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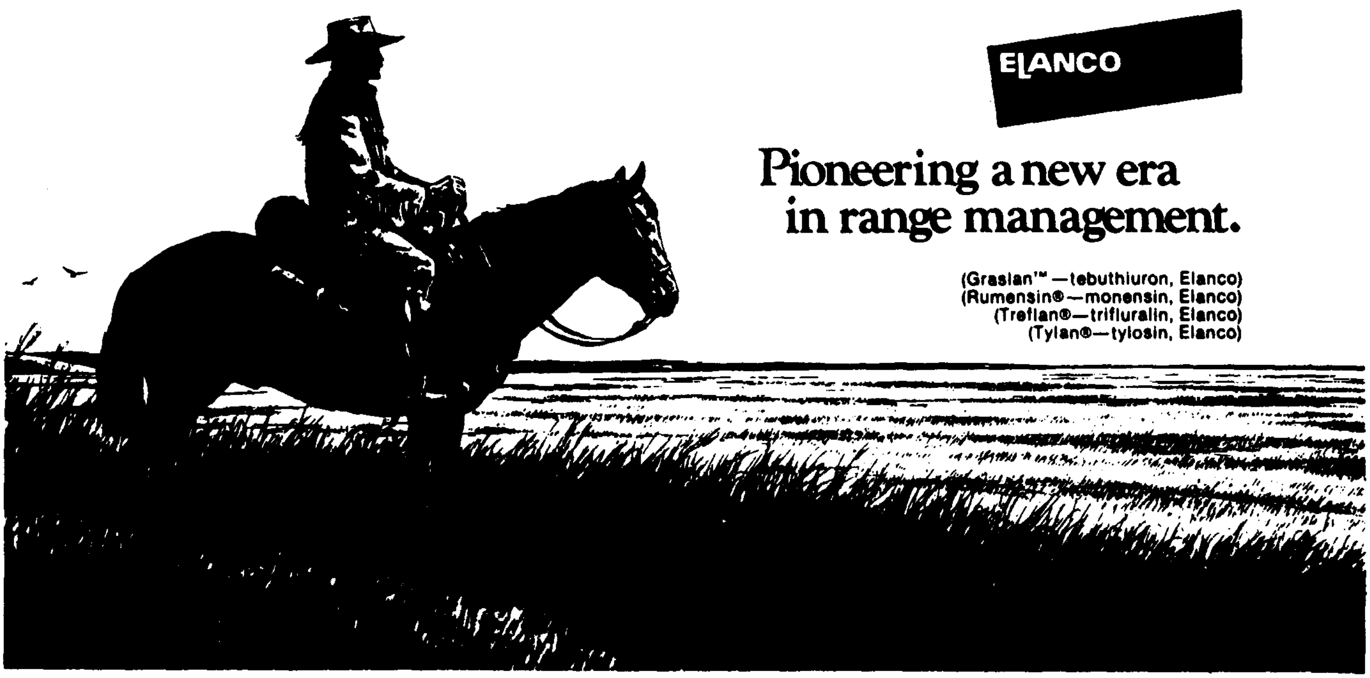
The **Journal of Range Management** serves as a forum for the presentation and discussion of facts, ideas, and philosophies pertaining to the study, management, and use of rangelands and their several resources. Accordingly, all material published herein is signed and reflects the individual views of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



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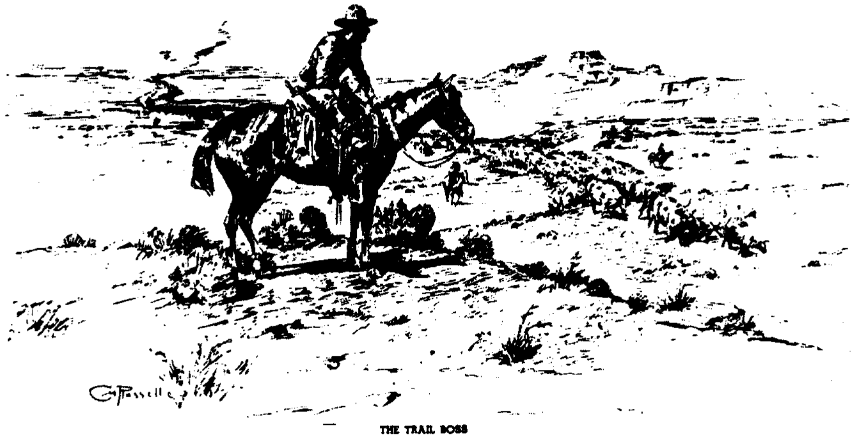

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Impacts of Cattle on Streambanks in Northeastern Oregon

J. BOONE KAUFFMAN, W.C. KRUEGER, AND M. VAVRA

Abstract

Impacts of a late season livestock grazing strategy on streambank erosion, morphology, and undercutting were studied for 2 years along Catherine Creek in northeastern Oregon. Streambank loss, disturbance, and undercutting were compared between grazing treatments, vegetation type, and stream-meander position. No significant differences were found among vegetation types or stream-meander location. Significantly greater streambank erosion and disturbance occurred in grazed areas than in exclosed areas during the 1978 and 1979 grazing periods. Over-winter erosion was not significantly different among treatments. However, erosion related to livestock grazing and trampling was enough to create significantly greater annual streambank losses when compared to ungrazed areas.

Vegetation is an important component of the riparian/stream ecosystem (Campbell and Franklin 1979, Jahn 1978). The effects from livestock grazing in these ecosystems have been shown to vary greatly depending upon the nature of the stream studied. Behnke and Zarn (1976), Dehlem (1979), Duff (1979), Gunderson (1968), and Heede (1977) found livestock grazing and excessive trampling caused a decrease in bank undercuts, increases in channel widths, and a general degradation of fish habitat. Buckhouse et al. (1981), Hayes (1978), and Knight (1978) found that stream channel movement did not occur more frequently in grazed riparian ecosystems than in ungrazed riparian ecosystems.

In 1978 a study was initiated to examine effects of late season cattle grazing in riparian ecosystems that are separated from upland communities. The objectives of this study were to compare streambank morphology, erosion, and undercutting between areas of streambanks that were grazed under a late season grazing strategy and areas of streambanks that were totally excluded from livestock grazing.

