture.

### Beef Production

Beef production was simulated for yearling heifers following McInnis et al. (1986). Data related to the production of beef from ecosystems in the Blue Mountains were available for yearling heifers but not for steers (Holechek 1980). Comparisons across strategies and pastures using heifer data provided consistent results even though few ranchers run all heifers in a given pasture and heifer gains will generally be lower than steer gains. The simulation model considered the amount of forage available for consumption in each ecosystem within a pasture and adjusted it for distance to water and slope in each of 5 periods of grazing during the year. Forage requirements were determined for the heifers and compared to the adjusted available forage in each season. Results of the model were pounds of beef production per acre by ecosystem within pastures. The simulation model was used predictively to convert the number of AUM's of grazing allocated to each ecosystem within a pasture to beef production. The model was forced to equate AUM production with the AUM's allocated.

Monetary benefits of beef production were taken as the value of the product derived from the use of forage on private lands by domestic livestock. Estimates were made of the amount of beef produced on each ecosystem area within a pasture and were multiplied by the adjusted average price of beef for the United States. Beef prices were taken as the 1977-1985 average received for steer and heifer beef in the United States (USDA 1986) and adjusted to the 1978 base year (\$54.32 per hundred weight). The analysis used the average price, a 25% higher value, and a 25% lower value to test the sensitivity of optimal strategies.

### Optimal Strategies

Optimal strategies were determined for each ecosystem by determining the greatest return above variable cost. Averages were

Table 3. Stocking rate in hectares per AUM as determined through the AUM allocation process.

Strategies	Ecosystem						Overall Average
	Douglas-Fir	Ponderosa Pine	Sage	Juniper	Mountain Grassland	Mountain Meadow	
Strategy C							
Ave <sup>1</sup>	1.55	1.53	1.84	2.32	2.07	0.43	1.83
SE	0.33	0.18	0.25	0.18	0.29	0.08	0.14
n	4	8	11	12	26	6	67
Strategy D							
Ave	1.66	1.25	1.43	2.22	1.82	0.54	1.63
SE	0.55	0.13	0.24	0.23	0.23	0.19	0.11
n	4	13	13	19	16	6	71
Strategy E							
Ave	1.37	1.54	1.31	1.93	1.22	0.30	1.31
SE	0.30	0.19	0.23	0.19	0.15	0.06	0.09
n	9	18	27	25	46	16	141

<sup>1</sup>Ave = average; SE = standard error of mean; n = sample size.

taken across pastures at the same strategy level. Variable costs were taken as the sum of the annualized costs for improvements, improvement maintenance, and management costs. Fixed costs were excluded from the analysis. Optimal strategies were determined for 27 different combinations of interest rates (3 rates), beef prices (3 levels), and management costs (3 levels). Stocking rates, costs, benefits, and net revenues were analyzed using analysis of variance procedures to determine differences among ecosystems and strategies.

## Results and Discussion

Management strategies implemented through EVAL were successful in providing increased grazing capacity (Quigley et al. 1986). During EVAL, strategies were implemented and monitored on 139 pastures (Table 2). Within these pastures Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), sagebrush (*Artemisia* spp.), juniper (*Juniperus* spp.), mountain grassland, and mountain meadow ecosystems were represented as characterized by Garrison et al. (1977). Sufficient data for analysis existed only for extensive, intensive, and commodity production (C, D, and E) strategies on private land. The western larch ecosystem was excluded from the analyses due to insufficient data across all strategy levels. The

optimal strategies described here are optimal above the environmental management (B) level.

## Stocking Rates

The anticipated pattern of less land required per AUM as management intensity increased was generally observed. Stocking rates were greater with strategy E (commodity production) level than with strategy C (extensive) on all ecosystems except for the ponderosa pine ecosystem, which were similar (1.53 hectares/AUM vs. 1.54 hectares/AUM) (Table 3). Private land pastures were generally small and tended to have uniform treatment on all ecosystems within a pasture. For example, when strategy E was implemented on a pasture with Douglas-fir, mountain meadow, and juniper, improvements included all 3 ecosystems with such practices as thinning, juniper control, and seeding. Thus, increased capacities were generally noted in all ecosystems within pastures at the E level. At strategy D (intensive), the implementation of cultural treatments may not have involved all ecosystems within a pasture but the entire pasture was included in the management strategy. Use may then shift away from other ecosystems within that pasture resulting in a relative reduction in capacity on those ecosystems. This different treatment is likely the reason for the decreased capacity between strategies C and D on Douglas-fir and mountain

**Table 4.** Costs, benefits, and net returns above variable costs (1978 dollars per hectare) on private land with interest rate at 7%, beef price at \$54.32 per hundred weight, and management costs at \$3.67 per AUM.

Strategies	Ecosystem						Overall Average
	Douglas-Fir	Ponderosa Pine	Sage	Juniper	Mountain Grassland	Mountain Meadow	
<b>Strategy C</b>							
Sample size	4	8	11	12	26	6	67
Costs							
Ave <sup>1</sup>	7.93	7.61	6.82	7.46	6.20	23.45	8.35
SE	1.83	0.86	1.06	2.08	0.40	5.19	0.86
Benefits							
Ave	23.45	28.66	25.62	16.65	25.25	107.46	31.43
SE	3.26	3.04	6.89	1.31	2.57	20.44	3.73
Net Returns							
Ave	15.49	21.05	18.80	9.22	19.03	84.01	23.08
SE	2.03	2.32	5.93	2.20	2.32	15.81	3.06
<b>Strategy D</b>							
Sample size	4	13	13	19	16	6	71
Costs							
Ave	6.62	12.43	11.64	8.55	9.91	43.37	12.97
SE	1.48	2.18	1.68	1.01	1.85	21.82	2.15
Benefits							
Ave	27.06	36.25	35.93	19.37	26.46	108.97	35.09
SE	8.45	3.90	6.42	2.52	5.51	36.42	4.45
Net Returns							
Ave	20.46	23.82	24.29	10.85	16.56	65.61	22.14
SE	7.17	3.85	5.07	2.40	4.57	17.94	2.77
<b>Strategy E</b>							
Sample size	9	18	27	25	46	16	141
Costs							
Ave	16.63	11.51	18.88	11.81	17.15	43.34	18.75
SE	4.89	2.22	2.57	2.40	2.17	4.82	1.41
Benefits							
Ave	48.60	37.24	52.78	29.87	57.70	166.13	60.93
SE	14.04	7.44	8.23	6.20	8.23	21.74	5.39
Net Returns							
Ave	31.97	25.72	33.90	18.06	40.55	122.76	42.18
SE	9.22	5.39	6.23	4.05	6.38	17.69	4.13

<sup>1</sup>Ave = average; SE = standard error of the mean.



meadow ecosystems. Analysis of variance showed significant differences in stocking rates among ecosystems ( $p<0.01$ ) and significant interaction between ecosystem and strategy ( $p<0.01$ ).

### Costs

All costs in a pasture were allocated to the ecosystems in the pasture based on the percentage of AUM's of grazing capacity that ecosystem contributed to the total. Improvement costs were taken from data gathered through the implementation phase of the EVAL project (Quigley et al. 1989). Management costs were determined on an AUM basis following Obermiller and Lambert (1984) and deflated to 1978. Management costs in 1978 dollars were \$3.67/AUM.

Costs by strategy and ecosystem at the intermediate interest rate (7%) and management cost (\$3.67/AUM) were calculated (Table 4). Costs were expected to be greater for higher strategy levels. Costs for strategy E were greater than those for strategy C for all ecosystems. Strategy D cost less than strategy C in the Douglas-fir ecosystem, and strategy E was less than the strategy D in the ponderosa pine ecosystem. These apparent inconsistencies relate to the relative shifts in capacity observed within pastures. If practices in a pasture resulted in a higher strategy but shifted the proportion of capacity away from 1 ecosystem to another, the share of costs allocated to the ecosystem with fewer relative AUM's decreased even though the strategy was more intense. Analysis of variance showed significant differences in costs among ecosystems ( $P<0.01$ ) and significant differences among strategies ( $P<0.01$ ).

### Benefits

The AUM allocation process estimated the grazing capacity for each ecosystem in a pasture. Data from each pasture were run through the beef simulation model to estimate pounds of beef produced within each ecosystem in each pasture (McInnis et al. 1986). All ecosystems showed increased benefits as the strategy changed from C to D to E (Table 4). Juniper consistently had the lowest benefits per acre while mountain meadow consistently had the highest. Analysis of variance showed significant differences among ecosystems ( $p<0.01$ ) and among strategies ( $p<0.01$ ).

### Optimal Strategies on Private Land

When beef prices, interest rates, and management costs were set at the medium level, the average net revenue for strategies C, D, and E were \$23.08, \$22.12, and \$42.18 per hectare, respectively, across all ecosystems. Strategy E was significantly greater than C and D ( $p<0.01$ ). Strategy E was optimal on all ecosystems (Table 4).

Varying price, management cost, and interest rates resulted in no changes in optimal strategies. Thus, across the price and cost levels studied, strategy E remained optimal on all ecosystems. This strategy reflects the most intensively managed level we studied. Net revenues from this level of management appear to be the greatest over a wide range of prices and interest rates.

The mountain meadow ecosystem had the greatest net revenue per hectare with the net revenue for strategy C exceeding that for strategy D. The juniper ecosystem had the lowest net revenue per hectare at each strategy level. There was nearly a seven-fold difference between juniper and mountain meadow net revenue per hectare (\$18.06 vs. \$122.79) at strategy E. A general conclusion from this analysis is that intensive management of private land will lead to the greatest net return over variable costs. The analysis did not consider fixed costs. The net returns over variable costs were positive for all strategy levels and all ecosystems studied. This indicates that the grazing strategy would be economically feasible, at least in the short-run. The net return over variable costs is available to pay for these fixed costs. It was not possible in this study to determine whether any of the management strategies

would be feasible in the long run when all costs of production are considered.

### Conclusions

For marketable beef, the economically optimal strategy for managing private land is for commodity production (strategy E). This level of management was optimal over a wide range of interest rates, management costs, and beef prices. Range management strategies as applied in the EVAL study were comprised of a mix of practices that had been individually subjected to a benefit-cost analysis. Each strategy was applied to achieve the highest return over variable costs at the given strategy level. These costs and benefits represent average precipitation years; years of below- or above-average precipitation may show different optimal strategies. Fixed costs were not included in this analysis. Practices were implemented only on those sites where the potential production was sufficient to cover the cost or to achieve a goal of management, such as early forage for spring turnout. In many instances juniper and sagebrush treatments were applied to abandoned cropland sites invaded by these species. These productive sites responded well to treatments and resulted in positive net benefits. Results indicated that intensively managed pastures, with practices selected using benefit-cost criteria, will result in greater returns above variable cost than less intensively managed pastures.

### Literature Cited

- Garrison, G.A., A.J. Bjugstad, D.A. Duncan, M.E. Lewis, and D.R. Smith. 1977. Vegetation and environmental features of forest and range ecosystems. USDA Agr. Handbk. 475.
- Gittinger, J.P. 1982. Economic analysis of agricultural projects, 2nd ed. Johns Hopkins Univ. Press, Baltimore.
- Heady, H.F., and J. Bartolome. 1977. The Vale rangeland rehabilitation program: the desert repaired in southeastern Oregon. Pac. Northwest Forest and Range Exp. Sta. Resour. Bull. PNW-70.
- Holechek, J.L. 1980. The effects of vegetation type and grazing system on the performance, diet, and intake of yearling cattle. Ph.D. Diss., Oregon State Univ., Corvallis.
- Mack, L.E. 1985. Annual report: economic analyses of alternative ranch management practices. Current Research Information System (CRIS) 1985 Annu. Rep., North Dakota State Univ., Fargo.
- McInnis, M.L., T.M. Quigley, and M. Vavra. 1986. Using computer simulation to estimate grazing capacity and beef production, p. 25-31. In: 1986 progress report...Research in rangeland management. Special Rep. 773. Oregon State Univ. Agr. Exp. Sta., Corvallis.
- Obermiller, F.W., and D.K. Lambert. 1984. Costs incurred by permittees in grazing livestock on public lands in various western states. Oregon State Univ. Ext. Serv. EM 8283.
- Pope, A.C., and J.F. Wagstaff. 1987. An economic evaluation of the Oak Creek range management area, Utah. Int. Forest and Range Exp. Sta. Gen. Tech. Rep. INT-224.
- Quigley, T.M., K. Gibbs, and H.R. Sanderson. 1986. Rancher response to changes in Federal permitted livestock numbers in eastern Oregon. Rangelands 8:276-278.
- Quigley, T.M., H.R. Sanderson, and A.R. Tiedemann. 1989. Managing interior northwest rangelands: the Oregon Range Evaluation Project. Pac. Northwest Res. Sta. Gen. Tech. Rep. PNW-GTR-238.
- Quigley, T.M., and H.R. Sanderson. 1989. Analysis of fence construction costs. Rangelands 11:183-186.
- Sanderson, H.R., T.M. Quigley, and L.R. Spink. 1988. Development and implementation of the Oregon Range Evaluation Project. Rangelands 10:17-23.
- USDA. 1986. Agricultural prices: 1985 summary. USDA, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, D.C.
- USDA Statistical Reporting Service. 1987. Agricultural prices: 1986 annual summary. Crop Reporting Board, Washington, D.C., June 1987. PR 1-3(87).
- Wagstaff, F.J. 1986. Range and ranch economics bibliography: 1968-85. Int. Forest Res. Sta. Gen. Tech. Rep. INT-216.
- Workman, J.P. 1986. Range economics. MacMillan Publ. Co., New York.

# Economic evaluation of spotted knapweed [*Centaurea maculosa*] control using picloram

DUANE GRIFFITH AND JOHN R. LACEY

## Abstract

Spotted knapweed is the most serious range weed problem in western Montana. Although picloram is often used to control knapweed, the economic feasibility of the practice has not been evaluated. We developed a model to economically evaluate spotted knapweed control on rangeland. Model functions describing the dynamics of the plant community preceding and following treatment were derived from field observations in western Montana. Economic returns per management unit were calculated for 3 scenarios: (1) no treatment, (2) containment, and (3) eradication of spotted knapweed. After tax costs and benefits of treatments were analyzed for a 20-year period and discounted to the present. An economic loss in current dollars of \$2.38/ha was incurred under the no treatment strategy when 25% of the management unit was initially infested with spotted knapweed and the weed was spreading to new acres and replacing desirable forage. After-tax present value of added AUMs in the eradication strategy was greater than the after-tax present value of added costs, \$3.41/ha and \$1.99/ha, respectively. As site productivity, value of an AUM, and rate of knapweed spread to new acres increased, economic returns increased relative to treatment costs. In contrast, herbicide treatment became less cost-effective as knapweed utilization by livestock increased. Thus, economic feasibility of spotted knapweed control varied with economic and biologic conditions.

**Key Words:** sensitivity analysis, picloram, capital investment analysis, economic feasibility, eradication, rangeland

Spotted knapweed (*Centaurea maculosa*) threatens range productivity in western Montana (Lacey et al. 1986). The introduced weed has invaded about 1.8 million hectares of range and pasture in Montana (Lacey 1987). Carrying capacity has been reduced to virtually zero on some sites (Bawtree and McLean 1977), and the loss of soil and water resources is a concern (Lacey et al. 1989). Spotted knapweed has the potential to reduce the annual gross revenue of Montana ranchers by \$155 million (Bucher 1984).

Investment decisions regarding knapweed control are complex. A herbicide treatment, picloram (22K) at 0.28 kg/ha active ingredient (AI), usually kills all established plants. The herbicide residual prevents seedling establishment for 2 to 4 years (Lacey et al. 1986). Initial treatment cost is approximately \$34/ha. Grass response varies with site potential and degree of knapweed control. Picloram often has to be reapplied because some knapweed seed is still viable after 7 years in the soil (Davis and Fay 1989). The effective life of the treatment varies with species and vigor of the grass community, amount of bare ground, organic matter, other soil characteristics, and subsequent management. These complexities have discouraged economic feasibility studies (Bucher 1984, Jensen 1984).

The objective of this study was to evaluate the economic feasibility of controlling spotted knapweed on rangeland. A model was developed and used to compare no action or no treatment, con-

tainment to prevent knapweed's spread to uninfested areas, and eradication strategies. Sensitivity analyses were used to assess a range of environmental and economic factors. Results should aid weed control decisions in the Northern Intermountain region.

## Methods and Procedures

Herbage production was modeled for 3 distinct spotted knapweed control strategies: (1) no action or no treatment, (2) containment to prevent its spread to uninfested areas, and (3) eradication. A 20-year time frame was used. Herbage production was limited to the biological potential of range sites.

Herbage and forage production were evaluated per management unit, a block of land managed under a single weed plan. Management units may consist of a few acres within a pasture, a pasture, a ranch, or several ranches. Herbage includes all grasses, forbs, and shrubs. Herbage is less restrictive than forage, which only includes material that is acceptable and available to grazing animals. Forage in a spotted knapweed-infested management unit includes all usable species including knapweed, within infested and uninfested areas.

## Rate of Knapweed Spread and Production

Number of hectares invaded annually by spotted knapweed depended on the size of initial infestation and the rate of spread (Eq. 1; Table 1). Knapweed herbage and forage production are influenced by rate of spread, and increases in density subsequent to initial infestation and utilization by livestock (Eqs. 2, 3).

## Herbage and Forage Production of Other Species

Production of desirable species included growth on knapweed-infested and uninfested areas of the management unit (Eqs. 4-6; Table 1). Production declined as knapweed density increased on infested sites, and as knapweed spread into new areas.

The rate of spotted knapweed spread to uninfested hectares was a variable in the model. If acreage records are accurate, spotted knapweed has spread in Montana at the rate of 27% per year since 1920 (Lacey 1983). Total herbage and forage included production of desirable species and knapweed (Eqs. 6, 7).

Herbage response to picloram treatment has been evaluated on spotted knapweed-infested sites in western Montana (Chicoine 1984, Lacey 1985, Bedunah 1989). Their data were used for estimating first-year herbage response. Knapweed production on a site prior to treatment explained 94% of the variation in post treatment grass response.

$$HR_t = +0.624 \text{ (kg/ha of spotted knapweed)} \\ (P < 0.0001)$$

$$R^2 = 0.88$$

where  $HR_t$  was the change in grass production occurring from the time of herbicide application through the first growing season. For example, if grass and knapweed averaged 100 and 800 kg/ha prior to treatment, respectively, total grass production during the first growing season was pre-treatment grass, 100 kg/ha, plus post-treatment grass,  $.624 \times 800$  kg/ha, or 599 kg/ha. An additional 30% of the difference between first year response on treated areas and average production on uninfested areas was assumed for year 2. For example,  $[(900 - 599) \times .30]$  or 90 kg/ha of additional

Authors are assistant professor, Agricultural Economics and Economics Department, Montana State University; and extension range management specialist, Animal and Range Sciences Department, Montana State University.

Research was funded in part by DOW Chemical Company. The use of trade names in this publication does not imply endorsement by Montana State University of the products named nor criticism of similar ones not mentioned.

Manuscript accepted 12 April 1990.

**Table 1. Equations used to estimate rate of spotted knapweed spread, spotted knapweed production, production of other species, and economics of spotted knapweed control.<sup>1</sup>**

<b>Rate of knapweed spread</b>	
$MA_y = (IA * (1 + S)^y \leq AM) - (IA(1 + S)^{y-1} \leq AM)$	(1)
<b>Knapweed production</b>	
$KI_y = (IP * (1 + I)^y \leq MK)$	(2)
$KU_y = ((IA * KI_y + \sum_{y=0}^{20} MA_y * KM_y) * P_k) \div AM$	(3)
<b>Herbage and forage production of other species</b>	
$FU_y = ((IA * FI_y + \sum_{y=0}^{20} MA_y * FM_y) * P_f) \div AM$	(4)
$UU_y = ((AM - (IA * (1 + S)^y \leq AM)) * AP * P_f) \div AM$	(5)
$TU_y = KU_y + FU_y + UU_y$	(6)
$TT_y = (IA_u * KI_y * P_k + IA_u * FI_y * P_f + UA_0 * AP * P_f + TA_0 * TR_{ky} * P_k + TA_0 * TR_{hy} * P_f) \div AM$	(7)
$IM_y = (TT_y + (TT_{y-1} * (1 + H)^y - TT_{y-1})) \leq (MM * P_f)$	(8)
<b>Economics</b>	
$PV_L = \sum_{y=0}^{20} ((TU_0 - TU_y) \div LB_{aum} * ATV_{aum})$	(9)
$PV_c = \sum_{y=0}^{20} ((CA_0 * (1 + i)^y * TA_y) * (1 - MTR) * D_y) \div AM$	(10)
$PV_b = \sum_{y=0}^{20} (((TT_y - TU_y) \div LB_{aum}) * ((V_0 * (1 + i)^y) * (1 - MTR) * D_y))$	(11)
<sup>1</sup> AM = Management unit size (ha), AP = Herbage produced on uninfested area (kg/ha) ATV <sub>aum</sub> = Inflated, tax adjusted, discounted value of an AUM (adjusts future benefits lost to present dollars) CA <sub>0</sub> = Treatment costs/ha during initial year of the analysis, year 0 D <sub>y</sub> = Tax adjusted discount factor for year y of the analysis (adjusts future cost to the present) FI <sub>y</sub> = Desirable herbage kg/ha in year y on infested areas that were untreated FM <sub>y</sub> = Desirable herbage kg/ha in year y on marginal area infested FU <sub>y</sub> = Non-knapweed forage available (kg/ha) in year y from desirable grasses and other herbage H = Annual rate of succession under improved management i = Expected inflation rate I = Annual rate of increase in knapweed density on infested areas IA = Size (ha) knapweed infestation in initial year IA <sub>u</sub> = Area (ha) of management unit initially infested but untreated under a containment strategy IP = Knapweed (kg/ha) on infested area during the initial year IM <sub>y</sub> = Total forage (kg/ha) in year y assuming treatment and improved management KI <sub>y</sub> = Knapweed (kg/ha) in year y on the initially infested but untreated areas KM <sub>y</sub> = Knapweed (kg/ha) on marginal areas during year y (newly infested in year y) KU <sub>y</sub> = Knapweed forage (kg/ha) in year y LB <sub>aum</sub> = Forage (kg) required for one AUM. MA <sub>y</sub> = Marginal ha, new ha, infested in year y MK = Maximum kg/ha of knapweed allowed on the management unit limited to 90% of the current average herbage kg/ha on uninfested areas MM = Maximum herbage (kg/ha) production on the management unit MTR = Marginal tax rate. P <sub>f</sub> = Percent of desirable herbage utilized by livestock, P <sub>k</sub> = Percent of knapweed utilized by livestock PV <sub>L</sub> = After-tax present value of AUMs/ha lost due to no action alternative (prorated over every ha in management unit) PV <sub>b</sub> = After-tax present value of the benefits received over the analysis period (prorated over every ha in management unit) PV <sub>c</sub> = After-tax present value of costs incurred over the analysis period (prorated over every ha in management unit) S = Annual rate of knapweed spread to uninfested ha TA <sub>0</sub> = Number of ha treated in year 0 TA <sub>y</sub> = Number of ha treated during year y TR <sub>ky</sub> = Desirable herbage (kg/treated ha) produced in year y TR <sub>ky</sub> = Knapweed (kg/treated ha) response to treatment in year y TT <sub>y</sub> = Total forage (kg/ha) in management unit available to livestock in year y TU <sub>0</sub> = Total forage (kg/ha) in management unit available to livestock during year 0 under the no action alternative TU <sub>y</sub> = Total forage (kg/ha) in management unit available to livestock in year y under a no action alternative UA <sub>0</sub> = Number of ha in management unit that are initially uninfested UU <sub>y</sub> = Forage (kg/uninfested ha) in year y V <sub>0</sub> = Value of AUM during year 0 Y = Year y of the analysis period	

grass would bring total desirable grasses to 689 kg/ha. In year 3, production was assumed to be equal to total herbage production on uninfested hectares prior to picloram treatment. Herbage production was constant from years 3 through 20, assuming that picloram was reapplied to prevent knapweed reestablishment.

Our model allows analysis of improved grazing management in conjunction with herbicide treatment (Eq. 8). However, analyses are not reported here because of the difficulty in separating treatment effects from improved management.

Daily forage requirements of ruminants average about 2% of their body weight on a dry weight basis (K. Havstad, pers. comm.). Thus, an animal unit or a 454-kg animal requires from 9–10 kg daily, or 299 kg per month. This does not include forage disappearance, trampling, and other losses. The added forage available after knapweed treatment was divided by 299 kg to determine additional AUMs available for each year of the analysis. Forage required per animal unit is a model variable.

## Economics

Spotted knapweed control requires a capital investment. Expenses may be concentrated during the initial period of an analysis or be spread throughout the life of the project. Net annual returns are often received over the life of the project.

Our model differs from Ethridge et al.'s (1984, 1987a, and 1987b) capital investment analyses in that forage, not livestock, was the end product. Thus, our approach eliminated the use of livestock enterprise budgets. Although we assume that individual livestock performance was not affected by the presence of knapweed, carrying capacity was reduced by the plant.

Present value analysis was used to evaluate the economic potential of spotted knapweed control (Table 1, Eqs. 9–11). Investments are economically feasible when the discounted stream of after-tax benefits are greater than the discounted stream of after-tax costs. Current treatments costs and benefits were adjusted annually during the analysis for inflation and taxes.

Taxes were a variable in our model. Tax effects cancel out of the model when the timing and amount of the costs of treatment equal the timing and amount of the benefits. Economic outcomes are influenced by taxes whenever the flow of costs and benefits are unequal.

We used the model to compare the no action, containment and eradication strategies on a 405-ha management unit. Economic assumptions included: cost of treatment = \$34/ha, AUM = \$10, nominal interest rate = 12%, inflation rate = 7%, and marginal tax rate = 15%. Biological assumptions include: initial infestation of spotted knapweed = 25% of management unit, knapweed utilization = 20%, utilization of desirable forage = 40%, AUM = 299 kg, annual rate of forage displacement by knapweed = 15%, annual rate of knapweed spread to new areas = 10%, and grazing management programs following herbicide treatment were not changed,

**Table 2. Herbicide treatment by year to control spotted knapweed on high- and low-producing sites as used in the sensitivity analysis<sup>1</sup>.**

Year	% Hectares Treated by Year	
	High-producing site	Low-producing site
1	100	100
3	60	80
6	30	60
9	15	40
12	5	20
15	5	10
18	5	10

<sup>1</sup>In a containment strategy, 20% of the infested hectare was treated in the first year, and 10% each following year. Retreatment schedule based on recommendations of weed scientists and land managers in Western Montana.

Table 3. Summary of no spotted knapweed treatment given the specified parameters, on a high-producing site.

Year(s) Treated	Number Infested Hectares	Average Knapweed Production (kg/ha)	Knapweed Utilized (kg/ha)	Total Herbage Utilized (kg/ha)	Stocking Rate (ha/AUM)	Change in Herbage Utilized (kg)	Present Value of Loss <sup>1</sup> (\$/ha)
Year 0	101	68	14	204	.59	0	\$ .00
Year 1	111	79	16	202	.60	2	.02
Year 2	122	93	19	199	.61	5	.05
Year 3	135	108	22	196	.62	8	.07
Year 4	148	125	25	193	.63	11	.10
Year 5	163	132	26	191	.63	13	.10
Year 6	179	135	27	191	.64	13	.10
Year 7	197	139	28	190	.64	14	.10
Year 8	217	143	29	189	.64	15	.11
Year 9	239	149	30	188	.64	16	.11
Year 10	263	155	31	187	.65	17	.11
Year 11	289	163	33	185	.65	19	.12
Year 12	318	173	35	183	.66	21	.12
Year 13	349	184	37	181	.67	23	.13
Year 14	384	197	39	178	.68	26	.14
Year 15	405	210	42	176	.69	28	.15
Year 16	405	223	45	173	.70	31	.15
Year 17	405	239	48	170	.71	34	.16
Year 18	405	256	51	167	.73	38	.17
Year 19	405	274	55	163	.74	41	.18
Year 20	405	293	59	159	.76	45	.18
Total							\$2.38

<sup>1</sup>Economic loss (\$/ha) is prorated over entire management unit.

thus long-term plant succession was not enhanced.

Economic impact of the no action strategy was estimated by allowing spotted knapweed to spread onto uninfested areas. Value of the forage displaced by the invading knapweed was calculated (Eq. 9; Table 1). Sensitivity analyses were used to assess the effects of site productivity, size of initial spotted knapweed infestation, value of AUMs, rate of spread, and knapweed utilization on economic feasibility of treatment.

#### Model Assumptions and Limitations

This analysis assumed that spotted knapweed control strategies were applied to rangeland formerly dominated by native bunchgrasses, such as bluebunch wheatgrass (*Pseudoroegneria spicata*) and rough fescue (*Festuca scabrella*). Large increases in native grass production occur during the first growing season following picloram treatment. By the third year, total herbage produced on infested areas approximates the total production on uninfested areas of the site. This level of production is maintained by proper grazing management and the periodic use of herbicides.

We did not separate out the effect of grazing intensity, grazing frequency, type of animal grazed, nor season of grazing on the expected forage response from treatment. However, knapweed reinvasion following herbicide treatment occurs more rapidly on sites dominated by lower-successional species or under grazing management that lowers the competitiveness of the native plants (C. Lacey, pers. comm.). Residual effectiveness of picloram treatments is influenced by clay and organic matter content of soils. Shallow gravelly sites require re-treatment more frequently than higher producing sites (Table 2).

#### Results

Present value of AUMs of \$2.38/ha was lost due to the no action alternative (Table 3). By not treating the initial infestation, spotted knapweed had spread over the entire management unit by year 15. However, knapweed production (kg/ha) was still increasing. Because of the increased knapweed, grazing capacity declined from .59 to .76 ha/AUM (Table 3). A total annual loss in current after-tax dollars of \$964 occurred.

After-tax present value of added AUMs obtained through the spotted knapweed eradication program was \$3.41/ha, which exceeded the present value of after-tax treatment costs, \$1.99/ha (Table 4). Thus knapweed control was economically feasible. The knapweed infestations were re-treated in years 0, 3, 6, 9, 12, 15, and 18. Carrying capacity was maintained at .56 ha/AUM (Table 4). Rather than calculating optimal treatment strategies (Ethridge et al. 1987), this treatment focused on the elimination of viable seeds. Viable seeds were assumed to have been eliminated by year 20.

#### Range Site Simulations

Follow-up herbicide treatments to suppress spotted knapweed seedlings increased the cost of eradication on the low-producing site relative to the high-producing site (Table 5). Productivity differences between the 2 sites resulted in a higher forage response on the high-producing site. Thus, knapweed treatment was more profitable on the high-producing site (Table 5).

After-tax benefits exceeded after-tax costs for 3 of the 4 situations on the high producing site (Table 5). For the less productive site, costs exceeded benefits for each of the control strategies (Table 5). Thus, spotted knapweed control should be emphasized on high-producing rather than on low-producing sites.

#### Forage Price Simulations

Spotted knapweed eradication became more feasible as AUMs increased in value (Table 6). Present value of added AUMs with treatment exceeded present value of costs on the high-producing site \$.05 and \$2.78 when AUMs were valued at \$6 and \$14, respectively.

Treatment became feasible on the low-producing site when AUMs were valued at \$14. Although cost of treatment is not altered, benefits are directly affected as the value of AUMs varies. Knapweed control becomes more cost-effective on low-producing sites when the value of forage increases.

#### Rate of Spotted Knapweed Spread Simulations

Economic losses increase geometrically with the rate of spotted knapweed spread (Table 7). Thus, measures to prevent weeds from

Table 4. Summary of spotted knapweed eradication, given the specified parameters, of a high-producing site.

Year(s) Treated	Number Infested Hectares	Average Knapweed Production (kg/ha)	Knapweed Utilized (kg/ha)	Total Herbage Utilized (kg/ha)	Stocking Rate (ha/AUM)	Change in Herbage Utilized (kg)	Present Value of Loss <sup>1</sup> (\$/ha)
Year 0	101	68	14	163	.74	\$-1.02	\$-.40
Year 1	20	1	0	209	.58	.00	.06
Year 2	0	0	0	216	.56	.00	.15
Year 3	61	7	1	215	.56	-.54	.16
Year 4	0	0	0	218	.56	.00	.20
Year 5	0	0	0	218	.56	.00	.20
Year 6	30	3	1	215	.56	-.23	.18
Year 7	0	0	0	218	.56	.00	.20
Year 8	0	0	0	218	.56	.00	.19
Year 9	16	2	0	215	.56	-.11	.18
Year 10	0	0	0	218	.56	.00	.19
Year 11	0	0	0	218	.56	.00	.19
Year 12	6	0	0	217	.56	-.04	.19
Year 13	0	0	0	218	.56	.00	.20
Year 14	0	0	0	218	.56	.00	.20
Year 15	6	0	0	217	.56	-.03	.20
Year 16	0	0	0	218	.56	.00	.21
Year 17	0	0	0	218	.56	.00	.21
Year 18	6	0	0	217	.56	-.03	.22
Year 19	0	0	0	218	.56	.00	.23
Year 20	0	0	0	218	.56	.00	.23
Total Values						\$-1.99	\$3.41

<sup>1</sup>Economic loss (\$/ha) is prorated over entire management unit.

Table 5. Net present value of after-tax costs and benefits of spotted knapweed treatment calculated for 2 range sites, 2 control strategies (each with 2 levels of initial infestation), and prorated over the management unit.<sup>1</sup>

Control Strategy and Initial Infestation	Site <sup>2</sup>			
	High-producing		Low-producing	
	Cost (\$/ha)	Benefit (\$/ha)	Cost (\$/ha)	Benefit (\$/ha)
Complete Control (100% of ha)	-7.89	+10.92	-10.77	+4.59
Complete Control (50% of ha)	-3.94	+6.87	-5.38	+3.53
Containment (25% of ha)	-1.52	+1.60	-1.52	+1.25
Containment (50% of ha)	-3.03	+2.43	-3.03	+1.73

<sup>1</sup>20% of knapweed utilized as forage; AUM valued at \$10.

<sup>2</sup>Current and potential productivity were 544 and 680, and 272 and 318 kg/ha for the high- and low-producing sites, respectively.

Table 6. Net present value of after-tax costs and benefits of eradicating knapweed calculated for 2 range sites, (each with 5 alternative AUM values), and prorated over the management unit<sup>1</sup>.

Value of AUM \$	Site <sup>2</sup>			
	High-producing		Low-producing	
	Cost (\$/ha)	Benefit (\$/ha)	Cost (\$/ha)	Benefit (\$/ha)
6	-1.99	+2.04	-2.69	+1.27
8	-1.99	+2.93	-2.69	+1.69
10	-1.99	+3.41	-2.69	+2.13
12	-1.99	+4.09	-2.69	+2.54
14	-1.99	+4.77	-2.69	+2.96

<sup>1</sup>25% of hectares initially infested; complete control strategy; 20% of knapweed utilized as forage.

<sup>2</sup>Current and potential productivity were 544 and 680, and 272 and 318 kg/ha for the high- and low-producing sites, respectively.

spreading onto previously uninfested range are important (Table 7).

Treatment of spotted knapweed was economically feasible on high producing sites when knapweed was spreading to new areas at a rate of 5% and replacing forage on infested hectares at a rate of 5%. The economic feasibility of treatment improved as the rate of spread increased. However, after-tax costs exceeded after-tax benefits on low-producing sites at the 5, 10, and 15% rates of spread (Table 7).

#### Livestock Use of Spotted Knapweed Simulations

Economic benefits from spotted knapweed control change as animal diets change. Herbicide control is more feasible when livestock are utilizing little or no knapweed (Table 8). On a high-producing site, after-tax costs (\$1.99) were higher than after-tax benefits (\$1.39) when 30% of the knapweed was used. When 25% or less of the knapweed on a high-producing site was utilized as forage, after-tax benefits exceeded after-tax costs.

After-tax costs exceeded after-tax benefits on low-producing sites when 30% of the knapweed was used. Treatment on low-

Table 7. Net present value of after-tax costs and benefits of spotted knapweed eradication calculated for 3 alternative rates of knapweed spread and forage replacement, on two range sites, and prorated over the management unit<sup>1</sup>.

Rates of Knapweed Spread & Forage Displacement (Percent)	Site <sup>2</sup>			
	High-producing		Low-producing	
	Cost (\$/ha)	Benefit (\$/ha)	Cost (\$/ha)	Benefit (\$/ha)
5 and 5	-1.99	+2.19	-2.69	+1.17
10 and 10	-1.99	+2.99	-2.69	+1.83
15 and 15	-1.99	+3.90	-2.69	+2.55

<sup>1</sup>25% of hectares initially infested; complete control strategy; 20% of knapweed utilized as forage; AUM valued at \$10.

<sup>2</sup>Current and potential productivity were 544 and 680, and 272 and 318 kg/ha for the high- and low-producing sites, respectively.

**Table 8. Net present value of after-tax costs and benefits of spotted knapweed eradication calculated for 6 alternative rates of utilization of spotted knapweed on 2 range sites, and prorated over the management unit<sup>1</sup>.**

% Utilization (Percent)	Site <sup>2</sup>			
	High-producing		Low-producing	
	Cost (\$/ha)	Benefit (\$/ha)	Cost (\$/ha)	Benefit (\$/ha)
5	-1.99	+38.55	-2.69	+3.94
10	-1.99	+32.73	-2.69	+3.33
15	-1.99	+26.92	-2.69	+2.72
20	-1.99	+3.41	-2.69	+2.11
25	-1.99	+2.40	-2.69	+1.51
30	-1.99	+1.39	-2.69	+ .89

<sup>1</sup>25% of hectares initially infested; complete control strategy; AUM valued at \$10.

<sup>2</sup>Current and potential productivity were 544 and 680, and 272 and 318 kg/ha for the high- and low-producing sites, respectively.

producing sites was not economically feasible if more than 15% of the knapweed was being utilized as forage (Table 8).

### Management Implications

A satisfactory understanding of the relation between economic and biologic variables was assumed in developing our model. Under the assumed conditions, the economic feasibility of spotted knapweed control varied with environment and economic variables. After-tax value of additional AUMs from treatment generally exceeded after-tax costs on high-producing sites. On low-producing sites, the combination of higher treatment costs and lower herbage response limited the economic feasibility of using picloram to treat knapweed.

Economic returns increased as the value of forage increased, and with an increased rate of knapweed spread. In contrast, eradication was less cost-effective on lower-producing sites, and when livestock increased their use of knapweed as forage.

Further research regarding the ecological relationship of spotted knapweed on rangelands is needed. More information on rate of

spotted knapweed spread, herbage response to treatment, the effect of grazing management on the life of the herbicide treatment, and livestock use of the weed will improve the ability of landowners to make correct economic decisions.

### Literature Cited

- Bawtree, A., and A. McLean. 1977. Rate of spread, potential range, losses and changes in pasture composition from diffuse and spotted knapweed in British Columbia. The Knapweed Sympos. Proc., Ministry of Agr., Victoria, B.C. Canada, Kamloops, British Columbia, p. 286.
- Bedunah, D. 1989. Grass response following spotted knapweed control. Techline. Dow Chemical, U.S.A. January.
- Bucher, R.F. 1984. The potential cost of spotted knapweed to Montana range users. Ext. Bull. 1316, Montana Coop. Ext. Serv. Dec. 1984.
- Chicoine, Timothy Kevin. 1984. Spotted knapweed control, seed longevity and migration in Montana. MS thesis, Montana State Univ.
- Davis, E.S., and P.K. Fay. 1989. The longevity of spotted knapweed seed in Montana. p. 67-72. In: Knapweed Sympos. Proc., Plant Soil Sci. Dept., and Ext. Serv., Montana State Univ., EB. 45. 1989.
- Ethridge, D.E., B.E. Dahl, and R.E. Sosebee. 1984. Economic evaluation of chemical mesquite control using 2,4,5-T. J. Range Manage. 37:152-156.
- Ethridge, D.E., R.D. Pettit, R.G. Sudderth, and A.L. Stoecker. 1987a. Optimal economic timing of range improvement alternatives: southern high plains. J. Range Manage. 40:555-559.
- Ethridge, D.E., R.D. Pettit, T.J. Neal, and V.E. Jones. 1987b. Economic returns from treating sand shinnery oak with tebuthiuron in West Texas. J. Range Manage. 40:346-348.
- Jenson, E.A. 1984. Data requirements for economic evaluations of a knapweed containment program. In: Knapweed Sympos. Proc., Plant & Soil Sci. Dept. and Coop. Ext. Serv., Montana State Univ. Bull. 1315. p. 27-36.
- Lacey, C. 1985. A weed education program, and the biology and control of spotted knapweed (*Centaurea maculosa* Lam.) in Montana. Master's Thesis, Montana State Univ., Bozeman, Mont.
- Lacey, C.A., J.R. Lacey, T.K. Chicoine, P.K. Fay, and R.A. French. 1986. Controlling knapweed on Montana rangeland. Ext. Serv., Montana State Univ., Cir. 311.
- Lacey, C. 1987. Report on noxious range weeds. Proc. of Montana Weed Control Annual Meeting.
- Lacey, J.R. 1983. A complete takeover by knapweed in 2001? Montana Farmer-Stockman, July 7, 1983:32-34.
- Lacey, J.R., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Tech. 3:627-631.