Study Area

The study area is located on the Hall Ranch, a unit of the Eastern Oregon Agriculture Research Center in the southwestern foothills of the Wallowa Mountains. The study area included a 3 km by 50-m section of Catherine Creek, a fourth order tributary of the Grande Rhonde River, which flows into the Snake River. Catherine Creek has an average discharge of 3.4 m^3/s (119 ft^3/s) (USGS 1981). Peak annual flows usually occur in late April, May, and early June. During the spring runoff period, discharges of over 14.2 m^3/s (500 ft^3/s) are common.

Approximately one-half of the streambank has been excluded from grazing by the construction of 5 exclosures alternating with grazed portions of the creek. Prior to the establishment of exclosures, there was a total of 5,473 m of streambank on the study area with 3,492 m considered accessible to livestock use. Accessible streambank is defined as an area where livestock movement was not impaired by steep cliffs, fences, or dense woody vegetation. Stocking intensity before the construction of exclosures was approximately 48–50 m of accessible streambank (MAS) per animal unit month (AUM). After exclosures were built, approximately 1,804 m of streambank were accessible to cattle, which increased stocking to 25–30 MAS/AUM with no change in cattle numbers in the pasture. The stocking rate during the study was approximately 1.3–1.7 ha/AUM.

Methods

Prior to grazing in 1978, 125 one-quarter inch diameter steel stakes were established along the bank using a stratified random selection process. Sixty-seven stakes were placed in exclosures and 58 stakes were in grazed areas. Stake locations were stratified according to 3 broad vegetational types. These types were streambanks with a herbaceous cover, a shrub cover, or a tree cover. Further stratification was based on stream-meander position, top-outside, middle-outside, and bottom-outside of the meander. The convex portion of the streambank was considered the outside bank, that portion of the streambank receiving the greatest amount of erosive energy from streamflows. Straight portions of the streambank as well as fill areas were also included.

At each sampling station, the distance from the sampling stake to streambank edge and depth of the bank undercut was measured. In addition, the bank height which was the distance between the top of the uppermost soil horizon and the stream bottom at banks' edge was measured. An azmuth reading of the exact direction of the line from the stake to the bank was recorded to insure the same points were measured each sampling period. Measurements were taken prior to grazing in 1978, after the 1978 grazing period, prior to the 1979 grazing period and immediately after the 1979 grazing period.

Streambank erosion or loss was tested using a $2 \times 3 \times 4$ factorial design. Factors included grazing treatment (grazed or exclosed from grazing), vegetation type (herbaceous, shrub, or tree) and channel morphology (straight, top-outside, middle-outside, and bottom-outside).

Changes in the mean depth of undercuts were tested between treatments using the Student's t-test. A disturbance index was formulated to monitor any disturbance or alteration to the streambank. The disturbance index was a measure of absolute change in stake to bank measurement, whether it was a loss or increase in distance. The index not only accounted for disturbance due to bank sloughoffs, but also accounted for an actual increase in the stake-bank distance caused by animal trampling, or other factors which, by breaking down the bank, could change the bank morphology and cause an increase in the stake to bank distance. The differences in disturbance index responses by grazing treatments was also tested with the Student's t-test. Percent of sampling points that were disturbed for grazed and ungrazed portions of the streambank were tested using chi-square techniques. A chi-square test was also used to compare differences among grazing treatments of the percent of sampling points with undercuts greater than 7.5 cm. Throughout this paper the term significant refers to $p \leq .05$ unless specified otherwise.

Seventy-six sampling stations were used in analysis as many stakes were lost due to several causes such as high flows, major channel changes, and vandalism. Stakes placed within gravel bars were also omitted because these did not provide reliable data since definition of streambank edge was particularly difficult.

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Table 1. Streambank alterations along Catherine Creek 1978-1979.

	Grazing season 1978	Winter 1978-1979	Grazing season 1979	Combined grazing seasons 1978+1979	Total annual change Aug. 1978–Aug. 1979
			Streambank Loss (cm)		
Exclosure	2	9	4	6	9
Grazed	14*	15	13*	27*	27*
	Disturbance Index (Mean cm. change from pre-treatment readings)				
Exclosure	3	14	5	7	14.0
Grazed	15*	25	15*	30.0*	40.4*

*Significant at $P \leq .05$, when comparing exclosure to grazed for each column.

Results and Discussion

Grazed areas had significantly greater streambank losses compared to exclosed areas (Table 1). No significant differences were found in the amount of annual streambank loss for either vegetation types or stream-meander position.

Herbaceous covered banks dominated by Kentucky bluegrass *(Poa pratensis)*, sedges (*Carex* spp.), rushes (*Juncus* spp.), and forbs had mean annual erosion losses of 14 cm, ranging from 0–107 cm. Shrub covered banks dominated by hawthorne *(Crataegus douglasii)*, snowberry *(Symphoricarpos albus)*, and/or Wood's rose *(Rosa woodsii)* had mean annual bank erosion of 28 cm, ranging from 0–188 cm. Tree covered banks dominated by black cottonwood *(Populus trichocarpa)* and/or thin leaf alder *(Alnus incana)* had mean annual bank erosion of 26 cm, ranging from 0–69 cm.

There were also no significant differences in bank erosion loss when comparing sampling points according to their stream-meander position. Sampling points on the top-outside of a meander in the creek had mean annual erosion losses of 18 cm. Middle-outside positions had mean annual erosion losses of 23 cm, bottom-outside positions had mean annual erosion losses of 5 cm, and straight sections of the streambank had mean annual erosion loss of 14 cm.

Grazed portions of the streambank had significantly greater disturbance indices and significantly fewer undercuts, less than 7.5, cm compared to areas exclosed for 2 years.

There was no significant difference in bank erosion or streambank loss during the nongrazing periods (late September–early August). This period included losses due to high winter and spring runoff events (Table 1).

At the onset of the study (August 1978), average bank undercuts in grazed and exclosed portions of the streambank were 23 cm and 16 cm deep, respectively, which were not significantly different. Approximately 72% of the undercuts were greater than 7.5 cm in both grazed and exclosed areas. Immediately after the 1978 grazing season there was still no significant difference in undercut depths with a mean depth of 19 cm and 15 cm in grazed and exclosed areas, respectively. Similar trends were noted during the 1979 grazing season. After 2 years of no grazing, 81% of the sampling points in exclosed areas had undercut depths greater than 7.5 which was significantly different from the 48% of the sampling points in grazed areas that had undercut depths of greater than 7.5. cm. Mean undercut depths in grazed areas had significantly decreased after 2 grazing seasons from 23 cm (August 1978) to 13.0 cm (September 1979). Changes in undercutting through time in the exclosed portions of the streambank was not significantly different.