# Blue grama response to Zn source and rates

E.M. WHITE

## Abstract

Surface-applied zinc (Zn) in range with claypan soils could increase herbage production, but the Zn concentration could become toxic to the crown and roots of blue grama (*Bouteloua gracilis*). Metallic Zn,  $\text{ZnCl}_2$ , and Zn chelate were applied in the greenhouse to the soil surface of pots with blue grama to determine the rate that would be toxic and the effect of Zn source on toxicity and herbage Zn content. Metallic Zn (dust, 30- and 40-mesh) was not toxic at rates below  $0.40 \text{ g Zn kg}^{-1}$  soil, but Zn chelate was toxic and  $\text{ZnCl}_2$  at the  $0.40 \text{ g Zn kg}^{-1}$  rate was toxic initially. After 2 years growth, salt was leached and herbage yields were not significantly different for different sources. Herbage Zn increased with increasing application up to about  $0.9 \text{ g Zn kg}^{-1}$  soil.  $\text{ZnCl}_2$ , applied to plants that were not Zn deficient, decreased growth; and half the plants died at rates of  $2 \text{ g Zn kg}^{-1}$  soil. Herbage from the  $2\text{-gm}$  rate had  $7.4 \text{ g Zn kg}^{-1}$ . DTPA-extracted soil Zn increased with increasing applications but not at the same rate for different sources. Metallic Zn or  $\text{ZnCl}_2$ , if applied at reasonable rates, is a satisfactory Zn source, but high rates of Zn chelate cause soil dispersion initially and should not be used on soil that disperses readily.

**Key Words:** *Bouteloua gracilis*, Zn toxicity, soil-DTPA Zn, herbage Zn-P interaction

Zinc applied in Hoagland-type solutions (Hoagland and Arnon 1938, Jacobson 1950) increased blue grama (*Bouteloua gracilis*) growth on claypan soils in the greenhouse (White and Gartner 1986). Each application of the solution contains a small amount of Zn. Surface applications of Zn on rangeland increase the concentration around blue grama roots to a level where it could become toxic. Beneficial and toxic effects of Zn on plants have been summarized by Knezek and Ellis (1980). Fertilization with acidic phosphates can solubilize soil Zn (Shuman 1988). Lindsay (1979) reported Zn and P can interact in the soil, and Tisdale et al. (1988) reported low Zn causes toxic P accumulations in the plant although the Zn content will appear normal. Wheat shoot weights are reduced by a Zn deficiency but the P contents are increased (Webb and Loneragan 1988) with the greatest increase being in older leaves. Zn deficiency in barley increases the shoot content of B, P,  $\text{NO}_3$ , S, Ca, Mg, K, and Cu but not Fe (Graham et al. 1987). Rauzi et al. (1969) reported blue grama herbage collected in rangeland had  $15 \text{ mg Zn kg}^{-1}$  in early summer, which decreased to about  $8 \text{ mg}$  in the fall. This amount is less than the  $20$  to  $40 \text{ mg Zn kg}^{-1}$  needed in feed for beef cattle (Nat. Research Council 1984). The effects of Zn source and application rates on blue grama growth were studied to determine if Zn toxicity is likely to be a problem where range is fertilized with surface-applied Zn.

## Materials and Methods

Cedar Butte loam (fine, montmorillonitic mesic Ustollic Natragids) was used in the greenhouse to grow blue grama in the following experiments. Cedar Butte loam has a 11-cm-thick E horizon with a pH of 5.7 to 5.8 and a very slowly permeable clay upper B horizon with a pH of 5.6. Cedar Butte and related soils support nonvigorous shortgrasses even in climatic cycles with above nor-

mal precipitation. Ten to 20% of the soils of central and western South Dakota have claypan dispersed by exchangeable sodium. These claypans prevent or reduce water infiltration into the lower subsoil, which in turn reduces root growth. Thus, shortgrasses on these areas are dependent on water and fertilizer elements in the upper soil layers. Fertilizer elements including Zn have been removed from these areas by prehistoric grazing, wind and water erosion, and likely in air-borne plant ash during prairie fires. Zn gradually has been depleted from the upper part of these soils which have pH's that are in the critical pH 5.5 to 6.5 range where soil Zn is not released as readily to plants as at more acid pH's (Thorne 1957).

## Experiment 1

The purpose was to determine if previous applications of minor elements to claypan-surface-soil in the greenhouse had a residual effect on bluegrama response to additional Zn applications. Soil used for a previous study (White and Gartner 1986) was crushed, and the replications of each treatment were composited and used to fill 5 plastic pots with  $1.5 \text{ kg}$  of soil. Thirty-mesh Zn metal was added at rates of  $0, 0.10, 0.20, 0.30$ , and  $0.40 \text{ g Zn kg}^{-1}$  soil. Thus, 5 Zn rates were superimposed across the 9 treatments used previously. These previous 9 were: water plus, additively in succession, NPK, B, Zn, Mn, Fe, Cu, Mo, and Co (White and Gartner 1986). Residual effects of the original minor elements on additions of more Zn as well as the Zn rate needed to maximize growth were studied in this experiment. The Zn rate on a pot area basis would be  $97, 195, 284$ , and  $390 \text{ kg ha}^{-1}$  ( $87$  to  $348 \text{ lbs acre}^{-1}$ ). These rates far exceed the  $5\text{--}15 \text{ kg Zn ha}^{-1}$  rates usually used (Murphy and Walsh 1972), but plant roots may be in contact with a high concentration around Zn granules. Thirty blue grama seeds were planted in pots and, after seedlings became established, culms were counted and herbage was harvested 5 times, dried, and weighed. Harvest periods were considered as replications. Inflorescences developed on some plants before herbage was harvested. Blue grama growth is controlled more by greenhouse temperature than by day length so harvest date is less important than growth stage.

## Experiment 2

The purpose was to determine if Zn is deficient in the subsoil from blue grama and if Zn added to the subsoil would increase blue grama growth. The  $0.1\text{--}0.3 \text{ m}$  layer of the claypan soil was placed in plastic pots ( $1.5 \text{ kg}$  soil,  $0.44 \text{ g NH}_4\text{NO}_3$ ,  $0.13 \text{ g KH}_2\text{PO}_4$ ,  $0.2 \text{ g CaHPO}_4$ ) and  $\text{ZnCl}_2$  to supply  $0, 0.1, 0.2, 0.4$ , or  $0.8 \text{ g Zn kg}^{-1}$  soil in 4 replications. Blue grama was planted and the herbage harvested 5 times when some plants developed inflorescences. Plants became N-deficient and chlorotic after the second harvest and were watered with a solution containing NPK (Hoagland and Arnon 1938).

## Experiment 3

The purpose was to determine if 1 Zn source and rate was better than another. Claypan surface soil ( $0\text{--}0.1 \text{ m}$ ) that had not been used previously was crushed, mixed, and  $1.5 \text{ kg}$  placed in plastic pots. Five replications were used for 17 treatments. The 17 were untreated check, surface-applied NPK, and surface-applied NPK with  $0.10, 0.20$ , or  $0.40 \text{ g Zn kg}^{-1}$  soil from 5 sources. The Zn sources were dust-, 40-mesh-, or 30-mesh-metallic Zn, Zn chelate

Author is professor, Plant Sciences Dept. (Soils), SD State Univ., Brookings, South Dakota 57007.

This is Journal Paper 2424, SD Agr. Exp. Sta., Brookings.

Manuscript accepted 20 April 1990.

(EDTA), or Zn chloride. The NPK amounts were respectively 0.10, 0.50, and 0.02 g kg<sup>-1</sup> soil. Thirty blue grama seeds were planted per pot, culms were counted after seedlings were established, and herbage was harvested 5 times, dried, and weighed after inflorescences developed on some plants.

The soil in the pots was allowed to dry after the fifth harvest, and blue grama was reseeded in the pots. Many seedlings died, possibly from Zn toxicity and/or salt accumulation (White and Gartner 1987). Salt was leached from the pots with distilled water, and 30 blue grama seeds were planted with subsequent establishment of an adequate number of plants. Herbage was harvested once, dried (60–70° C), weighed, and ground. The herbage ash, Zn, and P contents were determined for 3 of the 5 replications. Ash, determined gravimetrically, was solubilized in 2M HCl and Zn and P contents determined, respectively, by atomic absorption and with the ascorbic acid procedure (Watanabe and Olsen 1965). Soil from the 3 replications used for herbage Zn and P contents was sampled from the upper 0.05 m layer of the pots and DTPA-extracted Zn (Lindsay and Norvell 1978) was determined by atomic absorption.

#### Experiment 4

Pots with soil and blue grama plants used in Experiment 1 were used to determine the amount of Zn that would decrease growth of blue grama. Four replications of pots that received increasing amounts of Zn initially were further treated with 0, 0.2, 0.4, 0.8, and 1.6 g Zn as ZnCl<sub>2</sub> kg<sup>-1</sup> soil. The total Zn added from both treatments was 0, 0.3, 0.6, 1.1, and 2.0 g kg<sup>-1</sup> soil. Because chloride could be a factor, it was added as CaCl<sub>2</sub> in the same amounts as in the ZnCl<sub>2</sub> to 2 additional replications of pots. The herbage was harvested once, dried (60–70° C), weighed, ground, and analyzed for Zn and P as described previously.

#### Experiment 5:

The purpose was to determine if small Zn applications (ZnCl<sub>2</sub>) are fixed in the soil and if larger amounts remain in solution where they could be toxic. A 0.09 l solution containing 0, 1.44, 14.4, or 144 mg Zn (as ZnCl<sub>2</sub>) was equilibrated with 18 g of the claypan surface soil for 1, 168, and 336 hr, centrifuged, and the supernatant Zn concentration was determined by atomic absorption. The

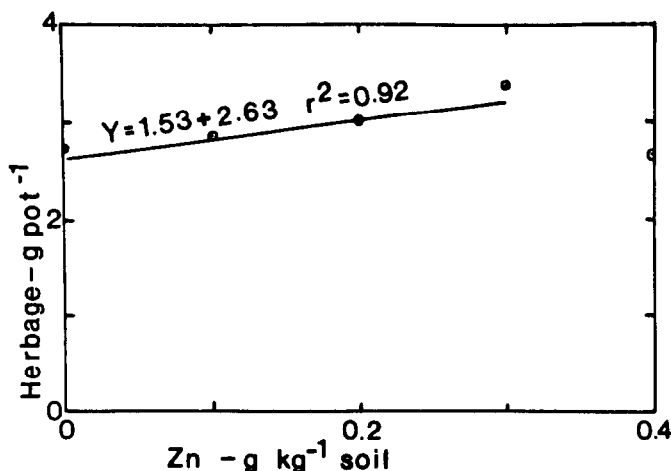


Fig. 1. Linear increase in blue grama herbage with Zn applications from 0 to 0.3 g kg<sup>-1</sup> soil and a decrease at 0.4 g kg<sup>-1</sup> soil.

centrifugate soil was allowed to dry without further treatment, crushed, extracted with DTPA (Lindsey and Norvell 1978), and the extracted Zn determined by atomic absorption. Solution occluded in the centrifugate soil cake was not considered because most of the free salt should be excluded (Wiklander 1964).

## Results and Discussion

#### Experiment 1

The mean herbage weights pot<sup>-1</sup> for the 5 harvests were 2.7, 2.8, 3.0, 3.4, and 2.7 g pot<sup>-1</sup>, respectively, for Zn application rates of 0, 0.10, 0.20, 0.30, and 0.40 g Zn kg<sup>-1</sup> soil. The herbage weight was positively related to Zn application rates up to 0.40 g Zn kg<sup>-1</sup> soil (Fig. 1). The 0.40 g Zn rate reduced the herbage weight, presumably because Zn became toxic. When the successively added elements in the Hoagland solutions are considered (Fig. 2), Zn did not improve herbage yield significantly over the untreated soil although herbage from the B treatment was significantly greater. However,

Table 1. Effect of Zn source and application rate on seedling establishment, herbage weight, herbage-ash, -Zn, and -P contents, and DTPA-extracted soil Zn amounts (Experiment 3).

Treat. <sup>2</sup> Zn Source	Zn g kg <sup>-1</sup> soil	1986		1987		1988				Soil DTPA Zn mg kg <sup>-1</sup>
		Plant No.	Herbage g/pot harvest	Plant No	Plant No.	Herbage g/pot harvest	Ash .	Herbage <sup>2</sup> Zn mg kg <sup>-1</sup>	P	
1. None	0.00	12.4	3.66	10.8	18.2	6.91	82	11	1.59	6
2. NPK	0.00	17.2	3.99	8.8	21.0	7.10	85	13	1.76	2
3. Dust	0.10	11.4	3.78	9.6	22.6	6.83	80	44	1.65	44
4.	0.20	6.0	3.45	9.0	17.6	7.41	82	71	1.87	103
5.	0.40	9.0	3.71	7.6	19.0	7.51	76	132	1.67	184
6. 30 mesh	0.10	9.4	3.54	8.8	20.4	6.81	83	39	1.78	52
7.	0.20	9.0	3.37	6.8	19.4	7.68	71	86	1.63	80
8.	0.40	10.0	3.48	9.8	22.2	7.20	77	167	1.80	124
9. 40 mesh	0.10	11.2	3.71	8.8	18.4	6.80	85	42	1.62	63
10.	0.20	13.2	3.62	10.2	20.4	7.50	76	74	1.66	94
11.	0.40	10.0	3.62	7.4	20.8	8.55	75	183	1.76	234
12. Chelate	0.10	1.8	1.55	6.2	21.2	7.41	72	121	1.86	35
13.	0.20	0.0	0.00	5.4	18.0	7.90	67	365	1.66	62
14.	0.40	0.0	0.00	0.8	15.8	7.71	75	905	2.08	111
15. Chloride	0.10	14.2	3.73	9.8	22.4	8.33	77	60	1.84	42
16.	0.32	19.2	3.68	9.2	20.6	8.44	73	242	1.81	78
17.	0.40	8.8	2.31	2.6	20.8	6.76	81	418	1.98	157
l.s.d. (p=0.05)		6.6	0.75	7.8	6.8	1.81	13	187	0.28	50

<sup>1</sup>NPK added to all Zn rates.

<sup>2</sup>Herbage and DTPA analysis for 3 of the 5 replications.



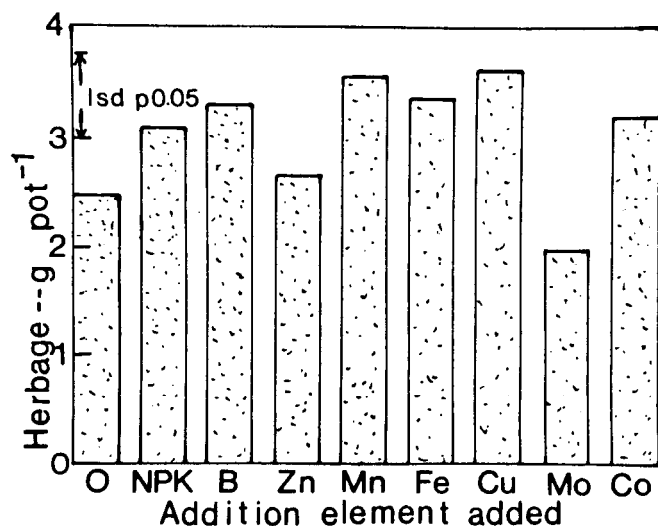


Fig. 2. Blue grama herbage weight as successively more elements are added to the watering solution.

the B and Zn treatments were not significantly different. The Mn and Cu treatments significantly increased herbage relative to the Zn treatment. Effects of adding Zn to soils previously treated with minor elements are not clear, but some synergistic relationship may occur between Zn and Mn, Cu, Fe, or Co. Soils that received Zn previously apparently contained sufficient residual Zn to supply the needs of the plants and possibly may be toxic if Mn, Cu, Fe, and/or Co are not added. Possibly B, as borate, and Mo, as molybdate, acted respectively to stimulate or reduce herbage weights either by interacting with phosphate or Zn and other minor elements in the plant.

### Experiment 2

The mean herbage weights of the 5 blue grama harvests from the ZnCl<sub>2</sub> fertilization of claypan subsoil were: 0 gm Zn kg<sup>-1</sup> soil—3.2 g herbage, 0.1—2.8, 0.2—2.6, 0.4—2.0, and 0.8—0.1. The mean herbage weights were negatively correlated ( $r = 0.99$ ,  $Y = -3.87X + 3.28$ ) to the Zn rate amounts. Applications of ZnCl<sub>2</sub> to subsoil decreased blue grama herbage relative to plants that received only NPK. Fertilization of the pot soils with KH<sub>2</sub>PO<sub>4</sub> and CaHPO<sub>4</sub> probably increased available Zn (Shuman 1988) so that further Zn additions caused toxicity. The toxicity increased with increasing Zn application.

### Experiment 3

The mean herbage from 5 harvests in 1986 (Table 1) was related more to the number of plants pot<sup>-1</sup> than to the treatment applied. For the Zn chelate treatment, the low seedling survival in 1986 and 1987 may have been caused by poor soil structure which reduced water infiltration and root penetration. Polyvalent cations which promote flocculation may have been complexed (chelated) so that the soil could disperse. Leaching with distilled water improved water infiltration and seedling survival for the Zn-chelate treatments in 1988. Use of chelates in soils which tend to have poor structure may be ill advised. Except for the chelate, the Zn source had little, if any, effect on seedling survival within any of the 3 years.

Herbage yields were not significantly different for any of the treatments in 1988 (Table 1). The herbage Zn content increased as the Zn application rate increased for each of the sources. The largest herbage Zn content was 905 mg kg<sup>-1</sup> and herbage yield was not reduced. Although not evident from the means, the herbage Zn and P contents were positively correlated ( $r = 0.54$ ,  $p = 0.05$ ). The Zn contents of plants treated with ZnCl<sub>2</sub> were intermediate to those

treated with the same amount of Zn in chelate or metallic material.

The DTPA-extracted soil Zn amount increased as the amount applied increased. The herbage Zn content and DTPA-extracted soil Zn tended to be related for any Zn source, but DTPA-Zn was less than would be expected relative to the herbage amount for the chelate and chloride sources (Table 1). Lindsay and Norvell (1978) indicated the DTPA-extraction solution could complex up to 654 mg Zn kg<sup>-1</sup> soil so the complexing capacity of the solution was not exceeded. Zn absorbed by the plant apparently came from slowly available forms, which implied that very soluble chelate and chloride Zn is complexed by the soil. If greenhouse data can be extrapolated to the field, a large application of Zn would be needed to increase the concentration of Zn in blue grama herbage to the 20–40 mg Zn kg<sup>-1</sup> that cattle may need. Herbage from the untreated and NPK treatments contained similar amounts of Zn, and increased solubilization of Zn by the application of acidic phosphates (Shuman 1988) did not have an effect, at least in the third season. However, Zn concentrations in the DTPA-extracted soil was less for the NPK treatment in comparison to the untreated soil. If Zn solubilization did occur, phosphate may have reacted with Zn subsequently to reduce the amount of DTPA-extracted Zn.

### Experiment 4

Blue grama herbage weight decreased and herbage Zn content increased as the Zn application increased from 0.3 to 2.0 g Zn kg<sup>-1</sup> soil (Table 2). Plants in 2 of the 4 replications died at the highest Zn

Table 2. Mean weight of blue grama herbage and its ash, Zn, and P content from plants treated with different amounts of ZnCl<sub>2</sub> or CaCl<sub>2</sub> (Experiment 4).

	Grams Zn (ZnCl <sub>2</sub> ) in kg <sup>-1</sup> soil					r <sup>2</sup> †
	0	0.30	0.60	1.10	2.0	
Herbage g pot <sup>-1</sup>	5.4	6.2	4.8	3.7	2.2	0.68
Ash mg g <sup>-1</sup>	57	59	60	85	111	0.69
Zn mg kg <sup>-1</sup>	8	21	32	405	7412	0.39
P mg kg <sup>-1</sup>	1442	1291	1195	1695	1307	0.00
Chloride added as CaCl <sub>2</sub> to equal amount in ZnCl <sub>2</sub>						
Herbage g pot <sup>-1</sup>	5.0	7.6	5.4	5.3	5.6	0.02
Ash mg g <sup>-1</sup>	73	58	59	60	60	0.14
Zn mg kg <sup>-1</sup>	25	7	19	5	10	0.17
P mg kg <sup>-1</sup>	1440	1220	1395	1380	1275	0.06

†Regression dependent on Zn or Cl applied is significant ( $p = 0.05$ ) if  $r^2 > 0.40$ .

rate. Plant vigor decreased and herbage became temporarily more chlorotic as added Zn increased. The decrease in vigor was not caused by the chloride ion because yields were not significantly different for the different CaCl<sub>2</sub> application rates. The herbage P contents were not significantly different ( $p = 0.05$ ) for plants treated with ZnCl<sub>2</sub> or CaCl<sub>2</sub>. The ash content increased as the Zn rate increased. Apparently chloride does not have a detrimental effect on blue grama growth so that ZnCl<sub>2</sub> is a satisfactory source at reasonable application rates.

### Experiment 5

The Zn absorbed increased as the solution Zn concentration increased. After 336 h with 1.44, 14.4, and 144 mg Zn in the equilibration solution, 98, 88, and 28% of the Zn was absorbed by 18 g soil. Zn fixation into relatively insoluble forms may occur. About half the Zn absorbed at each initial concentration was released to DTPA after 336 h. The surface area with absorbed or precipitated Zn may increase with increasing initial concentrations and control the release to DTPA. ZnCl<sub>2</sub> applied to the soil surface that is not absorbed could move downward in the solution phase and be absorbed in deeper layers for eventual release to plants.

**Table 3. Effect of solution Zn concentration and time on mean-equilibration-solution concentration, sorbed Zn, and subsequent DTPA-extracted soil Zn (Experiment 5).**

Initial 0.098 Zn Cl <sub>2</sub> -solution Zn mg	Equilibration Solution		Soil Zinc	
	Time	Zn	Sorbed	DTPA
	hours	mg		mg/18 g
0.00	1	0.006	nd	0.02
	168	0.005	nd	0.03
	336	0.005	nd	0.02
1.44	1	0.019	1.43	1.18
	168	0.054	1.38	0.86
	336	0.025	1.41	0.62
14.40	1	2.53	11.8	9.07
	168	2.05	12.4	8.33
	336	1.73	12.7	7.65
144.00	1	106	38.3	26.6
	168	114	30.0	20.2
	336	104	40.0	19.5
Source Time (hr)	Means			
	1	27.3	17.2	8.73
	168	29.0	14.6	7.34
	336	26.0	18.0	6.95
mg (Zn)	mg (Zn)			
	0	0.006	nd	0.02
	1.44	0.033	1.4	0.88
	14.4	2.10	12.3	8.35
	144.0	108.0	30.1	21.43

nd—not determined

Applied ZnCl<sub>2</sub> might be toxic for a short time to plants in direct contact, but the toxicity should dissipate rapidly.

### Summary and Conclusions

Metallic Zn, applied at rates from 0 to 0.40 g Zn<sup>-1</sup> claypan-surface soil in the greenhouse, increased blue-grama-herbage Zn in proportion to the amount applied. Zn chelate at all rates and chloride at the higher rate were initially detrimental to herbage production. After equilibration for 2 years and excess salt was leached, herbage production was not significantly different for the different Zn sources or from soil fertilized with acidic phosphate with Zn. Long-term effects of acidic phosphates on Zn deficient soils are not known, but presumably Zn would again become deficient eventually. At Zn rates up to 4 g Zn kg<sup>-1</sup> soil, herbage Zn ranged from 11 to 900 mg kg<sup>-1</sup> but, with ZnCl<sub>2</sub> applied at 0.30 to 2.0 g Zn kg<sup>-1</sup> soil, Zn increased from 21 to 7,400 mg kg<sup>-1</sup>. If 0.6, 1.10, and 2.0 g Zn kg<sup>-1</sup> soil were applied as ZnCl<sub>2</sub>, the mature plants became initially chlorotic; and at the highest rate, half the plants died. A normal color developed in all remaining plants in a few weeks. Plants treated with an equivalent amount of chloride as CaCl<sub>2</sub> did not become chlorotic. Blue grama apparently would adjust rapidly to very high surface applications of Zn. Soil absorption and fixation may occur to decrease toxic effects. Generalizing from the different experiments, Zn decreases herbage at rates equal or greater than 0.40 g Zn kg<sup>-1</sup> soil.

DTPA-extracted soil Zn ranged from about 1 to 1,100 mg kg<sup>-1</sup> (0.2 to 20 mg 18-g-soil<sup>-1</sup>) as the equilibration solution increased from 0 to 144 mg Zn 18-g-soil<sup>-1</sup>. For any single Zn source, herbage Zn increased with increasing DTPA soil Zn, but Zn-chelate- and Zn-chloride-treated blue grama had higher herbage Zn contents relative to DTPA soil Zn. Presumably, some applied Zn is fixed into forms that are available to plants but not to short-term DTPA extractions. Moderate applications of Zn on range would not be detrimental to blue grama and might increase the blue-grama-herbage Zn to the 20-40 mg kg<sup>-1</sup> level needed for beef cattle (Nat. Research Council 1984) although feeding of mineral supplements would likely be more economical.

### References

- Graham, R.D., R.M. Welch, D.L. Grunes, E.E. Cary, and W.A. Norvell. 1987. Effect of Zn deficiency on the accumulation of boron and other mineral nutrients in barley. *Soil Sci. Soc. Amer. J.* 51:652-657.
- Hoagland, D.R., and D.I. Arnon. 1938. The water-culture method for growing plants without soil. *California Agr. Exp. Sta. Cir.* 347.
- Jacobson, L. 1950. Maintenance of iron supply in nutrient solutions by a single addition of ferric potassium ethylenediamine tetra-acetate. *Plant Physiol.* 26:411-413.
- Knezek, B.D., and B.G. Ellis. 1980. Essential microelements IV: Copper, iron, manganese, and zinc. pp. 258-286. *In* B.E. Davies (ed.) *Applied soil trace elements*. John Wiley and Sons, Ltd.
- Lindsay, W.L. 1979. *Chemical equilibria in soil*. Wiley Interscience, New York.
- Lindsay, W.L., and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Sci. Soc. Amer. J.* 42:421-428.
- Murphy, L.S., and L.M. Walsh. 1972. Correction of micronutrient deficiencies with fertilizers. pp. 347-387. *In* J.J. Mortvedt (ed.) *Micronutrients in Agriculture*. Soil Sci. Soc. Amer., Madison, Wisc.
- National Research Council. 1984. *Nutrient requirements of beef cattle*, 6th Edit. Nat. Academy Press, Washington, DC. 90.
- Rauzi, F., L.I. Painter, and A.K. Kobrenz. 1969. Mineral and protein contents of blue grama and western wheatgrass. *J. Range Manage.* 22:47-49.
- Shuman, L.M. 1988. Effect of phosphorus level on extractable micronutrients and their distribution among soil fractions. *Soil Sci. Soc. Amer. J.* 52:136-141.
- Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1988. *Soil fertility and fertilizer*. Macmillan Co., New York.
- Thorne, W. 1957. Zinc deficiency and its control. *Advances in Agron.* IX: 31-65. Academic Press, Inc., New York.
- Watanabe, F.J., and S.R. Olson. 1965. Test of ascorbic acid method for determining phosphorus in water and NaHCO<sub>3</sub> extracts of soil. *Soil Sci. Soc. Amer. Proc.* 29:677-678.
- Webb, M.J., and J.F. Loneragan. 1988. Effect of zinc deficiency on growth, phosphorus concentration, and phosphorus toxicity of wheat plants. *Soil Sci. Soc. Amer. J.* 52:1676-1680.
- White, E.M., and F.R. Gartner. 1986. Blue grama response to zinc fertilization of claypan soil. *Soil Sci. Soc. Amer. J.* 50:1052-1054.
- White, E.M., and F.R. Gartner. 1987. Salinity effects on blue grama (*Bouteloua gracilis*) growth in the greenhouse. *SD Acad. Sci. Proc.* 66:76-84.
- Wiklander, L. 1964. Cation and anion exchange phenomenon. pp. 163-205. *In* F.E. Bear (ed.) *Chemistry of the soil*. Reinhold Pub. Corp. New York.

# Control of honey mesquite with clopyralid, triclopyr, or clopyralid:triclopyr mixtures

RODNEY W. BOVEY AND STEVEN G. WHISENANT

## Abstract

Greenhouse and field experiments were conducted to evaluate clopyralid formulations and triclopyr ester alone and in mixtures with clopyralid for control of honey mesquite. In the greenhouse, mixtures of the butoxyethyl ester of triclopyr enhanced the activity of the 2-ethylhexyl ester, the monoethanolamine salt and the free acid of clopyralid when applied in 1:1, 1:2 or 1:4 clopyralid:triclopyr mixtures at total rates of 0.07, 0.14, and 0.28 kg ae/ha. The activity of triclopyr was not enhanced by addition of clopyralid. In the field, mixtures of the 1-decyl ester of clopyralid + the butoxyethyl ester of triclopyr were usually more effective than either herbicide applied alone. Addition of 0.14 kg/ha of triclopyr to clopyralid applied at 0.28 kg/ha markedly increased canopy reduction and mortality by at least 47% compared to either herbicide applied alone. Basal pours of diesel oil alone at 0.9 L/tree were usually as effective as diesel oil fortified with esters of clopyralid, 2,4,5-T or triclopyr at 4.8 or 9.6 g/L. Basal sprays of diesel oil + esters of clopyralid, 2,4,5-T or triclopyr in concentrations of 4.8 or 9.6 g/L applied at 0.5 L/tree caused high mortality of honey mesquite trees similar to basal pours. Triclopyr or clopyralid at 4.8 g/L were less effective in diesel oil:water carrier (1:4 or 1:3), respectively, than in diesel oil carrier.

**Key Words:** herbicides, canopy reduction, mortality, foliar sprays, basal treatments

Honey mesquite (*Prosopis glandulosa* Torr.) is a woody legume that occurs as a weed problem on several million hectares of rangeland in the southwestern U.S. (Meyer et al. 1971). Jacoby et al. (1982) and Bovey and Meyer (1985) found that the monoethanolamine salt of clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) was superior at equivalent rates to 2,4,5-T [(2,4,5-trichlorophenoxy)acetic], dicamba (3,6-dichloro-*o*-anisic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), and triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid for the control of honey mesquite in the field. Mixtures of clopyralid + picloram or clopyralid + triclopyr (1:1) were as effective as clopyralid applied alone when similar rates were used. The addition of picloram or triclopyr to clopyralid enhanced the absorption and transport of clopyralid into the leaves and upper-stem phloem by 1 day after treatment versus clopyralid applied alone (Bovey et al. 1988).

The potassium salt, free acid, 1-decyl ester, 2-ethylhexyl ester and the monoethanolamine salt were evaluated to determine the most effective chemical formulation of clopyralid for control of honey mesquite (Bovey et al. 1989). With the exception of the 2-ethylhexyl ester, all formulations were about equally effective in killing greenhouse-grown plants at rates of 0.21 or 0.28 kg/ha applied foliar. An oil-soluble formulation of clopyralid such as the esters is desired for aircraft spraying and individual plant treat-

ment because of enhanced penetration of plant surfaces and miscibility with oil carriers and other oil-soluble herbicides. Triclopyr ester has been suggested to replace 2,4,5-T for basal treatments of honey mesquite (Welch 1988), but little data are available on its effectiveness. Therefore, our objectives were to compare the effectiveness of various clopyralid formulations alone and in combination with triclopyr ester for honey mesquite control as broadcast foliar sprays and as basal treatments.

## Materials and Methods

### Greenhouse-Foliar Sprays

Honey mesquite plants were grown from seed in the greenhouse in pots (12.7 cm diam by 12.7 cm deep) containing a mixture of Bleiblerville clay (fine montmorillonitic Udic Pellusterts), sand and peat moss 1:1:1 (v/v/v), from February to August 1987. Daytime temperature was 35° C, and night temperature was 25° C. Day length was 14 h with PAR  $\approx 800 \mu\text{m}^2/\text{sec}$  at midday during sunlight. Two plants were grown/pot, and each had a single woody stem with an average height of 33 cm and 12 leaves/plant. Pots were watered daily. A commercial fertilizer (13-13-13) was applied at 0.85 g/pot every 6 weeks.

Foliar sprays of the 2-ethylhexyl ester, the monoethanolamine salt and the free acid of clopyralid, and the butoxyethyl ester of triclopyr were applied alone and in 1:1, 1:2, and 1:4 clopyralid:triclopyr mixtures at 0.035, 0.07, 0.14, and 0.28 kg ae/ha total herbicide. Applications were made in May and June 1987 in 93 L/ha water carrier in a laboratory spray chamber (Bouse and Bovey 1967) to pots containing 3-month-old honey mesquite. Rates of herbicide selected were based on previous studies at which these rates killed a percentage of stem tissue on each plant below, at, and above 50% (Bovey and Meyer 1985, Bovey et al. 1989). The soil was protected from spray by placing vermiculite in the pot before treatment and discarding it immediately following treatment. Plants were returned to the greenhouse and watered after 24 hours and daily thereafter. Care was taken not to wash any herbicide from the plant onto the soil.

Two months after spraying, the response of treated plants to herbicides was evaluated by visually estimating the percentage of dead stem tissue on each plant. Plants with 100% dead stem tissue and no resprouts were considered dead. Six replications (pots) with 2 plants/replicate were used in a randomized complete block design. Data were subjected to analysis of variance, and means were compared by the Fisher Protected least significant difference (LSD) at the 5% level (Steel and Torrie 1980). The experiment was repeated, and data for the May and June 1987 treatments were presented separately due to the date by treatment interaction.

### Field-Foliar Sprays

Honey mesquite plants 1.5 to 2.0 m tall growing in a Wilson clay loam (fine, montmorillonitic thermic Vertic Ochraqualfs) near Bryan, Texas showed vigorous regrowth, usually multistemmed, on an area bulldozed several years before. Plants were numbered with metal tags in groups of 5 for each replication. Plants were  $>1$  m apart within the groups (replication). Treatments were applied on 13 July 1987 with 3 replications per treatment (total 15 plants)

Authors are research agronomist, USDA-ARS, Southern Crops Research Laboratory, Pest Management Research Unit; and associate professor, Dept. of Range Science, Texas A&M University, College Station 77843.

Contribution from the USDA, Agr. Res. Serv., in cooperation with the Texas Agr. Exp. Sta., College Station.

Mention of trademark name of proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

Manuscript accepted 9 May 1990.

**Table 1. Percent dead stem tissue of greenhouse-grown honey mesquite 2 months after foliar application of 13 herbicide treatments to 3-month-old plants using 3 clopyralid formulations in mixtures with triclopyr<sup>1</sup>.**

Herbicide	Herbicide rate (kg/ha)							
	0.035		0.07		0.14		0.28	
	May	June	May	June	May	June	May	June
<b>Clopyralid</b>	----- % -----							
2-ethylhexyl ester (2-EHE)	2	3	2	8	13	7	13	37
Monoethanolamine salt (MEA)	11	3	3	5	15	29	51	68
Free acid (FA)	4	3	18	32	36	61	69	88
<b>Triclopyr</b>								
Butoxyethyl ester (BEE)	20	29	20	29	57	74	100	93
<b>Clopyralid + triclopyr</b>								
2-EHE + BEE (1:1)			11	10	68	56	71	79
2-EHE + BEE (1:2)			5	30	73	84	72	89
2-EHE + BEE (1:4)			13	17	76	81	83	96
MEA + BEE (1:1)			13	28	41	53	76	95
MEA + BEE (1:2)			24	28	81	48	70	85
MEA + BEE (1:4)			19	37	68	76	91	93
FA + BEE (1:1)			22	53	62	86	94	95
FA + BEE (1:2)			36	54	85	92	91	93
FA + BEE (1:4)			33	51	77	64	100	100

<sup>1</sup>LSD<sub>(0.05)</sub> = 22% for May 1987 application and 24% for June 1987 application; untreated = 2% for May or June treatments.

arranged in a randomized complete block design. The entire experiment was repeated on 13 July 1988. The 2-ethylhexyl ester and the monoethanolamine salt of clopyralid were applied alone at 0.28 or 0.56 kg ae/ha, whereas the 1-decyl ester of clopyralid and the butoxyethyl ester of triclopyr were applied alone at 0.14, 0.28, or 0.56 kg/ha and in all paired mixtures at these rates except 0.56 + 0.56 kg/ha. The potassium salt of picloram + butoxyethyl ester of triclopyr were included at 0.28 + 0.28 kg/ha for comparison. The herbicides were broadcast sprayed on each honey mesquite tree in 190 L/ha of water at 210 kPa. A hand-carried 3 nozzle boom sprayer was used. Herbicide treatments were evaluated after 1 yr by estimating percent canopy reduction and/or mortality of each tree. Trees were considered dead if they were completely defoliated and had no living tissue or resprouts. Canopy reduction and mortality data were subjected to analysis of variance, and means were separated by the protected LSD procedure ( $p \leq 0.05$ ) (Steel and Torrie 1980). Data from the foliar sprays applied in 1987 and 1988 (Table 2) were pooled for presentation since there was no date by treatment interaction.

#### Field-Basal Treatments

For individual plant treatment, trees 3 to 5 m tall were selected in the same general area as the foliar spray treatments. Trees had 1 to 5 stems from a single crown with stems 7 to 25 cm in diam. Trees were treated during the dry season (August 1984, 1985, 1986, and 1987) when the soil was pulled away from the base of the plant to allow penetration of the diesel oil and/or herbicide to the buds on the crown (Welch 1988). Treatments in 1984 and 1985 consisted of diesel oil alone or diesel oil:water carriers with the butoxyethyl esters of 2,4,5-T or triclopyr as basal pours or sprays. When applied as pours, 0.9 L of liquid was applied/tree, and triclopyr was applied at 4.8, 9.6 or 19.2 g/L of carrier while 2,4,5-T was applied at 9.6 g/L. Basal sprays were applied by thoroughly wetting the lower 5 cm of stem to runoff. Amount of spray applied depended upon stem diam and averaged about 0.5 L/tree. In basal sprays, concentration of triclopyr was 4.8 or 9.6 g/L, and 2,4,5-T was applied at 9.6 g/L of carrier. Basal treatments in 1986 and 1987 consisted of diesel oil alone compared to diesel oil or diesel oil:

**Table 2. Percent canopy reduction and mortality of 1.5- to 2-m tall honey mesquite trees 1 yr after foliar application of ester formulations of clopyralid, triclopyr, and clopyralid:triclopyr mixtures on 13 July 1987 and 1988.**

Herbicide	Rate (kg/ha)	Honey mesquite control	
		Canopy reduction	Mortality
		----- (%) -----	-----
Clopyralid + triclopyr <sup>1</sup>	0.14 + 0.14	57	13
Clopyralid + triclopyr	0.14 + 0.28	82	33
Clopyralid + triclopyr	0.14 + 0.56	83	33
Clopyralid + triclopyr	0.28 + 0.14	87	57
Clopyralid + triclopyr	0.28 + 0.28	92	49
Clopyralid + triclopyr	0.28 + 0.56	94	57
Clopyralid + triclopyr	0.56 + 0.14	97	84
Clopyralid + triclopyr	0.56 + 0.28	94	57
Triclopyr (butoxyethyl ester)	0.14	40	3
Triclopyr (butoxyethyl ester)	0.28	57	3
Triclopyr (butoxyethyl ester)	0.56	69	10
Clopyralid (1-decyl ester)	0.14	20	0
Clopyralid (1-decyl ester)	0.28	39	10
Clopyralid (1-decyl ester)	0.56	87	50
Clopyralid (2-ethylhexyl ester)	0.28	49	3
Clopyralid (2-ethylhexyl ester)	0.56	83	47
Clopyralid (monoethanolamine salt)	0.28	69	33
Clopyralid (monoethanolamine salt)	0.56	94	80
Picloram + triclopyr <sup>2</sup>	0.28 + 0.28	86	33
Untreated	—	3	0
LSD <sub>(0.05)</sub>		12	29

<sup>1</sup>1-decyl ester of clopyralid plus the butoxyethyl ester of triclopyr

<sup>2</sup>potassium salt of picloram plus the butoxyethyl ester of triclopyr

water (1:3) carriers + 2-ethylhexyl ester of clopyralid at 4.8 or 9.6 g/L.

Basal treatments consisted of 3 replications per treatment with groups of 5 plants per replicate identified with numbered tags. The studies were arranged in a randomized complete block design for

each of 4 treatment dates (August 1984, 1985, 1986, and 1987). The 1984 and 1985 treatments were evaluated after 2 yr, and the 1987 and 1988 treatments were evaluated 1 yr following treatment by visually estimating percent canopy reduction and/or mortality of each tree. Trees were considered dead if they were completely defoliated and had no living tissue or resprouts. Canopy reduction and mortality data were subjected to analysis of variance, and means were separated by the protected LSD procedure ( $p \geq 0.05$ ) (Steel and Torrie 1980). Data from the basal treatments applied in 1986 and 1987 (Table 5) were pooled for presentation since there was no date by treatment interaction. Data for individual plant treatments applied in 1984 and 1985 were shown separately (Tables 3–4) because some treatments applied were different.