Since there was no change in undercutting of streambanks in exclosures that were grazed at almost half the current stocking rate for several years, the significant decrease in both the number and depth of undercuts in grazed areas is probably a function of the substantially increased intensity of use in grazed areas. This suggests there may be a threshold of response of rate of undercutting to stocking, but this study was not designed to determine response thresholds.

Overwinter events such as high water and ice floes also caused a great amount of streambank disturbance and erosional loss of banks along Catherine Creek. Late season grazing resulted in significantly greater annual bank sloughoff; however, there was no significant difference in total streambank loss between grazed and ungrazed areas when comparing only the overwinter period. Significantly greater streambank disturbance (e.g. undercut collapse, cave-ins, and sloughoffs) occurred in grazed areas compared to ungrazed areas at this time ($p \leq .10$). Livestock grazing may have weakened the streambank structure through trampling and forage removal to the point where ice floes and high water had a more damaging effect on grazed portions of the streambank.

Forage utilization along streambanks varied greatly among the vegetation types sampled. Herbaceous dominated streambanks were usually the most heavily utilized followed by shrub/herbaceous and tree/shrub/herbaceous covered streambanks. Streambanks dominated by grasses and/or grasslikes were utilized from 35 to 85% in grazed areas with a mean of 59% (Kauffman 1982). The shrub and tree dominated banks had lower utilization ranging from 10 to 60% with a mean of 22%. Vegetation utilization of communities in the exclosures was always less than 20%, which was primarily used by big game.

Streambanks dominated by grasses and grasslikes were composed of deep, moderately to well-developed fine textured soils. Soils in shrub and tree dominated streambanks characteristically were unstructured, medium-coarse textured, and rocky. Though degree of livestock utilization was greatest on herbaceous covered banks, streambank losses were not significantly different when compared to those of shrub and tree covered banks. Grazing preferences possibly mediated streambank losses among vegetation types with these different soil structures.

The accelerated erosion and increased bank disturbance related to livestock grazing is similar to findings of Behnke and Zarn (1976), Dahlem (1979), Gunderson (1968), and Marcuson (1977). The accelerated streambank loss along Catherine Creek is unlike the findings of Buckhouse et al. (1981) and Hayes (1978), who reported similar utilization rates. Hayes (1978) implied that utilization of the riparian vegetation was under 60%. Utilization of vegetation associated with the stream studied by Buckhouse et al. (1981) was 65–70%.[1] Buckhouse et al. (1981) found that while moderately grazed portions of Meadow Creek in Oregon had higher mean annual erosion losses than ungrazed areas, the differences were not significant. Most bank cutting losses on Meadow Creek were attributed to overwintering periods when high water, ice floes had a major influence on channel morphology.

Management Implications - Conclusion

After construction of exclosures animal use days increased from 48-50 MAS/AUM to 25-30 MAS/AUM. This increased animal use was significantly related to a following decrease in streambank undercuts in these grazed areas. Comparisons between grazed and exclosed areas for streambank erosion and disturbance are made only under the grazing intensity of 25–30 MAS/AUM accessible streambank. At these intensities significantly greater streambank

[1]File data, Pacific Northwest Forest and Range Experiment Station, United States Department of Agriculture-Forest Service, LaGrande, Oregon.

erosion and disturbance were measured in grazed areas compared to ungrazed areas.

When the status of streambank erosion, morphology, and bank undercuts are important considerations in making management decisions, it may be more useful to measure intensity of use with the numbers of animals per length of streambank rather than density of animals per unit area. Under this experimental design, the stocking rate of 1.3–1.7 ha/AUM was found to have few impacts on riparian vegetation (Kauffman 1982); however, streambank use at 25–30 MAS/AUM had significant impacts on streambank erosion.

These findings illustrated a greater erosional hazard for Catherine Creek than Buckhouse et al. (1981) or Hayes (1978) found with similar light to moderate intensities of livestock utilization. It is likely that some streams are more susceptible to disturbance by livestock than others. The implications of the level of accelerated erosion on Catherine Creek with respect to natural changes in this dynamic system are not clear. This level of erosion undoubtedly influences short-term changes in streambank morphology and perhaps siltation of the water column. Long term impacts related to aquatic life, water quality, terrestrial wildlife, stream structure, shape, and the perpetuating capabilities of riparian vegetation is difficult to precisely predict with currently available models. However, it is unlikely that responses remain linear over long time periods. It does appear, that for the present, management plans need to be geared for each particular riparian/stream ecosystem as responses from land use activities do vary greatly from stream to stream.

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Effects of Late Season Cattle Grazing on Riparian Plant Communities

J. BOONE KAUFFMAN, W.C. KRUEGER, AND M. VAVRA

Abstract

Livestock impacts on riparian plant community composition, structure, and productivity were evaluated. After 3 years of comparison between fall grazed and exclosed (nongrazed) areas, 4 plant communities out of 10 sampled displayed some significant species composition and productivity differences. Two meadow types and the Douglas hawthorne *(Crataegus douglasii)* community type had significant differences in standing phytomass. These also were utilized more heavily than any other communities sampled. Shrub use was generally light except on willow (*Salix* spp.)-dominated gravel bars. On gravel bars, succession appeared to be retarded by livestock grazing. Few differences were recorded in other plant communities sampled, particularly those communities with a forest canopy.

Riparian ecosystems have been identified as important zones of management because of their values as wildlife habitat (Ames 1977, Patton 1977, Thomas 1979), as a modifier of the aquatic environment and fisheries habitat (Cummins 1974, Duff 1979, Meehan et al. 1977), as a major constituent in maintenance of water quality and quantity (Horton and Campbell 1974), and as a valuable forage resource for livestock (Cook 1966, Reid and Pickford 1946). Johnson et al. (1977) stated that riparian habitat is the most productive and possibly the most sensitive of North American habitats and should be managed accordingly. However, these areas may also be among the more resilient of ecosystems following disturbance.

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Grazing management strategies discussed for riparian zone rehabilitation and/or maintenance include exclusion of livestock, alternative grazing strategies, changes in the kind and class of animals, managing riparian zones as special use pastures, and several basic range practices (e.g. salting, artificial reestablishment of riparian vegetation, upland water developments, and herders). Recently many riparian ecosystems in the western United States have been fenced and managed as special use pastures. Rather than indefinite exclusion of grazing, several grazing strategies have been suggested to utilize the riparian forage resource while preserving the integrity of the riparian/stream ecosystem (Claire and Storch in press, Platts 1978). One such system is a late season grazing strategy.

Objectives of this study were to compare differences in succession, composition, productivity, and structure between riparian plant communities that were ungrazed and riparian plant communities that were grazed under a late season grazing strategy (late August- mid September).

Study Area

The study area is located on the Eastern Oregon Agriculture Research Center near the town of Union, Ore., in the southwest foothills of the Wallowa Mountains. The study area is roughly a 50-m by 3-km strip of riparian vegetation adjacent to Catherine Creek. The study area was part of a 49-ha pasture which was comprised wholly of plant communities within the riparian zone associated with Catherine Creek. Adjacent uplands are dominated by mixed conifer and ponderosa pine *(Pinus ponderosa)* habitat types. Elevation along the creek is approximately 1,030 m. Mean annual precipitation for the study area was 60 cm. Precipitation for 1979 was lower than average and mean precipitation for 1978 and 1980 was higher than average.

Methods

Five livestock exclosures were constructed alternating with grazed portions of the study area. Exclosures were constructed in such a manner as to minimize alterations in normal livestock movements. Approximately one-half of the streambank and riparian vegetation within 50 m of the stream was excluded from grazing. Exclosed and grazed areas contained an adequate number of similar vegetation stands for meaningful comparisons to be made. Grazing began about August 25 and continued for 3 to 4 weeks depending on the amount of forage produced and livestock numbers grazing. The stocking rate on the riparian study area was approximately 1.3–1.7 ha/AUM.

The 10 most prevalent and widely occurring communities in the riparian zone were intensively sampled using species frequency, standing phytomass and, where appropriate, shrub density, and height measurements. The 10 communities sampled were dry meadow (*Poa pratensis*-mixed forbs); moist meadow (*Poa pratensis-Phleum pratense-Carex* spp. and forbs); Kentucky bluegrass-cheatgrass *(Poa pratensis-Bromus tectorum)*; cheatgrass *(Bromus tectorum)*, Douglas hawthorne/Kentucky bluegrass *(Crataegus douglasii/Poa pratensis)*; snowberry-Wood's rose *(Symphoricarpos albus-Rosa woodsii)*; gravel bars (*Salix* spp.-*Populus trichocarpa* sapling-mixed graminoids-mixed forbs); thin leaf alder/Kentucky bluegrass *(Alnus incana/Poa pratensis)*; ponderosa pine/Kentucky bluegrass *(Pinus ponderosa/Poa pratensis)*; and black cottonwood-mixed conifer (*Populus trichocarpa*-mixed conifer).

At the onset of the study in 1978, representative stands were stratified by ocular reconnaissance with respect to species composition, standing phytomass, and structure. If a stand was found to be significantly different from the others sampled, it was omitted for further comparisons. Within each selected stand, transects were randomly established, and plots were measured at 1/2-m intervals.

A 1/4-m^2 quadrat was used for frequency measurements with a 1/16-m^2 nested plot used to determine frequency for the prominent species which would normally have a frequency of 100% in the larger plot. Frequency was based on 30 plots per vegetation stand with 6-18 stands of each community measured. Usually half of the stands for each community sampled were in grazed areas and half of the stands were in ungrazed areas. Frequency was determined during late June to early July, the time when most perennial species were in an identifiable phenological state and the highest seasonal species diversity for most plant communities was expressed.

Shrub density, height and composition was measured using transects of 10, 1-m^2 plots, permanently established in 30 vegetation stands. Density and height measurements were recorded for all shrub species with a rooting stem base occurring totally within the plot. Because of the rhizomatous nature of many of the woody species, density estimates were recorded as rooting stem density and not as individual plant density.

Standing phytomass was determined using a 1/4-m^2 plot. Three stands of each community in both grazed and exclosed areas were measured by clipping 10 plots in each stand for a total of 30 plots in each community for each treatment. Plots were clipped in late July to mid August just prior to the onset of grazing. All forbs and graminoids that had their stem base within the plot were clipped, oven dried, and then weighed to obtain individual species dry weight estimates.

Estimation of utilization after cattle were removed in the fall was accomplished by an ocular estimate of 10-15 plots in each stand that was sampled for standing phytomass. Stubble heights of key forage species in meadow and Douglas hawthorne communities were estimated by randomly measuring 1 grazed plant per plot.

Plant species diversity and equitability values were generated from frequency data. The Shannon-Weaver information theory formula was used to calculate diversity (H'), where $H' = \Sigma p_i \log_e p_i$ (Shannon 1948). Here, pi is the frequency of the ith species ($i = 1,2,...S$). S is the number of species in the community, or species richness. Equitability is expressed as $J' = H'/H'\max$, where $H'\max$ is equal distribution of units between a given number of classes. $H'\max$ is calculated as $\log_e S$.

Changes in individual species frequency were tested with chi-square statistics. Standard analysis of variance and student-Newman-Keul's test were used to compare standing phytomass estimates of plant communities among both treatments and years. Changes in shrub density and heights between grazed and exclosed areas were tested using the Student's *t*-test (Steele and Torrie 1960).

Multivariate analysis of variance (MANOVA) was also used to test for differences in plant community composition (Morrison 1976). Population parameters used in the MANOVA were species diversity, species richness, community equitability, and standing phytomass. Wilk's lambda (λ) was the test statistic used to detect significant differences with the MANOVA (Neter and Wasserman 1974). When a significant λ was obtained, student-Neuman-Keul's test was used to determine where differences occurred. Fiducial limits for all statistical analyses were set at $p \leq 0.05$.

Results

Patterns of Utilization by Domestic Livestock

Utilization by livestock on the study area varied greatly, not only from community to community but often from stand to stand within particular communities. Dry meadows (Kentucky bluegrass-mixed forbs) and moist meadows (Kentucky bluegrass-timothy-mixed *Carex* spp.) were most preferred, and cattle utilized these communities more heavily than the other communities sampled. Greater than 60% of the forage produced in these communities was removed by livestock (Table 1).

In the dry meadow community, Kentucky bluegrass was utilized from 55–79% (Table 1). Average stubble heights for Kentucky bluegrass were 3 to 4 cm. Utilization of forbs in the dry meadow community was moderate to light, with utilization estimates of 33% of 1979, and 15% in 1978 and 1980.