**Table 3. Percent expected and actual mortality of 1.5- to 2-m tall honey mesquite trees 1 yr after foliar applications of ester formulations of clopyralid + triclopyr on 13 July 1987 and 1988.**

Clopyralid 1+ triclopyr (kg/ha)	Expected mortality ----- (%) -----	Actual mortality
0.14 + 0.14	0 + 3 = 3	13
0.14 + 0.28	0 + 3 = 3	33 <sup>1</sup>
0.14 + 0.56	0 + 10 = 10	33
0.28 + 0.14	10 + 3 = 13	57 <sup>1</sup>
0.28 + 0.28	10 + 3 = 13	49 <sup>1</sup>
0.28 + 0.56	10 + 10 = 20	57
0.56 + 0.14	50 + 3 = 53	84 <sup>1</sup>
0.56 + 0.28	50 + 3 = 53	57
	LSD <sub>(0.05)</sub> = 29	

<sup>1</sup>Synergistic mixtures (Data from Table 2).

## Results and Discussion

### Greenhouse-Foliar Sprays

There were usually no differences in the 3 clopyralid formulations or the butoxyethyl ester of triclopyr at 0.035 or 0.07 kg/ha in killing greenhouse-grown honey mesquite stems except that triclopyr was more effective than clopyralid formulations applied in June at 0.035 (Table 1). When applied in June, the free acid (FA) or clopyralid at 0.07 kg/ha was more effective than the 2-ethylhexyl ester (2-EHE) or the monoethanolamine salt (MEA) but not more effective than triclopyr. When applied in mixtures for a total of 0.07 kg/ha of herbicide, clopyralid formulations were frequently more effective than each clopyralid formulation applied alone at 0.035 kg/ha due to addition of triclopyr. The 1:1 and 1:2 mixtures of FA + triclopyr applied in June at a total of 0.07 kg/ha were the only combinations more effective than triclopyr applied alone at 0.035 or 0.07 kg/ha.

Addition of triclopyr to clopyralid for a total of 0.14 kg/ha of herbicide enhanced the activity of most clopyralid formulations applied alone at 0.07 or 0.14 kg/ha in killing honey mesquite stem tissue (Table 1). The activity of triclopyr was usually not enhanced by clopyralid since triclopyr was highly effective when applied alone.

Addition of triclopyr to clopyralid at a total of 0.28 kg/ha of herbicide increased the activity of all clopyralid formulations applied alone at 0.14 kg/ha and most applied alone at 0.28 kg/ha (Table 1). Combinations of the FA + triclopyr applied in June were not synergistic since the FA applied alone at 0.28 kg/ha killed 88% of the stem tissue. Since triclopyr alone killed a high percentage of stem tissue, addition of 1:1 and 1:2 mixtures of the 2-EHE and MEA clopyralid formulations with triclopyr in May reduced its effectiveness.

Data from the greenhouse are not consistent with data from the field relative to triclopyr effectiveness on honey mesquite. In the field, clopyralid was consistently more effective than triclopyr

**Table 4. Percent canopy reduction and mortality of 3- to 5-m tall honey mesquite trees 2 yr after application of herbicides as basal pours or basal sprays to individual plants August 1984<sup>1</sup>.**

Treatment	Rate/ tree (g/L)	Honey mesquite control	
		Canopy reduction	Mortality
		----- (%) -----	
<b>Basal pour<sup>2</sup></b>			
Diesel oil	—	88	53
Diesel oil + 2,4,5-T	9.6	100	100
Diesel oil + triclopyr	4.8	96	87
Diesel oil + triclopyr	9.6	100	100
Diesel oil + triclopyr	19.2	100	100
<b>Basal spray</b>			
Diesel oil + 2,4,5-T	9.6	89	67
Diesel oil + triclopyr	4.8	82	53
Diesel oil:water (1:4) + triclopyr	4.8	6	0
Diesel oil + triclopyr	9.6	95	73
Diesel oil:water (1:4) + triclopyr	9.6	95	80
Diesel oil:water (1:3) + triclopyr	9.6	92	73
Diesel oil:water (1:1) + triclopyr	9.6	95	87
Untreated	—	6	0
LSD <sub>(0.05)</sub>		23	33

<sup>1</sup>Butoxyethyl ester of 2,4,5-T or triclopyr

<sup>2</sup>0.9 L diesel oil, diesel oil:herbicide, or diesel oil:water herbicide mix applied/tree

(Bovey and Meyer 1985, Bovey et al. 1988, Jacoby et al. 1982). Greenhouse data suggested possible synergistic or additive effects resulted from use of clopyralid:triclopyr mixtures to control honey mesquite.

### Field-Foliar Sprays

Addition of triclopyr at 0.14, 0.28, or 0.56 kg/ha to the 1-decyl ester (1-DE) of clopyralid at 0.14 or 0.28 kg/ha significantly increased canopy reduction of honey mesquite when compared to clopyralid applied alone at 0.14 to 0.28 kg/ha (Table 2). The 1-DE of clopyralid applied at 0.14 kg/ha reduced the canopy by 20%, but the canopy was reduced 57 and 82% when 0.14 or 0.28 kg/ha of triclopyr was included, respectively. Mortality of honey mesquite

**Table 5. Percent canopy reduction and mortality of 3- to 5-m tall honey mesquite trees 2 yr after application of herbicides as basal pours or basal sprays to individual plants August 1985<sup>1</sup>.**

Treatment	Rate/ tree (g/L)	Honey mesquite control	
		Canopy reduction	Mortality
		----- (%) -----	
<b>Basal pour<sup>2</sup></b>			
Diesel oil	—	93	67
Diesel oil + 2,4,5-T	9.6	95	73
Diesel oil + triclopyr	4.8	86	60
Diesel oil + triclopyr	9.6	92	67
Diesel oil + triclopyr	19.2	99	87
<b>Basal spray</b>			
Diesel oil + 2,4,5-T	9.6	84	60
Diesel oil + triclopyr	4.8	89	53
Diesel oil:water (1:4) + triclopyr	4.8	22	7
Diesel oil + triclopyr	9.6	83	33
Diesel oil:water (1:4) + triclopyr	9.6	43	20
Untreated	—	13	0
LSD <sub>(0.05)</sub>		21	38

<sup>1</sup>Butoxyethyl ester of 2,4,5-T or triclopyr

<sup>2</sup>0.9 L diesel oil, diesel oil:herbicide, or diesel oil:water herbicide mix applied/tree

was significantly improved by most mixtures over clopyralid applied alone except for applications of clopyralid + triclopyr at 0.14 + 0.14 and 0.56 + 0.28 kg/ha, respectively. Mortality caused by triclopyr was also improved by addition of clopyralid at all combinations except for clopyralid + triclopyr at 0.14 + 0.14 and 0.14 + 0.56 kg/ha, respectively. Clopyralid + triclopyr mixtures were not synergistic in increasing canopy reduction, but clopyralid + triclopyr mixtures of 0.14 + 0.28, 0.28 + 0.14, 0.28 + 0.28 and 0.56 + 0.14 kg/ha were synergistic in increasing mortality in honey mesquite (Table 3). Synergism is defined as the phenomenon whereby the effect of 2 substances acting together is greater than the sum of their individual effects. For example, clopyralid alone at 0.28 kg/ha killed 10% of the plants; whereas, triclopyr alone at 0.28 kg/ha killed 3% of the honey mesquite for expected mortality of 13%. When combined at 0.28 + 0.28 kg/ha, mortality was significantly increased to 49% (Table 3).

Bovey and Meyer (1985) indicated that triclopyr could be substituted for equal portions of clopyralid in a 1:1 mixture without reducing the effectiveness of clopyralid on honey mesquite. The mixture improves the spectrum of weeds controlled and reduces clopyralid residues and treatment cost. Data in this report suggest that certain clopyralid:triclopyr mixtures are synergistic. The MEA salt of clopyralid was highly effective on honey mesquite and was significantly more effective than triclopyr at 0.56 kg/ha (Table 2). The 2-EHE of clopyralid was about equally effective as the 1-DE. Picloram + triclopyr at 0.28 + 0.28 kg/ha was about equally effective to clopyralid + triclopyr at the same rate (Table 2).

#### Field-Basal Treatments

Canopy reduction was not significantly different, but mortality was, between application of diesel oil pours alone then when fortified with 2,4,5-T or triclopyr in August 1984 (Table 4). Treatment with 9.6 g/L 2,4,5-T or triclopyr killed all plants. Basal sprays were as effective as basal pours, but when 1:4 diesel oil:water carrier was used with 4.8 g/L of triclopyr, canopy reduction was only 6% and killed no trees. Use of 9.6 g/L triclopyr in diesel oil or diesel oil:water carrier resulted in killing 73% or more of the trees. Apparently, higher herbicide concentration overcame any limitations resulting from using water in the basal spray.

Canopy reduction or mortality from applications of diesel oil pours alone were no different than diesel oil fortified with 2,4,5-T or triclopyr in the 1985 treatments (Table 5). Basal sprays of triclopyr at 4.8 or 9.6 g/L in diesel oil:water carrier killed few plants.

There was no advantage of fortifying diesel oil with the 2-EHE of clopyralid for basal pours since canopy reduction and mortality were no different among diesel oil or diesel oil + clopyralid (Table 5). Basal pours using diesel oil or diesel oil:water carriers (1:3) with 4.8 or 9.6 g/L clopyralid were equally effective. Basal sprays using diesel oil + clopyralid were markedly more effective than diesel oil applied alone (Table 6). Diesel oil:water carrier (1:3) with 4.8 g/L clopyralid was less effective than the same carrier with 9.6 g/L clopyralid or diesel oil + 4.8 g/L clopyralid.

These studies suggested that low rates of the 1-DE of clopyralid + triclopyr (0.28 + 0.14 kg/ha) caused high canopy reduction (87%)

**Table 6. Percent canopy reduction and mortality of 3- to 5-m tall honey mesquite trees 1 yr after application of herbicides as basal pours or basal sprays to individual plants August 1986 and 1987<sup>1</sup>.**

Treatment	Rate/ tree (g/L)	Honey mesquite control	
		Canopy reduction	Mortality
		----- (%) -----	
<b>Basal pour<sup>2</sup></b>			
Diesel oil	—	99	90
Diesel oil + clopyralid	4.8	96	86
Diesel oil + clopyralid	9.6	98	90
Diesel oil:water (1:3) + clopyralid	4.8	97	87
Diesel oil:water (1:3) + clopyralid	9.6	99	97
<b>Basal spray</b>			
Diesel oil	—	93	53
Diesel oil + clopyralid	4.8	99	93
Diesel oil + clopyralid	9.6	98	90
Diesel oil:water (1:3) + clopyralid	4.8	97	83
Diesel oil:water (1:3) + clopyralid	9.6	99	97
Untreated	—	3	0
LSD <sub>(0.05)</sub>		6	4

<sup>1</sup>2-ethylhexyl ester of clopyralid

<sup>2</sup>0.9 L diesel oil, diesel oil:herbicide, or diesel oil:water herbicide mix applied/tree

and mortality (57%) of honey mesquite when applied as foliar sprays. Basal pours of diesel oil alone were as effective as diesel oil fortified with esters of clopyralid, 2,4,5-T, or triclopyr, but in 1984 the addition of 2,4,5-T or triclopyr improved mortality. Basal sprays of diesel oil + esters of clopyralid, 2,4,5-T, or triclopyr produced high mortality in honey mesquite trees. Herbicide activity was sometimes reduced when diesel oil:water carrier was used with 4.8 g/L triclopyr or clopyralid esters compared to diesel oil carrier.

#### Literature Cited

- Bouse, L.F., and R.W. Bovey. 1967. A laboratory sprayer for potted plants. Weeds 15:89-91.
- Bovey, R.W., and R.E. Meyer. 1985. Herbicide mixtures for control of honey mesquite (*Prosopis glandulosa*). Weed Sci. 33:349-352.
- Bovey, R.W., H. Hein, Jr., and R.E. Meyer. 1988. Phytotoxicity and uptake of clopyralid in honey mesquite (*Prosopis glandulosa*) as affected by adjuvants and other herbicides. Weed Sci. 36:20-23.
- Bovey, R.W., H. Hein, Jr., and F.N. Nelson. 1989. Phytotoxicity, absorption and translocation of five clopyralid formulations in honey mesquite (*Prosopis glandulosa*). Weed Sci. 37:19-22.
- Jacoby, P.W., C.H. Meadors, M.A. Foster, and F.S. Hartmann. 1982. Honey mesquite control and forage response in Crane County, Texas. J. Range Manage. 35:424-426.
- Meyer, R.E., H.L. Morton, R.H. Haas, and E.D. Robison. 1971. Morphology and anatomy of honey mesquite. USDA-ARS Tech. Bull. 1423.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. McGraw-Hill Book Co., New York.
- Welch, T.G. 1988. Suggestions for chemical weed and brush control on rangeland. Texas Agr. Ext. Serv. B-1466.

# Late season control of honey mesquite with clopyralid

P.W. JACOBY, R.J. ANSLEY, AND C.H. MEADORS

## Abstract

Herbicides were applied aerially to honey mesquite (*Prosopis glandulosa* Torr.) in the Rolling Plains and Edwards Plateau land resource areas of Texas to evaluate efficacy during late season applications. Although other herbicides gave higher levels of above ground mortality, clopyralid caused higher whole plant mortality throughout the growing season than 2,4,5-T or 2,4,5-T + picloram, both of which were ineffective when applied in September. Mixtures of clopyralid + picloram also were less effective when applied during later periods in the growing season, suggesting picloram added little or even reduced the efficacy of clopyralid for late season control of honey mesquite. Triclopyr alone or in combination with picloram was ineffective in controlling honey mesquite in the fall. Clopyralid in the fall was most effective when applied at rates of 0.56 kg ha<sup>-1</sup> or more. Dosage response of honey mesquite in late season applications (late August to October) was practically identical to that found for applications made in June and July, which indicates that clopyralid provides constant levels of mortality throughout the growing season. This research supports the practice of extending the season of applications with clopyralid into the fall. Application in the fall might allow more rangeland to be treated for honey mesquite reduction and also reduce risks associated with drift damage to crops during their most susceptible periods of growth in early to mid-summer.

**Key Words:** *Prosopis glandulosa*, brush control, picloram, triclopyr, 2,4,5-T

Herbicidal control has been an efficient method of controlling honey mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.) in Texas and neighboring states of Oklahoma and New Mexico for more than 40 years (Scifres 1980). Many of the practices and recommendations currently employed in the control of honey mesquite are based on the performance of the herbicide 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] which is no longer registered for use in the USA. As new herbicides such as triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy] acetic acid and clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) have been registered for controlling honey mesquite, the recommendations for their use have followed those established for 2,4,5-T (Welch 1988). Recommendations for application include spraying within 40 to 90 days after budbreak (Fisher et al. 1959) or when soil temperature reaches 24° C or more (Dahl and Sosebee 1984). Maximum daily photosynthetic rate has been found to be highly correlated with herbicidal control of honey mesquite, but until recently, the unavailability of special instrumentation for determination of this rate in the field has prevented the utilization of this parameter in timing applications of herbicides (Meyer et al. 1983).

These recommendations have limited aerial application of foliarly absorbed herbicides to a period from mid-May to early July.

Authors are professor, postdoctoral research associate, and research associate, Texas Agricultural Experiment Station, P.O. Box 1658, Vernon, Texas 76384.

Published with the approval of the director, Texas Agricultural Experiment Station as TA-25213. Research was funded in part by University Lands-Surface Leasing Interests, Univ. Texas System, Midland; E. Paul and Helen Buck Waggoner Foundation, Vernon; and Brush Control and Range Improvement Association, Albany.

This paper 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 Federal agencies before they can be recommended. Commercial products are mentioned in this publication solely for the purpose of providing specific information. Mention of a product does not constitute a guarantee or warranty of performance by the Agricultural Experiment Station or an endorsement over products not mentioned.

Manuscript accepted 18 May 1990.

This short interval has reduced the amount of rangeland that can be treated in some regions, and resulted in application at a time that coincides with the most susceptible stages in the growth of cotton (*Gossypium hirsutum* L.) and many other crops sensitive to herbicides (Jacoby et al. 1990). This situation has caused restrictions to be placed on the use of herbicides where crops and rangeland exist in proximity to each other. Landowners in areas with susceptible crops often are forced to spray honey mesquite before the trees develop adequate foliage and during a physiological stage of growth less than ideal for herbicide absorption and translocation. Bovey et al. (1986) found that amounts of clopyralid detected in treated plants were similar throughout the growing season rather than being highest in early summer as with other herbicides.

Field observations of honey mesquite response to clopyralid during periods of stress or insect damage led us to formulate the hypothesis that efficacy of clopyralid could be more seasonally dynamic than 2,4,5-T, picloram or triclopyr. Our objective was to quantify honey mesquite response to clopyralid and other herbicides during the latter part of the growing season.

## Materials and Methods

Herbicides were applied aerially on rangeland near Vernon, Texas, in the Rolling Plains land resource area in June, July, and September of 1981 and 1982 to evaluate the relative effects of seasonality on efficacy in controlling honey mesquite. Clopyralid, 2,4,5-T and 2,4,5-T + picloram were applied at 0.56 kg ha<sup>-1</sup> in a 1:6 mixture of diesel oil and water at a volume of 18.7 L ha<sup>-1</sup> from a fixed wing aircraft. Treatments replicated 2 or 3 times were applied in a randomized complete block design. Prior to application, the aircraft spraying system was calibrated for the desired swath width, and during the installation of treatments, residual spray solution was drained and measured following each application and the spraying system was purged prior to applying the next treatment.

Additional applications were installed near Vernon in October 1986 and in the Edwards Plateau land resource area near Ozona in October of 1986 and 1987 and in late August of 1988. Herbicide treatments included additional rates of clopyralid, clopyralid + picloram or triclopyr, and triclopyr + picloram in order to evaluate dosage response.

Soils near Vernon are deep clay loams (Pachic Argiustolls) and those near Ozona are shallow clays (Typic Chromusterts) and clay loams (Petrocalcic Calciustolls) overlying limestone parent material.

Plant response was evaluated after at least one complete growing season following treatment to determine if trees had survived by retaining aerial tissue, resprouted, or succumbed. Plants without visible live tissue were classified as having whole plant mortality (WPM). Trees devoid of original live aerial tissue but having sprouts were classified as having above ground mortality (AGM). Any plant having visible live tissue was considered alive. Approximately 100 individual honey mesquite plants were examined in a 10-m belt transect oriented diagonally across each replicate plot, and percentages of AGM and WPM within the treated stand were used in analysis of variance.

## Results and Discussion

### Seasonal Trends

Honey mesquite treated with herbicides in June, July, and Sep-

**Table 1. Comparisons of above ground mortality (AGM) and whole plant mortality (WPM) in stands of honey mesquite on rangeland aerially sprayed with herbicides on 3 dates during the growing season during 1981 and 1982 near Vernon, Texas.**

Herbicide	Rate (kg ha <sup>-1</sup> )	Plant response					
		AGM	WPM	AGM	WPM	AGM	WPM
		----- (%) -----					
		----- (1981) <sup>1</sup> -----					
		19 June		7 July		18 Sept	
Clopyralid	0.56	84	68	68	54	92	78
2,4,5-T	0.56	86	23	93	22	1	0
2,4,5-T + Picloram (1:1)	0.56	100	58	94	35	58	42
		----- (1982) <sup>2</sup> -----					
		25 June		14 July		7 Sept	
Clopyralid	0.28	60	52	39	29	50	41
	0.56	69	61	62	54	83	74
Clopyralid + Picloram (1:1)	0.56	64	51	72	63	65	42
	1.12	93	73	84	68	79	58
Clopyralid + Picloram (1:2)	0.42	65	50	57	44	41	22
	0.84	88	73	58	39	42	24
Clopyralid + Picloram (1:4)	0.70	84	51	58	39	45	19
2,4,5-T	0.56	85	17	35	10	1	0
2,4,5-T + Picloram (1:1)	0.56	95	49	93	20	8	1

<sup>1</sup>For mean separation in 1981, L.S.D.<sub>.05</sub> for AGM and WPM is 20 and 33, respectively.

<sup>2</sup>For mean separation in 1982, L.S.D.<sub>.05</sub> for AGM and WPM is 22 and 19, respectively.

tember of 1981 near Vernon were controlled more effectively with clopyralid across all dates of application than with either 2,4,5-T or 2,4,5-T + picloram at rates of 0.56 kg ha<sup>-1</sup> (Table 1). Both 2,4,5-T and 2,4,5-T + picloram produced higher levels of above ground mortality (AGM) than clopyralid when applied in June and July 1981, but in mid September applications, clopyralid caused 92% AGM compared to 1 and 58% for 2,4,5-T and 2,4,5-T + picloram, respectively. Clopyralid also produced significantly higher whole plant mortality (WPM) than the other 2 herbicides in September 1981.

Clopyralid applied at 0.56 kg ha<sup>-1</sup> in 1982 produced a similar trend to that observed in 1981 by producing higher AGM and WPM in September than in June or July (Table 1). In contrast to this trend, both 2,4,5-T and 2,4,5-T + picloram diminished in

efficacy as the growing season advanced. Levels of AGM were generally lower for clopyralid than those for 2,4,5-T or 2,4,5-T + picloram in June and July, but WPM produced by clopyralid at either 0.28 or 0.56 kg ha<sup>-1</sup> was greater than the other 2 herbicides. When treated with 2,4,5-T or 2,4,5-T + picloram, aerial portions of most honey mesquite in a stand were destroyed but most of the plants survived by sprouting from dormant buds located near the basal stem. Conversely, honey mesquite treated with clopyralid usually failed to sprout when the above ground tissue was destroyed; however, many trees maintained a portion of the original foliage as opposed to those in stands treated with either 2,4,5-T or 2,4,5-T + picloram.

Clopyralid was significantly more effective when applied at 0.56 than at 0.28 kg ha<sup>-1</sup> except in June when the lower rate provided 52% WPM compared to 61% for the higher rate (Table 1). Efficacies of clopyralid and clopyralid + picloram at 0.56 kg ha<sup>-1</sup> were similar during June and July applications, but the mixture was significantly less effective in causing WPM in September. Clopyralid at 0.56 kg ha<sup>-1</sup> produced 74% WPM in September, which was much higher than that produced by the mixture of 0.56 kg ha<sup>-1</sup> of clopyralid and an equal amount of picloram. All mixtures of clopyralid + picloram showed a tendency toward loss of efficacy with later application dates. Higher rates of 1:1 and 1:2 mixtures of clopyralid + picloram produced higher AGM and WPM than lower rates of these mixtures during June applications but not in July or September. These results suggest that picloram added little or even diminished efficacy of clopyralid applied to honey mesquite in September.

#### Late Season Dosage Response

Clopyralid applied from 0.28 to 1.12 kg ha<sup>-1</sup> near Vernon demonstrated a positive dosage response in AGM and WPM (Table 2). A similar response was seen at Ozona except overall mortality rates were higher. Trees treated with clopyralid showed closely correlated levels of AGM and WPM, reaffirming the tendency for trees not to resprout to the extent seen in other herbicides such as 2,4,5-T, 2,4,5-T + picloram or triclopyr.

Clopyralid + picloram (1:1) showed no dosage response in WPM at the Vernon site; however, dosage response was evident in AGM at both Ozona and Vernon. At Ozona, levels of WPM increased

**Table 2. Comparisons of above ground mortality (AGM) and whole plant mortality (WPM) in stands of honey mesquite on rangeland aerially sprayed with herbicides in 1986 near Vernon and Ozona, Texas.**

Herbicide	Rate	Vernon		Ozona	
		AGM WPM		AGM WPM	
		----- (%) -----			
	(kg ha <sup>-1</sup> )	18 October		4 October	
Clopyralid	0.28	28	21	55	54
	0.56	52	46	79	79
	0.84	74	65	90	89
	1.12	88	82	97	96
Clopyralid + Picloram (1:1)	0.56	46	37	43	42
	1.12	63	50	75	71
	1.68	70	55	90	86
	2.24	74	45	93	88
		27 September		4 October	
Triclopyr	0.56	3	0	10	6
	0.84	5	0	33	24
	1.12	23	0	16	6
Triclopyr + Picloram (1:1)	0.56	24	1	14	11
	1.12	12	0	23	19
Triclopyr + Picloram (3:2)	1.38	33	3	40	26
Triclopyr + Picloram (2:1)	1.68	36	3	58	35
L.S.D. .05		37	27	31	23



**Table 3. Comparisons of above ground mortality (AGM) and whole plant mortality (WPM) in stands of honey mesquite on rangeland aerially sprayed with herbicides in 1987 and 1988 near Ozona, Texas.**

Herbicide	Rate (kg ha <sup>-1</sup> )	1 Oct. 1987		25 Aug. 1988	
		AGM	WPM	AGM	WPM
		----- (%) -----			
Clopyralid	0.28	45	40	43	34
	0.56	80	70	67	58
	0.84	76	71	83	78
	1.12	79	72	94	91
Clopyralid + Picloram (1:1)	0.56	66	48	13	10
	1.12	63	48	55	43
	1.68	71	65	86	74
	2.24	76	69	91	83
Clopyralid + Picloram (1:2)	0.84	56	42	23	16
Clopyralid + Picloram (2:1)	0.84	61	55	46	38
Clopyralid + Triclopyr (1:2)	0.84	50	37	68	63
Clopyralid + Triclopyr (2:1)	0.84	54	44	84	80
Clopyralid + Triclopyr (1:1)	0.56	59	37	55	45
	1.12	50	34	89	84
Triclopyr + Picloram (1:1)	0.56	42	14	39	24
	1.12	53	23	—	—
Triclopyr	0.56	25	8	55	10
	0.84	26	3	49	23
	1.12	45	20	62	25
L.S.D. .05		21	22	35	36

significantly when the mixture contained 0.56 kg ha<sup>-1</sup> of clopyralid.

Triclopyr alone or in combinations caused less than 40% AGM in honey mesquite and gave practically no WPM at Vernon (Table 2). These treatments also gave low efficacies at Ozona, with most treatments providing lower levels of mortality than produced with a 0.28 kg ha<sup>-1</sup> rate of clopyralid.

Applications applied in October 1987 and late August 1988 near Ozona produced high levels of efficacy when 0.56 kg ha<sup>-1</sup> or more of clopyralid was applied (Table 3). In 1987, combinations of clopyralid + picloram were less effective than produced by clopyralid alone. Triclopyr was less effective when applied alone or in combination with picloram. Triclopyr + clopyralid mixtures gave increased WPM over those produced by either triclopyr or triclopyr + picloram mixtures; however, levels of AGM were similar among these treatments. In 1988, triclopyr applied in late August produced higher efficacy than triclopyr applied in October 1987. Combinations of clopyralid + triclopyr that contained at least 0.56 kg ha<sup>-1</sup> of clopyralid produced more than 80% WPM when applied in August. This efficacy was equivalent to that produced by 0.84 kg

ha<sup>-1</sup> of clopyralid alone or combined with an equal amount of picloram. Clopyralid at 0.28 ha<sup>-1</sup> alone or mixed with an equivalent amount of picloram gave relatively low efficacy compared to either higher rates of clopyralid alone or mixtures containing clopyralid.

Mortality data from experiments including rates of clopyralid applied from 0.28 to 1.12 kg ha<sup>-1</sup> were utilized to develop the regression equation:

$$Y = 25.9 + 55.8 X$$

where Y is WPM as a percentage and X is the rate of clopyralid in kg ha<sup>-1</sup>. This equation had a standard error of  $\pm 6.5\%$  and a correlation coefficient of 0.86. Whole plant mortality from clopyralid applied at rates of 0.28, 0.56, 0.84, and 1.12 kg ha<sup>-1</sup> was predicted to be 41, 57, 73, and 88%, respectively. This equation is practically identical to one derived from dosage response data in experiments conducted in western Texas from 1979 to 1982 for clopyralid applied in June and July which gave the equation  $Y = 25.1 + 56.1 X$ .

These data, derived from large scale field experiments at several locations in western Texas over several years of tests and evaluations, indicate that a given rate of clopyralid has the potential to produce similar levels of efficacy from June to October.

#### Management Implications

The ability of clopyralid to control honey mesquite during late season applications could result in more rangeland being treated for brush management than is presently treated during the traditional early to mid summer period. Late season applications of clopyralid could permit honey mesquite to be treated in areas presently restricted because of proximity to susceptible crops.

#### Literature Cited

- Bovey, R.W., H. Hein, and R.E. Meyer. 1986. Concentration of 2,4,5-T, triclopyr, picloram, and clopyralid in honey mesquite (*Prosopis glandulosa*) stems. *Weed Sci.* 32:211-217.
- Dahl, B.E. and R.E. Sosebee. 1984. Timing—the key to herbicidal control of mesquite. *Manage. Note 2*, Dept. Range and Wildl. Manage., Texas Tech Univ., Lubbock.
- Fisher, C.E., C.H. Meadors, R. Behrens, E.D. Robison, P.T. Marion, and H.L. Morton. 1959. Control of mesquite on grazing lands. *Texas Agr. Exp. Sta. Bull.* 935.
- Jacoby, P.W., C.H. Meadors, and L.E. Clark. 1990. Effects of triclopyr, clopyralid and picloram on growth and production of cotton. *J. Prod. Agr.* 3:297-301.
- Meyer, R.E., J.D. Hanson, and A.J. Dye. 1983. Correlation of honey mesquite response to herbicides with three plant variables and soil water. *J. Range Manage.* 36:613-615.
- Scifres, C.J. 1980. Brush management—Principles and practices for Texas and the Southwest. Texas A&M Univ. Press, College Station.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics—A biometric approach. McGraw-Hill Book Co., New York.
- Welch, T.G. 1988. Suggestions for chemical weed and brush control on rangeland. *Texas Agr. Ext. Serv. Bull.* 1466.

# Willow planting success as influenced by site factors and cattle grazing in northeastern California

SCOTT D. CONROY AND TONY J. SVEJCAR

## Abstract

In recent years there has been an increasing emphasis on reestablishment of woody vegetation in degraded riparian zones. In this study we evaluated the influence of grazing and selected site factors on survival and leader growth of planted Geyer willow (*Salix geyeriana* Anderss.) cuttings. Three grazing treatments (early summer, late summer, and non-use) were evaluated on each of 3 streams in broad, low-gradient meadows with silt loam soils in the northern Sierra Nevada. The streams were perennial with terraces often 1.0 to 1.5 m above streambottom. Unrooted Geyer willow cuttings were planted to 30-cm soil depth in early May 1987 at 3 streamchannel locations (streambottom, streambank, and stream terrace) within each of the grazing treatments. Survival, associated community type, and cover class were determined for 2,700 plantings. Leader length and grazing intensity were measured for 694 surviving cuttings in 1988. Percent soil moisture and water table depth were determined for a subset of the willow cuttings. There was no significant ( $P > 0.05$ ) effect of grazing treatment on either willow survival or growth despite 3.5 to 5 times more defoliation use of the willow cuttings in the grazed pastures. Streamchannel location did significantly ( $P \leq 0.05$ ) affect willow survival (streambottom = 83%, streambank = 34%, and stream terrace = 3%) but not individual plant leader length. Survival of willow cuttings for *Carex nebrascensis*/*Juncus nevadensis*, bareground, *Deschampsia caespitosa*/*Carex nebrascensis*, and *Artemisia* sp. dominated sites was 76, 60, 44, and 2%, respectively. However, leader length was significantly ( $P \leq 0.05$ ) greater for bareground sites than for sites supporting vegetation. Cover class was not a good indicator of survival, but as might be expected from the results on the bareground sites, leader length for the 0–5% class was 1.8 times the length of the next class. There was a clear relationship between water table depth, soil moisture, and willow planting survival but not between moisture measurements and leader length. Once the water table has declined to the point that *Artemisia* sp. can survive on a site, the chances of successfully replanting willows are minimal. However, even during the drought years of this study (<50% of average annual precipitation) a survival rate of 60% or greater was achieved by planting into *Carex nebrascensis* communities or bareground in the streamchannel.

**Key Words:** soil moisture, water table, survival, riparian, *Salix geyeriana*

Improper use of riparian ecosystems by cattle can change, reduce, or eliminate vegetation bordering streams (Kauffman and Krueger 1984). This often leads to erosion, bankcutting, and lowering of the water table, which contributes to the loss of many riparian plant species (Marlow 1987). Riparian zones altered by widened channels, frequent channel realignments, and poorly vegetated banks and floodplains can be rehabilitated by reestab-

lishing plants in the riparian streamside zone (VanHaveren and Jackson 1986). Establishment of woody plants is critical in the restoration of many riparian areas (Volny 1984). Methods for interplanting woody species onto unstable streambanks have not been fully developed and need further study (Platts et al. 1987, Skovlin 1984). Willow (*Salix* sp.) transplants are recommended because they are usually locally available, native, easily established, relatively inexpensive to plant, provide more stability to the site than many other woody plants, and grow rapidly (Schultze and Wilcox 1985, Gray et al. 1984).

Success of willow planting can be affected by grazing (Eckert 1975, Platts et al. 1987), soil moisture (Platts et al. 1987, Fege 1983), and species of willow planted (Platts et al. 1987). The objectives of this study were to determine survival and growth of unrooted Geyer willow (*Salix geyeriana* Anderss.) cuttings as influenced by time of grazing and site factors.

## Materials and Methods

### Study Site

The study was conducted during 1987 and 1988 on the east slope of the northern Sierra Nevada near Lake Davis in Plumas County, California, at an elevation of 1,765 meters. Study sites were located at 10 km north of the town of Portola. Pastures were located at 3 Lake Davis tributaries: Cow, Freeman, and Big Grizzly creeks. Species in the riparian zones include silver sagebrush (*Artemisia cana* Pursh)<sup>1</sup>, mountain big sagebrush (*A. tridentata* var. *vaseyana* Nutt.), Nebraska sedge (*Carex nebrascensis* Dewey), tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), Kentucky bluegrass (*Poa pratensis* L.), Sandberg bluegrass (*Poa sandbergii* Vasey), Nevada rush (*Juncus nevadensis* Wats.), and Geyer willow. Soils are moderately well-drained silt and silt loams. The 29-year mean annual precipitation is 96 cm, 85% occurring between October and April mainly as snow. Precipitation was 50% and 46% of the 29-year mean during 1987 and 1988, respectively. Spring typically brings rain on snow, which results in large peak streamflows that overtop the streambanks. Streamflow is typically less than 100 m<sup>3</sup>/h during late summer and streams may have intermittent flows during dry years. The mean daily minimum and maximum air temperatures between May and October during the 2-year period were 0° C and 24° C, respectively. The mean soil temperature at 15 cm depth between May and August was 16° C. The study sites were historically heavily grazed season-long by cattle. Freeman and Big Grizzly creeks were fenced to exclude livestock in 1985 and 1986, respectively. Reaches of Cow, Freeman, and Big Grizzly creeks are classified as C3, C6, and F4 stream types (Rosgen 1985). Stream-bottoms were downcut 1.0 to 1.5 m below the stream terrace, and the width cut by the stream ranged from about 4 to 10 m.

### Willow Planting

Willow cuttings were planted on a transect line intercept system (Platts et al. 1983). Thirty transects, spaced 3 m apart, were located downstream from a random point in each pasture. Each transect was perpendicular to the general stream axis, crossed the stream,

Authors are range conservationist, USDA-Forest Service, P.O. Box 7, Blairsden, California 96103; and range scientist, USDA-Agricultural Research Service, 920 Valley Road, Reno, Nevada, 89512. Reprint requests should be sent to Svejcar's current address: USDA-ARS, HC 71 4.51 Hwy 205, Burns, Oregon 97720. At the time of the research, Conroy was a graduate assistant at University of Nevada, Reno. The authors thank W.S. Platts, S. Swanson, G.F. Gifford, S. Jenkins, and J. Trent for their suggestions during the course of the research. Constructive comments on the manuscript were provided by W. Leiminger and P. Doeschner.

Manuscript accepted 18 May 1990.

<sup>1</sup>Formerly *Salix elaeagnifolia* Hook. (1982).

Table 1. Pasture size, stocking rates, forage standing crop means and standard errors (in parentheses), and comparison of 1988 to 1987 forage standing crop.

Pasture	Area (ha)	Stocking rate (ha/AUM)		Forage standing crop (kg/ha)		1988 Forage standing crop (% of 1987)
		-1987-	-1988-	---1987---	---1988---	
Cow Creek						
Ungrazed	2.7	—	—	1,864(114)	700( 62)	38
Grazed Early	2.7	1.1	1.2	541( 79)	369( 17)	68
Grazed Late	2.7	0.8	1.1	658( 42)	335( 13)	51
Freeman Creek						
Ungrazed	2.5	—	—	2,079(162)	995( 49)	48
Grazed Early	2.5	1.1	1.1	1,239(175)	259( 13)	21
Grazed Late	2.5	0.7	1.2	1,151( 93)	283( 17)	25
Big Grizzly Creek						
Ungrazed	1.6	—	—	5,151(302)	2,858(180)	55
Grazed Early	4.0	0.9	1.2	1,128(105)a <sup>1</sup>	457( 24)	41
Grazed Late	3.5	0.6	1.0	419( 49)b	462( 34)	110

<sup>1</sup>Standing crop means for grazed pastures within years and streams with different letters differ at  $P \leq 0.05$ .

and extended 10 m from the top of both banks. Ten unrooted willow cuttings were planted in the same relative locations on each transect. Thus, there were 300 cuttings per pasture or 2,700 for the entire experiment.

The willow cuttings were collected from onsite 2+ year-old stems of Geyer willow shrubs the first week of April 1987 just before bud flush, as recommended by Fege (1983) and Platts et al. (1987). Mean diameter and length of the cuttings was 10.5 mm and 42.3 cm, respectively. Cuttings were stored at 0° C for 1 month, then soaked 2 days in water as recommended by Petersen and Phipps (1976) and planted vertically with 30 cm below ground during the first week of May, 1987. Survival of willow cuttings, total leader length, and number of grazed primary branches were recorded during September 1987 and 1988. Cuttings were considered alive if any aboveground growth was visible, and total leader length was the sum of all shoots growing from the cutting.

#### Grazing Treatments

A randomized complete block model was used for the grazing study. Nine pastures were fenced, 3 each on Cow, Freeman, and Big Grizzly creeks with early and late summer grazed and ungrazed treatments randomly assigned within blocks. Typically, season-long grazing has been from 20 June to 20 September on these particular allotments. Thus, the early and late grazing periods in 1987 were 22 June to 7 August and 4 August to 23 September, respectively. In 1988 the grazing periods were 21 June to 1 July and 18 August to 31 August, respectively. Initial stocking rates were based on estimated production, and stocking rates were adjusted during the grazing period to obtain similar use on grazed pastures within blocks. Standing crop of forage species was estimated using the comparative yield method (Haydock and Shaw 1975). Pastures size, stocking rates, and forage standing crop are presented in Table 1.

#### Environmental Factors

The microsite (30-cm radius) associated with each willow cutting was classified in 3 ways: (1) planting location was described as streambottom, streambank, or stream terrace; (2) community type was described as Nebraska sedge/ Nevada rush, tufted hairgrass/- Nebraska sedge, silver sagebrush/ Sandberg bluegrass, mountain big sagebrush/ Sandberg bluegrass, or bareground; and (3) cover class of associated vegetation was ocularly estimated at 0–5%, 6–25%, 26–50%, 51–75%, or 76–100%. The streambottoms' location was within 0.5 m of the edge of the stream during early summer

flow, the streambank location was about halfway between the stream edge and the beginning of the stream terrace, and the stream terrace is the floodplain that existed before the stream downcut.

Volumetric moisture content of the soil was determined at 15, 30, and 60 cm depths using the neutron scattering method. Installation of the neutron probe soil tubes and calibration of the Campbell Pacific Nuclear Model 503<sup>2</sup> hydroprobe were done according to Brakensiek et al. (1979). Water table levels were monitored using perforated PVC observation wells installed to a 150-cm depth. The neutron probe soil tubes and the observation wells were installed within 30 cm of 5 willow cuttings along 2 randomly selected transects per pasture. Soil moisture and water table levels were measured for this subset of 90 sites (10 per pasture) 6 times from May through August about every 3 weeks in 1987 and 1988.

#### Data Analysis

The data were analyzed using the general linear models (GLM) procedure in SAS (SAS 1985). Two-way analysis of variance models were used for location by grazing treatment, community type by grazing treatment, and cover class by grazing treatment. Because of the number of sampling points for a given community type or cover class was not equal among treatments, we analyzed these data using the GLM procedure for unequal sample size and by averaging values for each community type and cover class within a pasture. The 2 analyses yielded the same statistical results, indicating that no bias was introduced by having unequal sample sizes. All treatment comparisons were made using the LSD ( $P < 0.05$ ) test.

#### Results

##### Year Effect

Most of the cuttings that survived to the end of the first growing season also survived to the end of the second season. Of the total 2,700 cuttings, 32% were alive in September 1987, and 26% were alive in September 1988. Because potential long-term survival is of interest, we will present survival and growth data from 1988, the second growing season.

##### Cattle Grazing

Survival and total leader length of the willow cuttings were not significantly different for the grazing treatments (Table 2); thus subsequent analyses are averaged over grazing treatment, except in cases where a significant interaction occurred. The number of grazed primary leaders was significantly less for the ungrazed

<sup>2</sup>Mention of trade name does not indicate endorsement by the USDA.

**Table 2. Survival (%), total leader length (cm), number of grazed leaders, and average leader length (cm) means and standard errors (in parentheses) for unrooted willow plantings by grazing treatment.**

Response variable	Ungrazed	Grazed early	Grazed late
Survival (%)	33(8)	18(1)	26(4)
Total Leader Length (cm)	61(2)	91(39)	77(27)
No. Grazed Leaders	0.2(0.0)a <sup>1</sup>	0.7(0.1)b	1.0(0.1)b
Avg. Leader Length (cm)	29(2)	32(10)	28(8)

<sup>1</sup>Row means with different letters differ at  $P \leq 0.05$ .

pastures than the grazed pastures. We noted deer tracks in the streambottoms, which might explain some of the leader removal in the ungrazed pastures. Average primary leader length was not different among grazing treatments.

#### Environmental Factors

Survival differed ( $P \leq 0.05$ ) among the 3 planting locations, being highest in the streambottom and lowest on the stream terrace (Table 3). Differences in leader length between planting locations were not significant.

**Table 3. Survival (%) and leader length (cm) means and standard errors (in parentheses) for unrooted willow plantings by community type and planting location. Data was collected at the end of the second growing season; a total of 2,700 willows were planted.**

	Survival (%)	Leader length (cm)
Community type		
Cane/June <sup>1</sup>	76( 6)a <sup>2</sup>	64(13)b
Bareground	60(13)b	108(17)a
Dece/Cane	44( 8)b	46( 5)b
Arca/Posa	2( 1)c	—
Artr/Posa	2( 1)c	—
Location		
Streambottom	83( 2)a	87(23)
Streambank	34( 7)b	62(10)
Stream terrace	3( 1)c	46( 5)

<sup>1</sup>Cane = *Carex nebrascensis*; June = *Juncus nevadensis*; Dece = *Deschampsia caespitosa*; Posa = *Poa sandbergii*; Arca = *Artemisia cana*; Artr = *A. tridentata* var. *vaseyana*.

<sup>2</sup>Both grazing treatment by community type, and grazing treatment by location analyses were conducted. Neither interaction terms nor grazing treatment effects were significant ( $P_{0.05}$ ) for either analysis; therefore, we have presented means averaged over grazing treatment. Different letters indicate treatment separation ( $P < 0.05$ ) within community types or location.

Survival of willow cuttings differed among community types (Table 3). Survival was highest for the Nebraska sedge/Nevada rush community type and lowest for the 2 sagebrush community types. The bareground sites had the longest leader length, about 1.7 and 2.3 times as long as lengths in the Nebraska sedge/Nevada rush and tufted hairgrass/Nebraska sedge community types respectively (Table 3).

Survival was highest for the 76–100% cover class in the ungrazed pastures but highest for the 0–5% cover class in the early grazed pastures (Table 4). This probably explains the grazing treatment by cover class interaction. Differences in survival by cover class in the late grazed pastures were not significant. Leader length decreased as cover class increased. The 0–5% cover class had 1.8 to 3.1 times longer leaders than the other cover classes.

Soil moisture and water table depth analyses for all measurement dates yielded similar results. However, the soil moisture and water table depth measurements taken 75 days after planting appeared to best explain the survival results at the water measurement stations. Soil moisture, water table depth, and survival of the subset of willows planted at the water measurement stations were highest on the streambottom, intermediate on the streambank, and lowest on the stream terrace (Table 5). Leader length differences

**Table 4. Survival (%) and leader length (cm) means and standard errors (in parentheses) for unrooted willow plantings by grazing treatment and cover class (%) of vegetation within 30 cm. There was a grazing treatment by cover class interaction for survival, but not for leader length. Data was collected at the end of the second growing season; a total of 2,700 willows were planted.**

Grazing treatment	0–5%	6–25%	26–50%	51–75%	76–100%
----- % Survival -----					
Ungrazed	41(12)ab <sup>1</sup>	16(10)b	23(10)b	33( 8)b	65( 9)a
Grazed					
Early	54(10)a	10( 2)b	7( 3)b	12( 1)b	22( 8)b
Late	47(16)	19( 6)	13( 4)	25( 9)	31(16)
----- Leader length (cm) -----					
Ungrazed	95( 8)	63( 8)	53( 7)	49( 5)	43( 3)
Grazed					
Early	161(35)	71(26)	45(13)	45(14)	37( 7)
Late	147(20)	64( 8)	52( 9)	47(10)	28( 2)
Overall Mean	113(18)a	63( 9)b	52( 9)b	50( 8)b	37( 5)b

<sup>1</sup>Row means with different letters differ at  $P \leq 0.05$ .

were not significant among locations even though leader lengths of streambottom cuttings were at least 2.5 times those of the other 2 locations.

Soil moisture and water table depth were highest for the Nebraska sedge/Nevada rush, tufted hairgrass/Nebraska sedge, and bareground community types (Table 5). Leader length differences at the water measurement stations were not significant, even though bareground willow planting leader length was at least 1.9 times leader lengths in the sedge community types. Survival of willow cuttings in the bareground sites was about twice that of the tufted hairgrass/Nebraska sedge community type even though soil moisture and water table depth were lower in the bareground sites. The 2 sagebrush community types had the lowest soil moisture and survival, and deepest water table. There were too many plots in the sagebrush community types with 0% survival to compare leader lengths with the other community types.

No significant differences were found for soil moisture, water table depth, survival, or leader length for the willow cutting subset at the water measurement stations among cover classes, although leader lengths for the 0–5% and 6–25% cover classes were 5 and 2.5 times longer, respectively, than those of the other cover classes (Table 5).

#### Discussion

Grazing of willow cuttings is generally considered detrimental to establishment (Eckert 1975, Platts et al. 1987). However, in this study we did not find a significant grazing effect on survival of planted willows. The willow cuttings were defoliated 3.5 to 5 times more in the grazed pastures compared to the ungrazed pastures, but this use did not appear to significantly affect survival or leader length. It is possible that carbohydrate reserves in the cuttings were sufficient to offset grazing effects on survival during the first 2 years (Fege and Brown 1984) or that frequency of defoliation of the willow cuttings was low enough for grazing not to be a factor (Taylor 1986). Grazing intensity apparently was light enough to not be harmful to the cuttings. Defoliation in the ungrazed pastures was attributed primarily to deer. There is some indication that grazing may have resulted in an increased number of leaders but the difference was not significant. Cattle diet selectivity tends towards shrubs during the latter part of the grazing season as the herbaceous forage matures (Roath and Krueger 1982) or becomes

**Table 5. Water table depth (cm) and soil moisture (% volume at 30 cm depth) means and standard errors (in parentheses) on 17 July 1987. Second year survival (%) and leader length (cm) means and standard errors for unrooted willows planted at the same measurement sites (n = 90).**

	Community type				
	Cane/June <sup>1</sup>	Bareground	Dece/Cane	Arca/Posa	Artr/Posa
Water table depth (cm)	41(13)a <sup>2</sup>	73(12)b	64( 6)ab	121(2)c	122(9)c
Soil moisture (%v)	51( 6)a	43( 8)ab	54(10)a	36(4)bc	30(1)c
Survival (%)	64(12)a	52( 2)a	22(12)b	6(6)b	8(8)b
Leader length (cm)	90(17)	170(50)	61(33)	---	---
	Cover class				
	0-5%	6-25%	26-50%	51-75%	76-100%
Water table depth (cm)	80(10)	89(12)	112(15)	98(29)	70(17)
Soil moisture (%v)	43( 7)	37( 5)	37( 6)	45(10)	46( 6)
Survival (%)	48( 6)	34( 6)	14(14)	25(13)	32(15)
Leader length (cm)	172(53)	109(38)	---	47(19)	34( 6)
	Location				
	Streambottom	Streambank	Stream Terrace		
Water table depth (cm)	27( 6) <sup>1</sup>	73( 6)b	126(7)c		
Soil moisture (%v)	53( 3)a	44( 4)b	36(2)c		
Survival (%)	73( 7)a	45( 6)b	7(4)c		
Leader length (cm)	171(69)	69(20)	59(9)		

<sup>1</sup>Cane = *Carex nebrascensis*; June = *Juncus nevadensis*; Dece = *Deschampsia caespitosa*; Posa = *Poa sandbergii*; Arca = *Artemisia cana*; Artr = *A. tridentata* var. *vaseyana*.  
<sup>2</sup>Grazing treatment by community type, grazing treatment by cover class, and grazing treatment by location analyses were conducted. Neither interaction terms nor grazing treatment effects were significant ( $P < 0.05$ ) for any of the analyses; therefore, we have presented means averaged over grazing treatments. Different letters indicate treatment separation ( $P \leq 0.05$ ) within rows.

less available (Kauffman et al. 1983). Our results however, showed no difference in use of the willow cuttings between early and late season grazing.

The grazing intensity of this study may have maintained an adequate forage standing crop to prevent heavier use of willow cuttings during the late grazing season compared to the early season grazing. Skovlin (1984) reported that intensity of use may be more important to riparian vegetation maintenance than season of use.

Planting location was the best indicator of willow planting survival in that the highest mean survival (83%) could be achieved by simply planting into the streambottom. The closer the cuttings were to the water table the higher the soil moisture and planting survival (Table 5). Poor stream terrace survival precludes the establishment of wide willow corridors along most streams, although some situations may warrant planting longer cuttings into the water table (York 1985). Eckert (1975) measured 90% survival for willows planted within 30 to 90 cm of the water table and no survival for cuttings 180 cm from the water table. Platts et al. (1987) and Schultze and Wilcox (1985) advise not planting willows in a high permanent water table because of reduced growth. In this study leader length followed a pattern similar to survival, the wetter the site the longer the leaders, although the differences were not significant. Generally, the base of willow cuttings in the streambottoms were at the mean water table depth.

As would be expected, community types were not uniformly distributed across streamchannel locations. This point must be considered when interpreting willow survival. The Nebraska sedge/Nevada rush community type had the highest willow survival, followed by the bareground community type, and then the tufted hairgrass/Nebraska sedge community type. These commun-

ity types had 68%, 37%, and 34%, respectively, of their samples at the streambottom location. The bareground and tufted hairgrass/-Nebraska sedge community types had 58% and 31% respectively, of their sample locations on the streambank. The Nebraska sedge/-Nevada rush and tufted hairgrass/Nebraska sedge community types had about the same mean soil moisture but willow planting survival in the Nebraska sedge/Nevada rush community type was significantly higher. Both these community types had about the same number of samples in each cover class. Apparently competition is related to the species of the competitors and soil moisture is not the only factor involved. Other authors have reported that competition for space, light, moisture, and nutrients may decrease planting survival (Platts et al. 1987, Monsen 1983, Patterson et al. 1981).

The bareground community type had the deepest mean water table and the lowest mean soil moisture of the 3 community types. However, there was more total leader length for the bareground community type than for the other 2 community types, indicating that factors other than soil moisture influenced leader growth. The 0-5% cover class had a significantly longer leader length than the other cover classes presumably because a large number of the 0-5% samples were from bareground sites. The 2 sagebrush community types, located primarily on the stream terraces, had significantly deeper water tables relative to the other community types, and only 2% planting survival. Cover class was not a good indicator of survival and survival appeared to be related to community type and soil moisture factors.

#### Recommendations

Even during the 2 drought years of this study, willow cuttings were successfully established in moderately grazed pastures. However, the establishment of a "willow corridor" extending very far

from the streambottom appears unlikely. Second year survival of 83 and 76% could be achieved by planting into streambottom sites or Nebraska sedge/Nevada rush community types, respectively. Response of individual species may vary; however, the Geyer's willow used in this study was not adversely affected by waterlogged conditions, as has been reported for some other species. It appears that successful establishment of Geyer's willow can be achieved by planting in locations where the base of the cutting is within 20 to 30 cm of the water table during mid-summer.

### Literature Cited

- Brakensiek, D.L., H.B. Osborn, and W.J. Rawls.** 1979. Field manual for research in agricultural hydrology. Agr. Handb. 224. USDA-SEA.
- Eckert, R.E.** 1975. Improvement of mountain meadows in Nevada. USDI-BLM Res. Rep. ARS, Reno, Nev.
- Fege, A.S.** 1983. The practices and physiological basis of collecting storing and planting *Populus* hardwood cuttings. In: Short rotation intensive culture: twelve years research. USDA-Forest Service Gen. Tech. Rep. NC-91. North Central Forest Exp. Sta., St. Paul, Minn.
- Fege, A.S., and G.N. Brown.** 1984. Carbohydrate distribution in dormant *Populus* shoots and hardwood cuttings. Forest. Sci. 30:999-1010.
- Gray, R.L., R. Snieckus, and G. Wilcox.** 1984. Riparian revegetation in California, p. 26-32. In: Cal-Neva Wildl. Trans. Western Section Wildlife Society and California-Nevada Chapter American Fisheries Society, Reno, Nev.
- Haydock, K.P., and N.H. Shaw.** 1975. The comparative yield method for estimating dry matter yield of pasture. Australian J. Exp. Agr. Anim. Husb. 15:663-670.
- Kauffman, J.B., and W.C. Krueger.** 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. J. Range Manage. 37:430-438.
- Kauffman, J.B., W.C. Krueger, and M. Vavra.** 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36:685-691.
- Marlow, C.B.** 1987. Controlling riparian damage with little forage loss. Montana Agr. Exp. Sta., Montana Agrosearch. 2:7.
- Monsen, S.B.** 1983. Plants for revegetation of riparian sites within the Intermountain region, p. 83-89. In: S.B. Monsen and N. Shaw (eds.) Managing Intermountain rangelands—improvement of range and wildlife habitats. USDA-Forest Serv. Gen. Tech. Rep. INT-157. Intermountain Forest and Range Exp. Sta., Ogden, Utah.
- Munz, P.A., and D.D. Keck.** 1959. A California flora. Univ. of California Press, Berkeley.
- Patterson, D.W., C.U. Finch, and G.I. Wilcox.** 1981. Streambank stabilization techniques used by the Soil Conservation Service in California, p. 452-458. In: R.E. Warner and K.M. Hendrix (eds.) California riparian systems: ecology, conservation, and productive management. Univ. of California Press, Berkeley.
- Petersen, L.A., and H.M. Phipps.** 1976. Water soaking pretreatment improves rooting and early survival of hardwood cuttings of some *Populus* clones. USDA-Forest Serv. Tree Planters' Notes. 27:12-22.
- Platts, W.S., W.F. Megahan, and G.W. Minshall.** 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA-Forest Serv. Gen. Tech. Rep. INT-138. Intermountain Forest and Range Exp. Sta., Ogden, Utah.
- Platts, W.S., C. Armour, G.D. Booth, M. Bryant, J.L. Bufford, P. Culpin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, J.S. Tuhy.** 1987. Methods for evaluating riparian habitats with applications to management. USDA-Forest Serv. Gen. Tech. Rep. INT-221. Intermountain Forest and Range Exp. Sta., Ogden, Utah.
- Roath, L.R., and W.C. Krueger.** 1982. Cattle grazing influence on a mountain riparian zone. J. Range Manage. 35:100-103.
- Rosgen, D.L.** 1985. A stream classification system, p. 91-95. In: R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, and R.H. Hamre (eds.) Riparian ecosystems and their management: reconciling conflicting uses. USDA-Forest Serv. Gen. Tech. Rep. RM-120. Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo.
- SAS Institute.** 1985. SAS/STAT guide for personal computers. SAS Institute Inc. Cary, N.C.
- Schultze, R.F., and G.I. Wilcox.** 1985. Emergency measures for stream-bank stabilization: an evaluation, p. 59-61. In: R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, and R.H. Hamre (eds.) Riparian ecosystems and their management: reconciling conflicting uses. USDA-Forest Serv. Gen. Tech. Rep. RM-120. Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo.
- Skovlin, J.M.** 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge, p. 1001-1103. In: Developing strategies for rangeland management. Westview Press, Boulder, Colo.
- Taylor, D.M.** 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. J. Range Manage. 39:254-258.
- VanHaveren, B.P., and W.L. Jackson.** 1986. Concepts in stream riparian rehabilitation, p. 280-289. In: Trans. of the 51st North Amer. Wildl. and Natur. Resources Conf. Wildl. Manage. Inst., Washington, D.C.
- Volny, S.** 1984. Riparian stands. Develop. in Agr. and Managed-forest Ecology. 14:423-453.
- York, J.C.** 1985. Dormant stub planting techniques, p. 513-514. In: R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, and R.H. Hamre (eds.) Riparian ecosystems and their management: reconciling conflicting uses. USDA-Forest Serv. Gen. Tech. Rep. RM-120. Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo.

# Biomass productivity and range condition on range sites in southern Arizona

WILLIAM E. FROST AND E. LAMAR SMITH

## Abstract

Range condition is usually defined by similarity of current to climax or potential vegetation. It is often assumed that rangelands in low condition are biologically less productive than those in higher condition. The objective of this study was to determine if range condition (ecological status) is related to total productivity or to forage production for livestock. Adjacent areas along fence-lines representing differences in range condition were sampled in 58 locations. These comparisons represented 31 different range sites across southern Arizona. Weight by species of above-ground peak standing crop current year's growth of vegetation was estimated using the dry-weight-rank/comparative yield methods. Range condition was rated with Soil Conservation Service range site descriptions. Species were classified as forage or non-forage to estimate forage available for cattle. In 75–85% of comparisons of good condition sites to fair condition, good to poor, and fair to poor, total current year's standing crop did not differ significantly. Where differences were significant, productivity was not consistently more on the high condition class. Forage production, however, was more from the stand in the higher condition class in about 2/3 of the comparisons. We concluded that in southern Arizona rangelands in higher condition (higher seral) classes usually produce more forage for cattle than lower condition classes on the same range site. Nevertheless, it is not usually true that total biomass productivity on low condition range is less than the same range site in higher condition.

**Key Words:** forage production, biomass production

Condition of rangeland is commonly defined in terms of the similarity of the present vegetation to the climax or potential vegetation of the range site (Smith 1979). This climax or "ecological" approach (Dyksterhuis 1949, 1952) is a measure of "ecological status" (RISC 1983) of the vegetation which, presumably, is independent of its value for a specific use. This approach has been the basis for most of the reporting of "range condition" on both public and private rangelands in the United States.

It seems logical that classification of range condition should reflect current productivity of rangeland in relation to its inherent potential as determined by climate, soil, and topographic position. Thus, both resource managers and laymen may implicitly assume that ranges in "poor" condition are biologically less productive than those in "good" condition. Reports on range condition have stated this assumption explicitly. For example, the Bureau of Land Management (1979) stated that 135 million out of 170 million acres of public domain were in "fair condition or worse" and concluded "there is no question that vegetation production is far below potential." These statements imply that ranges are less productive than they could be for all uses, not just livestock grazing. Such conclusions may be incorrect.

Change in the rating of range condition is based on increase in relative amount of some species and decrease in others. In the climax approach to condition assessment a change from "good" to

"poor" condition means the species which increase are considered to be of lower successional status than those which decrease. If the species which increase are less palatable, less available, or less digestible for a specific herbivore than those which decrease, forage value of the vegetation may be diminished for that animal. In some cases forage production for livestock has been shown to be greater on good condition ranges than on poor condition ranges as rated by the climax approach (Goebel and Cook 1960, Cook et al. 1962, Christie and Hughes 1981, Powell et al. 1982 and others). In other cases, poor or fair condition rangeland may produce more forage for livestock than good condition range (e.g., Cook et al. 1965). There is no reason that we know of to suppose that similarity to "climax" should be correlated to forage production for any particular animal. Therefore, instances where such correlations do occur must be specific to certain vegetation types. Otherwise, these correlations may reflect a bias toward forage species for specific animals in describing the presumed climax vegetation.

Less information is available to indicate whether total site productivity is related to climax-based ratings of range condition. All the studies cited above reported only forage production, not total biomass production. Chew and Chew (1965) found that primary productivity in desert shrub communities in Arizona was similar regardless of major species or life form, and that it was similar to rates reported in the literature from widely separated areas with similar areas with similar precipitation. Evenari et al. (1975) and Fischer and Turner (1978) also concluded that precipitation, rather than vegetation composition, is the main determinant of biomass production in semiarid areas. Friedel (1981), working in a semi-arid region of Australia, found no relationship between range condition assessed as similarity to climax and species diversity or total productivity. She also found there were no significant differences in total standing crop or percentage of green material present in different condition classes. This work was done in *Astrelba* grasslands, open woodlands, and *Acacia* shrublands.

Based on the evidence available, we hypothesized that productivity of rangeland vegetation in arid/semiarid areas is determined primarily by site characteristics (precipitation, soil, topography) which influence the main limiting factor, moisture. Therefore, species or life form composition have relatively little effect on total biomass production, except where extreme disturbance (e.g., around water holes) or areas of large, denuded patches of crusted or "scalded" soil prevent reasonable populations of plants. From this hypothesis, the objective of this study was to determine if range condition (ecological status) is related to total vegetation productivity or to forage production for livestock on a cross-section of range sites in southern Arizona.

## Methods

Vegetation data were collected at 58 locations selected to represent a variety of range sites in several Major Land Resource and Sub-Resource Areas in southern Arizona (Table 1). All locations had a mixture of plant life forms and species. Each location was sampled on both sides of a fence-line which provided a comparison of 2 range condition classes on the same range site.

Actual productivity (plant biomass produced per year) of rangeland vegetation is difficult to measure because different species and

Authors are research associate, California Agricultural Technology Institute, California State University, Fresno; and associate professor, Division of Range Resources, University of Arizona. At time of research senior author was graduate research associate, Division of Range Resources, University of Arizona.

This work was supported by the USDA under Agreement No. 59-2041-1-2-087-0 and is based on a dissertation by the senior author at the University of Arizona.

Manuscript accepted 11 May 1990.

Table 1. Range sites sampled within Major Land Resource Areas (MLRA) and Sub-Resource Areas (SRA) within Southern Arizona.

MLRA/SRA	Range sites sampled		Number of locations	Characteristic vegetation
D39 Arizona and New Mexico Mountains				
D39-4 AZ Interior Chaparral-Grassland	Deep Sandy Loam	16-20 p.z.	1	Shrub live oak ( <i>Quercus turbinella</i> )
	Loamy Upland	12-16 p.z.	2	manzanita ( <i>Arctostaphylos</i> spp.),
	Limy Upland	12-16 p.z.	1	grama grasses ( <i>Bouteloua</i> spp.), squirrel tail ( <i>Sitanion hystrix</i> )
D40 Central Arizona Basin and Range				
D40-2 Phoenix Desert Shrub	Limy Slopes	7-10 p.z.	2	Creosotebush ( <i>Larrea tridentata</i> ),
	Loamy Upland	7-10 p.z.	2	saguaro ( <i>Carnegiea gigantea</i> ),
	Sandy Loam Upland	7-10 p.z.	3	fluffgrass ( <i>Erioneuron pulchellum</i> )
	Shallow Upland	7-10 p.z.	1	bush muhly ( <i>Muhlenbergia porteri</i> )
D40-3 Central Arizona Desert Grassland-Shrubs	Loamy Slopes	10-12 p.z.	1	Paloverde ( <i>Cercidium</i> spp.),
	Loamy Hills	10-12 p.z.	1	Joshua Tree ( <i>Yucca brevifolia</i> ),
	Sandy Loam Upland	10-12 p.z.	1	creosotebush, big galleta ( <i>Hilaria rigida</i> ), dropseeds ( <i>Sporobolus</i> spp.)
D40-1 Upper Sonoran Desert Shrub	Deep Sandy Loam	10-12 p.z.	1	Paloverde, saguaro, creosotebush,
	Deep Sandy Loam	12-15 p.z.	1	mesquite ( <i>Prosopis juliflora</i> ),
	Limy Fan	10-12 p.z.	1	bursage ( <i>Ambrosia</i> spp.),
	Limy Slopes	12-15 p.z.	1	tobosagrass ( <i>Hilaria mutica</i> ),
	Limy Upland	10-12 p.z.	2	Arizona cottontop ( <i>Digitaria californica</i> ).
	Loamy Bottom	10-12 p.z.	1	
	Loamy Hills	12-15 p.z.	3	
	Sandy Loam Upland	12-15 p.z.	3	
	Shallow Upland	10-12 p.z.	1	
D41 Southwestern Arizona Basin and Range Basin and Range				
D41-2 Chihuahuan Desert Shrub	Limy Fan	7-10 p.z.	2	Creosotebush, mesquite,
	Limy Upland	7-10 p.z.	2	tarbrush ( <i>Flourensia cernua</i> )
	Loamy Upland	7-10 p.z.	4	black grama ( <i>Bouteloua eriopoda</i> )
	Sandy Loam Upland	7-10 p.z.	4	bush muhly, three awns ( <i>Aristida</i> spp.).
D41-3 Chihuahuan Semi-desert Grassland	Limy Upland	12-16 p.z.	1	Mesquite, whitethorn
	Limy Slopes	12-16 p.z.	2	( <i>Acacia constricta</i> ), yucca
	Loamy Upland	12-16 p.z.	3	( <i>Yucca</i> spp.), grama grass
	Sandy Loam Upland	12-16 p.z.	3	( <i>Bouteloua</i> spp.), plains lovegrass ( <i>Eragrostis intermedia</i> ) plains bristlegrass ( <i>Setaria macrostachya</i> ), Arizona cottontop
D41-1 Mexican Oak-Pine Woodland and Oak Savanna				
	Deep Sandy Loam	16-20 p.z.	2	Liveoaks ( <i>Quercus</i> spp.)
	Limy Upland	16-20 p.z.	2	grama grasses, cane bermudagrass
	Loamy Upland	16-20 p.z.	2	( <i>Bothriochloa barbinodis</i> ),
	Sandy Loam Upland	16-20 p.z.	2	Texas bluestem ( <i>Schizachyrium cirratum</i> ).

life forms differ in phenology. Therefore, the standing crop of current year's growth was estimated at the approximate time of peak standing crop for all vegetation and considered an index to annual productivity. Data were collected from August through October, 1985. Rainfall data for representative locations (Table 2) indicate that 1984 was considerably wetter than average and 1985 slightly wetter than average, thus biomass production was probably above average at most or all locations.

Species composition by weight was estimated using the dry weight rank method (t'Mannetje and Haydock 1963). The comparative yield method (Haydock and Shaw 1975), a double sampling procedure, was used to estimate total annual standing crop (or current year's growth for woody species). Standing crop and species composition data were collected using 40 cm × 40 cm quadrats, with a minimum of 4 and a maximum of 10 transects of

25 quadrats each for each stand sampled. The dry weight rank and comparative yield methods have been extensively tested in these vegetation types and found to give estimates of species composition and standing crop which agree closely with those obtained by harvesting or weight estimate techniques (Smith and Despain, in press; Despain and Smith, in press). Forage production for cattle was calculated by multiplying percent composition of forage species by the total estimated standing crop. Forage was defined as "browse and herbage which is available and may provide food for grazing animals" (RISC 1983). Species known to be used by cattle were considered forage.

Estimates of botanical composition on a dry-weight basis were used to assign each sample area to a condition class according to Soil Conservation Service range site descriptions and procedures. A *t*-test was conducted to determine if the 2 range condition classes



**Table 2. Precipitation in Tucson, Phoenix, and Safford, Arizona during 1984 and 1985.**

Month	Tucson		Phoenix		Safford	
	1984	1985	1984	1985	1984	1985
			(mm)			
Jan.	13	32	9	24	31	19
Feb.	0	37	0	9	0	11
Mar.	0	5	0	0	0	19
Apr.	13	12	32	4	14	20
May	1	0	0	0	20	0
June	24	0	3	0	23	1
July	192	71	124	28	82	57
Aug.	68	21	21	4	80	17
Sep.	34	28	68	26	29	82
Oct.	28	35	6	10	11	52
Nov.	13	41	23	43	5	22
Dec.	80	8	82	28	59	0
Total	466	290	368	176	354	300
Long Term Average	288		168		218	

at each location had significantly different total annual standing crop of all vegetation and of forage species (Little and Hills 1978). The number of condition class comparisons were: 21 fair to good; 24 poor to fair; and 13 poor to good. Data from all locations within each precipitation zone were pooled and subjected to an analysis of variance to determine if significant differences ( $p \leq .05$ ) in mean total annual standing crop or forage production existed among classes.

### Results

Paired comparisons of total annual standing crop revealed that, generally, there was no difference between different condition classes on the same range site (Table 3). Comparisons of fair to

**Table 3. Total standing crop comparisons by range condition classes. Number of areas with significantly higher standing crop ( $p = .10$ ).**

Condition class comparison	Good	Fair	Poor	No difference
Fair to Good	3	2		16
Poor to Fair		4	2	18
Poor to Good	2		0	11

good condition classes showed that in 76% of the cases no significant differences ( $p \leq .10$ ) existed. In 14% of the comparisons the good condition class had larger standing crop, and in 10% the fair condition class had a larger standing crop. The same pattern occurred in the poor to fair condition class comparisons with no difference 75% of the time, fair condition having a larger standing crop 17% of the time, and poor condition having a larger standing crop 8% of the time. Even when poor condition was compared to good condition there was rarely a significant difference in standing crop. Only 15% of the comparisons showed a larger standing crop for good condition than for poor condition, while the other 85% were not significantly different (Table 3).

Amounts of forage for cattle were better related to condition class assessments than was the total annual standing crop (Table 4). Good condition class areas had significantly ( $p \leq .10$ ) more forage than the fair condition class areas 62% of the time, while fair condition stands had more forage than good in 14% of the comparisons, and there was no difference in the remaining 24% of the cases. Similarly, in 24 comparisons of fair to poor condition stands

**Table 4. Forage production comparisons by range condition classes. Number of areas with significantly higher forage production ( $p = .10$ ).**

Condition class comparison	Good	Fair	Poor	No difference
Fair to Good	13	3	—	5
Poor to Fair	—	15	4	5
Poor to Good	9	—	3	1

the fair condition area had more forage in 63% of the cases, the poor condition area produced more forage in 17% of the comparisons, and there was no difference 20% of the time. When compared to poor condition stands, areas assessed in good condition had more forage in 69% of the locations, the poor condition stand produced more forage in 23% of the locations, and there was no difference in the remaining 8% of the comparisons (Table 4).

Analysis of variance of the data pooled for all range sites in each precipitation zone showed that there was no significant difference ( $p = .05$ ) in total annual standing crop among the 3 condition classes in any of the 3 zones (Table 5). On the other hand, production of cattle forage was significantly greater for good condition

**Table 5. Means of total annual standing crop and forage production grouped by range condition classes.**

Condition class	Total annual standing crop (kg/ha)	Forage production (kg/ha)	Proportion of forage in standing crop (%)
7" - 10" precipitation			
Good	649a	571a	88
Fair	678a	446b	66
Poor	638a	332c	52
10" - 16" precipitation			
Good	960a	803a	84
Fair	991a	664b	67
Poor	927a	465c	50
16" - 20" precipitation			
Good	1331a	1062a	80
Fair	1326a	898b	68
Poor	1241a	633c	51

(Means in columns within precipitation zone followed by the same letter are not significantly different ( $p = .05$ ).

than for fair condition stands and also greater for fair condition stands when compared to poor condition stands in each of the precipitation zones (Table 5). Forage species averaged 34, 28, and 26% of the total species encountered in sampling the 7-10 inch, 10-16 inch and 16-20 inch precipitation zones, respectively.

### Discussion

It was found that across a variety of range sites in Arizona range condition class was not related to total standing crop of annual biomass. These results support the hypothesis that differences in composition of the vegetation on a range site which result in different range condition classes using the climax approach do not usually indicate changes in overall productivity of the range ecosystem. These results agree with those of Chew and Chew (1965), Evenari et al. (1975), Fischer and Turner (1978), and Friedel (1981). For these semiarid/arid desert shrub and desert grassland rangelands, range condition ratings of "fair" or "poor" using the climax or potential vegetation as a standard should not imply that productivity of rangeland vegetation is "far below its potential" as some reports have stated. Such statements should be avoided by

agencies reporting "ecological condition" of rangelands.

The amount of forage for cattle differed among range condition classes. Generally, good condition areas produced the most forage, followed by fair condition stands, with poor condition areas producing the least forage. These results are similar to those reported by Goebel and Cook (1960), Cook et al. (1962), Christie and Hughes (1981), and Powell et al. (1982). Nevertheless, this relationship was found in only 60% of the locations sampled. In 20% of the comparisons, the lower condition class had more forage than the higher class, and in the remaining 20% of the cases there was no difference. The general trend of increasing forage for cattle as range condition improves (vegetation becomes more similar to "climax") indicates that either climax vegetation is more productive of cattle forage than seral stages, or a bias toward cattle forage has been introduced into the range site descriptions. Since the relationship of forage production to range condition is not consistent, use of condition classes as indicators of carrying capacity of "initial stocking rate" for cattle should be applied with caution by range managers.

The results obtained were based on data collected in 1 growing season. This study encompassed a broad spectrum of range sites with annual precipitation ranging from about 170–500 mm (7–20 inches). The differences in species composition measured at each location were the result of several to many years of different land use. Although total production is known to fluctuate in relation to amount of yearly precipitation, species composition would not change drastically in 1 or 2 years because most of the important species are long-lived perennials. If weather were a significant factor determining the relationship of biomass or forage production to range condition classes, one might expect it to show greatest effects in wet years when different plant species or life forms could express their full potential for production. That few consistent differences were noted in a relatively wet year suggests that even fewer would be evident in drier years.

If range condition, or ecological status, assessed by similarity to climax vegetation is not reliably related to overall productivity of the range ecosystem and not consistently related to forage production for livestock either, then we must question whether such ratings provide any useful information at all to managers and policy makers. "Ecological status" seems to be a concept too complex to evaluate using one attribute (composition) on a simple linear scale (see Wilson and Tupper 1982). The approach now being developed by some agencies of rating condition in relation to a "desired plant community" which provides the best mix of resource values for specific management objectives, including the fundamental objective of soil conservation, appears to have promise for management and policy decisions for multiple use of rangelands.

## Literature Cited

- Bureau of Land Management. 1979. Managing the public rangelands—Public Review Draft. BLM/U.S. Dep. of Interior.
- Chew, R.M., and A.E. Chew. 1965. The primary productivity of a desert-shrub (*Larrea tridentata*) community. Ecol. Monogr. 35:355-375.
- Christie, E.K., and P.G. Hughes. 1981. Interrelationships between net primary production, ground storey condition and grazing capacity of *Acacia aneura* rangelands of semi-arid Aust. Agr. Sys. 12:191-211.
- Cook, C. Wayne, Kent Taylor, and Lorin E. Harris. 1962. The effect of range condition and intensity of grazing upon daily intake and nutritive value of the diet on desert ranges. J. Range Manage. 15:1-6.
- Cook, C. Wayne, Mervyn Kothmann, and Lorin E. Harris. 1965. Effect of range condition and utilization on nutritive intake of sheep on summer ranges. J. Range Manage. 18:69-73.
- Despain, D.W., and E.L. Smith. (In Press). The comparative yield method for estimating range production. pp. 44-56. In: G.B. Ruyle (ed.) Some Methods for Monitoring Vegetation of Rangelands and Other Natural Areas. Arizona Coop. Ext. Serv., Univ. Arizona. Tucson.
- Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. J. Range Manage. 2:104-115.
- Dyksterhuis, E.J. 1952. Determining the condition and trend of ranges (pastoral pastures). Proc. 6th Int. Grassland Congr. p. 1322-1327.
- Evenari, M., E.D. Schulze, L. Kappen, U. Buxchbom, and O.L. Lange. 1975. Adaptive mechanisms in desert plants. p. 111-129. In: Physiological adaptations to the environment. F.J. Vernberg (ed.). Intext Educ. Publ., New York.
- Fischer, R.A., and Neil C. Turner. 1978. Plant productivity in the arid and semiarid zones. Annu. Rev. Plant Physio. 29:277-317.
- Friedel, M.H. 1981. Studies of central Australian semidesert rangelands. I. Range condition and the biomass dynamics of the herbage layer and litter. Aust. J. Bot. 29:219-231.
- Goebel, Carl J., and C. Wayne Cook. 1960. Effect of range condition on plant vigor, production and nutritive value of forage. J. Range Manage. 13:307-313.
- Haydock, K.P., and N.H. Shaw. 1975. The comparative yield method for estimating dry matter yield of pasture. Austr. J. Exp. Agr. and Anim. Husb. 15:663-670.
- Little, Thomas M., and F. Jackson Hills. 1978. Agricultural experimentation: Design and analysis. John Wiley and Sons. New York. 350 pp.
- Powell, David J., D.C. Clanton, and J.T. Nicholls. 1982. Effect of range condition on the diet and performance of steers grazing native sandhills range in Nebraska. J. Range Manage. 35:96-99.
- Range Inventory Standardization Committee. 1983. Guidelines and terminology for range inventories and monitoring. RISC Report to Soc. for Range Manage., Albuquerque. 13 pp.
- Sampson, Arthur W. 1952. Range management: Principles and practices. John Wiley and Sons. New York.
- Smith, E. Lamar. 1979. Evaluation of the range condition concept. Rangelands. 1:52-54.
- Smith, E. Lamar. 1984. Use of inventory and monitoring data for range management purposes. pp. 809-842. In: Developing strategies for rangeland management. Nat. Res. Council/Nat. Acad. of Sciences. Westview Press. Boulder, Colo.
- Smith, E.L., and D.W. Despain. In Press. The dry-weight rank method of estimating plant species composition. pp. 24-43. In: G.B. Ruyle (ed.) Some Methods for Monitoring Vegetation of Rangelands and Other Natural Areas. Arizona Coop. Ext. Serv., Univ. Arizona. Tucson.
- t' Mannetje, L., and K.P. Haydock. 1963. The dry-weight-rank method for the botanical analysis of pasture. J. Brit. Grass. Soc. 18:268-275.
- Wilson, A.D., and G.J. Tupper. 1982. Concepts and factors applicable to the measurement of range condition. J. Range Manage. 35:684-698.

# Effects of competition on spatial distribution of roots of blue grama

DEBRA P. COFFIN AND WILLIAM K. LAUENROTH

## Abstract

The spatial distribution of roots of the perennial grass blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths] was evaluated under 2 competitive conditions. The radioisotope  $^{14}\text{C}$  was used to label roots of blue grama plants growing with and without neighboring plants of the same lifeform. The majority of labeled blue grama roots (>75%) were found within 5 cm of the plant and within 10 cm of the soil surface. Labeled roots extended at least 30 cm from the edge of the plant and to depths of at least 90 cm. Root system morphology was insensitive to changes in competitive conditions. Based on our estimates of the depth and breadth of the root system of an average blue grama plant, roots associated with at least 4 other blue grama plants of average size and separated by average distances of 10 cm might occur within the volume of soil associated with roots of this plant. The distribution of total root biomass was not representative of the distribution of labeled roots, even when neighboring grasses were removed.

**Key Words:** root distribution, intralifeform competition, shortgrass steppe,  $^{14}\text{C}$ , radioisotope labeling, plant community structure

In the shortgrass steppe and other semiarid grasslands, soil water is the most frequent control on plant growth and community structure (Noy-Meir 1973, Lauenroth et al. 1978, Parton et al. 1981). Shortgrass steppe plant communities of the central and southern Great Plains of the United States are dominated by the perennial grass, blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths], which accounts for 75–90% of aboveground net primary production on most sites (Dodd and Lauenroth 1979). Because of the overwhelming dominance by blue grama, the strongest competitive interactions for belowground resources in these grasslands is most likely between individual blue grama plants rather than between plants of different species or lifeforms (e.g., Cable 1969, Parrish and Bazzaz 1976).

Spatial distributions of roots of grassland species have been evaluated in several ways, including the use of soil pits (e.g., Weaver 1919, 1958) and radioactive tracers, such as  $^{14}\text{C}$  and  $^{32}\text{P}$  (e.g., Neilson 1964, Reynolds and Fraley 1989). Several studies have been conducted in shortgrass communities to evaluate the distribution of total (Bartos and Sims 1974, Leetham and Milchunas 1985, Liang et al. 1989) and labeled root biomass (Singh and Coleman 1974, Lee 1990). However, the spatial distribution of total and labeled roots of individual blue grama plants, effects of neighboring grasses on the distribution, and the relationship between the distribution of total and labeled root biomass have not been evaluated. The objectives of this study were to evaluate: (1) the spatial distribution of roots of blue grama plants; (2) the effects of intra-lifeform competition on the root distribution; (3) the overlap in root systems among neighboring blue grama plants; and (4)

the relationship between the distribution of labeled roots of a blue grama plant and the distribution of total root biomass.

## Methods

Study was conducted at the Central Plains Experimental Range (CPER). The CPER is located in northcentral Colorado, USA, approximately 60 km northeast of Fort Collins (40° 49' N, 107° 47' W). Mean annual precipitation over the past 45 years was 311 mm (SD = 79 mm) and mean monthly temperatures ranged from -5° C in January to 22° C in July. Moderate grazing by cattle occurs throughout the area. Relative basal cover of all plants at most sites ranges from 25–40%, of which 85–90% is accounted for by blue grama (Milchunas et al. 1989). A number of other perennial grasses, succulents, shrubs, and forbs account for the remainder.

In 1982, 10 blue grama plants were randomly selected within a 0.5-ha temporary cattle enclosure. Five of these were randomly selected as controls. Each of the 5 remaining plants occupied the center of a 1-m radius circle from which all other grass individuals were removed by clipping below the soil surface (grass removals). Removal of grasses continued on a monthly basis during the 1982–1985 growing seasons until the blue grama plants were labeled with  $^{14}\text{C}$  as  $^{14}\text{CO}_2$  on 25 July 1985.