Kentucky bluegrass utilization in the moist meadow community was moderate to heavy, with an estimated utilization of 67-80% (Table 1). Mean stubble heights were measured at 4 to 7 cm (Table 2). In the grazed moist meadow stands, meadow timothy was utilized 60–76% and sedges were utilized 65–81% (Table 2). Mean stubble heights for meadow timothy were 9 cm to 14 cm (Table 2). The only forb utilization of any consequence in moist meadows was that of the northwest cinquefoil *(Potentilla gracilis)* and white clover *(Trifolium repens)*. In many stands northwest cinquefoil utilization estimates were greater than 70%. White clover was generally utilized 60% or greater.

Another community that apparently was preferred by cattle as a forage source included the Douglas hawthorne community, particularly those stands with a relatively open canopy. Utilization in Douglas hawthorne stands ranged from 25–47% with the more open stands of Douglas hawthorne receiving the heaviest utilization. Stubble heights of Kentucky bluegrass in Douglas hawthorne communities were less than 8 cm (Table 2).

On gravel bars utilization was light to moderate with less than

Table 1. Standing phytomass and percent utilization for grazed and ungrazed plant communities along the Catherine Creek Study Area.

	1978		1979		1980		1978		1979		1980	
	Thin leaf alder *(Alnus incana/ Poa pratensis)*						Dry Meadow (*Poa pratensis*-Mixed forbs)					
	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed
Standing phytomass (kg/ha)	1080	1206	962	1193	1369+	1609	2620	3950*	2829	2463+	3371	4173*+
% Utilization	25	T	16	5	14	3	44	2	70	1	67	T
	Douglas hawthorne *(Crataegus douglasii/ Poa pratensis)*						Moist meadow (*Poa pratensis-Phleum pratense*-mixed *grasslikes and forbs)*					
	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed
Standing phytomass (kg/ha)	1784	1691	1462	1632	1813	2498*+%	7150	6990	6553	3497+*	8750+	9180*
% Utilization	25	2	47	1	37	3	66	T	73	2	59	T
	Black cottonwood (*Populus trichocarpa*-mixed conifer)						Cheatgrass (*Bromus tectorum*-mixed forbs)					
	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exlosed	Grazed	Exclosed	Grazed	Exlosed
Standing phytomass (kg/ha)	2668	2597	1291+	938+	2139+	1602+%	1920	2001	974	1093+	2020+	1702
% Utilization	23	1	11	1	9	T	11	T	2	T	1	T
	Ponderosa pine *(Pinus ponderosa/ Poa pratensis)*						Kentucky bluegrass-cheatgrass *(Poa pratensis-Bromus tectorum)*					
	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed
Standing phytomass (kg/ha)	1655	1632	1390	1553	1457	1962	2173	3275	2162	1990	—	—
% Utilization	27	T	17	T	10	T	37	T	57	T	—	—
	Gravel Bar Communities						Snowberry/ Wood's *(Symphoricarpos albus-Rosa woodsii)*					
	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed	Grazed	Exclosed
Standing phytomass (kg/ha)	1973	2345	1389	1016	2156	2779	3964	3643	3987	3213	—	—
% Utilization	18	8	19	2	40	T	15	4	15	2	—	—

*Significant difference among treatments within the same year ($p \geq .05$)
+Significant change of same treatment compared to previous year ($p \geq .05$).
%Significant difference between 1978-1980 within the same treatment ($p \geq .05$).

40% of the total available forage utilized (Table 1). A preference for willows, black cottonwood saplings, and white clover was observed.

Utilization of those plant communities containing a dense canopy cover (black cottonwood, ponderosa pine, and thin leaf alder communities) was light, usually less than 20%, and always less than 30% (Table 1). It appeared that Kentucky bluegrass in forested communities was not as palatable as in meadow communities. Observations in forested communities indicated a lower plant density with fewer tillers per plant but greater leaf blade length compared to those found in meadow or open communities. Lodging was also a more common occurrence in communities possessing an overstory canopy. Utilization by cattle occurred almost exclusively on plants that were not lodged.

The cheatgrass community was the least preferred of all communities sampled. Autumn regrowth was the only detectable forage utilized in cheatgrass stands. Utilization in 1978 was 14% while less than 2% of the total available standing phytomass was utilized in 1979 or 1980 (Table 1).

Shrub utilization for the entire riparian ecosystem was neither constant from year to year nor from community to community. Shrub utilization by cattle was generally light except in the gravel bar community and on very palatable shrubs. In stands on gravel bars, livestock most preferred black cottonwood saplings with a mean utilization of 84, 31, and 50% in 1978, 1979, and 1980, respectively. Willow utilization (primarily *Salix rigida* and *Salix exigua)* ranged from 27–48%. Utilization on exclosed gravel bar communities, primarily by big game was always less than 5% for all shrub species. Cattle utilization of palatable shrubs such as blue elderberry *(Sambucus cerulua)* and goosecurrents (*Ribes* spp.) was heavy, and was often greater than 100% of the current year's growth. Douglas hawthorne shrubs with a height of less than 1-m were preferred by cattle, particularly in low density hawthorne stands or as solitary shrubs in meadow communities. Utilization often exceeded 50% of the current year's growth on many individuals. Douglas hawthorne shrubs exceeding 2m in height were rarely browsed as heavily as the smaller hawthorne shrubs. Snowberry was utilized 9 to 36% in ponderosa pine, snowberry-Wood's rose, and black cottonwood communities. Utilization of the other shrub species was less than 10%. Precipitation, and subsequently forage production, was lower in 1979 than 1978 or 1980 and shrub utilization for all shrub species was lower in 1979 than 1978 or 1980.

Impacts of Livestock on Species Composition

Species composition differences between the grazed and ungrazed treatments were evident after 3 years in the moist meadow community. In addition, phenological and temporal differences in the growing season have occurred. In some stands the onset of the growing season, anthesis, and dormancy in exclosed areas occurred as much as 2 weeks later in the year compared to grazed areas. Significant increases in mesic/hydric species such as lineleaf indianlettuce *(Montia linearis)*, willowweeds (*Epilobium* spp.), and sedges have occurred in some exclosed stands of moist meadows. In 1980, lineleaf indianlettuce had a mean frequency of 3% in grazed stands compared to a mean frequency of 16% in exclosures,

Table 2. Mean stubble heights (cm) of selected graminoids in the 3 plant communities most preferred by livestock and estimated utilization percent of that species.