The labeling procedure was adapted to field conditions from Milchunas et al. (1985). Clear plastic tents supported by aluminum tubing were placed over each of the 10 blue grama plants. The tents were secured at the base with soil to prevent  $^{14}\text{CO}_2$  leakage during the labeling period. After an initial drawdown of  $\text{CO}_2$ , approximately  $3.7 \times 10^5$  Bq (10 microCi)  $^{14}\text{C}$  per gram of aboveground plant tissue were released into the tent. Biomass of each plant was estimated using the aboveground surface area of the plant ( $\text{m}^2$ ) and the average biomass of blue grama on an area basis ( $\text{g}/\text{m}^2$ ). The time necessary to reach the  $\text{CO}_2$  compensation point was estimated by monitoring  $^{14}\text{CO}_2$  in the tents with a thinend-window Geiger-Mueller meter. When the  $^{14}\text{C}$  level no longer declined, unlabeled  $\text{CO}_2$  was released in the tent. Three drawdowns of  $\text{CO}_2$  after the release of the  $^{14}\text{CO}_2$  resulted in an uptake efficiency of approximately 95%. The tents were manually shaken to promote airflow and the temperature inside the tents was monitored throughout the 2-hour labeling period.

Sampling did not begin until at least 4 weeks after labeling to allow the incorporation of labile  $^{14}\text{C}$  into structural compounds. Paired (5-cm diameter, 90-cm deep) samples were collected along three 30-cm lines radiating (0°, 90°, and 180°) from the center of each plant. Samples were collected at 5, 15, and 30 cm from the edge of each plant. Each pair was combined to form 1 sample with only a single pair being extracted from the center of each plant (total n/plant = 10). Each core was separated into depth increments of 0–10, 10–25, 25–50, and 50–90 cm. The remaining half of each quadrat was utilized in an excavation study of blue grama roots (Lee 1990).

Roots (live and dead) were separated from the soil with a hydropneumatic elutriation system that uses air and water pressure to deposit roots on a fine mesh screen (Smucker et al. 1982). Root material was dried at 100° C, weighed, and ground through a micro-Wiley mill to pass a 40-mesh screen. Plant material was combusted in a Packard Model 306 tri-carb sample oxidizer using

Authors are research associate and professor, Range Science Department and Natural Resource Ecology Laboratory, Colorado State University, the senior author was graduate research assistant, Range Science Department, Colorado State University, Fort Collins.

Research was funded by National Science Foundation, Shortgrass Steppe Long-Term Ecological Research Project (BSR-8114822) and the Colorado State Experiment Station Project, Long-Term Grassland Ecosystem Research. The CPER is administered by the USDA-ARS. Authors thank D.G. Milchunas and D.L. Hazlett for constructive comments on the manuscript; D.G. Milchunas and C.A. Lee for assistance in the field and laboratory; O.E. Sala for helpful discussions; and P.C. Coffin for drawing the figures.

Manuscript accepted 16 May 1990.

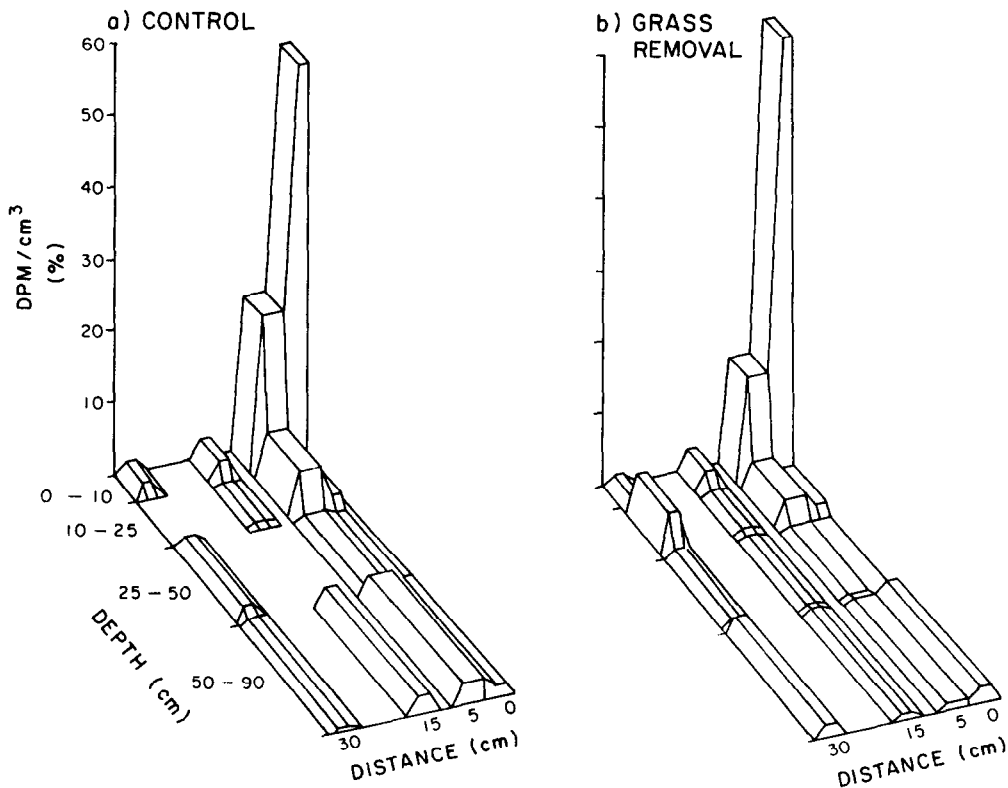


Fig. 1. Location of labeled roots (% of total DPM/cm<sup>3</sup>) by depth and distance for blue grama plants (a) without (control) and (b) with neighboring grasses removed (grass removal). No significant differences between treatments. Within each treatment, percentages of labeled roots found beneath and at 5 cm distance are significantly different from each other and from the remaining depths and distances ( $P < 0.05$ ). Remaining depths and distances are not significantly different from each other.

a Carbosorb CO<sub>2</sub> trap and Permaflour cocktail. <sup>14</sup>C activity was determined by liquid scintillation counting. Data are reported on an ash-free, quench, and background-corrected basis.

Disintegrations per minute on a volume basis (DPM/cm<sup>3</sup>) for each depth and distance from the edge of a plant were calculated and summed to obtain a total DPM for the plant. Percentage of the total DPM at each depth and distance was used to estimate the location of labeled roots for plants with and without neighboring grass plants.

Analysis of variance was used to evaluate effects of the removal of plants and location of roots by depth and distance from the shoot on labeled roots and biomass of roots in a 2×4×4 factorial design. Tukey's Q values were used to compute least significant ranges (LSR) and to evaluate significantly different means at the  $P < 0.05$  level (Sokol and Rohlf 1981).

Overlap in root systems of neighboring blue grama plants was calculated using the location of the labeled roots and an estimated average distance between plants (10 cm; based on the size distribution and basal cover of blue grama plants from Coffin and Lauenroth [1988]). Calculation of the proportion of roots attributed to each plant at each distance location (0, 5, and 10 cm) was based on the calculated overlap in the distribution of labeled roots for 2 adjacent plants. Values for 10 cm were estimated by interpolating between the 5 and 15 cm distances. Spatial heterogeneity of root densities at a particular depth in the soil, as well as among depths, was evaluated using the total calculated amount of roots at each location between 2 blue grama plants.

## Results and Discussion

### Spatial Distribution of Blue Grama Roots

Labeled roots from individual blue grama plants, with or without neighboring grass plants, extended at least 30 cm from the edge

of the plant and to a depth of at least 90 cm (Fig. 1). A large proportion of labeled roots from plants with (>77%) and plants without neighboring grasses (>75%) was found directly beneath and at the edge (5 cm distance) of the target blue grama plant in the upper 10 cm of the soil. Percentages of labeled roots found beneath and at 5-cm distance from the plant were significantly different from each other and from the remaining depths and distances. The remaining depths and distances were not significantly different from each other.

The dominance and persistence of blue grama in this region is likely related to the functional aspects of its root distribution relative to the distribution of water in the soil profile (Lauenroth et al. 1978). Most precipitation events (>80%) in the shortgrass region are small ( $\leq 5$  mm) (Sala and Lauenroth 1982) and they wet only the upper soil layers where the majority of blue grama roots are located. As such, blue grama can respond rapidly to small amounts of rainfall (Sala and Lauenroth 1982, Lauenroth et al. 1987). Likewise, this pattern of distribution of roots suggests blue grama has the structural capacity to access water stored at relatively deep depths in the soil profile (90 cm) during intervals between small rainfall events.

### Effects of Competition on Blue Grama Root Distribution

Distributions of labeled roots of plants with and without neighboring grasses were not significantly different (Fig. 1). The absence of any measured effect of neighboring grass plants on the labeled rooting pattern of blue grama suggests that a blue grama plant has only a limited ability to exploit resources beyond the edge of its canopy (>10 cm), regardless of resource availability. Factors related to soil type, including bulk density, texture, and impediments, might also be contributing factors affecting root depth and spatial extension of blue grama plants (Weaver and Darland 1949, Fox et al. 1953). Our results suggest, however, that full-size blue

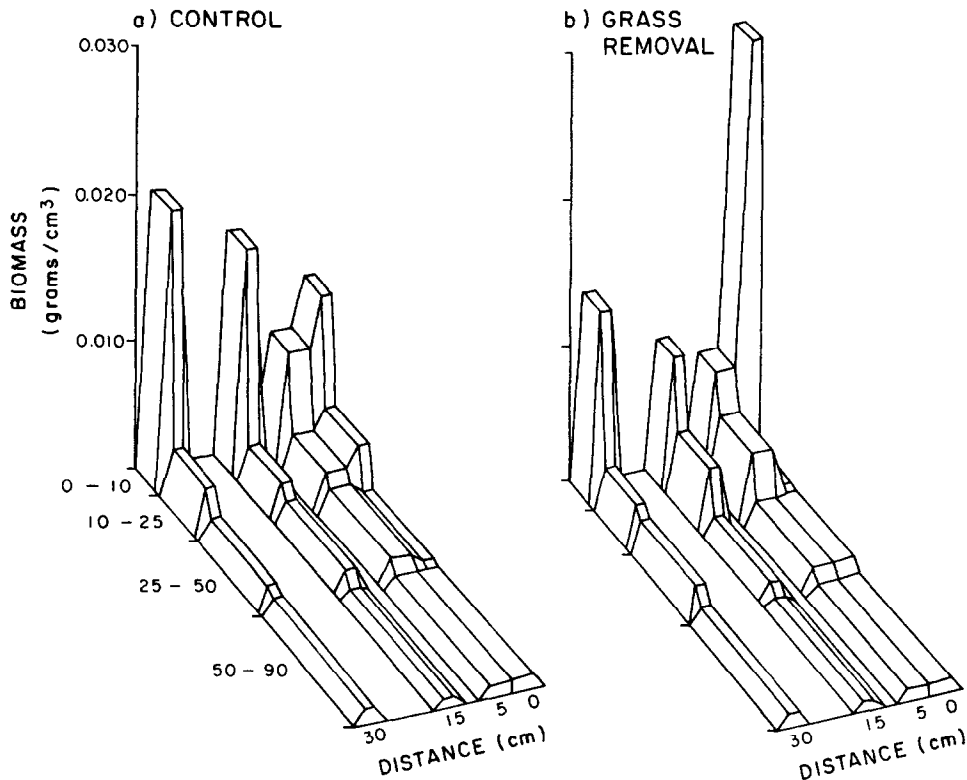


Fig. 2. Location of total root biomass (g/cm<sup>3</sup>) by depth and distance for blue grama plants (a) without (control) and (b) with neighboring grasses removed (grass removal). No significant differences between treatments, depths or distances.

grama plants growing on a particular soil type would be expected to have similar root distributions.

#### Overlap in Blue Grama Root Systems

The relatively small estimated average distance between neighboring blue grama plants, as compared to the rather broad spatial distribution of their roots, resulted in a large degree of calculated overlap in root systems between neighboring plants. The analysis showed roots of both plants occurred at each of 12 depth and distance locations from the target plant (Table 1a). The greatest potential for intraspecific competitive interactions, based on the same percentage of roots of both plants at a particular location, occurred beneath the plants for depths from 10–50 cm, and by definition, for all depths in the space between plants (Table 1a). Most roots beneath a plant and within 10 cm of the soil surface (87%) belonged to that plant rather than to a neighboring plant.

Table 1. Calculated overlap of labeled roots for 2 blue grama plants separated by 10 cm.<sup>1,2</sup>

(a) Percentage contribution of targeted blue grama plant roots to total roots present at various depths and distances from targeted plant.

Depth (cm)	Distance (cm)		
	0	5	10
0–10	87	50	13
10–25	50	50	50
25–50	50	50	50
50–90	36	50	64

The root system of a blue grama plant may interact with roots of a number of other blue grama plants. Based on our estimates of the depth and breadth of the root system, the total volume occupied by roots of an average full-size blue grama plant with a basal cover of

320 cm<sup>2</sup> is 0.45 m<sup>3</sup>. Roots of at least 4 other blue grama plants of average size and separated by average distances of 10 cm may occur within the volume of soil associated with roots of this plant.

Spatial heterogeneity of root densities between 2 blue grama plants, based on the total calculated amount of roots at each location, indicated areas of relatively low root biomass at the soil surface between plants, and beneath the plants at other depths (Table 1b). Microsite variability in root densities of blue grama

Table 1. (continued)

(b) Total amount of labeled roots (sum of % activity at each location) for 2 plants.

Depth (cm)	Distance (cm)		
	0	5	10
0–10	64.4	43.6	64.4
10–25	3.5	12.4	3.5
25–50	0.3	1.6	0.3
50–90	4.1	5.7	4.1

<sup>1</sup>Distribution of roots for each plant is from Fig. 1a.

<sup>2</sup>Values for 10 cm were estimated using the mean of percentages from the 5 and 15 cm distances.

may be a result of differences in resource availability, morphologic constraints on rooting patterns, or a combination of factors. Additional experimental studies are necessary to distinguish among these possibilities. Spatial heterogeneity in root biomass for grass species has also been found in a Patagonian steppe community (Soriano et al. 1987).

#### Relationship Between Labeled and Total Root Biomass Distributions

The majority of total sampled root biomass (labeled and unlabeled) for plants with and without neighboring grass plants occurred in the upper 10 cm of the soil profile (>70%) whereas the

upper 25 cm contained greater than 87% of the biomass (Fig. 2). The location of the majority of root biomass in the upper soil layers is consistent with previous estimates for shortgrass plant communities (Bartos and Sims 1974, Singh and Coleman 1974, Leetham and Milchunas 1985, Liang et al. 1989). The distribution of total root biomass was not representative of the distribution of labeled roots, even when neighboring grasses were removed. The distribution of labeled roots and total root biomass were not similar for plants with (Figs. 1a, 2a) or without neighboring plants (Figs. 1b, 2b). This lack of correspondence between the 2 distributions was the result of important contributions to biomass by neighboring plants for control plants, while large quantities of dead roots, presumably from the neighboring grass plants that had been killed, were found during an excavation of the plots where removals had occurred (Lee 1990).

### Conclusions

The dominance of blue grama in shortgrass steppe plant communities is likely related to the vertical and horizontal distribution of its root system. The limited ability of blue grama root distributions to respond to the presence or absence of neighboring plants might be important for the persistence of other species and maintenance of species diversity in these communities, especially after disturbances. The large potential for competitive interactions between neighboring blue grama plants is also likely to be an important factor for plant community structure. The poor relationship between the distribution of labeled roots and distribution of total root biomass suggests caution should be exercised in sampling root systems of individual plants.

### Literature Cited

- Bartos, D.L., and P.L. Sims. 1974. Root dynamics of a shortgrass ecosystem. *J. Range Manage.* 27:33-36.
- Cable, D.R. 1969. Competition in the semidesert grass-shrub type as influenced by root systems, growth habits, and soil moisture extraction. *Ecology* 50:27-38.
- Coffin, D.P., and W.K. Lauenroth. 1988. The effects of disturbance size and frequency on a shortgrass plant community. *Ecology* 69:1609-1617.
- Dodd, J.L., and W.K. Lauenroth. 1979. Analysis of the response of a grassland ecosystem to stress, p. 43-58. *In*: N.R. French (Ed.). *Perspectives in grassland ecology*. Ecological Studies Vol. 32. Springer-Verlag, New York.
- Fox, R.L., J.E. Weaver, and R.C. Lipps. 1953. Influence of certain soil-profile characteristics upon the distribution of roots of grasses. *Agron. J.* 45:583-589.
- Lauenroth, W.K., J.L. Dodd, and P.L. Sims. 1978. The effects of water- and nitrogen-induced stresses on plant community structure in a semiarid grassland. *Oecologia (Berl.)* 36:211-222.
- Lauenroth, W.K., O.E. Sala, D.G. Milchunas, and R.W. Lathrop. 1987. Root dynamics of *Bouteloua gracilis* during short-term recovery from drought. *Function. Ecol.* 1:117-124.
- Lee, C.A. 1990. The spatial distribution of root systems for three plant life-forms in the shortgrass steppe. M.S. Thesis. Colorado State Univ., Fort Collins.
- Leetham, J.W., and D.G. Milchunas. 1985. The composition and distribution of soil microarthropods in the shortgrass steppe in relation to soil water, root biomass, and grazing by cattle. *Pedobiologia* 28:311-325.
- Liang, Y.M., D.L. Hazlett, and W.K. Lauenroth. 1989. Biomass dynamics and water use efficiencies of five plant communities in the shortgrass steppe. *Oecologia (Berl.)* 80:148-153.
- Milchunas, D.G., W.K. Lauenroth, P.C. Chapman, and M.K. Kazempour. 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. *Vegetatio* 80:11-23.
- Milchunas, D.G., W.K. Lauenroth, J.S. Singh, C.V. Cole, and H.H. Hunt. 1985. Root turnover and production by  $^{14}\text{C}$  dilution: Implications of carbon partitioning in plants. *Plant and Soil* 88:353-365.
- Neillson, J.A., Jr. 1964. Autoradiography for studying individual root systems in mixed herbaceous stands. *Ecology* 45:644-646.
- Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. *Annu. Rev. Ecol. Syst.* 4:25-52.
- Parrish, J.A.D., and F.A. Bazzaz. 1976. Underground niche separation in successional plants. *Ecology* 57:1281-1288.
- Parton, W.J., W.K. Lauenroth, and F.M. Smith. 1981. Water loss from a shortgrass steppe. *Agr. Meteorol.* 24:97-109.
- Reynolds, T.D., and L. Fraley, Jr. 1989. Root profiles of some native and exotic plant species in southeastern Idaho. *Environ. Exp. Bot.* 29:241-248.
- Sala, O.E., and W.K. Lauenroth. 1982. Small rainfall events: An ecological role in semiarid regions. *Oecologia (Berl.)* 53:301-304.
- Singh, J.S., and D.C. Coleman. 1974. Distribution of photo-assimilated  $^{14}\text{C}$  in the root system of a shortgrass prairie. *J. Ecol.* 62:359-365.
- Smucker, A.J.M., S.L. McBurney, and A.K. Srivastava. 1982. Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. *Agron. J.* 74:500-503.
- Sokal, R.R., and F.J. Rohlf. 1981. *Biometry*. Second Ed., Freeman, New York.
- Soriano, A., R.A. Golluscio, and E. Satorre. 1987. Spatial heterogeneity of the root system of grasses in the Patagonian arid steppe. *Bull. Torrey Bot. Club* 114:103-108.
- Weaver, J.E. 1919. The ecological relations of roots. *Cargenie Inst. Wash. Pub.* 286.
- Weaver, J.E. 1958. Summary and interpretation of underground development in natural grassland communities. *Ecol. Monogr.* 28:55-78.
- Weaver, J.E., and R.W. Darland. 1949. Soil-root relationships of certain native grasses in various soil types. *Ecol. Monogr.* 19:303-338.

# Seedstalk production of mountain big sagebrush enhanced through short-term protection from heavy browsing

FRED J. WAGSTAFF AND BRUCE L. WELCH

## Abstract

Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* Nutt.) is an important browse species on many key mule deer winter ranges in the western United States. Big sagebrush on many of those ranges is declining due to the lack of recruitment. Plants subjected to heavy (> 80% use) browsing produce 50 to 93% fewer seedstalks than those not subject to such use. The objectives of this study were to determine: (1) whether protection from browsing for 1 winter would increase the number of seedstalks the following fall; (2) if protection increased length of seedstalk; (3) if there is a relationship between seedstalk length and number of seeds per seedstalk; and (4) if increasing seed production increased seedling establishment. Fifty-eight plots containing 344 plants at 4 sites in north-central Utah were established. At each plot, plants were randomly assigned to be either protected or browsed. The protected plants produced significantly ( $P < 0.05$ ) more seedstalks than those browsed during the previous winter. Length of seedstalks on a given plant and among plants showed considerable variation, and the data indicated no clear differences between average seedstalk length on browsed and protected plants. Seed per unit length of seedstalk was also highly variable. No seedlings were found during 7 years of observations of the original plot or in 4 years for the 57 plots established in 1986, regardless of the numbers of seedstalks on a plant. Seed production does not appear to be a limiting factor in seedling establishment for the study populations.

**Key Words:** *Artemisia tridentata* ssp. *vaseyana*, mountain big sagebrush, seedstalk production, browsing, seed production

Big sagebrush (*Artemisia tridentata* Nutt.) is a major plant in a large and important ecosystem in western North America (Beetle 1960). Within the literature most early studies are descriptive in nature and a great number of papers deal with control by various means. The investigations of the effects of various control and management strategies revealed much about the biology of big sagebrush, and several workers have published studies about its taxonomy (Winward and Tisdale 1977, Hironaka et al. 1983, McArthur 1983, Winward 1983). Of the 4 major subspecies of big sagebrush, mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) was utilized by wintering mule deer most frequently along the Wasatch Front of Utah. It also is important as browse in other areas (Nagy 1979, McAdoo and Klebenow 1979, Welch 1983b, Personius et al. 1987, Young et al. 1989). Some localities are known to produce plants that are exceptionally preferred (Welch 1983a, Welch et al. 1986, McArthur et al. 1987).

In sagebrush stands on the foothills adjacent to the urban area known as the Wasatch Front of Utah, much plant mortality of mountain big sagebrush is evident and is of concern because urban encroachment is reducing the area available for wintering mule deer.

Heavy winter browsing (>80% use) is believed to reduce the

number of seedstalks produced the following growing season. If continued, heavy browsing can reduce plant vigor and may cause large reductions in plant stands (Smith 1949, Smith and Gaufin 1950, Cook and Stoddard 1960, Welch et al. 1987, McArthur et al. 1988).

We believe the low production of seedstalks may be due to heavy mule deer browsing, and the resulting low seed production per sagebrush plant may be an important factor in the lack of recruitment in mountain big sagebrush populations along the Wasatch Front. We developed this study to determine: (1) if protection from browsing for 1 winter would increase the number of seedstalks, (2) if protection increased length of seedstalks, (3) if seed production was correlated with seedstalk length, and (4) if increased seed production increased seedling establishment.

## Methods and Materials

This study was conducted in the foothills of the Wasatch mountains in north-central Utah near the city of Provo. The Hobbie Creek and Pleasant Grove sites near the lower edge of the ssp. *vaseyana* type are about 1,027 m elevation and the Diamond Fork site is slightly higher, about 1,646 m. Soils, sampled at several locations at all of the sites, were derived from limestone parent material. The soils are alluvial and of a loamy texture with no restrictive layers. A chemical analysis of the soils found no major nutritive or chemical deficiencies or restrictions.

The 4 sites chosen for study are used as winter range by mule deer. At all sites big sagebrush plants exhibit the effects of heavy browsing. Cattle graze the Diamond Fork area on a rest rotation system, and the other 3 sites have been closed to livestock grazing for over 20 years. Sagebrush populations in each of the study areas have 40–50% dead plants and no observed recruitment for the past several years.

The site named Hobbie Creek 1 includes the area fenced in 1983 to provide foundation seed for 'Hobbie Creek' mountain big sagebrush. Since the area was quite small, only 1 plot was established. Six years of observation for this site are included in tables 1 and 4. The other sites were studied to expand the data base and to determine whether a one-season rest would have a significant effect on seedstalk production.

At each site plants of approximately the same size were randomly selected and grouped into plots of 4, 6, or 20 plants arranged so that no plant in a plot was more than 61 m away from the most distant plant in that plot. The plots were widely distributed across each site in case environmental differences within the site were present but not readily apparent. At the Hobbie Creek 2 site, 21 plots of 6 plants each were established; at Pleasant Grove 27 plots of 6 plants each; at Diamond Fork 9 plots of 4 plants; and the Hobbie Creek 1 site had 1 plot of 20 plants. A total of 58 plots with 344 plants total were included. At each plot, the treatment was assigned randomly to half of the plants. To prevent browsing, a wire cage was constructed of net field fencing sides and chicken wire tops supported by 2 steel posts 2 m tall, large enough to assure 30 cm of space around the plant and tall enough to provide 30 cm of headspace. Seedstalks were counted and measured on all of the

Range economist and principal research plant physiologist, Intermountain Research Station, Forest Service, USDA, Ogden, Utah 84401.

The use of trade or firm names in this paper is for reader information and does not imply endorsement by the USDA of any product or service.

Manuscript accepted 6 May 1990.

plants on the Hobbie Creek 1 plot from 1984 to 1989, and on the other plots in the fall of 1986 to 1989. At each site we selected 100 seedstalks at random from protected plants and a like number from browsed plants. Four size classes and 2 form classes were used to stratify the sample, and the number of seeds per stalk were counted. Statistical analysis was completed using Student's *t*-test and analyses of variance procedures of the Minitab (tm) software package (Ryan et al. 1985). Comparisons on seedstalk numbers and length were made between treatments for 6 years on the Hobbie Creek 1 plot and 1 year on all other plots. The number-of-seeds per stalk study was conducted for 1987 only.

## Results and Discussion

Analyses of data for the Hobbie Creek 1 site indicate a significant treatment difference in seedstalk production in each of the 6 years. The data in Table 1 show a trend toward increasing seed production for each year of protection. How long this trend will continue is uncertain. On this plot the relatively low plant density may be a partial explanation of this continual increase.

**Table 1. Average number of seedstalks per plant on mountain big sagebrush at one site (Hobbie Creek 1) in north central-Utah.**

Year	Protected	Browsed	Increase
1984	116	6	110*
1985	165	11	154*
1986	183	12	171*
1987	206	65*	141*
1988	240	18	222*
1989	336	6	330*

\*Significant at the 0.05 level.

There were significant differences in various characteristics of the study plants due to the treatment (protection during 1 winter). Seed stalk production in 1987 was significantly greater at the 2 Hobbie Creek sites. The Diamond Fork site had significantly lower seed stalk production on both browsed and protected plants in 1987. Considerable variation was noted in our data because seed-stalk production is a function of genetics, plant age, vigor, climate, site characteristics, and browsing pressure. Variation in seed production among sagebrush populations of the same subspecies has been noted in other studies (Young et al. 1989, Wagstaff and Welch 1990). Seedstalk production on protected plants for 1984-1989 increased significantly ( $P<0.05$ ) on the Hobbie Creek 1 site and for all plots in 1987. All browsed plants with the exception of those plots at the Diamond Fork site also had greater numbers of seed-stalks in 1987. Browsed plants on all plots showed a return to low levels of seedstalk in 1989. Difference in production between years is probably due to a combination of factors including favorable moisture during the 1987 growing season. Additional information can be gained by looking at certain characteristics of the plants at each of the sites as shown in Tables 4 and 5.

We conclude that for the subject populations the protection of mountain big sagebrush plants from browsing by wintering mule deer for 1 winter resulted in an increased number of seedstalks.

**Table 2. Average number of seedstalks per plant on mountain big sagebrush at 3 sites in north-central Utah.**

Year	Hobbie Creek			Pleasant Grove			Diamond Fork		
	Protected	Browsed	Increase	Protected	Browsed	Increase	Protected	Browsed	Increase
1986		11			6			5	
1987	178	61	119*	153	11	142*	75	7	62*
1988		18			7			6	
1989		16			5			7	

\*Significant at the 0.05 level.

**Table 3. Seeds per seedstalk of single-stemmed and branched seedstalks of mountain big sagebrush in north-central Utah 1987.**

Length of stem (cm)	Type of seedstalk					
	Single stem			Branched		
	Pct. with No. seed	Max No. seeds	Avg. No. seeds	Pct. with No. seed	Max No. seeds	Avg. No. seeds
0-15.24	50*	9	6	5	115	8
15.25-25.4	33*	104	17	3	718	156*
>25.5	0	183	69	0	1601	319*

\*Significant at the 0.05 level.

Lengths of seedstalks were not significantly different at the 2 Hobbie Creek sites and Diamond Fork. The length difference at Pleasant Grove in 1987 may be attributable to heavier use of browsed plants, which was also indicated by seedstalk numbers (Table 2).

The data led us to conclude that lack of seed production is not responsible for the low recruitment of plants in the study populations. We found no recruitment around study plants even though mountain big sagebrush has been noted for aggressiveness and ability to increase (Blaisdell et al. 1982). Still, it may be desirable to enhance seed production because mountain big sagebrush propagates only from seed and climatic conditions suitable for establishment occur sporadically (Johnson and Payne 1968, Brunner 1972, Young and Evans 1975, Caldwell 1979, Walton et al. 1986).

Several studies show a considerable variability in germination and establishment of seedlings due to a combination of climatic factors such as temperature and moisture (Johnson and Payne 1968, Young and Evans 1975, Harniss and McDonough 1976).

We could find nothing in the literature to indicate a method of predicting whether conditions favorable to seedling establishment would occur in any given year. In a recent study we found considerable seedling establishment in 1988, after seedbed preparation, at various levels of seed production and dispersal by mother plants,

**Table 4. Selected characteristics of seed stalks on mountain big sagebrush plants on 1 site (Hobbie Creek 1) in north-central Utah.**

Characteristic	1984	1985	1986	1987	1988	1989
Seed stalks max/plants						
Protected	182*	389*	419*	429*	432*	460*
Browsed	26	11	12	65	14	6
Percent of plants with zero						
Protected	0	0	0	0	0	0
Browsed	20*	10*	10*	10*	10*	10*
Avg. length (cm)						
Protected	28.6	21.7	20.8	22.6	21.7	24.0
Browsed	19.7	18.7	18.1	18.2	19.0	22.2

\*Differences significant at the 0.05 level.



**Table 5. Selected characteristics of seed stalks on mountain big sagebrush plants on three sites in north-central Utah.**

Characteristics	Hobble Creek 2			Pleasant Grove			Diamond Fork		
	1986	1987	1989	1986	1987	1989	1986	1987	1989
Seed stalks max/plants									
Protected		----- 535* -----			----- 476* -----			----- 426* -----	
Browsed	94	273	81	45	77	38	18	36	19
Percent of plants with zero									
Protected		----- 0 -----			----- 4 -----			----- 17 -----	
Browsed	49	2*	21	44	25*	42	42	50*	29
Avg. length (cm)									
Protected		----- 17.91 -----			----- 18.16* -----			----- 14.94 -----	
Browsed	18.24	17.91	23.4	6.46	9.68	7.2	13.97	11.25	12.1

\*Difference significant at the 0.05 level.

although that winter and spring set records for low precipitation (Wagstaff and Welch 1989).

Presence of seed is a necessary condition to seedling establishment, but other factors such as plant competition and climate may also be limiting. We found no seedlings on our study plots during 6 years of observations, even though many plants produced seed sufficient to cover the effective distribution area at a rate of several hundred seeds per square meter. Managing those factors that can be controlled, such as increased seed production, by protecting or otherwise controlling browsing levels may enhance the chances of establishing seedlings.

We have also observed that within the study populations, some plants are not browsed to the degree most other plants are. Because these plants are not used as heavily, they are producing far more seed and stand a greater chance of leaving progeny. Therefore, it seems possible that the more desirable plants will be the first to disappear from the populations, and unless they receive periodic rest they will leave insufficient progeny to replace themselves. The population structure would then shift toward a higher proportion of apparently less desirable plants.

### Literature Cited

- Beetle, A.A. 1960. A study of sagebrush. The section *tridentata* of *Artemisia*. Laramie, Wyo. Wyoming Exp. Sta. Bull. 368.
- Blaisdell, J.P., R.B. Murray, and E.D. McArthur. 1982. Managing intermountain rangelands-sagebrush-grass ranges. USDA Forest Serv. Intermountain Forest and Range Exp. Sta. Gen. Tech. Rep. INT-134.
- Brunner, J.R. 1972. Observations of *Artemisia tridentata* in Nevada. J. Range Manage. 25:205-208.
- Caldwell, M.M. 1979. Physiology of sagebrush. P. 74-85. In: The sagebrush ecosystem—a symposium; 1978 April; Utah State Univ. College of Nat. Resour. Logan, Utah.
- Cook, C.W., and L.A. Stoddard. 1960. Physiology responses of big sagebrush to different types of herbage removal. J. Range Manage. 13:14-16.
- Harniss, R.O., and W.T. McDonough. 1976. Yearly variation in germination of three subspecies of big sagebrush. J. Range Manage. 29:167-168.
- Hironaka, M., M.A. Fosberg, and A.H. Winward. 1983. Sagebrush-grass habitat types of southern Idaho. Moscow, Ida.; Univ. Idaho, Forest, Wildlife, and Range Exp. Sta. Bull. 35.
- Johnson, J.R., and G.F. Payne. 1968. Sagebrush reinvasion as affected by some environmental influences. J. Range Manage. 21:209-213.
- McAdoo, J.K., and D.A. Klebenow. 1979. Native faunal relationships in sagebrush ecosystems. P. 50-61. In: The sagebrush ecosystem, a symposium; 1978 April; Utah State Univ., College of Nat. Resour. Logan.
- McArthur, E.D. 1983. Taxonomy, origin, and distribution of big sagebrush (*Artemisia tridentata*) and allies (subgenus *Tridentatae*). P. 3-11. In: Proc. 1st Utah shrub ecology workshop; K.L. Johnson (ed.). Utah State Univ., Logan.
- McArthur, E.D., A.C. Blauer, and S.C. Sanderson. 1988. Mule deer induced mortality of mountain big sagebrush. J. Range Manage. 41:114-116.
- McArthur, E.D., S.B. Monsen, and B.L. Welch. 1987. Shrubs and forbs for revegetation plantings in the sagebrush ecosystem. P. 29-39. In: Integrated pest management on rangeland-state of the art in the sagebrush ecosystem. J.A. Onsager (ed.). ARS-50; USDA Agr. Res. Serv., Springfield, Va.
- Nagy, J.G. 1979. Wildlife nutrition and the sagebrush ecosystem. P. 164-168. In: The sagebrush ecosystem. A symposium; 1978 April; Utah State Univ., College of Nat. Resour. Logan.
- Personius, T.L., C.L. Wamboldt, J.R. Stephens, and R. Kelsey. 1987. Crude terpenoid influences on mule deer preferences for sagebrush. J. Range Manage. 40:84-88.
- Ryan, B.F., B.L. Joiner, and T.A. Ryan, Jr. 1985. Minitab Handbook 2nd ed. Duxbury Press, Boston, Mass.
- Smith, A.D. 1949. Effects of mule deer and livestock upon a foothill range in northern Utah. J. Wildl. Manage. 13:421-423.
- Smith, A.D., and D.M. Gaufin. 1950. The use of movable paddocks in the study of forage preferences of mule deer and livestock. Trans North Amer. Wildl. Conf. 15:512-518.
- Wagstaff, F.J., and B.L. Welch. 1990. Rejuvenation of mountain big sagebrush on mule deer winter ranges using onsite plants as a seed source. P. 171-174. In: Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Gen. Tech. Rep. INT-276.
- Walton, T.P., R.S. White, and C.L. Wamboldt. 1986. *Artemisia* reproductive strategies: a review with emphasis on plains silver sagebrush. P. 67-74. In: Proc. symposium on the biology of *Artemisia* and *Chrysothamnus*. Gen. Tech. Rep. INT-200, USDA Forest Serv., Intermountain Res. Sta., Ogden, Utah.
- Welch, B.L. 1983a. Big sagebrush: nutrition, selection, and controversy. P. 15-19. In: Proc. 1st Utah ecology workshop; K.L. Johnson (ed.), Utah State Univ., Logan.
- Welch, B.L. 1983b. Improving the nutritive value of winter range forage. P. 158-164. In: Managing intermountain rangelands—improvement of range and wildlife habitats. S.B. Monsen, and N. Shaw (compilers). Gen. Tech. Rep. INT-157, USDA Forest Serv., Intermountain Res. Sta., Ogden, Utah.
- Welch, B.L., E.D. McArthur, D.L. Nelson, J.C. Pederson, and J.N. Davis. 1986. 'Hobble Creek' a superior selection of low-elevation big sagebrush. USDA Forest Serv. Intermountain Res. Sta. Res. Pap. INT-370.
- Welch, B.L., E.D. McArthur, and R.L. Rodriguez. 1987. Variation in utilization in big sagebrush accessions by wintering sheep. J. Range Manage. 40:113-115.
- Winward, A.H. 1983. Using sagebrush ecology in wildland management. P. 15-19. In: Proc. 1st Utah shrub ecology workshop. K.L. Johnson (ed.) Utah State Univ., Logan.
- Winward, A.H., and E.W. Tisdale. 1977. Taxonomy of the *Artemisia tridentata* complex in Idaho. Moscow, Ida.; Univ. Idaho, Forest Wild. and Range Exp. Sta. Bull. 19.
- Young, J.A., and R.A. Evans. 1975. Germinability of seed reserves in a big sagebrush community. Weed Sci. 23:358-364.
- Young, J.A., R.A. Evans, and D.E. Palmquist. 1989. Big sagebrush (*Artemisia tridentata*) seed production. Weed Sci. Vol. 37.

# Influences of temperature and water stress on germination of plains rough fescue

J.T. ROMO, P.L. GRILZ, C.J. BUBAR, AND J.A. YOUNG

## Abstract

Germination of 12 collections of plains rough fescue (*Festuca altaica* Trin. subsp. *hallii* (Vasey) Harms) from Saskatchewan was evaluated in 55 constant and alternating temperature regimes ranging from 0 to 40° C. Combined influences of temperature and water stress on germination were studied by incubating seeds in a gradient of osmotic potentials at constant temperatures of 5, 10, 15, 20, and 25° C and under regimes where temperatures were either increased from 10 to 25° C or decreased from 25 to 10° C. Seeds germinated in 80 to 87% of the 55 temperature regimes tested with maximum total germination between populations ranging from 34 to 100%. Germination was highest most often at constant temperatures of 15 and 20° C, but seeds germinated over a wide range of temperatures. Germination rate and total germination responded to the interacting effects of temperature and osmotic potential. Under constant temperatures, 71 to 88% of the variation in germination was accounted for by osmotic potential. Seeds germinated fastest, in the highest numbers, and over the broadest range of osmotic potentials at 10 to 20° C. Germination was higher and more rapid over the range of osmotic potentials when temperatures increased from 10 to 25° C than when they declined from 25 to 10° C. Osmotic potential accounted for 65 to 74% of the variation in germination. The plastic response of germination to temperature suggested that while this factor does not limit regeneration of plains rough fescue from seed, germination is severely restricted by declining osmotic potentials. These moisture limitations reflected adaptations that preclude germination under conditions of transient moisture or low moisture availability. Plains rough fescue should be planted in the spring when temperatures are rising and soil moisture is highest.

**Key Words:** seedbed ecology, water stress, *Festuca altaica* subsp. *hallii*, temperature variation, reproduction, degree days

Plains rough fescue (*Festuca altaica* Trin. subsp. *hallii* (Vasey) Harms), (Harms 1985) is the sole dominant of the Fescue Prairie of central Saskatchewan and Alberta (Coupland and Brayshaw 1953, Coupland 1961). There is a paucity of information describing the germination ecology of this perennial. This lack of knowledge stems from the fact that this grass infrequently produces seed (Johnston and MacDonald 1967, Toynbee 1987) and that most of the Fescue Prairie has been severely disturbed by agricultural activities. Johnston and MacDonald (1967) reported that the closely allied rough fescue (*Festuca altaica* Trin. subsp. *scabrella* (Torrey) Hulten) produced abundant seed in only 4 years during a 65-year period in Alberta. In Saskatchewan a copious seed crop was produced by plains rough fescue in 1987 (Toynbee 1987), affording an excellent opportunity to study its germination requirements.

Authors are associate professor and graduate research assistants, Department of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon, S7N, 0W0; and range scientist, USDA-ARS, Reno, Nevada 89512.

This paper is dedicated to the memory of Alexander Johnston, who spent most of his career studying the native flora of the Fescue Prairie in the foothills of Alberta. His research provided a foundation for our understanding of the ecology of Fescue Prairie.

The authors thank Drs. L.E. Eddleman, R. Horton, R.E. Redmann, and A. Schwarz for manuscript reviews.

Manuscript accepted 18 May 1990.

Objectives of this study were to: 1. characterize germination-temperature relationships for several collections of plains rough fescue from Saskatchewan, and 2. identify its germination response to various temperatures and osmotic potentials. This information will assist those charged with developing strategies for reestablishing and managing Fescue Prairie.