	1978		1979				1980			
	Grazed	Exclosed	Grazed		Exclosed		Grazed		Exclosed	
Communities	Util. %	Util. %	Stubble Ht. (cm)	Util. Ht. (cm)	Stubble (%)	Util. Ht. (cm)	Stubble Ht. (cm)	Util. (%)	Stubble	Util.
Dry meadows (*Poa pratensis*-Mixed forbs)										
Poa pratensis	55	2	3	79	29	1	4	77	34	0
Juncus balticus	26	—	12	50	—	—	10	40	—	—
Carex sp.	40	—	4	90	—	—	—	0	—	—
Phleum pratense	T	0	—	—	23	10	—	—	74	0
Bromus carinatus	T	—	—	T	23	14	—	—	20	0
Agropyron repens	—	—	4	90	—	—	—	—	—	
Moist meadows (*Poa pratensis-Phleum pratense*-Mixed grasslikes)										
Poa pratensis	67	T	4	80	29	2	7	68	48	T
Phleum pratense	76	15	9	76	37	3	14	60	66	2
Carex sp.	65	0	8	81	34	3	20	65	66	T
Juncus balticus	55	0	12	43	29	T	—	0	—	0
Douglas hawthorne (*Crataegus douglasii*/ *Poa pratensis*-Mixed forbs)										
Poa pratensis	40	2	6	59	33	10	8	48	33	3
Juncus balticus	—	—	14	17	—	—	4	85	—	—
Phleum pratense	—	—	—	—	—	—	9	38	51	T

— Indicates particular species was not measured in the analysis.
T Indicates a trace of utilization was detected (usually less than 2%).

with a frequency of up to 47% in some exclosed stands. Conversely in exclosures, significant decreases were apparent in meadow timothy and in some forbs such as leafy-bract aster *(Aster foliaceus),* and northwest cinquefoil. In grazed stands, frequency of meadow timothy ranged from 73-89% for the 3 years of the study while in exclosures it significantly declined from 91% in 1978 to 40% in 1980.

Those areas which are susceptible to trampling damage have also experienced changes in species composition with cessation of grazing (Table 3). In areas with gravelly, loosely structured soils, cheatgrass dominates the portions of the stand utilized by livestock while quackgrass *(Agropyron repens)* now dominates the area within an exclosure. In the exclosure, perennial and biennial forbs are invading and colonizing the area while outside the exclosure the stands are basically dominated by annuals. A well-developed litter layer is forming in the exclosed area.

On gravel bar communities, density of cottonwood saplings significantly increased in exclosures after 2 years rest. Twenty-four rooting stems per meter^2 were measured in exclosed stands, compared to 13 rooting stems per meter^2 in grazed stands. In ungrazed stands, the mean height of black cottonwoods significantly increased from 19 cm in 1978 to 30 cm in 1979. Mean height of black cottonwoods in grazed areas was not significantly different between years where they remained 10–12 cm high. In addition, 1979 density of McKenzie willow *(Salix rigida)* was significantly greater in exclosures with a density of 3.8 per meter^2 compared to 1.0 per meter^2 in grazed areas. On gravel bar communities, observed changes in shrub composition included increased density and height of willows and black cottonwood in the ungrazed area while the grazed area remained dominated by a low cover of black cottonwoods.

Impacts of Livestock on Standing Phytomass and Productivity

Though small species composition changes have occurred, multivariate analysis indicated no significant differences in total species diversity (H′), species richness (S), or equitability (J′), between grazing treatments for all communities sampled. However, significant differences using MANOVA were detected in the standing phytomass component of some plant communities. In general, the communities with the greatest amount of standing phytomass in the field layer were the communities exhibiting the greatest response to cessation of grazing. These communities (primarily meadow and Douglas hawthorne communities) were also the areas most heavily utilized by cattle as a forage source. Vegetation stands with a low standing phytomass in the field layer generally displayed little response to cessation of grazing after 3 years rest.

Significant differences in the total standing phytomass estimate for moist meadow communities as well as for standing phytomass estimates for many individual species within moist meadows were noted. Pretreatment standing phytomass estimates were approximately 7,000 kg/ha for both grazed and exclosed areas (Table 1). During 1979 moist meadow stands that were grazed changed very little with a mean standing phytomass of 6,550 kg/ha. In exclosures, the standing phytomass estimate significantly decreased to 3,500 kg/ha in 1979. This decline in standing phytomass did not continue into 1980. In 1980 standing phytomass of moist meadows in exclosures increased to 9,180 kg/ha. This was a significant increase over the phytomass estimate for 1979 phytomass estimates. There was no significant difference in total standing phyto-

Table 3. Average percent frequency of major plant species on a grazed and ungrazed cheatgrass plant community on gravelly soils after 3 years.

Species	Percent frequency Exclosure	Percent frequency Grazed
Grasses		
Bromus tectorum	5	100
Agropyron repens	100	—
Poa pratensis	20	25
Bromus racemosus	—	20
Forbs		
Epilobium paniculatum	50	40
Veronica arvensis	15	5
Microsteris gracilis	55	70
Taraxacum officinale	5	—
Collomia linearis	50	5
Lactuca serriola	35	—
Rumex acetosella	10	10
Achillea millefolium	10	—
Collinsia parviflora	10	—
Erodium cicutarium	5	10
Polygonum douglasii	—	15
Fragaria virginiana	—	5
chickweeds (*Caryophyllaceae* sp.)	—	25
unknowns	10	—

mass between treatments during 1980. Standing phytomass in grazed areas during 1980 was 8,750 kg/ha.

Individual species within moist meadows had different reactions to cessation of grazing. Standing phytomass for meadow timothy in grazed areas was estimated at 2,310 kg/ha in 1978, 1,420 kg/ha in 1979, and 2,040 kg/ha in 1980. In exclosures standing phytomass estimates for meadow timothy were 1,860 kg/ha in 1978, 170 kg/ha in 1979, and 720 kg/ha in 1980. When comparing grazed and ungrazed treatments, significant differences in standing phytomass estimates for meadow timothy occurred in 1979 and 1980. It was apparent that the decreased abundance of meadow timothy in exclosed moist meadows was related to cessation of grazing. Large carex spp. *(Carex aquatillis, Carex stipata* and *Carex rostrata)* responded in exclosed moist meadows with a significant increase in standing phytomass from 810 kg/ha in 1979 to 2,960 kg/ha in 1980. There was no significant difference between years in standing phytomass of the sedges in grazed areas. In moist meadow communities it appeared that without grazing, succession towards a more mesic/hydric plant community was occurring. In exclosures exotic grasses, such as meadow timothy, and forbs more attuned to drier environments decreased and were being replaced by native sedges and forbs more attuned to wetter environments.