## Materials and Methods

Three germination experiments were conducted. Germination of 12 collections of plains rough fescue from Saskatchewan was evaluated in 55 constant and alternating temperature regimes ranging from 0 to 40° C in the first experiment. In the second experiment seeds of 8 collections were incubated at 5, 10, 15, 20, and 25° C in a gradient of osmotic potentials that was created by using polyethylene glycol (PEG) to depress osmotic potentials. Eight collections were evaluated in the third experiment, which was designed to evaluate germination response under various osmotic potentials when temperatures were either increased from 10 to 25° C or reduced from 25 to 10° C.

Seeds of plains rough fescue were collected in Saskatchewan at 8 sites in 1987 and 4 sites in 1988 (Table 1). Seed production was

**Table 1.** Locations and descriptions of sites where plains rough fescue seed was collected in Saskatchewan.

Site	Legal Description	Associated Vegetation
----- 1987 -----		
Strawberry Hills	T37,R4,Sec.12,W3	Potr <sup>1</sup> , Elco
West Allan Hills	T31,R3,Sec.21,W3	Potr, Elco
East Allan Hills	T31,R1,Sec.15,W3	Potr, Elco
Biddulph Prairie	T34,R6,Sec.12,W3	Stco, Stsp, Agda
Pinto Butte	T5,R12,Sec.13,W3	Agda, Stsp, Syoc
Radisson	T39,R10,Sec.29,W3	Potr, Elco, Agda
Sonningdale	T40,R12,Sec.32,W3	Potr, Elco, Stsp, Agda
Cypress Hills	T8,R29,Sec.9,W3	Potr, Pofr, Dain
----- 1988 -----		
Sonningdale	T40,R12,Sec.32,W3	Potr, Elco, Stsp, Agda
Cypress Hills	T8,R29,Sec.15,W3	Agtr, Potr, Pofr, Dain
Wood Mountain	T4,R3,Sec.12,W3	Pofr, Agda, Stsp
Eagle Hills	T41,R16,Sec.26,W3	Potr, Stsp

<sup>1</sup>Potr = *Populus tremuloides*, Elco = *Eleagnus commutata*, Stco = *Stipa comata*, Stsp = *Stipa spartea* var. *curtiseta*, Agtr = *Agropyron trachycaulum*, Agda = *Agropyron dasytachyum*, Pofr = *Potentilla fruticosa*, Dain = *Danthonia intermedia*, Syoc = *Symphoricarpos occidentalis*

extremely poor in 1988, thus we were able to repeat collections again only from the Sonningdale and Cypress Hills locations. No seeds were produced at any of the sites in 1989. After seeds were collected, they were taken to the laboratory, cleaned, and stored in paper envelopes in darkness at room temperature. Germination tests were conducted 4 to 6 months following collection.

## Experiment 1-Influence of 55 Constant and Alternating Temperature Regimes on Germination

Twenty-five seeds were placed in each closed petri dish on 1 mm thick germination paper that was kept moist with water, and incubated at 4 weeks in dark germinators at 55 constant and

alternating temperatures. Alternating temperature regimes consisted of a 16-hour cold period and an 8-hour warm period, at all possible higher temperatures in each 24-hour interval. For example, 2° C (cold period) was alternated with 5, 10, 15, 20, 25, 30, 35, and 40° C (warm period), whereas 25° C (cold period) alternated only with 30, 35, and 40° C (warm period). Germination was recorded after 1, 2, and 4 weeks of incubation; seeds were considered germinated when the radicle was at least 5 mm long. A randomized complete block design with 4 replications was used.

Germination parameters from the temperature-germination regression equations are defined as: 1. Mean germination—the average germination of the 55 temperatures regimes; 2. Mean of regimes with some germination (regimes with 0% germination are excluded); 3. Percentage with some germination—the percentage of the 55 temperature regimes in which some seeds germinated; 4. Maximum—the highest germination of the 55 temperature regimes; 5. Maximum mean—the average germination of the temperature regimes with maximum germination, and; 6. Percentage with maximum germination—the percentage of the 55 temperature regimes with germination not lower than the maximum germination minus one-half its 95% confidence interval. The frequency of maximum is the percentage of the time that each temperature regime supports maximum germination. This value is determined across the collections, providing an estimate of the optimum temperatures for germination. Details of the statistical procedures provided by Evans et al. (1982).

#### Procedures Used for Experiments 2 and 3

Ecological interpretation of many germination experiments is difficult because tests are conducted for specific periods of time over a range of temperatures. These arbitrary incubation periods introduce time as a confounding factor because seeds are not receiving equal thermal units at all temperatures. Therefore, in Experiments 2 and 3 the length of incubation periods was based on a set number of degree days using 0° C as the base temperature. This was done because germination is a temperature-sensitive process, and the use of degree days integrates both time and temperature (Johnson and Thornley 1985).

Solutions were prepared to depress osmotic potentials to -0.3, -0.6, -0.9, -1.2, and -1.5 MPa by adding PEG (M.W. 20,000) to distilled water. Distilled water was used as the control (0.0 MPa).

Osmotic potentials of these PEG solutions were determined with a Wescor vapor pressure osmometer.

A randomized complete block design with 50 seeds in each of 4 replications was used. Seeds were incubated in closed petri dishes on 1 mm thick germination paper that was moistened by adding 7 mL of water or PEG solution. These petri dishes were enclosed and sealed in polyethylene bags to prevent desiccation. Germination counts were made at 2-day intervals; a seed was considered germinated when the plumule and radicle were both at least 5 mm long. Germinated seeds were removed from petri dishes, and after completing the incubation period the ungerminated seeds were dissected to determine if they were filled. Thus, data for Experiments 2 and 3 are expressed as a percentage of florets that actually had fully developed caryopses.

#### Experiment 2—Constant Temperature-Osmotic Potential Effects on Germination

Seeds were incubated at 5, 10, 15, 20, and 25° C in darkness for 400 degree days. Mean osmotic potentials and standard errors (n=4) for the PEG solutions used for the 1987 collections were  $-0.20 \pm 0.02$ ,  $-0.50 \pm 0.01$ ,  $-0.81 \pm 0.02$ ,  $-0.90 \pm 0.03$ ,  $-1.17 \pm 0.02$  MPa. They were  $-0.29 \pm 0.01$ ,  $-0.68 \pm 0.02$ ,  $-0.99 \pm 0.02$ ,  $-1.27 \pm 0.03$ , and  $-1.64 \pm 0.05$  MPa for the 1988 collections. Temperature and osmotic potential treatments were factorially applied within collections.

#### Experiment 3—Ascending and Descending Temperatures and Osmotic Potential Effects on Germination

The effects of osmotic potential, and temperatures decreasing from 25 to 10° C and increasing from 10 to 25° C, were studied in Experiment 3. Temperatures were increased or decreased at a rate of 0.5° C per day, but the actual change in degree days depended on temperatures. Seeds were incubated for 600 degree days and germination was tallied using the procedures described in Experiment 2. Mean osmotic potentials and standard errors (n=4) were  $-0.22 \pm 0.02$ ,  $-0.71 \pm 0.02$ ,  $-1.15 \pm 0.05$ ,  $-1.64 \pm 0.06$  MPa for the 1987 collections and  $-0.34 \pm 0.01$ ,  $-0.58 \pm 0.01$ ,  $-0.78 \pm 0.03$ ,  $-0.95 \pm 0.02$ , and  $-1.08 \pm 0.04$  MPa for the 1988 collections. Within collections the treatments were factorially applied using temperature regimes and osmotic potentials as the main effects.

**Table 2. Germination parameters for plains rough fescue seed collected in Saskatchewan and incubated in 55 temperature regimes. See Table 1 for information regarding collections.**

Germination parameter	Seed Source											
	Strawberry Hills	West Allan Hills	East Allan Hills	Biddulph Prairie	Pinto Butte	Radisson	Sonningdale 1987	Sonningdale 1988	Cypress Hills 1987	Cypress Hills 1988	Wood Mountain	Eagle Hills
Mean (%) <sup>1</sup>	28	35	31	26	12	36	41	15	17	27	27	27
Mean with some germination (%) <sup>2</sup>	36	42	36	33	14	44	48	18	19	31	32	32
Percentage with some germination <sup>3</sup>	80	84	85	80	84	84	85	85	87	87	84	85
Percentage with maximum germination <sup>4</sup>	7	4	7	4	7	5	5	5	13	5	4	4
Maximum Mean (%) <sup>5</sup>	67	90	73	70	32	86	96	43	36	67	73	74
Maximum Germination (%) <sup>6</sup>	70	92	76	71	34	89	100	45	38	70	74	76
Total Filled Seed (± s.e.)	91 ± 1	98 ± 1	93 ± 2	90 ± 2	65 ± 5	97 ± 1	99 ± 1	76 ± 4	68 ± 10	85 ± 1	84 ± 4	91 ± 2

<sup>1</sup>Mean germination is the average germination of the 55 temperature regimes tested.

<sup>2</sup>Mean of regimes with some germination excluding regimes with no germination.

<sup>3</sup>Percentage with some germination is the percentage of the 55 temperature regimes in which some seeds germinated.

<sup>4</sup>Percentage with maximum germination is the percentage of the 55 temperature regimes having maximum germination.

<sup>5</sup>Maximum mean is the average germination of the temperature regimes with maximum germination.

<sup>6</sup>Maximum germination is the highest germination observed in the 55 temperature regimes.

## Data Analyses for Experiments 2 and 3

Since we were not able to collect seeds from plants grown under uniform environmental conditions, it was deemed inappropriate to make comparisons of germination responses among collections because of environmental influences on parent plants. Therefore, after transforming total germination percentage and germination rate (%/degree day) (Maguire 1962) with  $\arcsin \sqrt{p}$  each collection was subjected to factorial analysis of variance using temperature or temperature regime and osmotic potentials as main effects (Snedecor and Cochran 1980). Variance components were then estimated from analysis of variance by determining the percentage of the total variation that was accounted for by the main effects and their interactions. The best fit polynomial response curves were then developed for total germination and germination rate in Experiment 3 (Steel and Torrie 1980). All statistical analyses were conducted at the  $P \leq 0.05$  probability.

## Results

### Influence of 55 Constant and Alternating Temperature Regimes on Germination

Mean total germination over all temperature regimes ranged from a high of 41% for the 1987 Sonningdale collection to a low of 12% for the Pinto Butte collection (Table 2). The 1988 Sonningdale collection had the second lowest total germination percentage of the 12 sources tested, showing that large year-to-year variation existed.

Seeds germinated in 80 to 87% of the temperature regimes tested, with total germination at these temperatures averaging from 14 to 48% (Table 2). Maximum total germination was 70% or higher in 9 of the 12 collections tested. Germination was maximum in 4 to 13% of the regimes with means varying between 32 and 96%.

For the 1987 collections 7 temperature regimes supported maximum germination at least once; it occurred with a frequency of 80% at 15/15 and 20/20° C (Table 3). These same temperature

**Table 3. Frequency of maximum germination for temperature-germination profiles for all collections of plains rough fescue seed collected Saskatchewan.**

Frequency of maximum germination (%)										
Cold-period temperature (° C) 16-hr	Warm-period temperature (° C) 8-hr									
	0	2	5	10	15	20	25	30	35	40
	----- 1987 -----									
0										
2										
5										
10										
15						80	40	10		
20							80	60	10	
25								10		
30										
35										
40										
----- 1988 -----										
0										
2										
5										
10										
15						100	25			
20							100			
25								25		
30										
35										
40										

regimes provided optimal conditions for germination of all collections in 1988.

Complete response surfaces are presented for the Cypress Hills and Sonningdale collections made in 1987 and 1988 (Tables 4 and

**Table 4. Estimated total germination (%) and confidence intervals for the 1987 and 1988 Cypress Hills collections of plains rough fescue seeds incubated for 4 weeks in darkness at 55 constant and alternating temperatures.<sup>1</sup>**

Cold-period temperature (° C) 16-hr	Warm-period temperature (° C) 8-hr									
	0	2	5	10	15	20	25	30	35	40
	----- 1987 -----									
0	0(5)	0(4)	1(3)	2(3)	3(3)	3(3)	2(3)	0(3)	0(4)	0(5)
2		6(4)	8(3)	9(2)	10(3)	9(3)	8(3)	6(3)	3(3)	0(4)
5			17(3)	18(2)	18(2)	18(2)	17(2)	15(2)	12(2)	8(4)
10				29(3)	30(2)	29(2)	27(2)	25(2)	22(2)	18(3)
15					37(4)	36(3)	34(2)	32(2)	28(3)	24(4)
20						38(4)	36(3)	34(2)	30(3)	26(4)
25							35(4)	32(2)	28(2)	23(4)
30								26(4)	22(3)	17(4)
35									11(4)	6(4)
40										0(6)
----- 1988 -----										
0	0(7)	0(6)	2(5)	8(4)	11(5)	11(5)	8(5)	3(4)	0(5)	0(8)
2		9(6)	13(4)	19(4)	22(4)	21(4)	18(4)	12(4)	3(4)	0(7)
5			28(5)	33(3)	36(3)	35(3)	31(3)	25(3)	15(3)	3(5)
10				53(5)	54(3)	52(3)	48(3)	41(3)	30(3)	17(5)
15					67(5)	64(4)	59(3)	50(3)	39(4)	25(5)
20						70(6)	63(4)	54(3)	42(4)	27(6)
25							62(5)	52(4)	39(4)	24(5)
30								44(5)	30(4)	14(5)
35									15(6)	0(6)
40										0(9)

<sup>1</sup>Maximum values are underlined and defined as those values not lower than the maximum minus 1/2 its confidence interval ( $P \leq 0.05$ ). The values in parentheses are one-half the confidence interval.

**Table 5. Estimated total germination (%) and confidence intervals for the 1987 and 1988 Sonningdale collections of plains rough fescue seeds incubated for 4 weeks in darkness at 55 constant and alternating temperatures.<sup>1</sup>**

Cold-period temperature (° C) 16-hr	Warm-period temperature (° C) 8-hr									
	0	2	5	10	15	20	25	30	35	40
----- 1987 -----										
0	0(7)	0(6)	0(5)	2(5)	<u>4(5)</u>	<u>4(5)</u>	1(5)	0(5)	0(6)	0(8)
2		12(6)	16(5)	20(4)	21(4)	21(4)	18(4)	13(4)	5(5)	0(7)
5			40(5)	44(3)	45(3)	44(4)	40(4)	35(3)	27(4)	16(6)
10				75(5)	75(4)	73(4)	69(4)	62(4)	53(4)	42(5)
15					<u>95(6)</u>	92(4)	87(4)	79(4)	69(4)	57(6)
20						<u>100(6)</u>	<u>94(4)</u>	86(4)	75(4)	62(6)
25							91(6)	81(4)	70(4)	56(6)
30								66(6)	54(4)	39(6)
35									27(7)	11(7)
40										0(10)
----- 1988 -----										
0	0(5)	0(4)	0(3)	1(3)	3(3)	4(3)	3(3)	1(3)	0(4)	0(5)
2		3(4)	5(3)	8(2)	10(3)	10(3)	9(3)	6(3)	2(3)	0(4)
5			16(3)	18(2)	19(2)	18(2)	16(2)	13(2)	8(2)	1(4)
10				32(3)	32(2)	30(2)	27(2)	22(2)	15(2)	8(3)
15					<u>42(4)</u>	39(3)	34(2)	28(2)	21(3)	11(4)
20						<u>45(4)</u>	39(3)	32(2)	23(3)	12(4)
25							<u>41(4)</u>	32(2)	22(2)	11(4)
30								31(4)	19(3)	6(4)
35									13(4)	0(4)
40										0(6)

<sup>1</sup>Maximum values are underlined and defined as those values not lower than the maximum minus 1/2 its confidence interval ( $P \leq 0.05$ ). The values in parentheses are one-half the confidence interval.

5). These were the only sites where collection was possible in both years. Year-to-year and site-to-site variability are reflected in both sources with the Cypress Hills collection displaying highest total germination and optimal temperatures that were more restricted in 1988 than in 1987. The Sonningdale collection showed a reversed response with highest and lowest total germination in 1987 and 1988, respectively, but the range of optimum temperatures varied little. Much of this variation between collections is attributed to variation in the percentage of filled seeds (Table 2); however, dormancy can not be ruled out as a contributor to some of this variation.

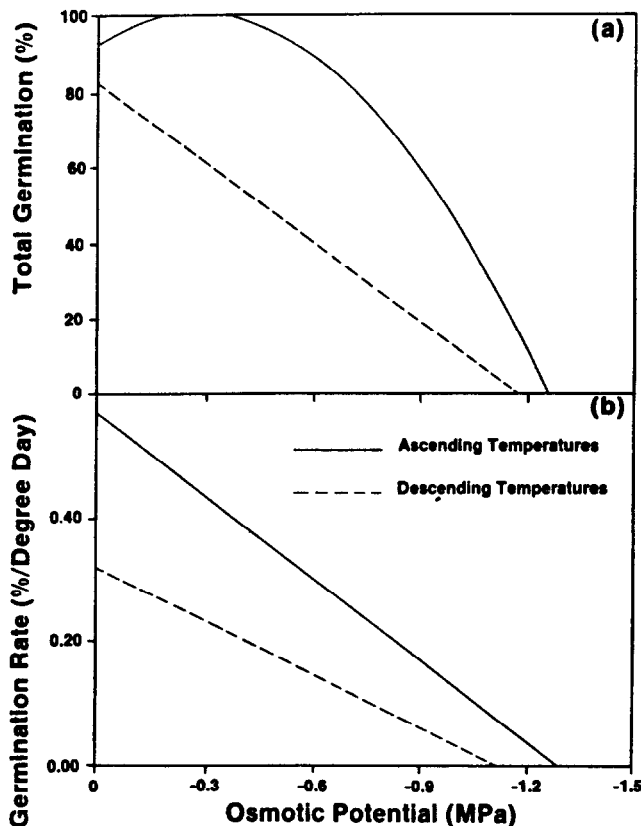
#### Constant Temperature-Osmotic Potential Effects on Germination

Germination of all collections was the product of the interacting effects of temperature and osmotic potential. Generally, total germination and germination rate were lowest at 5 and 25° C and highest at intermediate temperatures (Tables 6 and 7). Total germination was highest and seeds germinated most rapidly over the broadest range of osmotic potentials at 10 to 20° C. Over the entire temperature range, germination was severely restricted by declining osmotic potentials; no seeds germinated at osmotic potentials below -0.81 and -0.99 MPa for the 1987 and 1988 collections, respectively.

Analysis of variance showed that 71 to 88% of the variation in total germination was accounted for by osmotic potential. The combined effect of temperature and the interacting effects of temperature and osmotic potential accounted for 10 to 23% of the variation. These variance components implicated water stress as the primary determinant of germination.

#### Ascending and Descending Temperatures and Osmotic Potential Effects on Germination

Total percent germination was higher and germination rate more rapid over a broader range of osmotic potentials when incubated under temperatures that were increasing from 10 to 25° C than when temperatures declined from 25 to 10° C (Fig. 1a and 1b).



**Fig. 1a and 1b. Response curves for (a) total germination and (b) germination rate for the West Allan Hills collection of plains rough fescue incubated in a gradient of osmotic potentials with temperatures ascending from 10 to 25° C and descending from 25 to 10° C. Regression equations for the response curves are presented in Table 8.**

**Table 6. Mean total germination (%) and standard errors for the temperature and osmotic potential interaction for 8 collections of plains rough fescue seed incubated for 400 degree days (base temperature equals 0° C) at temperatures between 5 and 25° C in a gradient of osmotic potentials.**

Osmotic Potential (MPa)	Total germination (%)					Standard error
	Temperature (° C)					
	5	10	15	20	25	
----- Biddulph Prairie-1987 -----						
0.00	64.0	85.0	83.3	83.5	56.3	
-0.20	54.0	75.0	77.5	84.8	56.5	
-0.50	8.0	15.0	67.5	50.0	9.5	
-0.81	0.0	0.0	14.5	4.5	0.5	
-0.90	0.0	0.0	0.0	0.0	0.0	2.9
----- Strawberry Hills-1987 -----						
0.00	77.0	92.0	95.0	87.5	83.0	
-0.20	77.5	88.0	85.0	86.5	70.5	
-0.50	20.5	22.0	78.5	54.8	21.0	
-0.81	0.0	0.0	28.0	0.5	0.5	
-0.90	0.0	0.0	0.0	0.0	0.0	2.6
----- Radisson-1987 -----						
0.00	76.0	95.5	96.0	94.5	73.0	
-0.20	79.0	81.0	85.5	93.5	73.5	
-0.50	17.5	23.5	79.0	64.5	17.0	
-0.81	0.0	0.0	22.0	8.5	0.5	
-0.90	0.0	0.0	0.0	0.0	0.0	2.3
----- Allan Hills-1987 -----						
0.00	83.0	97.5	94.5	94.5	81.5	
-0.20	86.0	89.0	85.8	94.0	71.5	
-0.50	36.5	21.5	88.5	74.5	20.0	
-0.81	0.0	0.0	19.5	14.0	0.5	
-0.90	0.0	0.0	0.0	0.0	0.0	2.2
----- Cypress Hills-1988 -----						
0.00	75.0	60.0	79.0	68.0	63.5	
-0.29	75.5	83.5	88.5	66.5	52.0	
-0.68	14.5	67.0	65.5	25.0	12.0	
-0.99	0.0	29.0	3.5	0.0	0.0	
-1.27	0.0	0.0	0.0	0.0	0.0	3.9
----- Wood Mountain-1988 -----						
0.00	69.5	80.0	77.5	80.5	75.5	
-0.29	46.0	85.0	77.5	69.5	60.0	
-0.68	4.5	61.5	60.5	43.5	13.0	
-0.99	0.0	12.5	0.0	0.0	0.0	
-1.27	0.0	0.0	0.0	0.0	0.0	3.4
----- Sonningdale-1988 -----						
0.00	54.5	77.0	78.0	71.0	64.5	
-0.29	36.5	75.5	81.0	60.5	40.5	
-0.68	3.3	54.5	49.5	23.5	8.0	
-0.99	0.0	3.5	2.5	0.0	0.0	
-1.27	0.0	0.0	0.0	0.0	0.0	5.1
----- Eagle Hills-1988 -----						
0.00	81.5	87.5	85.5	76.0	60.0	
-0.29	61.0	86.5	68.0	70.0	70.0	
-0.68	5.5	74.0	63.5	28.5	17.0	
-0.99	0.0	13.5	0.0	0.0	0.0	
-1.27	0.0	0.0	0.0	0.0	0.0	3.0

**Table 7. Mean germination rate (%/degree day) and standard errors for the temperature and osmotic potential interaction for 8 collections of plains rough fescue seed incubated for 400 degree days (base temperature equals 0° C) at temperatures between 5 and 25° C in a gradient of osmotic potentials.**

Osmotic Potential (MPa)	Total germination (%)					Standard error
		Temperature (° C)				
5	10	15	20	25		
----- Biddulph Prairie 1987 -----						
0.00	0.21	0.43	0.43	0.37	0.21	
-0.20	0.17	0.31	0.33	0.33	0.19	
-0.50	0.02	0.04	0.21	0.15	0.02	
-0.81	0.00	0.00	0.03	0.01	0.01	
-0.90	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Strawberry Hills-1987 -----						
0.00	0.28	0.49	0.49	0.41	0.34	
-0.20	0.25	0.37	0.37	0.36	0.24	
-0.50	0.05	0.07	0.27	0.17	0.05	
-0.81	0.00	0.00	0.07	0.01	0.01	
-0.90	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Radisson-1987 -----						
0.00	0.28	0.51	0.52	0.46	0.33	
-0.20	0.26	0.35	0.37	0.40	0.28	
-0.50	0.05	0.07	0.27	0.19	0.03	
-0.81	0.00	0.00	0.06	0.02	0.01	
-0.90	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Allan Hills-1987 -----						
0.00	0.31	0.51	0.50	0.46	0.35	
-0.20	0.28	0.39	0.36	0.39	0.26	
-0.50	0.12	0.06	0.30	0.23	0.05	
-0.81	0.00	0.00	0.05	0.04	0.01	
-0.90	0.00	0.00	0.00	0.00	0.00	
					0.01	
----- Cypress Hills-1988 -----						
0.00	0.67	0.46	0.46	0.36	0.23	
-0.29	0.49	0.57	0.47	0.30	0.18	
-0.68	0.05	0.32	0.24	0.08	0.03	
-0.99	0.00	0.09	0.01	0.00	0.00	
-1.27	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Wood Mountain-1988 -----						
0.00	0.57	0.61	0.50	0.44	0.36	
-0.29	0.23	0.56	0.40	0.31	0.22	
-0.68	0.01	0.28	0.21	0.13	0.03	
-0.99	0.00	0.03	0.00	0.00	0.00	
-1.27	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Sonningdale-1988 -----						
0.00	0.42	0.57	0.42	0.37	0.25	
-0.29	0.18	0.47	0.37	0.27	0.20	
-0.68	0.01	0.22	0.17	0.07	0.02	
-0.99	0.00	0.01	0.01	0.00	0.00	
-1.27	0.00	0.00	0.00	0.00	0.00	
					0.02	
----- Eagle Hills-1988 -----						
0.00	0.66	0.69	0.54	0.40	0.24	
-0.29	0.32	0.57	0.34	0.32	0.25	
-0.68	0.01	0.34	0.23	0.09	0.05	
-0.99	0.00	0.04	0.00	0.00	0.00	
-1.27	0.00	0.00	0.00	0.00	0.00	
					0.02	

In all cases total germination-osmotic potential relationships were quadratic in the increasing temperature regime; conversely, total germination declined linearly as osmotic potentials declined under the descending temperature regime for all collections (Table 8; Fig. 1a). Whether under the ascending or descending temperature regime, germination rate declined in a linear fashion as osmotic potentials decreased (Table 8; Fig. 1b).

Water stress was the major contributor to variation observed in total germination. Sixty-five to 74% of the variation in total germination

was accounted for by osmotic potential, while 25–34% of the variation was partitioned into the influence of temperature regime and the interacting effects of temperature regime and osmotic potential.

## Discussion

Temperature does not appear to place major restrictions on the germination of plains rough fescue; seeds can be expected to germinate over a wide thermal gradient. However, moisture availabil-

**Table 8.** Regression equations for total germination and germination rate in ascending and descending temperature regimes for 8 collections of plains rough fescue seeds incubated for 600 degree days (base temperature equals 0° C) in a gradient of osmotic potentials. Y is total germination (%) or germination rate (%/degree day) and X is osmotic potential (-MPa).

Collection and year	Temperature regime			
	Ascending Regression Equation	R <sup>2</sup>	Descending Regression Equation	R <sup>2</sup>
----- Total germination (%) -----				
--- 1987 ---				
Biddulph	Y=82.5-5.4X-38.7X <sup>2</sup>	0.93	Y=72.2+61.2X	0.82
Allan Hills	Y=92.8-60.0X-104.7X <sup>2</sup>	0.96	Y=83.2+71.3X	0.89
Strawberry Hills	Y=89.4-28.4X-68.7X <sup>2</sup>	0.97	Y=85.2+72.3X	0.90
Radisson	Y=91.4-12.1X-27.7X <sup>2</sup>	0.95	Y=77.9+61.6X	0.77
--- 1988 ---				
Wood Mountain	Y=71.9-41.4X-111.5X <sup>2</sup>	0.87	Y=80.2+72.7X	0.85
Cypress Hills	Y=73.8-31.2X-101.2X <sup>2</sup>	0.91	Y=67.0+55.1X	0.76
Eagle Hills	Y=86.5-53.7X-156.7X <sup>2</sup>	0.95	Y=88.0+80.5X	0.83
Sonningdale	Y=70.6-73.2X-171.2X <sup>2</sup>	0.93	Y=69.3+61.1X	0.75
----- Germination Rate (%/degree day) -----				
--- 1987 ---				
Biddulph	Y=0.43+0.34X	0.97	Y=0.21+0.24X	0.82
Allan Hills	Y=0.56+0.44X	0.98	Y=0.31+0.28X	0.89
Strawberry Hills	Y=0.51+0.38X	0.98	Y=0.32+0.28X	0.91
Radisson	Y=0.50+0.38X	0.98	Y=0.30+0.25X	0.79
--- 1988 ---				
Wood Mountain	Y=0.43+0.42X	0.90	Y=0.31+0.30X	0.85
Cypress Hills	Y=0.46+0.45X	0.93	Y=0.24+0.22X	0.90
Eagle Hills	Y=0.54+0.56X	0.93	Y=0.34+0.34X	0.90
Sonningdale	Y=0.50+0.52X	0.91	Y=0.25+0.24X	0.87

ity imposes severe limitations on its germination, especially at the extremes of the range of temperatures tested. This finding was highlighted by compartmentalizing variance of germination where-in moisture stress accounted for the largest percentage of total variation.

Plants possessing seeds with exacting requirements for germination can establish more successfully than those with few restrictions (Hegarty 1978). However, in an environment with changing moisture conditions the opportunities for germination may be reduced for seeds with specific moisture requirements. If moisture stress is low, seeds of plains rough fescue can germinate over a broad range of temperatures; but water stress overrides temperature influences, and narrows the conditions where germination will occur. This response presumably reflects an adaptive strategy because plains rough fescue is generally restricted to habitats with cooler and moister conditions than those of the Mixed Prairie of the northern Great Plains (Coupland and Brayshaw 1953, Ayyad and Dix 1964). Such an adaptation protects against germination under conditions of transient or low soil moisture, limiting most germination to periods with protracted conditions of high soil moisture.

These data clearly illustrated that germination is potentially high when seedbed temperatures are moderate. That maximum germination occurred most frequently at 15/15 and 20/20° C, and seeds germinated over the broadest range of osmotic potentials at temperatures between 10 and 20° C, is strong evidence that moderate temperatures are optimum for germination. Similar results were reported for rough fescue, with maximum germination occurring in 6 of the same 55 regimes, with a frequency of 100% at 15/20° C (Young and Evans 1982). Johnston (1961) reported that total germination for rough fescue was highest at 13, 18, and 24° C and it was lowest at 30° C.

This range of optimal germination temperatures is similar to that in the soils of the Fescue Prairie during July and August (Johnston et al. 1971) when most seeds of plains rough fescue shatter from plants. Seeds of plains rough fescue apparently do not

have an after-ripening requirement, since preliminary tests showed germination of freshly harvested seeds averaged 81% and 87% at 10° C and 20° C, respectively (Romo, unpublished data). Therefore, provided seeds reach safe sites, they can germinate immediately upon ripening.

Exposure to the descending temperature regime and water stress reduced germination, and this reduction was not overcome by exposure to progressively lower temperatures. Relatively warm soil temperatures and water deficits are usually simultaneous events in Fescue Prairie. Providing seed mortality does not occur, dormancy induced by warm temperatures and water stress may act to preserve a portion of the seedbank for germination at a later date. However, a seedbank for the closely allied rough fescue is negligible (Johnston 1961). Induction of dormancy under these conditions may also serve to block germination that would otherwise predispose seedlings to temperature and moisture conditions that may not be conducive for their growth and survival.

With increasing temperatures, the restrictions imposed by water stress were not as strong as those imposed by declining temperatures. In Fescue Prairie, an increasing temperature regime is characteristic of spring. In spring, soils usually have high moisture content because of moisture recharge from snowmelt and early precipitation. Increasing temperatures also provide conditions favorable for growth of seedlings (Smoliak and Johnston 1968). However, the germination response observed under increasing temperatures in the present study may be modified by overwinter chilling of seeds. Stratification of plains rough fescue seeds at 2° C reduces germination under an ascending temperature regime (Romo, unpublished data).

The basic biological limitation of sexual reproduction in plains rough fescue is its infrequent production of seed. Exact reasons for this sporadic flowering are not known (Johnston and MacDonald 1967). Since plains rough fescue is a long-lived and weakly rhizomatous plant, high rates of regeneration from seed may not be necessary for maintenance of populations (Grime 1979). This proposition assumes that asexual reproduction is not being limited

and mortality rates are not altered. However, most remaining stands of plains rough fescue are severely depleted because of imprudent grazing management. In these depleted stands vegetative expansion is reduced, and the importance of regeneration from seed is elevated compared to pristine stands.

Complicating this issue of sexual regeneration is the fact that microenvironmental conditions of most Fescue Prairie has been substantially transformed by grazing. Temperature extremes of the soils are greatest and soil moisture is reduced (Johnston 1961, Johnston et al. 1971). Cold and warm temperatures, and widely fluctuating temperatures, greatly reduced germination of this grass, and water stress is a major determinant of germination. Thus, the combination of high seed production and conditions favorable for germination and growth are probably a rare sequence of events that are made more unlikely by improper grazing activities.

### Management Implications

Plains rough fescue has the ability to germinate over a broad range of temperatures, but severe restrictions are imposed by reduced moisture availability. These characteristics together with the fact that seeds germinated more rapidly and in higher numbers over a wider range of osmotic potentials when temperatures were increased from low to high temperatures suggest that this species should be planted in early spring when seedbed temperatures are increasing.

### Literature Cited

- Ayyad, M.A., and R.L. Dix. 1964. An analysis of a vegetation-microenvironmental complex on prairie slopes in Saskatchewan. *Ecol. Monogr.* 34:421-442.
- Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. *J. Ecol.* 49:135-167.
- Coupland, R.T., and T.C. Brayshaw. 1953. The Fescue grassland in Saskatchewan. *Ecology* 34:386-405.

- Evans, R.A., D.A. Easi, D.N. Book, and J.A. Young. 1982. Quadratic response surface analysis of seed germination trials. *Weed Sci.* 30:411-416.
- Grime, J.P. 1979. Plant strategies and vegetation processes. John Wiley and Sons. New York.
- Harms, V.L. 1985. A reconsideration of the nomenclature and taxonomy of the *Festuca altaica* complex (Poaceae) in North America. *Madrono* 32:1-10.
- Hegarty, T.W. 1978. The physiology of seed hydration and dehydration, and the relation between water stress and the control of germination: a review. *Plant, Cell and Environ.* 1:101-119.
- Johnson, I.R., and J.H.M. Thornley. 1985. Temperature dependence of plant and crop processes. *Ann. Bot.* 55:1-24.
- Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta. *Can. J. Plant Sci.* 41:615-622.
- Johnston, A., and M.D. MacDonald. 1967. Floral initiation and seed production in *Festuca scabrella* Torr. *Can. J. Plant Sci.* 47:577-583.
- Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on Fescue Grassland soils. *J. Range Manage.* 24:185-188.
- Maguire, J.D. 1962. Speed of germination-aid in selection and evaluation of seedling emergence and vigor. *Crop Sci.* 2:176-177.
- Smoliak, S., and A. Johnston. 1968. Germination and early root growth of grasses at four root-zone temperatures. *Can. J. Plant Sci.* 48:119-127.
- Snedecor, G.W., and W.C. Cochran. 1980. Statistical methods. The Iowa State University Press, Ames.
- Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Book Co., New York.
- Toynbee, K. 1987. Prolific flowering year for plains rough fescue at the Kernen Prairie. *Bluejay* 45:142-143.
- Young, J.A., and R.A. Evans. 1982. Temperature profiles for germination of cool season range grasses. USDA Agr. Res. Serv. Pub. ARR-W-27.

### Statement of Ownership, Management, and Circulation

(Act. of August 12, 1970, Sec. 3685, Title 39, United States Code)

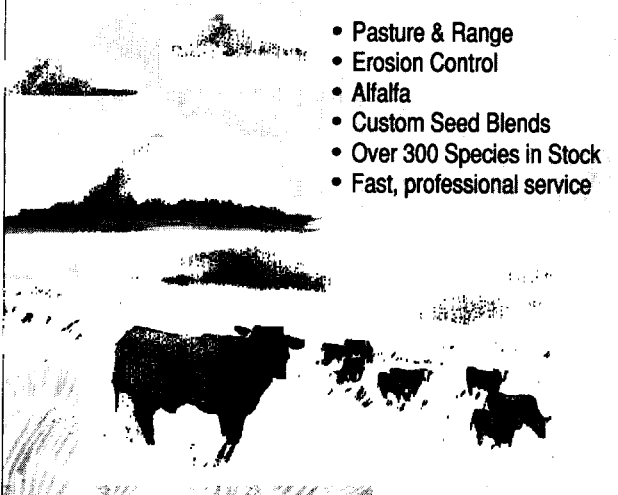
1. Title of Publication: Journal of Range Management
2. Date of Filing: September 28, 1990
3. Frequency of Issue: Bimonthly
4. Location of Office of Publication: 1839 York Street, Denver, Colo. 80206
5. Location of General Business Office: Same
6. Name and Address of:  
Publisher: Society for Range Management, 1839 York Street, Denver, Colo. 80206  
Editor: Gary Frasier, USDA-ARS, Crops Research Laboratory, 1701 Center Ave, Fort Collins, Colo. 80526  
Managing Editor: Peter V. Jackson III, 1839 York Street, Denver, Colo. 80206
7. Owner: Society for Range Management, 1839 York Street, Denver, Colo. 80206
8. Known Bondholders, Mortgagees, etc.: Wyatt Company, 1850 M. Street NW #700, Washington, DC 20036
9. For Completion by Nonprofit Organizations Authorized to Mail at Special Rates: The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes have not changed during preceding 12 months.
10. Extent and Nature of Circulation

	Avg. for 12 months	Actual for issue nearest filing date
A. Total copies printed	5,117	5,665
B. Paid Circulation		
1. Dealers, counter sales	0	0
2. Mail subscriptions	5,103	5,275
C. Total paid circulation	5,103	5,275
D. Free distribution	14	14
E. Total distribution	5,117	5,289
F. Copies not distributed	716	376
G. Total	5,833	5,665

I certify that the statements made by me above are correct and complete.—Peter V. Jackson, Managing Editor.

# granite

# SEED



- Pasture & Range
- Erosion Control
- Alfalfa
- Custom Seed Blends
- Over 300 Species in Stock
- Fast, professional service

Call or Fax for our Catalog (801) 531-1456, Fax (801) 768-3967  
Granite Seed Co., P.O. Box 177, Lehi, Utah 84043



# Cutting frequency and cutting height effects on rough fescue and Parry oat grass yields

WALTER D. WILLMS

## Abstract

A study was made in the Rough Fescue Grasslands of southwestern Alberta to determine the yield response of rough fescue (*Festuca scabrella* var *campestris* Rydb.) and Parry oat grass (*Danthonia parryi* Scribn.) to 5 cutting frequencies and 3 heights over a 3-year period. The same plants were cut either 1, 2, 4, 8, or 16 times over a 16-week period beginning in mid-May, at 16-, 8-, 4-, 2-, or 1-week intervals, respectively, and at heights of either 5, 10, or 15 cm above ground level. Yield response to cutting treatments differed significantly from the first to the third treatment year. In the first year, rough fescue and Parry oat grass produced most forage when cut at a height of 5 cm with 1, 2, or 4 cuts. By the third year, rough fescue produced the greatest yields with a single cut after 16 weeks and Parry oat grass produced the greatest yields when cut at 10 or 15 cm at 8-week intervals. The data confirm the high sensitivity of rough fescue to grazing while the plant is growing and suggest that the greatest benefit from the Rough Fescue Grasslands may be derived by grazing in fall or winter. Summer grazing favors Parry oatgrass, which is more tolerant than rough fescue, but forage production on the grassland is reduced.

**Key Words:** grasslands, simulated grazing, clipping, interval, intensity, harvest

Rough fescue (*Festuca scabrella* var *campestris* Rydb.) is the dominant climax species of the Rough Fescue Grasslands in southwestern Alberta. Although rough fescue may form nearly pure stands, Parry oat grass (*Danthonia parryi* Scribn.) is usually found in association with it throughout the region (Johnston and Dormaar 1970) and may dominate on sites having shallow soils (Moss and Campbell 1947, Looman 1969). Both species are tufted with mostly basal leaves and few reproductive tillers; but rough fescue is a large plant with the vegetative portion about 50 cm in height (Johnston 1961) whereas Parry oat grass is about 20 cm in height. Rough fescue is deep rooted and, of the native species, is the most productive forage on good condition range in the foothills region. Stout et al. (1981) found that cumulative yield of rough fescue reached a maximum by the end of July.

Grazing affects the relative proportions of each species in the grassland, with light grazing reducing the composition of rough fescue and increasing Parry oat grass (Looman 1969). As a result, Parry oat grass is often the most productive forage species on grazed range (Moss 1955). In one study, grazing reduced the composition of rough fescue from 42% with no grazing to 38% with light grazing (1.2 AUM/ha) and 2% with very heavy grazing (4.8 AUM/ha). At the same time, Parry oat grass increased from 19% of basal area with no grazing to 48% with heavy grazing (2.4 AUM/ha) but decreased to 35% with very heavy grazing (Willms et al. 1985). The susceptibility of rough fescue to defoliation was demonstrated in a greenhouse study by Johnston (1961) where 20% defoliation, achieved by cutting individual plants of rough fescue at 12-cm heights every 4 weeks, resulted in a reduction of 48% root growth and 21% top growth. Sinton (1980) reported depressed first-year forage yields in a rough fescue (*F. hallii* Vasey) community following a single harvest at several dates from 8 April to 18

October. McLean and Wikeem (1985) clipped individual plants of rough fescue weekly in single-year treatments for various durations from May to August. They found that the greatest yield decrease occurred when plants were clipped at 5-cm heights from mid-May to late June and the least when cutting ceased in May. Plant mortality was not affected when the cutting height was 20 cm.

Rough fescue and Parry oat grass are valuable forage species for livestock production and rangeland conservation, and yet no information is available on their response to repeated annual defoliation under specific harvesting regimes. Although single-year treatments can provide useful information on the plant response to grazing, repeated yearly treatments are more realistic because cows tend to regaze plants in consecutive years. Furthermore, the implementation of time-controlled grazing systems allows greater control of livestock distribution, thereby enabling better control of defoliation. As a result, more management options are available, which increases the need for information on plant response to grazing regimes. Therefore, a study was conducted to measure the effects of repeated annual defoliation, in relation to number of cuts during the growing season and cutting heights, on the yield of rough fescue and Parry oat grass.

## Materials and Methods

### Site Description

The study was made in the Porcupine Hills of southwestern Alberta at Stavely, the Agriculture Canada Research Substation about 85 km northwest of Lethbridge. The vegetation is representative of the Rough Fescue Association described by Moss and Campbell (1947). The soils are classified as Orthic Black Chernozemic (Udic Haploboroll) developed on till overlying sandstone. Annual precipitation data at the substation were not available, but averaged 614 mm on 2 similar areas within 65 km. However, precipitation over the growing season was below the long-term average in each year of the study (Table 1). The study area was

**Table 1. Precipitation during the growing season at the Stavely Substation over the period of study.**

Total	Precipitation (mm)					
	April	May	June	July	August	
1983	30	21	28	57	32	168
1984	23	46	71	27	1	168
1985	20	23	0	31	99	173
1986	11	52	78	77	38	256
1987	22	3	27	63	60	175
34-yr average	64	70	99	55	60	348

located on a southwest slope with less than a 5% grade. The area had experienced either no grazing or only light fall grazing from 1949 until 1982, when it was fenced to exclude livestock.

### Treatments

The effects of cutting intensity at 5-, 10-, or 15-cm heights (CH5, CH10, and CH15, respectively) and cutting frequency, every 1, 2, 4, 8, or 16 weeks (FR16, FR8, FR4, FR2, and FR1, respectively),

Author is range ecologist, Agriculture Canada Research Station, Lethbridge, Alberta T1J 4B1. Contribution 3878941.  
Manuscript accepted 2 June 1990.

**Table 2.** Observed significance levels (OSL) of F ratios indicating the repeatability of yield responses for rough fescue and Parry oat grass in the first and third year of treatment. Also OSL's of differences in yield response between the 2 years.

Source	Rough fescue			Parry oat grass		
	1st	3rd	Difference	1st	3rd	Difference
Cutting frequency (F)	0.003	<0.001	0.006	0.400	0.105	0.384
linear (1F)	0.271	<0.001	0.002	0.300	0.248	0.578
quadratic (qF)	0.784	0.002	0.012	0.785	0.399	0.376
cubic (cF)	<0.001	<0.001	0.994	0.247	0.052	0.150
quartic (quF)	0.012	0.001	0.312	0.242	0.077	0.389
Cutting height (H)	0.059	0.123	0.007	0.173	0.072	0.069
linear (1H)	0.025	0.057	0.003	0.092	0.038	0.036
quadratic (qH)	0.742	0.572	0.995	0.764	0.466	0.545
F × H	0.038	0.269	0.041	0.110	0.379	0.255
1F × 1H	0.014	0.301	0.107	0.055	0.111	0.227
qF × 1H	0.957	0.129	0.424	0.859	0.128	0.457
cF × 1H	0.007	0.153	0.004	0.113	0.256	0.283
quF × 1H	0.093	0.308	0.056	0.029	0.408	0.054
1F × qH	0.461	0.170	0.180	0.384	0.778	0.452
qF × qH	0.846	0.923	0.836	0.916	0.371	0.530
cF × qH	0.631	0.671	0.523	0.557	0.453	0.857
quF × qH	0.354	0.194	0.940	0.107	0.829	0.116

over a 16-week period from 15 May to the end of August were evaluated in a 3 × 5 factorial experiment with 10 subsamples and 2 or 3 blocks in a randomized complete block design. The blocks were contiguous to one another and cutting treatments in each block were initiated in different years: for rough fescue, treatments were begun in 3 blocks in either 1983, 1984, or 1985; for Parry oat, treatments were begun in 2 blocks in either 1984 or 1985. Consequently, the blocking factors were site and year. The treatments were repeated over 3 consecutive treatment years on the same plants in each block. The subsampling unit consisted of individual plants of either species, which were systematically selected within belts about 5-m wide by taking the first suitable plants encountered and then randomly partitioning among treatments. Parry oat grass plants were selected within the same belts as rough fescue plants in 1984 and 1985. Plants were considered suitable for selection only if they were clearly defined by purity and boundary.

In the first week of May, in the year that treatments in a block were initiated, all new plants selected were pretreated by cutting to a height of 15 cm and clearing litter and competing vegetation in a 5-cm wide perimeter from around the base. Cutting at this time removed standing litter but also a small quantity of green herbage from most rough fescue plants. The green herbage was hand-separated from the litter and added to the total yield of the plant. The first scheduled cutting was then begun on or about 15 May for FR16, 22 May for FR8, 5 June for FR4, 3 July for FR2, and 28 August for FR1. These dates were adhered to for the initial and repeated treatment of each block. The treatments were applied by cutting plants to the required heights as measured from the ground. Throughout the summer, plants invading within the 5-cm perimeter were removed. All harvested herbage was oven dried and weighed. Annual production was calculated for each plant as the sum of the partial yields at each harvest.

#### Statistical Analysis

The effects of cutting frequency and height and their interaction on production were analyzed with a generalized least squares analysis of variance model. Cutting frequency was transformed to a natural log scale and single degree of freedom polynomial contrasts, to the highest possible order, were used to evaluate the trends and their complexity. Yields obtained after 1, 2, or 3 years of repeated treatment from each block were evaluated in a separate analyses. In the analysis, plant area was used as a covariate to

adjust yield for plant size. The block effect and its interaction with individual main effects, or their interaction, was the appropriate error term for specific F-ratios. The effect of repeated treatment over time, from the first to third year, was evaluated by subtracting yields in the third year from yields in the first year and testing the differences. Procedures followed Rowell and Walters (1976).

Data for rough fescue and Parry oat grass were analyzed separately as well as in a combined analysis for these years when both were studied. Where the analyses were combined by species, only the variables pertaining to species effects are reported.

Plant growth for each species was measured as the yield taken from plants clipped for the first time at FR16 to FR1 (CH5). Therefore, growth could be determined only in the first year each block was treated.

Regrowth of plants from the FR2 CH5 to 15 treatments was further evaluated because of an apparently large effect of that treatment on total yield. Regrowth from about 3 July to 28 August was compared with growth of previously unclipped plants in the first treatment year and, in another test, regrowth in the first treatment year was compared with regrowth in the third treatment year. In the first test, the 4 treatments (df = 3) were growth (1) and regrowth (2, 3, 4) from CH5 to 15 and the error term was the interaction of treatment × block (df = 6 for rough fescue or df = 3 for Parry oat grass). The second test was analyzed as a split plot with cutting height (df = 2) as the main effect and treatment year (df = 1) as the secondary effect. In this test, the error term for the main effects was the interaction between treatment year × block and the error term for the secondary effects, or its interaction with the main effect, was the treatment year × block × cutting height interaction (df for both error terms was 4 for rough fescue and 2 for Parry oat grass). A single degree of freedom test was used to compare specific means (Steel and Torrie 1980).

#### Results

Yields of rough fescue were greatest with a single harvest near the end of August (Fig. 1) and decreased significantly in a non-linear trend with increased cutting frequency (Table 2). Cutting height had a significant ( $P = 0.025$ ) linear effect in the first treatment year but no effect ( $P > 0.05$ ) in the third year. A significant interaction of cutting frequency and height was detected in the first treatment year but not in the third year.

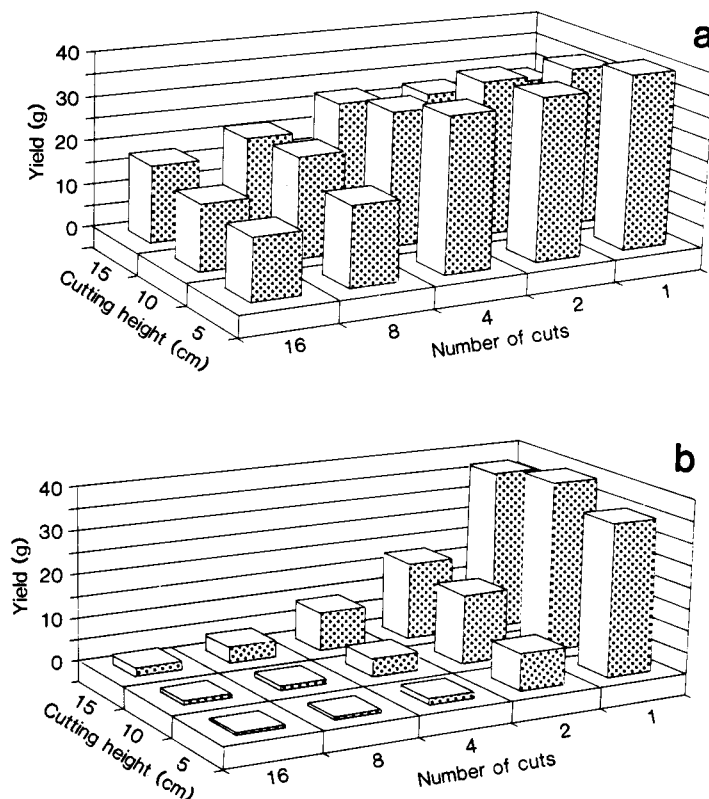


Fig. 1. Average of 3 yield responses of rough fescue to cutting frequency (number of cuts over a 16-week period) and height: a) first-year response, b) third-year response.

Differences in rough fescue yield response from the first to the third year were most noticeable in the mid-frequency ranges of the cutting heights (Table 2). The difference between years 1 and 3 was significant ( $P < 0.01$ ) by cutting frequency and height (Table 2). The second and third year results were similar in response to frequency ( $P = 0.86$ ), height ( $P = 0.31$ ), and the interaction of frequency and height ( $P = 0.98$ ).

In the first year of treatment, Parry oat grass yields were greatest with 1 or 2 cuts during the growing season (Fig. 2a). Neither cutting frequency, cutting height nor their interaction was significant ( $P > 0.10$ , Table 2). By the third year of treatment, greatest dry matter yields were produced with 2 cuts at 15-cm height (Fig. 2b). Both cutting frequency ( $P = 0.052$ ) and cutting height ( $P = 0.038$ ) affected yields but their interaction did not ( $P > 0.11$ ). Cutting height had a significant linear effect ( $P = 0.036$ ) on the yield response from the first to the third year of treatment (Table 2) but cutting frequency and its interaction with height had no effect. The second and third year results were similar in response to frequency ( $P = 0.86$ ), height ( $P = 0.31$ ), and the interaction of frequency and height ( $P = 0.98$ ).

Rough fescue and Parry oat grass responded similarly to cutting frequency ( $P = 0.12$ ), cutting height ( $P = 0.80$ ), and the interaction of frequency and height ( $P = 0.59$ ) in the first year of treatment. However, by the third year of treatment, the yield response of rough fescue and Parry oat grass to frequency was different [ $(P = 0.001)$ , Figs. 1b and 2b], whereas their response to cutting height and its interaction with frequency was similar ( $P > 0.67$ ).

Average forage yields of plants ( $g \pm 1$  SEM) cut at 5-cm height, in the first treatment year, for the first time on or about 15 May (FR16), 22 May (FR8), 5 June (FR4), 3 July (FR2), and 28 August (F1) were, respectively, 9.7 (0.95), 12.6 (1.22), 27.4 (2.83), 35.7

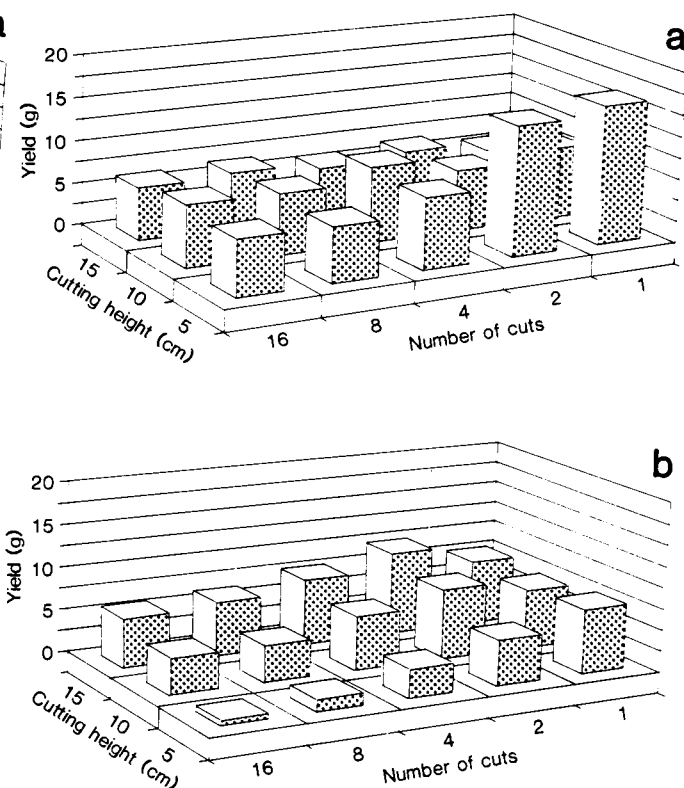


Fig. 2. Average of 2 yield responses of Parry oat grass to cutting frequency (number of cuts over a 16-week period) and height: a) first-year response, b) third-year response.

(2.87), and 50.7 (3.60) for rough fescue in 3 blocks, and 1.8 (0.34), 2.6 (0.36), 3.8 (0.28), 7.4 (0.76), and 11.9 (1.40) for Parry oat grass in 2 blocks. Thus, growth for the period from 3 July to 28 August of previously untreated plants was 15.0 (28%) and 4.6 g (39%) for rough fescue and Parry oat grass, respectively (Table 4).

Table 3. Average change in yield response of rough fescue due to cutting frequency (number of cuts over a 16-week period) and height with repeated treatment over 3 years (observed significance levels for tests of specific trends are reported in Table 2).

Cutting height (cm)	Cutting frequency				
	1	2	4	8	16
5	13.2	28.7	33.9	17.7	13.8
10	-3.1	19.4	26.5	21.7	14.3
15	-8.9	9.4	18.1	17.5	15.5

Regrowth from 3 July to 28 August over all cutting heights, in the first year of treatment of rough fescue and Parry oat grass plants, was significantly less than growth for the same period (Table 4). As a proportion of total yield, regrowth of rough fescue was less while Parry oat grass was similar.

Plant mortality, defined as zero live tillers within a plant, by treatment after the first/second years of cutting, for rough fescue was: FR16 CH5, 23/37%, FR8 CH5, 20/33%, FR4 CH5, 0/3%; FR16 CH10, 3/3%; FR8 CH10, 3/3%; FR4 CH10, 3/3%; and FR4 CH15, 0/3%. Parry oat grass experienced no mortality after the first year and 5% mortality in treatments FR16 CH5, FR16 CH10, and FR8 CH10 after the second year. There was no plant mortal-

**Table 4.** Comparison of plant growth, during the period July through August, with regrowth for the same period of plants (F2 CH5 to 15) harvested once on 3 July in the first year of treatment or following repeated harvests on 3 July and 28 August in the third year of treatment.

	Rough fescue		Parry oat grass	
	g/plant	Proportion <sup>1</sup>	g/plant	Proportion <sup>1</sup>
Growth (1)	15.03	0.279	4.62	0.388
First year				
CH5 (2)	3.49	0.081	3.74	0.310
CH10 (3)	4.78	0.113	2.80	0.357
CH15 (4)	4.47	0.151	2.52	0.351
Third year				
CH5 (5)	1.87	0.215	1.82	0.416
CH10 (6)	3.53	0.208	2.75	0.422
CH15 (7)	4.09	0.236	3.72	0.456
Contrasts <sup>2</sup>				
1 vs 2, 3, 4	0.034	0.004	0.013	0.111
1 vs 2	0.054	0.002	0.100	0.102
1 vs 3	0.078	0.011	0.016	0.196
1 vs 4	0.071	0.060	0.011	0.228
2, 3, 4, vs 5, 6, 7	0.040	0.002	0.615	0.071

<sup>1</sup>Proportion of growth or regrowth, from about 3 July to 28 August, to total annual yield.

<sup>2</sup>Probabilities that means are equal.

ity in other treatments.

Reproductive culms became noticeable in rough fescue by mid-May, flowering occurred by June, and seeds had ripened by mid-July. Parry oat grass flowered about 4 weeks later.

### Discussion

Rough fescue was highly susceptible to defoliation during the growing season regardless of the cutting frequency or height. While plant mortality was not a factor with fewer cuts (FR2 or FR4), plant yield was significantly reduced from that of a single harvest after the growing season (FR1).

Rough fescue mortality after 3 years of repeated cutting was considerably less than that reported by McLean and Wikeem (1985), who found an average mortality of 92% after the first year among plants cut at about the severity level of FR16 CH5. The high mortality may be partly due to competing vegetation which was left in place instead of being removed as in this study. A few surviving tillers are significant for the recovery of overgrazed Rough Fescue Grasslands because they provide the basis for regeneration; heavily grazed plants do not produce seed.

Rough fescue yields at a moderate cutting frequency (FR2 and FR4) were not reduced until after the first year, thereby demonstrating the need for at least 2 years of repeated treatment when assessing plant response. The severe response to a single cut in July may be due to reduced carbohydrate reserves found in some grasses prior to seed formation (Smith 1972). Although carbohydrates were not analyzed, and their significance to regrowth is questionable (Caldwell et al. 1981, Richards 1986), McLean and Wikeem (1985) suggest that depressed vigor in response to weekly cuts from May to July was the result of reduced regrowth potential due to lower carbohydrate reserves. Caldwell et al. (1981) believed that regrowth potential was less related to carbohydrate reserves than to species potential.

While rough fescue decreases with overgrazing, Parry oat grass increases with a corresponding decrease in forage yield (Willms et al. 1985, 1986b). This trend was also demonstrated in the present study, which showed that Parry oat grass was less productive than rough fescue but also less affected by cutting frequency or height.

Although the severe cutting treatments resulted in the death of some plants and a substantial reduction in yield of the survivors, by the third treatment year the moderate cutting treatments enhanced yields and, presumably, plant vigor.

The July cutting (FR2) appeared critical for either reducing yields in rough fescue or increasing yields in Parry oat grass in comparison with those from a single harvest (F1). Regrowth in both rough fescue and Parry oat grass was impaired after cutting in the first year but, while rough fescue regrowth averaged 28.3% (4.25 g) of growth, regrowth of Parry oat grass averaged 65.3% (3.02 g) (Table 4).

The continued reduction of regrowth to the third year appears to be at least partly caused by a year effect, perhaps interacting with litter removal, since the FR1 yields were also less than in the first treatment year when litter was first removed (Table 3). Litter is important in conserving water and enhancing yields in water-limiting environments (Willms et al. 1986a), which likely persisted over the duration of the study (Table 1). Although repeated annual cutting in late August only may have reduced yields, this possibility appears remote, particularly with Parry oat grass, which produced the greatest yields with 2 cuts (Fig. 2b).

The relative susceptibilities of rough fescue and Parry oat grass to grazing have long been recognized. However, the nature of that response was not clear. This study demonstrated that Parry oat grass can withstand frequent but less intense defoliation, and rough fescue can not. This leads to the conclusion that the Rough Fescue Grasslands are managed most efficiently with a single defoliation at the end of the growing season or, in practice, by extending the grazing season into fall or winter.

The contrasting responses of the 2 species to grazing present constraints or opportunities for their management. For the Rough Fescue Grasslands to yield the greatest sustained quantity of forage, they must be grazed after the growing season in order to maintain them in a healthy state. Grazing systems that do not incorporate dormant-season grazing are unlikely to prevent the decline of rough fescue in the grassland. Overgrazing will severely reduce rough fescue and recovery may require more than 30 years (Willms et al. 1985). Season-long moderate or light grazing pressure may not be desirable because it results in overgrazed and undergrazed patches (Willms et al. 1988) with a net effect of reduced grazing efficiency. On the other hand, heavy sustained grazing pressure will eliminate grazed patches and produce more beef per unit area (Willms et al. 1986b) but mostly from Parry oat grass. Therefore, without considering subsequent effects on the soil, grazing recommendations to produce maximum beef would be to manage for either Parry oat grass under summer grazing or for rough fescue under fall and winter grazing. The former recommendation is not desirable because the soils may deteriorate (Johnston et al. 1971) and watershed properties weaken (Naeth 1988).

The present study did not examine all possible strategies for grazing during the growing season nor did it evaluate the cost of delayed grazing in terms of weathering losses of dry matter, nutrients, and animal performance. More work needs to be done in order to provide a more complete analysis. The choices presented to the grazing manager are: to sacrifice rough fescue in order to maximize beef production; to graze inefficiently at low or moderate stocking rates that result in overgrazed or undergrazed patches; or to delay grazing until after the growing season and sustain maximum productivity.

### Literature Cited

- Caldwell, M.M., J.H. Richards, D.A. Johnson, R.S. Nowak, and R.S. Dzurec. 1981. Coping with herbivory: photosynthetic capacity and resource allocation in two semiarid *Agropyron* bunchgrasses. *Oecologia* (Berl) 50:14-24.

- Johnston, A. 1961.** Comparison of lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta. *Can. J. Plant Sci.* 41:615-622.
- Johnston, A., and J.F. Dormaar. 1970.** Observations on *Danthonia parryi*. *Can. J. Plant Sci.* 50:115-117.
- Johnston, A., J.F. Dormaar, and S. Smoliak. 1971.** Long-term grazing effects on fescue grassland soils. *J. Range Manage.* 24:185-188.
- Looman, J. 1969.** The fescue grasslands of Western Canada. *Vegetatio* 19:128-145.
- McLean, A., and S. Wikeem. 1985.** Rough fescue response to season and intensity of defoliation. *J. Range Manage.* 38:100-103.
- Moss, E.H. 1955.** The vegetation of Alberta. *Bot. Rev.* 21:493-567.
- Moss, E.H., and J.A. Campbell. 1947.** The fescue grasslands of Alberta. *Can. J. Res.* 25:209-227.
- Naeth, M.A. 1988.** The impact of grazing on litter and hydrology in Mixed Prairie and Fescue Grassland ecosystems of Alberta. PhD. Thesis, Univ. of Alberta, Edmonton.
- Richards, J.H. 1986.** Plant response to grazing: the role of photosynthetic capacity and stored carbon reserves, p. 428-430. *In: Rangelands: A resource under siege.* Proc. 2nd Internat. Rangelands. Congr., Cambridge Univ. Press, Sydney.
- Rowell, J.G., and D.E. Walters. 1976.** Analyzing data with repeated observations on each experimental unit. *J. Agr. Sci.* 87:423-432.
- Sinton, H.M.M. 1980.** Effect of burning and mowing on *Festuca hallii* (Vasey) Piper, *Festuca scabrella* Torr. M.Sc. Thesis, Univ. of Alberta, Edmonton.
- Smith, D. 1972.** Carbohydrate reserves of grasses, p. 318-333. *In: Youngner, V.B. and C.M. McKell (eds.). The biology and utilization of grasses.* Academic Press, New York.
- Steel, R.G.D., and J.H. Torrie. 1980.** Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill Book Co., New York.
- Stout, D.G., A. McLean, and D.E. Quinton. 1981.** Growth and phenological development of rough fescue in the interior of British Columbia. *J. Range Manage.* 34:455-459.
- Willms, W.D., J.F. Dormaar, and G.B. Schaalje. 1988.** Stability of grazed patches on rough fescue grasslands. *J. Range Manage.* 41:503-508.
- Willms, W.D., S. Smoliak, and A.W. Bailey. 1986a.** Herbage production following litter removal on Alberta native grasslands. *J. Range Manage.* 39:536-540.
- Willms, W.D., S. Smoliak, and J.F. Dormaar. 1985.** Effects of stocking rate on rough fescue grassland vegetation. *J. Range Manage.* 38:220-225.
- Willms, W.D., S. Smoliak, and G.B. Schaalje. 1986b.** Cattle weight gains in relation to stocking rate on Rough Fescue Grassland. *J. Range Manage.* 39:182-186.

# Some effects of precipitation patterns on mesa dropseed phenology

ROBERT P. GIBBENS

## Abstract

Phenology of mesa dropseed [*Sporobolus flexuosus* (Thurb.) Rydb.] was studied from 1979 to 1987 on the Jornada Experimental Range in southern New Mexico. Growing season (March through November) precipitation ranged from 99 to 308 mm during the 8-year period. Foliage height and number of leaves were recorded weekly for individually marked culms on 20 plants. New culms usually appeared during the first week in March and green leaf tissue often persisted until the end of November. Correlation analyses of accumulated weekly height increments and accumulated weekly precipitation showed that growth was highly dependent upon rainfall ( $r = 0.81$  to  $0.97$ ). Leaf formation was also correlated with rainfall ( $r = 0.79$  to  $0.98$ ). Even in relatively wet years there were 1 or 2 periods of no growth. In drier years, no growth periods totaled as much as 87 days. Periods of rapid growth occurred only after rainfall events  $> 13$  mm. The first exertion of seed heads occurred as early as the last week of July and as late as the second week of October. The temporal plasticity of mesa dropseed phenology indicates that it is well adapted to the arid environment.

**Key Words:** grass growth, leaf development, arid zones, rangeland, *Sporobolus flexuosus*, Chihuahuan Desert

An understanding of plant phenology, or the temporal occurrence of growth phases, is basic to sound resource management, e.g., determination of range readiness and development of geographically oriented resource management models (Costello 1939,

---

Author is range scientist, Jornada Experimental Range, Agricultural Research Service, USDA, P.O. Box 30003, Dept 3JER, New Mexico State Univ., Las Cruces 88003.

The use of trade names does not constitute an official endorsement or approval by the United States Department of Agriculture.

Appreciation is expressed to Dr. John T. Hennessy who assisted in data collection in 1979 and 1980 and to James M. Lenz who assisted in subsequent years.

Manuscript accepted 19 May 1990.

Lieth and Radford 1971). The relatively recent development of methods for quantifying phenological observations (West and Wein 1971, Haun 1973) increases their utility in resource management applications.

Much phenological research has been concerned with the influence of climatic variables upon crop plants (Abbe 1905, Thornthwaite 1952) and upon regional responses of selected indicator species (Gilbert 1961, Caprio 1966). Phenological studies of weed species have been made so that optimum timing of control measures could be achieved (Finnerty and Klingman 1962, McCarty and Scifres 1969, Hyder et al. 1962, Young and Evans 1974, Roundy et al. 1981). Comparative phenological development of species in native plant communities has received considerable attention (Ahlgren 1957, Ahshapanek 1962, Hulbert 1963, Dickinson and Dodd 1976, McCarty 1986).

Many studies have related phenological phases to accumulated degree days or solar-thermal units (Caprio 1971, White 1979, Frank and Hofmann 1989). However, in desert areas precipitation has been found to be the critical factor in plant phenology (Went 1949, Beatley 1974). The purpose of this study was to determine the effect of precipitation patterns on the growth and development of mesa dropseed [*Sporobolus flexuosus* (Thurb.) Rydb.], an important forage species in the northern Chihuahuan Desert.

## Materials and Methods

This study was conducted on the Jornada Experimental Range (JER) 37 km north of Las Cruces, New Mexico. The 78,266-ha JER lies principally on undulating plains of the closed Jornada Basin at an elevation of about 1,260 m. Mean monthly maximum temperatures are highest in June ( $36^{\circ}$  C) and lowest in January ( $13^{\circ}$  C). Long-term average annual precipitation is 230 mm with 52% occurring in July, August, and September. Summer precipita-

tion is mostly from high intensity, short-duration, convective storms covering small areas. Winter precipitation comes from low-intensity frontal storms covering broad areas. Snow is infrequent. The frost-free period averages 200 days, but the effective growing season, when soil water and temperature are favorable, is often 90 days or less (Paulsen and Ares 1962).

The Jornada basin was formerly dominated by black grama [*Bouteloua eriopoda* (Torr.) Torr.]; but shrubs, e.g., honey mesquite (*Prosopis glandulosa* Torr.), creosote bush [*Larrea tridentata* (DC.) Cov.], and tarbush (*Flourensia cernua* DC.), now dominate most of the basin (Buffington and Herbel 1965). With the breakup of the black grama stands, mesa dropseed, a relatively short-lived perennial grass which reproduces readily from seed, has become a dominant species and a major source of forage (Paulsen and Ares 1962).

Phenological observations of mesa dropseed began in 1979 and continued through 1987. In 1979 and 1980, observations were made at 2 sites (A and B). In 1981, observations were made only at site A. Because of the termination of other studies at sites A and B and to conserve travel time, observations were moved to a new site (C) in 1982 and continued at this site through 1987. Observations were also made at a fourth site (D) from 1985 to 1987. Site A was 5 km from site B and site C was 17 km from site D.

Soils of the study sites were sandy loams or loamy sands and included coarse-loamy, mixed, thermic Typic Calciorthids of the Wink series (site A), coarse-loamy, mixed, thermic Typic Haplar-

gids of the Onite series (sites B and D), and loamy, mixed, thermic, shallow Typic Paleorthids of the Simona series (site C) Bullock and Neher 1980).

At each site, 20 randomly selected plants were marked with numbered stakes. Each season, 1 emerging culm on each plant was marked with colored electrical wire. Extended foliage height of the marked culm was measured weekly. Emergence of all leaves on marked culms was rated on a 10-point scale from 0 to 1, with 0.1 denoting the appearance of the tip of the leaf and 1 denoting the appearance of the ligule from the subtending sheath. Thus, by summing the number of wholly and partially emerged leaves for each culm, a leaf emergence number or index was obtained weekly. Phenological events such as inflorescence emergence, flowering, and seed fall, also were rated on a 10-point scale. In 1979 and 1980, drying of individual leaves was not recorded and observations were terminated after growth had ceased. In subsequent years, drying of individual leaves on marked culms was rated on a 10-point scale and observations continued until no, or very little, green tissue was present. Periods of no growth were defined as those when average leaf and height growth did not increase more than 0.05 leaf emergence units and 0.05 cm, respectively.

The plants were within livestock exclosures but experienced herbivory by insects, rodents, and lagomorphs (large native ungulates did not use the areas). Fences of 2.54-cm mesh were erected around plots after 1981 in an attempt to reduce lagomorph grazing but were only partially successful. When a marked culm was grazed

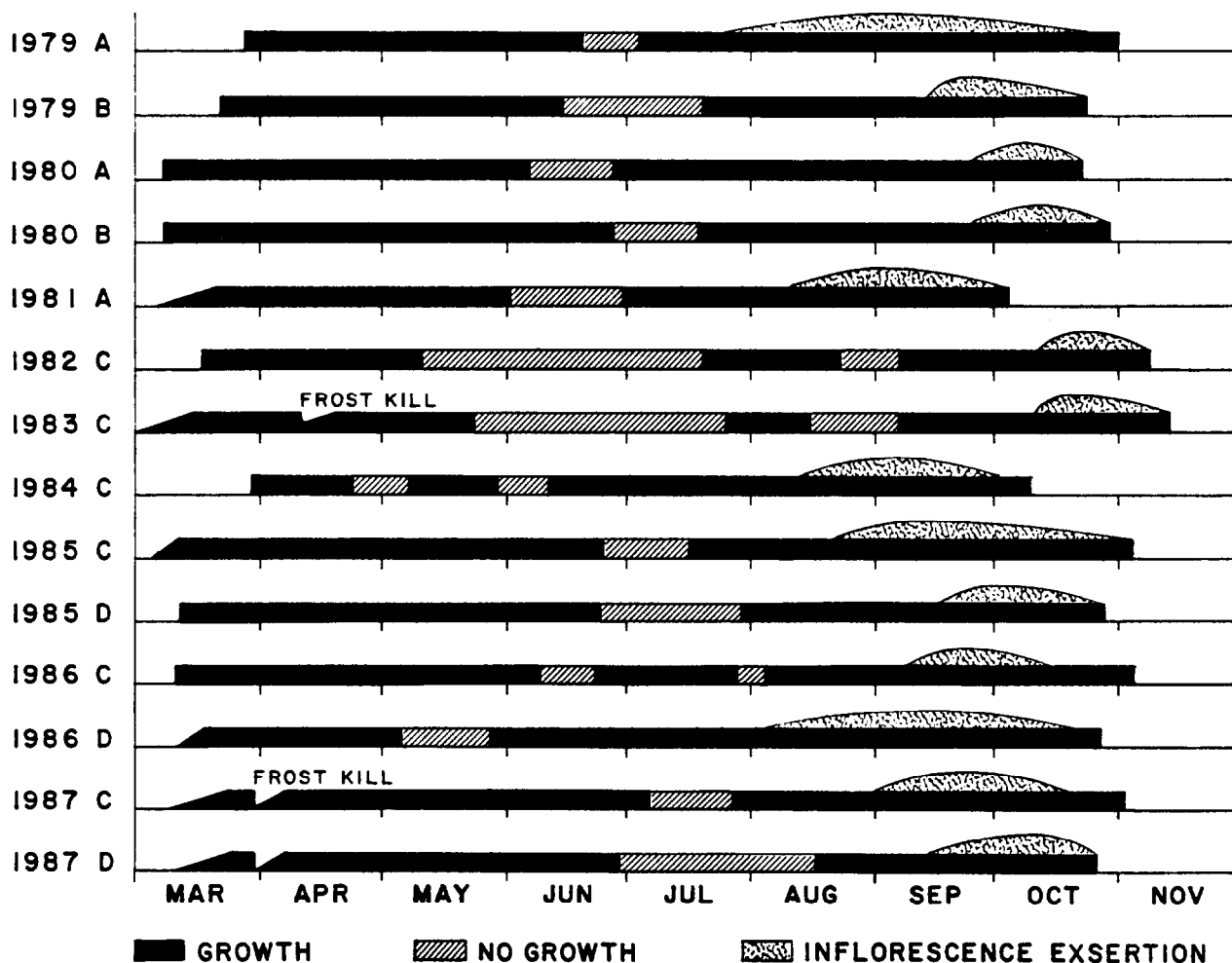


Fig. 1. Periods of growth, no-growth and inflorescence exertion for mesa dropseed during a 9-year period at 4 sites in southern New Mexico. All plants did not have emerged culms until growth bars achieve full width. Period of maximum inflorescence exertion is indicated by maximum bar width.

or the growing point damaged by insects, a new culm was marked. This meant that the number of culms from which an average weekly growth increment could be obtained was usually less than 20. The level of herbivory was so high that rarely was it possible to observe a given culm throughout the season.

Belfort, weighing-type, recording-rain gauges were maintained at all study sites. Correlation and regression analyses were used to determine relationships between accumulated weekly height increments, accumulated weekly increases in number of leaves, and accumulated weekly precipitation. Statistical significance was assumed at  $P \leq 0.05$ . The rainfall accumulation period extended from the day following one plant measurement date up to and including the next measurement date. To see if there was a delay in plant response to rainfall inputs, the rainfall accumulation period was lagged from 1 through 5 days, i.e., the last day of rainfall accumulation was the day prior to plant measurements, 2 days prior to measurement, etc., up to 5 days (the minimum measurement interval).

## Results and Discussion

New tillers or culms of mesa dropseed usually originated from basal buds below ground level, although occasionally a bud at an elevated node initiated a new culm. New culms usually began to appear during the first week of March but there was considerable variation among plants and years. For example, in 1980 all marked plants had emerged culms on 7 March; in 1983, 55% of marked plants had emerged culms on 1 March but not all plants until 14 March. In 1987, new culms were present on 50% of the plants on 9 March but culms did not emerge on all plants until 23 March (Fig. 1). Minimum temperatures were often below freezing in March, and in 1983 50% of marked culms were killed by frost (Fig. 1). On 30 March 1987, the minimum temperature recorded at the JER headquarters was  $-9^{\circ}\text{C}$  (NOAA 1987). All culms were killed by the freeze (Fig. 1) but the plants immediately initiated new culms and a new set was marked for observation on 6 April.

There was a great deal of variability in precipitation within and among years and among sites (Table 1). One might expect that

**Table 1.** Precipitation during December to February and during March to November at the study sites in southern New Mexico.

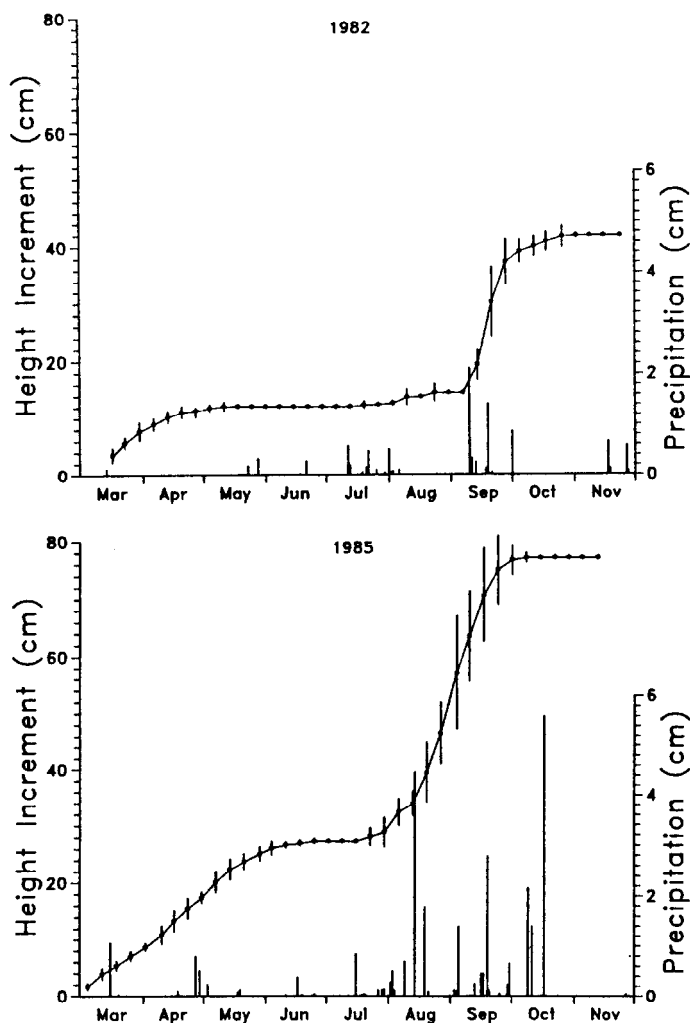
Year	Site	Dec-Feb	Mar-Nov
		- mm -	
1979	A	61	203
1979	B	60	165
1980	A	40	186
1980	B	73	139
1981	A	26	235
1982	C	16	99
1983	C	76	161
1984	C	8	297
1985	C	77	289
1985	D	99	232
1986	C	10	268
1986	D	12	308
1987	C	54	243
1987	D	56	148

winter precipitation (December to February) would have some effect upon spring growth. However, regression of accumulated leaf and height increments upon December–February precipitation at 4, 6, and 8 weeks following culm initiation revealed a very weak relationship ( $P \geq 0.05$ ). Coefficients of determination ( $R^2$ ) for height did not exceed 0.1 and number of leaves present had a maximum  $R^2$  of 0.18 at 8 weeks.

Precipitation during the growing season (March to November)

was highly variable among years, ranging from 99 to 308 mm (Table 1). Temporal distribution of precipitation within seasons varied greatly and had a pronounced effect upon the growth of mesa dropseed. In every year there were periods when growth of the plants was arrested, apparently by lack of soil water. Among years, the periods of arrested growth varied widely and occurred from April through September, although they were concentrated in June and July (Fig. 1). No-growth periods were especially pronounced in 1982 and 1983, when they totaled 86 and 87 days, respectively. In 1982, during the 10 May–19 July period, 55% of the study plants had no green culms for part of the period and the plants were essentially dormant. This early drought was broken by a series of small rainfall events (none larger than 6 mm) which began on 21 July and continued intermittently until 5 August. Rapid growth did not occur until after a 21-mm rainfall event on 9 September. In 1983, rapid growth did not occur until after precipitation events of 4 and 15 mm on 7 and 9 September, respectively. The effect of individual rainfall events upon height growth of mesa dropseed is illustrated in Fig. 2 for a relatively dry (1982) and wet (1985) year.

For all years and sites, growth was most rapid after rainfall events  $>13$  mm. Studies of soil water regimes of loamy sands and sandy loams on the JER showed that daily precipitation  $<13$  mm



**Fig. 2.** Accumulated weekly height increments of mesa dropseed and daily precipitation during a relatively dry (1982) and wet (1985) year. Vertical lines on height curves denote  $\pm 1$  standard deviation.



did not contribute to soil water at depths >10 cm (Herbel and Gibbens 1987). Thus, it appears that mesa dropseed growth is most rapid following rainfall events which will supply soil water at depths below 10 cm. Chu et al. (1979) showed that a perennial form of *Bromus catharticus* Vahl. subjected to water deficits lasting 10 to 28 days produced 48% more leaves than controls which were watered daily. The rapid growth rates of mesa dropseed following major rainfall events indicate a similar response may occur.