Annual fluctuations in total standing phytomass in dry meadows were similar to those of moist meadows. In exclosed areas, 1979 phytomass was significantly less than phytomass measured in 1978 and 1980 in exclosures (Table 1). In contrast, grazed dry meadows had relatively stable phytomass estimates for all years of the study. A significant difference in standing phytomass between treatments was measured in 1978 and 1980, where there was no significant difference in standing phytomass in 1979, the year of low production in exclosures.

Phytomass for the forb component of dry meadows excluded from grazing was significantly less than that for dry meadows that were grazed. In exclosures, the forb component of dry meadows steadily declined each year of the study. Phytomass of forbs in exclosures was 300, 140, and 110 kg/ha for 1978, 1979, and 1980, respectively. Phytomass of forbs in grazed areas was 590, 430, and 470 kg/ha successively for the 3 years of the study.

After 3 years of no livestock grazing, the Douglas hawthorne/Kentucky bluegrass communities in exclosed areas had significantly higher phytomass than grazed areas (Table 1). Standing phytomass was not different in the previous years between treatments. This increase in standing phytomass was attributed exclusively to an increase in phytomass of Kentucky bluegrass. Estimates for Kentucky bluegrass in exclosures increased from 1,380 kg/ha and 1,300 kg/ha for the first 2 years of the study, respectively, to 2,176 kg/ha in 1980.

In the forested communities (black cottonwood-mixed conifer, ponderosa pine, and thin leaf alder communities), few changes in standing phytomass occurred after 3 years of cessation from grazing. No significant differences in standing phytomass between treatments were encountered in these communities (Table 1), nor were there significant differences in total standing phytomass on gravel bars dominated by willows and black cottonwood saplings.

Cheatgrass communities showed little response to the different grazing treatments after 3 years and no significant differences have been noted due to treatment effects in phytomass estimates of either the graminoid or forb component in the stands sampled, except as related to areas with extreme trampling. There were no significant differences in snowberry-Wood's rose communities or Kentucky bluegrass-cheatgrass communities in 1979 after 1 year of treatment effects. These communities were not sampled in 1980.

Discussion

The effect of grazing on plant community composition and structure were apparent in the vegetation stands where a change in species composition in the exclosed areas occurred. Similar observations have been made in other riparian ecosystems (Hayes 1978, Dobson 1973). Dobson (1973) concluded the effect of grazing had been to open up the vegetation, creating more niches in which plants could establish themselves. Utilization on woody vegetation was light in all communities with the exception of use in the gravel bar community and on the highly palatable shrubs in other areas.

Carothers (1977), Crouch (1979), and Glinski (1977) have observed that grazing pressures on woody vegetation prevented the establishment of seedlings, thus producing an even-aged nonreproducing vegetation community. Few seedlings or saplings were found in shrub density transects for thin leaf alder and black cottonwood-mixed conifer communities indicating that there was little, if any, regeneration of either alders or cottonwoods. These communities appeared to succeed in an approximate seral order of black cottonwood sapling communities formed on gravel bars to willow-dominated communities, to thin leaf alder dominated-communities. Mature black cottonwood-mixed conifer communities appear to be succeeding thin leaf alder communities at many sites in the study area.

Examination of the woody species composition on willow-black cottonwood sapling-dominated gravel bars indicated that grazing was probably retarding the progression of this sere. This phenomenon was observed at several locations of willow-cottonwood dominated communities bisected by exclosure fences at the onset of the study. After 3 years, shrub density and height appeared to be greater in the exclosed portion of the stands and thin leaf alder and some species of willows that were not found in grazed areas were present. Conversely, the grazed portions of these stands of vegetation were dominated by stands of black cottonwood and willow species of lower stature and lower densities. Although it was too early to determine if a late season grazing strategy has a definite negative impact on succession to woody-dominated communities and hence the long-term structural diversity of this riparian ecosystem, early evidence and observations indicated that this was happening.

Though it could be argued that late season grazing would increase intensity of utilization of the shrub component in a riparian zone, this would probably not be as severe as the shrub utilization in upland (nonriparian) communities in this season. Late in the growing season, the herbaceous component was still succulent and palatable in the riparian zone whereas the herbaceous vegetation in uplands generally was not. In this riparian zone, observations indicated that shrub use by cattle was related to availability of herbaceous vegetation and the palatability of the particular shrub species. Discernable utilization of shrubs did not begin each year until the latter part of the grazing season. As long as herbaceous vegetation was available in the riparian zone, shrub utilization did not occur to greater extent due to late season grazing. This is similar to extensive observations by Hall (pers. comm.)[1] in the Blue Mountains of Oregon that little shrub utilization, except on highly palatable species occurs when a stubble height of 10 cm or greater is present. A definite shift in preference to less palatable species occurs at this point, which is increasingly apparent when stubble height is reduced below 5 cm.

Herbage removal by livestock appeared to be an important factor in altering seasonal phenology of the mesic/hydric meadow communities. In the ungrazed moist meadow communities, onset of the growing season occurred approximately 2 weeks after the grazed moist meadow communities in 1979 and 1980. Examination of phenology of individual plants in meadows indicated that at the time of anthesis for most grasses, sedges, and perennial forbs in grazed areas, most of the vegetation in exclosed areas was still in a vegetative form. The dense litter layer formed in exclosed meadows probably kept soil temperatures below levels for initiation of growth for longer periods of time than in grazed areas in which there was a smaller litter layer. Sharrow and Wright (1977) found similar soil temperature relationships between areas in which the litter layer had been removed by fire and unburned control plots containing a litter layer. They attributed increased soil temperatures to increased increased solar exposure of the soil surface due to litter removal.

[1]Frederick C. Hall, plant ecologist, USDA Forest Service, Pacific Northwest Region, Portland, Oregon 97208.

The increased soil moisture due to litter layer accumulation could also be an important factor for the increased abundance of the more mesic/hydric species and the decreased abundance of species more attuned to drier environments in the exclosed moist meadows.

Impact of livestock trailing and trampling was localized primarily in those communities with moist or saturated soils susceptible to compaction by livestock and in those communities with very fragile, loosely consolidated gravelly soils susceptible to physical damage by the uprooting of established vegetation. Communities with saturated soils present for the entire summer were the only vegetation stands with a potential for severe compaction damage during the late season grazing period. In the majority of the vegetation stands, soil moisture was low enough to minimize potential physical damage to the soils. Some evidence of vegetation recovery due to cessation of grazing was noted on those areas with loosely consolidated unstructured gravelly soils (Table 3).