Typically, the first leaf produced on a mesa dropseed culm was short (0.7 to 5 cm) and the leaves became progressively longer (up to 40 cm) until the 4th or 5th leaf was produced. The number of leaves on culms producing inflorescences varied from 4 to 15 but the mode was 7. The first leaves to emerge usually died by mid-season and it was not unusual for all leaves to die by the time the inflorescence had completed exertion. An example of the cumulative weekly leaf increment and the percentage of dead (or missing) leaves is shown in Figure 3. The bimodal curve of dead leaf percentage is typical; the percentage of dead leaves increases during

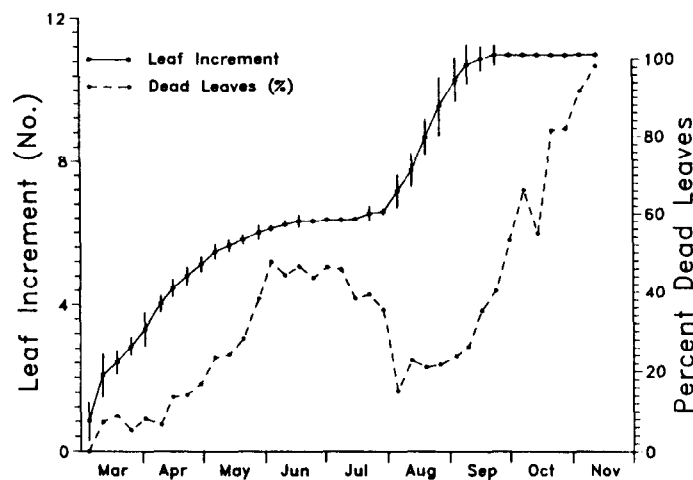


Fig. 3. Accumulated weekly leaf increments and percentage of dry (or missing) leaves of mesa dropseed in southern New Mexico at each sampling date in 1985. The decline in percentage of dry leaves in October was caused by the loss of culms to herbivory and the substitution of culms with different numbers of leaves rather than to production of new leaves. Vertical lines on height curve denote  $\pm 1$  standard deviation.

no-growth periods, declines during periods of rapid growth, and then increases until the end of the season. Rains that fell in late October or November did not result in new leaf production, even on vegetative culms. Late rains did slow leaf drying and green tissue persisted longer in years when such rains occurred.

No attempt was made to determine when growing points changed from the vegetative phase to the reproductive phase. In several perennial grasses, e.g., big bluestem (*Andropogon gerardii* Vitman) and switchgrass (*Panicum virgatum* L.), this transition occurs several weeks before inflorescences begin to exert from subtending sheaths (Rice 1950). Inflorescence exertion began as early as 24 July (1979, site A) and as late as 11 October (1982, site C) (Fig. 1). There was a large difference in inflorescence emergence times between A and B in 1979 (Fig. 1). Site B received 38 mm less rainfall than site A (Table 1). Also, site B, which had been sprayed with 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] for mesquite control in 1975, 1976, and 1977, developed an extremely dense stand of annuals in 1979, and I believe the competition for soil water possibly contributed to the delay in inflorescence exertion. Annuals were not abundant at site A.

Usually only 1 inflorescence was produced per culm although occasionally 1 or 2 secondary inflorescences were produced. This

occurred only in years with favorable rainfall patterns, e.g., 1985, when about 10% of the culms produced secondary inflorescences. Nodes from which secondary inflorescences originated varied from 3 to 11 but the most common nodes of origin were 4, 5, and 6. In dry years, e.g., 1982 and 1983, few culms produced inflorescences and none exerted fully. Growing conditions determine whether vegetative or reproductive parts are produced by developing phytomers (Evans 1940). Mesa dropseed responded similarly to Arizona cottontop [*Trichachne californica* (Benth.) Chase] (Cable 1971), continuing to producing inflorescences late in the fall, if soil water was available. Most of the late season inflorescences did not fully exert.

Flowering usually began 4 to 5 days after inflorescences began to exert. Weekly observations were not sufficiently frequent to fully document flowering periods. It was not unusual for seeds to be formed on the upper part of an inflorescence before the lower inflorescence branches had exerted. Seed shatter was usually completed on all inflorescences by mid-to-late November.

Correlation coefficients between accumulated weekly rainfall and accumulated height and leaf indices were significant ( $P \leq 0.05$ ) and relatively high (Table 2). This emphasizes the dependence of

Table 2. Correlation coefficients ( $r$ ) for correlations between accumulated weekly leaf increment and accumulated weekly precipitation and between accumulated culm height and accumulated weekly precipitation for mesa dropseed in southern New Mexico. Number of weeks included in analyses are given.

Year	Site	Weeks	Accumulated leaf index	Accumulated culm height
- r -				
1979	A	29	0.95	0.97
1979	B	29	0.84	0.81
1980	A	34	0.79	0.83
1980	B	34	0.89	0.96
1981	A	31	0.97	0.96
1982	C	35	0.93	0.95
1983	C	38	0.92	0.91
1984	C	29	0.98	0.96
1985	C	36	0.89	0.95
1985	D	34	0.95	0.96
1986	C	35	0.96	0.95
1986	D	34	0.98	0.98
1987	C	35	0.94	0.92
1987	D	34	0.91	0.87

plant growth upon summer rainfall. The relatively low correlation coefficients for site B in 1979 may have resulted from the competition from annual plants mentioned above. The low correlation coefficients for site A in 1980 may have resulted from the lack of large rainfall events. During July, August, and September 1980 the largest daily rainfall amount was 10 mm. In other words, there were no rainfall events that caused a marked increase in plant growth rate. When rainfall accumulation periods were lagged 1 to 5 days the maximum increase in correlation coefficients was only 0.02, indicating that plant response to rainfall inputs was quite rapid.

## Conclusions and Management Implications

To be successful in the environment of the northern Chihuahuan Desert, a species must be able to cope with extended periods of intra-seasonal drought. The temporal plasticity of mesa dropseed phenology indicates that it is well adapted to its environment. Although growth responses in wet and dry years were compared in this study, it must be emphasized that both wet and dry years are part of the normal, long-term weather pattern in the northern

## Chihuahuan Desert.

Livestock graze mesa dropseed throughout the year but only during the green forage period is protein content high enough to meet animal requirements (Nelson et al. 1970). The spring months in the northern Chihuahuan Desert are often a period of critical shortage of green forage for grazing animals (Paulsen and Ares 1962). Although mesa dropseed begins growth early in the spring, it does not provide much available forage because the first leaves are relatively short and often protected by culms of the previous season. Also, as shown by this study, there is a high frequency of drought-induced periods of no-growth during spring and early summer. Thus, range managers cannot count on mesa dropseed as a forage resource until 1 or 2 weeks after significant rainfall events (>13 mm). To take full advantage of mesa dropseed forage, range managers need to pay close attention to the temporal and spatial distribution of summer rains and adjust stocking density and distribution accordingly. The goal should be to utilize mesa dropseed as much as possible consistent with maintaining plant vigor and permitting some seed production because, in the long-term, it is a transient forage resource. Severe droughts, such as occurred in the 1950's, result in the virtual disappearance of mesa dropseed on many sites; however, mesa dropseed reproduces readily from seed and can recover quickly from droughts (Herbel et al. 1972).

## Literature Cited

- Abbe, C. 1905. A first report on the relations between climates and crops. USDA Bull. 36, Weather Bur. 342.
- Ahlgren, C.E. 1957. Phenological observations of nineteen native tree species. Ecology 38:622-628.
- Ahshapanek, D. 1962. Phenology of a native tall-grass prairie in central Oklahoma. Ecology 43:135-138.
- Beatley, J.C. 1974. Phenological events and their environmental triggers in Mojave Desert ecosystems. Ecology 55:856-863.
- Buffington, L.C., and C.H. Herbel. 1965. Vegetation changes on a semidesert grassland range from 1858 to 1963. Ecol. Mongr. 35:139-164.
- Bullock, H.E., Jr., and R.E. Neher. 1980. Soil survey of Dona Ana County area of New Mexico. SCS, USDA in cooperation with BLM and New Mexico Agr. Exp. Sta.
- Cable, D.R. 1971. Growth and development of Arizona cottontop [*Trichachne californica* (Benth.) Chase]. Bot. Gaz. 132:119-145.
- Caprio, J.M. 1966. Pattern of plant development in the western United States. Montana Agr. Exp. Sta. Bull. 607.
- Caprio, J.M. 1971. The solar-thermal unit theory in relation to plant development and potential evapotranspiration. Montana Agr. Exp. Sta. Circ. 251.
- Chu, A.C.P., H.G. McPherson, and G. Halligan. 1979. Recovery growth following water deficits of different duration in prairie grass. Australian J. Plant Physiol. 6:255-263.
- Costello, D.F. 1939. Weather and plant-development data as determinants of grazing periods on mountain range. USDA Tech. Bull. 1190.
- Dickinson, C.E., and J.L. Dodd. 1976. Phenological pattern in the short-grass prairie. Amer. Midl. Natur. 96:367-378.
- Evans, M.W. 1940. Developmental morphology of the growing point of the shoot and the inflorescence in grasses. J. Agr. Res. 61:481-520.
- Finnerty, D.W., and D.L. Klingman. 1962. Life cycles and control studies of some weed bromegrasses. Weeds 10:40-47.
- Frank, A.B., and L. Hofmann. 1989. Relationship among grazing management, growing degree-days and morphological development for native grasses on the Northern Great Plains. J. Range Manage. 42:199-202.
- Gilbert, E.F. 1961. Phenology of sumacs. Amer. Midl. Natur. 66:286-300.
- Haun, J.R. 1973. Visual quantification of wheat development. Agron. J. 65:116-119.
- Herbel, C.H., F.N. Ares, and R.A. Wright. 1972. Drought effects on a semidesert grassland range. Ecology 53:1084-1093.
- Herbel, C.H., and R.P. Gibbens. 1987. Soil water regimes of loamy sands and sandy loams on arid rangelands in southern New Mexico. J. Soil and Water Conserv. 42:442-447.
- Hulbert, L.C. 1963. Gates' phenological record of 132 plants at Manhattan, Kansas, 1926-1995. Kans. Acad. Sci. 66:82-106.
- Hyder, D.N., F.A. Sneva, and V.H. Freed. 1962. Susceptibility of big sagebrush and green rabbitbrush to 2,4-D as related to certain environmental, phenological, and physiological conditions. Weeds 10:288-295.
- Lieth, H., and J.S. Radford. 1971. Phenology, resource management, and syngraphic computer mapper. Bioscience 21:62-69.
- McCarty, M.K. 1986. A fifteen-year phenological record of pasture plants near Lincoln, Nebraska. Weed Sci. 34:218-224.
- McCarty, M.K., and C.J. Scifres. 1969. Life cycle studies with musk thistle. Nebraska Agr. Exp. Sta. Res. Bull. 230.
- National Oceanic and Atmospheric Administration. 1987. Climatological data, New Mexico, March. Vol. 91, No. 3.
- Nelson, A.B., C.H. Herbel, and H.M. Jackson. 1970. Chemical composition of forage species grazed by cattle on an arid New Mexico range. New Mexico State Univ., Agr. Exp. Sta. Bull. 561.
- Paulsen, H.A., Jr., and F.N. Ares. 1962. Grazing values and management of black grama and tobosa grasslands and associated shrub ranges of the Southwest. USDA, Forest Service Tech. Bull. 1270.
- Rice, E.L. 1950. Growth and development of five species of range grasses in central Oklahoma. Bot. Gaz. 111:361-377.
- Roundy, B.A., J.A. Young, and R.A. Evans. 1981. Phenology of salt rabbitbrush (*Chrysanthemum nauseosum* ssp. *consimilis*) and greasewood (*Sarcobatus vermiculatus*). Weed Sci. 29:448-454.
- Thornthwaite, C.W. 1952. Climate in relation to planting and irrigation of vegetable crops. p. 290-295. In: Proc. VIIIth Gen. Assem.-XVIIth Congr. Internat. Geographical Union, Washington, D.C.
- Went, F.W. 1949. Ecology of desert plants. II. The effect of rain and temperature on germination and growth. Ecology 30:1-13.
- West, N.E., and R.W. Wein. 1971. A plant phenological index technique. Bioscience 21:116-117.
- White, L.M. 1979. Relationship between meteorological measurements and flowering of index species to flowering of 53 plant species. Agr. Meteorol. 20:189-204.
- Young, J.A., and R.A. Evans. 1974. Phenology of *Chrysanthemum viscidiflorum* subspecies *viscidiflorum* (Hook.) Nutt. Weed Sci. 22:469-475.

## Technical Notes

# A technique to determine seed location in relation to seedbed preparation treatments

VON K. WINKEL AND BRUCE A. ROUNDY

### Abstract

Distribution of seeds buried by different seedbed preparation techniques can be determined by seeding small plots at a high rate, wetting the soil and extracting soil cores in plastic vials. Seeds can be located with a dissecting scope when cores are split in half. Although the technique may slightly underestimate the percentage of small buried seeds like those of Lehmann lovegrass (*Eragrostis lehmanniana* Nees), it permits the analysis of large numbers of samples.

**Key Words:** seed placement, seedbed preparation, seed depth, seed burial, revegetation

Artificial seeding of semiarid rangelands is often unsuccessful partly because of limited understanding of the response of seeds to different seedbeds. Of particular interest is the effect of seedbed preparation treatments on seed placement, and the location of seeds that produce emergent seedlings. Seeds buried too deeply may not produce emergent seedlings. In contrast, seeds buried too shallow may also fail to produce seedlings due to limited soil water.

Several seed location techniques are used. Most are used to determine total populations of viable seeds in the seedbank (Malone 1967, Jerling 1983, Staaf et al. 1987), or numbers of seeds at various depths in the seedbed (Moore and Wein 1977, Fay and Olson 1978, Granstrom 1982, Pareja et al. 1985). Other methods are used to determine numbers of seeds that survive (Archibold 1979) or are stimulated to germinate or emerge by various cultural treatments (Wesson and Wareing 1969). Interest has recently developed in assessing the accuracy of seed placement by drills (Choudhary et al. 1985, Kaviani et al. 1985).

Most seed location techniques involve: (1) germinating seeds from seedbed samples, (2) sieving to isolate seeds, (3) tracing seedlings to their seeds, and (4) X-raying seedbed samples.

Determining the effects of seedbed preparation techniques on seed placement and seedling emergence requires a seed location technique that determines seed depths with minimal disturbance in fragile seedbeds. The method should be rapid to permit analysis of samples in highly variable seedbeds.

Our objective is to describe a new seed location technique used to help determine the location of seeds after various seedbed preparation treatments on a sandy loam soil in southern Arizona, and show evidence of its accuracy as an estimator of seed location.

### New Technique

Plots 1 m<sup>2</sup> in area were broadcast seeded to cover the surface with a single layer of seeds of either 'Vaughn' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), 'A-130' blue panic (*Panicum antidotale* Retz.), 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees) or 'Cochise' atherstone lovegrass (*Eragrostis lehmanniana* Nees × *E. tricolor* Coss and Dur.). Plots were then treated with heavy cattle trampling (herding 5 cattle around a 6-m<sup>2</sup>

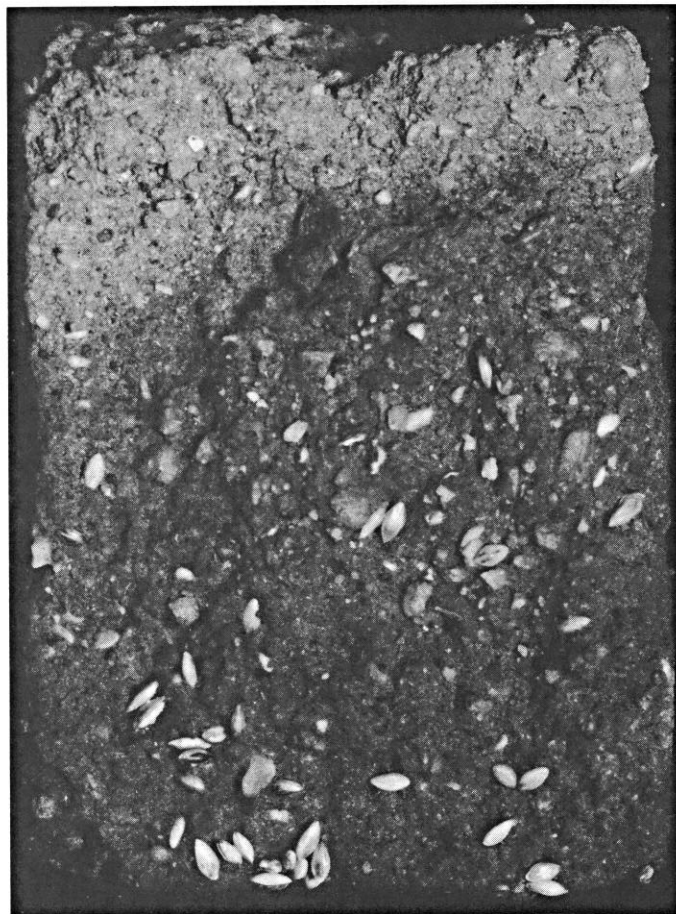


Fig. 1. View of split soil plug showing blue panic seeds (3X).

paddock for 20 minutes), light cattle trampling (approximately 10 hoof prints per m<sup>2</sup>), land imprinting, root plowing or ripping, or left undisturbed. Plots that were imprinted or lightly or heavily trampled by cattle were seeded before treatment, while plowed or ripped plots were seeded after plowing or ripping. The soil was a sandy loam (fine, mixed, thermic Ustollic Haplargid). Plots were sampled after treatment when the soil was dry by protecting the seedbed with a layer of cotton cloth and then sprinkling the sample area with water until the soil was saturated to 3 to 5 cm. Plots were also sampled after rain when the soil water content was near field capacity. Soil plugs were collected by inserting a 3.5-cm diameter by 6-cm high plastic vial into the seedbed. The vial was extracted from the soil, capped, immersed in liquid nitrogen until the soil was frozen (10–20 seconds) and placed in an ice chest lined with dry ice for transport to a freezer. Freezing the soil plugs has the potential to move seeds slightly and therefore is recommended only to minimize disturbance during transport.

In the laboratory, each frozen soil plug was placed upright in a shallow water bath for about 2 minutes until it slid easily from the

Authors are former graduate research associate and associate professor, School of Renewable Natural Resources, University of Arizona, Tucson 85721. Winkel is currently scientist EG and G Energy Measurements, P.O. Box 1912 M/S P-03, Las Vegas, Nevada 89125.

Research was funded by USDA Rangeland Research Grants program. Published as Arizona Agricultural Experiment Station Paper.

Manuscript accepted 15 March 1990.

vial. After thawing, each plug was carefully split in half with a micro spatula. Each half was then placed in a cradle made from a plastic vial cut in half, and the cradle was placed in a soil plug holder. The holder was placed under a dissecting scope, the outline of each soil plug was drawn on a plastic transparency and each visible seed was located and marked on the transparency (Fig. 1).

Seed depth was determined by measuring the distance from the seed to the soil surface. The data were recorded as percent of seeds found at particular depths in the seedbed.

Ease in locating seeds in the plugs was dependent upon seed size. Sideoats grama and blue panic seeds ( $5 \times 1$  mm. and  $2 \times 1$  mm) were easily seen under a lighted magnifying glass or dissecting scope set at 10 power. Lehmann and Cochise lovegrass seeds ( $0.75 \times 0.5$  mm) required a dissecting scope set at 20 to 30 power. Because buried seeds were often obscured by soil, numbers of buried seeds in relation to surface seeds could have been slightly underestimated.

The technique was used during the summers of 1987 and 1988. Approximately 1,440 soil plugs were collected during each year. Plugs were collected immediately after seedbed preparation, after summer thunderstorms, and after seedling emergence. A crew of 3 to 4 people collected approximately 500 plugs in about 4 hours. In the laboratory, each plug was analyzed in about 10 minutes. Approximate cost per plug including labor was \$1.00. The technique permitted quantification of depth of seed burial and seedling emergence. This information was helpful in explaining differences in seedling emergence associated with the different seedbed preparation treatments (Winkel et al. 1991).

#### Technique Test

An experiment was conducted to determine the accuracy with which the method estimated the percent of seeds at different depths. Three wooden boxes  $100 \times 20$  by 10-cm deep were filled with sandy loam soil (fine, mixed, thermic Ustollic Haplargid) passed through a 2-mm sieve. While filling the boxes, seeds of Lehmann lovegrass, blue panic, and sideoats grama, (1 species per box) were spread evenly at 5-mm intervals from 20-mm deep to the soil surface with the following percentages of total seeds: 20 mm, 5%; 15 mm, 10%; 10 mm, 15%; 5 mm, 20%; and the soil surface, 50%. After sowing, the soil was sprinkled with water until saturated and then 20 soil plugs per box from randomly preselected positions were extracted and examined as described above.

Data from the 40 plug halves per box were pooled, and estimated seed percentages from the plugs were compared to the known percentages with correlation analysis. Coefficients of determination ( $r^2$ ) between percentages of known and estimated seeds at different depths of sideoats grama, blue panic, and Lehmann lovegrass were 0.80, 0.72, and 0.92, respectively (Fig. 2). Comparisons of regression lines with 1 to 1 lines indicated that the technique overestimated the percentage of all 3 species on the surface, and underestimated the percentage of all species and particularly Lehmann lovegrass at all other depths (Fig. 2). The small size of Lehmann lovegrass seeds may limit their visual detection and result in underestimation. The seed location technique permitted estimation of the location of ungerminated and germinated seeds of different species in various seedbeds.

Although this technique is impractical for determining seed location for normal seeding rates, its use with extremely high rates can help determine the effects of seedbed preparation treatments on seed burial. Relative seed burial under high seeding rates should be similar to those under normal rates for a given seedbed preparation treatment.

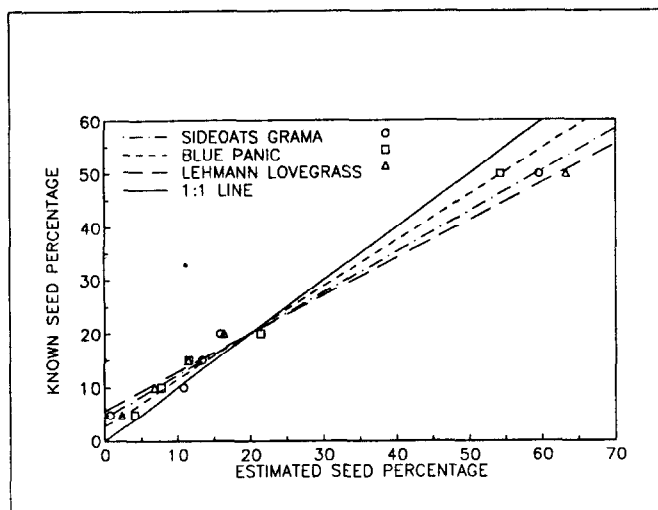


Fig. 2. Linear regressions of estimated percentage of total seeds found on known percentage of total seeds placed at different soil depths for 3 grass species using a vial sampling technique. Each symbol is the mean of 20 samples. Coefficients of determination ( $r^2$ ) for sideoats grama, blue panic and Lehmann lovegrass were 0.80, 0.72 and 0.92, respectively. Regression equations for sideoats grama, blue panic, and Lehmann lovegrass are  $Y = 0.77(X) + 4.58$ ,  $Y = 0.87(X) + 2.85$  and  $Y = 0.71(X) + 5.78$ , respectively.

#### Literature Cited

- Archibold, O.W. 1979. Buried viable propagules as a factor in postfire regeneration in northern Saskatchewan. *Can. J. Bot.* 57:54-58.
- Choudhary, M.A., G.P. Yu, and C.J. Baker. 1985. Seed placement effects on seedling establishment in direct-drilled fields. *Soil Till. Res.* 6:79-93.
- Fay, P.K., and W.A. Olson. 1978. Technique for separating weed seed from soil. *Weed Sci.* 26:530-533.
- Granstrom, A. 1982. Seed banks in five boreal forest stands originating between 1810 and 1963. *Can. J. Bot.* 60:1815-1821.
- Jerling, L. 1983. Composition and viability of the seed bank along a successional gradient on a Baltic sea shore meadow. *Holarctic Ecol.* 6:150-156.
- Kaviani, N., R.N. Gibbs, and R.F. Horrell. 1985. Seed placement measuring technique for direct drilling machines—a note. *New Zealand J. Exp. Agr.* 13:191-194.
- Malone, C.R. 1967. A rapid method for enumeration of viable seeds in soil. *Weed Sci.* 15:381-382.
- Moore, J.M., and R.W. Wein. 1977. Viable seed populations by soil depth and potential site recolonization after disturbance. *Can. J. Bot.* 55:2408-2412.
- Pareja, M.R., D.W. Stanforth, and G.P. Pareja. 1985. Disturbance of weed seed among soil structural units. *Weed Sci.* 33:182-189.
- Staaf, H., M. Jonsson, and L. Olsen. 1987. Buried germinative seeds in mature beech forests with different herbaceous vegetation and soil types. *Holarctic Ecol.* 10:268-277.
- Wesson, G., and P.F. Wareing. 1969. The role of light in the germination of naturally occurring populations of buried weed seeds. *J. Exp. Bot.* 20:402-413.
- Winkel, V.K., B.A. Roundy, and D.K. Blough. 1991. Effects of seedbed preparation and cattle trampling on burial of grass seeds. *J. Range Manage.* 44:(In Press).

# Book Reviews

## **Terroirs Pastoraux et Agropastoraux en Zone Tropicale.**

1987. Gestion, aménagements et intensification fourragère Audru J., Boudet G., Cesar J., Dulieu D., Gaston A., Mandret G., Merlin P., Rippstein G., Roberge G., Tournain B. (Tropical Zone pastoral and agro pastoral lands-administration, management and forage enhancement) Institut d'Elevage et de Médecine Vétérinaire des Pays Tropicaux. Département du Centre de Coopération Internationale en Recherche Agronomique pour le Développement. 48 pp.

This is a collection of eleven articles summarizing the results and ideas developed during several years of range study, mostly in the area formerly known as French West Africa. Lacking an overall editor, the accounts are uneven though inter-connected. Some, such as one on "Continuous monitoring of tropical pastoral ecosystems," are brief and quite superficial—there is nothing new in the assertion that continuous monitoring is a tool contributing to technology transfer from research to range management. Others are quite detailed and specific, for example "Natural pastures in the humid tropics," which proposes a 3- or 4-year burning cycle to control woody invaders and over-sowing with *Andropogon gayanus* to improve forage yields and ground cover.

The other titles are:—

Sahelian pastoral lands: our present understanding and management; Enhanced forage production and irrigation in the dry tropics; Natural rangelands in arid East Africa-Djibouti; Pasture improvements in the Djibouti *Hyphaene tebaica* (palm) stands; Natural pastures in the humid tropics; Forage enhancement in sub-humid northern Ivory Coast; Forage enhancement of the humid tropical plateaux; Invasion of high-elevation pastures in north-west Cameroon by *Pteridium aquilinum* (bracken) and its eradication; Pasture improvement in the Pacific islands; and Forage resources and stock-raising in Asia

Each article is supported by a substantial bibliography but many of the references are to sources which would be very difficult to access. The average librarian in North America will have trouble with B.D.P.A.-B.C.O.M. Paris for example. This use of unexplained acronyms is not helpful. The authors do not make much use of the considerable body of relevant literature from east, central, and southern Africa.

There is a brief English language summary of each article, but they have unfortunately been written in very stilted English so that I found the original French easier to comprehend than the translations—thus "trials rehabilitation of some rangelands...to save the environment of places in setting process are described ..." gives one cause to wonder.

For the researcher or practitioner working in North America, this book has little of direct value. It will, however, be useful reading for anyone contemplating development or extension work in Sahelian Africa or elsewhere. Not least of its merits is the emphasis on local perspectives and involvement of local peoples in proposed developments.

(I can provide translations on request).—*R.M. Strang*

**Rangelands. 1988.** Edited by Bruce A. Buchanan. University of New Mexico Press, Albuquerque. 89 p. U.S. \$22.50.

*Rangelands* is a collection of six essays, one describing past, present, and future trends in rangeland management and research, and five others providing similar philosophical chronologies of the subdisciplines of grazing management, watershed management,

wildlife management, plant manipulation and rangeland economics. The compilation was likely conceived as a summary of trends in range science and management. The essays are generally informative and when considered collectively, they cover the major aspects of work on rangelands.

There is no hint in the introduction for whom these essays are intended. Most are written in layman's language with much technical jargon eliminated. The essay on wildlife habitat is more technical, is somewhat incongruous, and contains a discourse on applying dietary overlap percentages to calculate animal-unit equivalents which I believe is ill-conceived (see *J. Range Manage.*, 39:471.). The range economics essay contains interesting data on trends in ranching. As the last essay, it seems annexed in much the unfortunate way that, as the authors point out, economics research is often attached posteriorly to range research.

The essay format is demanding of authors, because of the history of fine writing in the genre. Ideally, an essay should be revelational, beyond informational, with abundant wit to increase palatability. All the essays of *Rangelands* are written more in the style of scientific papers, a style only informational, and mostly lacking in the wit which the essay format demands. The resulting collection will be technically enlightening to some readers, but will likely be found stylistically arid by most.—*David L. Scarnecchia*, Washington State University, Pullman

**Rangeland Management in Pakistan. 1989.** Noor Mohammad. International Centre for Integrated Mountain Development, Kathmandu, Nepal. 193 p.

This book is a welcome addition to the available literature concerning range management in Asia. Some of the contents will also be useful to land managers in Africa and the Middle East.

In essence, *Rangeland Management in Pakistan*, is organized as a textbook and should have general appeal to undergraduate students and government officials in Pakistan, and to practicing land managers involved in international activities. It is well organized and proceeds in a logical sequence from plant resources to livestock production. I am privileged to have visited many of the study sites.

The book is divided into eight chapters. The chapters I found particularly interesting were Range Resources, Range Improvements, and three chapters (5, 7, and 8) dealing with grazing problems. The interactions of human and livestock populations, and their effects in ecological change are also presented. The author emphasizes the importance of grassland restoration and stresses the need to control progressive desertification.

Photographs and tables are generally clear, and in most cases, plant community and animal photographs are matched with the text. More vegetation photographs would be desirable because these rangelands are infrequently observed by land managers outside Pakistan.—*Jerry R. Cox*, USDA, Agricultural Research Service, Tucson, Arizona.

# INSTRUCTIONS FOR AUTHORS (from revised *Handbook and Style Manual*)

## Eligibility

The *Journal of Range Management* is a publication for reporting and documenting results of original research and selected invitational papers. Previously published papers are unacceptable and will not be considered for publication. Exceptions to this criterion are research results that were originally published as department research summaries, field station reports, abstracts of presentations, and other obscure and nontechnical handout publications. Manuscripts submitted to the *JRM* are the property of the *Journal* until published or released back to the author(s). Manuscripts may not be submitted elsewhere while they are being considered for this journal. Papers not accepted for publication are automatically released to the authors.

## Kinds of Manuscripts

*Journal Articles* report original findings in Plant Physiology, Animal Nutrition, Ecology, Economics, Hydrology, Wildlife Habitat, Methodology, Taxonomy, Grazing Management, Soils, Land Reclamation (reseeding) and Range Improvement (fire, mechanical chemical). *Technical Notes* are short articles (usually less than two printed pages) reporting unique apparatus and experimental techniques. By invitation of the Editorial Board, a *Review* or *Synthesis Paper* may be printed in the journal. *Viewpoint* articles or *Research Observations* discussing opinion or philosophical concepts regarding topical material or observational data are acceptable. Such articles are identified by the word *viewpoint* or *observations* in the title.

## Manuscript Submission

Contributions are addressed to the Editor, Gary Frasier, *Journal of Range Management* USDA-ARS, Crops Research Laboratory, 1701 Center Ave., Fort Collins, 80526. Manuscripts are to be prepared according to the instructions in this handbook. If the manuscript is to be one of a series, the Editor must be notified. Four copies of the complete manuscript, typed on paper with numbered line spaces, are required. Authors may retain original tables and figures until the paper is accepted, and send good quality photocopies for the review process. Receipt of all manuscripts is acknowledged at once, and authors are informed about subsequent steps of review, approval or release, and publication.

Manuscripts that do not follow the directives and style in *Journal* handbook will be returned to the authors before being reviewed. A manuscript number and submission date will be assigned when the paper is received in the appropriate format.

## Manuscript Review

Manuscripts are forwarded to an Associate Editor, who usually obtains two or more additional reviews. Reviewers remain anonymous. These reviews have the major responsibility for critical evaluation to determine whether or not a manuscript meets scientific and literary standards. Where reviewers disagree, the Associate Editor, at his discretion, may obtain additional reviews before accepting or rejecting a manuscript. The Associate Editor may also elect to return to the author those manuscripts that require revision to meet format criteria before the *Journal* review.

The Associate Editor sends approved manuscripts, with recommendations for publication, to the Editor, who notifies the author of a projected publication date. Manuscripts found inappropriate for the *JRM* are released to the author by the Associate Editor. Manuscripts returned to an author for revision are *returned to the*

*Associate Editor for final acceptability of the revision*. Revisions not returned within 6 months, are considered terminated. Authors who consider that their manuscript has received an unsatisfactory review may file an appeal with the Editor. The Editor then may select another Associate Editor to review the appeal. The Associate Editor reviewing the appeal will be provided with copies of all correspondence relating to the original review of the manuscript. If the appeal is sustained, a new review of the manuscript may be implemented at the discretion of the Editor.

Authors should feel free to contact the Associate Editor assigned to their manuscript at any stage of the review process: to find out where the paper is in the process; to ask questions about reviewer comments; to ask for clarification or options if a paper has been rejected.

## Page Proofs

Page proofs are provided to give the author a final opportunity to make corrections of errors caused by editing and production. Authors will be charged when extensive revision is required because of author changes, even if page charges are not assessed for the article. One author per paper will receive page proofs. These are to be returned to the Production Editor, 1839 York Street, Denver, Colorado 80206, within 48 hours after being received. If a problem arises that makes this impossible, authors or their designates are asked to contact the Production Editor immediately, or production and publication may proceed without the author's approval of his edited manuscript.

## Page Charges and Reprint Orders

Authors are expected to pay current page charges. Since most research is funded for publication, it will be assumed that the authors are able to pay charges unless they indicate otherwise in writing, when submitting a manuscript. When funds are unavailable to an author, no page charges will be assessed. Only the Editor will have knowledge of fund status of page charges; the Associate Editors and reviewers will accept or reject a manuscript on content only.

An order form for reprints is sent to one author with the page proofs or shortly thereafter. Information as to price and procedure are provided at that time. The minimum order is 100; no reprints are provided free of charge.

## Basic Writing Style

Every paper should be written accurately, clearly, and concisely. It should lead the reader from a clear statement of purpose through materials and methods, results, and to discussion. The data should be reported in coherent sequence, with a sufficient number of tables, drawings, and photographs to clarify the text and to reduce the amount of discussion. Tables, graphs and narrative should not duplicate each other.

Authors should have manuscriptous data and will speed *JRM* review processes.

Particular attention should be given to literature cited: names of authors, date of publication, abbreviations or names of journals, titles, volumes, and page numbers.

It is not the task of Associate Editors or *Journal* reviewers to edit poorly prepared papers or to correct readily detectable errors. Papers not properly prepared will be returned to the author.

Each author agrees that the material furnished for the *Journal* has not been published previously elsewhere.

The corresponding author will be given an opportunity to read and correct the edited manuscript as page proofs, but if he fails to return pages proofs to the editor of the *Journal* within the time specified by the editor, production and publication may proceed without the author's approval of his edited manuscript.

The author(s) will receive no monetary return from the Society for the use of material contained in the manuscript.

I(we) agree to the foregoing terms:

Author (print or type) \_\_\_\_\_ Date \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

Author (print or type) \_\_\_\_\_ Date \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

Author (print or type) \_\_\_\_\_ Date \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

Author (print or type) \_\_\_\_\_ Date \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

Author (print or type) \_\_\_\_\_ Date \_\_\_\_\_

Signature \_\_\_\_\_ Citizen of (country) \_\_\_\_\_

I(we) agree to the foregoing terms except item 7. I(we) am unable to sign a copyright release for reasons stated below:

\_\_\_\_\_

Send this form and 4 copies of manuscript on line-numbered paper to:

Editor  
*Journal of Range Management*  
USDA-ARS  
Crops Research Laboratory  
1701 Center Ave  
Fort Collins, Colorado 80526



***Journal of Range Management***  
**Manuscript Submission and Copyright Release Form**

This form must be completed and submitted with the manuscript. If the manuscript is not accepted for publication, this affidavit shall have no legal effect and may be considered null and void.

PLEASE PRINT

1. Manuscript Title:

---

---

2. Name and Address of Corresponding Author:

Name 

---

 Address 

---

---

---

 Telephone (    ) 

---

3. Membership:

I(we) affirm that at least one of the authors is a current member of the Society for Range Management.

4. Assurance of Content:

I(we) have read this manuscript and I(we) hereby affirm that the content of this manuscript or a major portion thereof has not been published in a refereed journal, and it is not being submitted for publication elsewhere.

5. Section Preference:

- |  |   |
|--|---|
| <input type="checkbox"/> Plant Physiology          | <input type="checkbox"/> Improvements         |
| <input type="checkbox"/> Plant Ecology             | <input type="checkbox"/> Reclamation          |
| <input type="checkbox"/> Animal Ecology            | <input type="checkbox"/> Soils                |
| <input type="checkbox"/> Plant-Animal Interactions | <input type="checkbox"/> Hydrology            |
| <input type="checkbox"/> Grazing Management        | <input type="checkbox"/> Economics            |
| <input type="checkbox"/> Animal Physiology         | <input type="checkbox"/> Measurement/Sampling |

6. Publication Costs:

The current charge for publication is \$60 per printed page in the *Journal* for members for the first 3 printed pages. Page 4 and beyond is \$100/pg. For nonmembers the charge is \$100/pg. Reprints may be ordered. The following agency or individual will be responsible for publication costs:

Name 

---

Address 

---

7. Copyright Release:

*Copyright laws make it necessary for the Society to obtain a release from authors for all materials published. To this end we ask you to grant us all rights, including subsidiary rights, for your article.*

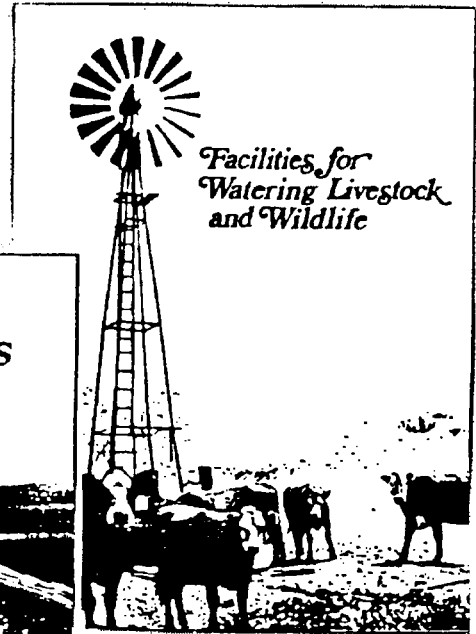
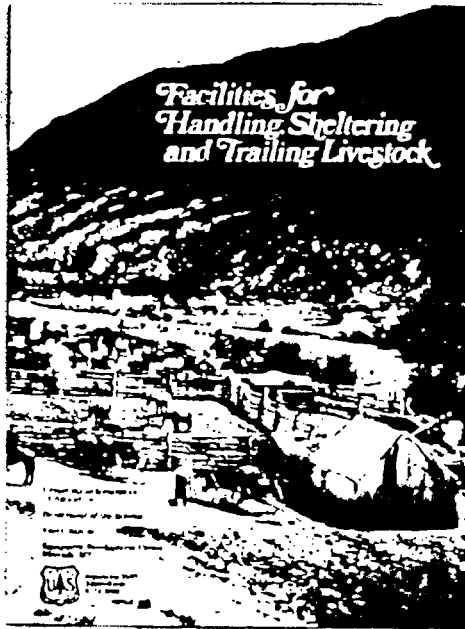
*Whereas the Society is undertaking to publish the *Journal of Range Management*, of which the undersigned is author of one or more parts, the author grants and assigns exclusively to the Society for its use any and all rights of whatsoever kind or nature now or hereafter protected by the copyright laws (common or statutory) of the United States and all foreign countries in all languages in and to the above-named article, including all subsidiary rights. The Society, in turn, grants to the author(s) the right of republication in any book of which he is author or editor, subject only to his giving proper credit in the book to the original *Journal* publication of the article by the Society.*

(OVER)



Now Available through SRM

# Range Handbooks



You've learned the science, now pick up the art of Range Management. Three range handbooks recently published by the U.S. Forest Service, Missoula, Montana, are now available from the Society for Range Management in Denver. Order copies for your professional in range management today.

**Fences (\$10.00)**

**Facilities for Watering Livestock and Wildlife (\$6.00)**

**Facilities for Handling, Sheltering and Trailing Livestock (\$5.00)**

*(Postage additional)*

*Order from:*

**Society for Range Management  
1839 York Street  
Denver, CO 80206  
(303)355-7070**