Management Implications

Ideally the results of proper management would be to perpetuate, rehabilitate, or improve the resources associated with riparian ecosystems. It must be recognized that no 2 streams or stream segments are the same and methods of management to restore disturbed streamsides to their former productive state will vary considerably (Claire and Storch in press). Even within a single segment of a riparian ecosystem the diversity of plant community types should be considered. Because of the great community diversity, and differing ecological tolerances of riparian plant communities, a management practice that may be beneficial for one community in a riparian zone may not be beneficial to another community in the same area. Herein lies what may be a fundamental problem in the future of riparian zone management: managing the riparian ecosystem in such a way as to be of the greatest benefit to the communities which are deemed most important for whatever use or uses are most preferred for that particular riparian ecosystem.

This study indicated that fall grazing had major influences on some communities and no discernable influence on others. If the impacts of fall cattle grazing on plant communities are perceived as acceptable, then consideration of other effects and consequences of this grazing strategy may be important, depending on management objectives. These effects and consequences of this grazing strategy include, among other things, utilization of the forage resource by livestock, maintenance of water quality, minimization of disturbance to avian communities, minimization of physical impacts on soils, increased calf gains, improved condition of mother cows, and improved utilization of upland plant communities (Claire and Storch in press, Kauffman 1982, Vavra and Phillips 1979). Conversely, the late season grazing strategy was found to significantly increase streambank erosion and cause a significant short-term decrease in small mammal densities, although the impact on mammals did not appear to affect carryover densities (Kauffman et al. 1982, Kauffman et al. 1983).

Late in the grazing season, vegetation growing in riparian zones generally is more palatable and of higher nutritive quality than vegetation in upland plant communities. Several sedges common to riparian zones of the Pacific Northwest outrank key upland forage species in late season protein and energy content (McLean et al. 1963, Paulsen 1969, Skovlin 1967). Vavra and Phillips (1979) found improved dry matter digestibility, improved protein levels, lowered acid detergent fiber, and lowered lignin contents in diets of fistulated heifers grazing this riparian study area during late August–early September, compared to what upland pastures provided up to 1 month preceding this period. Daily intake rates also were greater in the riparian zone than in upland pastures either before or after this period.

There are many economic, aesthetic, and management factors that must be considered before fence construction and implementation of a special use pasture grazing system. Riparian zones in many mountain grazing allotments provide up to 20% of the total forage produced (Reid and Pickford 1946, Roath and Krueger 1982). Often due to livestock distribution problems this fraction of total forage produced supplies up to 80% of the total forage consumed by livestock (Roath and Krueger 1982). Rather than fence pastures of equal size, fencing areas of similar ecological responses could be implemented. Fencing uplands in separate pastures from riparian types is a start in this direction, when areas are productive enough to be effectively managed as separate pastures.

Land and/or livestock management flexibility is easily attained when the riparian zone is fenced separately and used as a special use pasture for late season grazing. Utilization of upland forages could be achieved independently from management requirements of the riparian zone, thereby allowing for proper use of the uplands without overuse of the riparian zone. And, depending on environmental conditions for a given year, length of grazing in riparian areas could be optimized to achieve desired use levels for the key riparian species, whether they be woody or herbaceous species.

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Management Considerations to Enhance Use of Stock Ponds by Waterfowl Broods

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Abstract

Use of 36 livestock watering ponds by mallard (*Anas playtrhynchos*), blue-winged teal (*A. discors*), and total broods was tested against 32 habitat variables from 1977 and 1978. Pond size, shallow water areas with submersed vegetation, number of natural wetlands in a 1.6-km radius, and emersed vegetation composed of smartweed (*Polygonum* spp.) and spikerush (*Eleocharis* spp.) were associated with increased use of ponds by total broods. When analyzed by species, small grain on the surrounding section and height and density of shoreline vegetation were associated with increased use of ponds by mallard broods; percent of shoreline with trees and percent arrowhead (*Sagittaria* spp.)/water plantain (*Alisma* spp.) were associated with decreased use of ponds by mallard broods. Percent river bulrush (*Scirpus fluviatilis*)/burreed (*Sparganium* spp.) was associated with decreased use of ponds by blue-winged teal.

Approximately 220,000 livestock watering ponds (stock ponds) have been constructed on the northern high plains (Bue et al. 1964), of which 88,000 are in South Dakota (Ruwaldt et. al 1979). These ponds were constructed to improve livestock utilization of forage on rangelands, but they have also received considerable use by waterfowl (Bue et al. 1952, 1964; Smith 1953; Ruwaldt et al. 1979). Many public land managers and private land owners have indicated interest in management strategies designed to increase the value of these ponds for alternate uses while maintaining use by livestock. This study was conducted to further identify habitat variables important to the use of stock ponds by waterfowl broods.

Study Area

The study was conducted in Jones and Lyman counties in south central South Dakota. The study area was 1,235 km², bordered by the towns of Murdo to the west and Vivian to the east. Native vegetation was typical of mixed grass prairie (Johnson and Nichols 1970:8). Principal land uses of this area were pasture (71-80%) and wild hay (3-6%), with crops (milo, sorghum, wheat, sunflowers) making up the remainder (Johnson and Nichols 1970).

Methods

Thirty-six stock ponds were selected for study based on 2 criteria: (1) they were at least 2.5 km from the nearest other study pond; and (2) they were between 0.6 and 3.0 ha in size. The selection criteria was designed to reduce the chance of broods moving from one study pond to another as a result of census efforts and to reduce, if possible, the influence of pond size on use of the pond by waterfowl broods. All ponds were larger than the minimum size recommended by Lokemoen (1973) for waterfowl.

Waterfowl broods were counted in July and August 1977 and 1978. Two census techniques were used to increase accuracy of brood use data (Hammond 1970). Broods were first counted by hidden observers with a 25X spotting scope during the 2.5 hours prior to sunset and following sunrise. Flush counts were conducted by different personnel after the morning observations (Rumble and Flake 1983). Species, brood size, and age-class (Gollop and Marshall 1954) were used to identify broods and eliminate duplication in combining data from the 2 surveys.

Thirty-two variables considered to be important to use of ponds by waterfowl broods were collected for each pond. Specific conductivity, pH, and the disappearance depth of a secchi disc (Beeton 1958) were recorded. Percent of pond with emersed vegetation and percent composition of emersed vegetation on each pond were estimated. Categories of emersed vegetation were as follows: cattail (*Typha* spp.); round-stemmed bulrushes (*Scirpus acutus* and *S. validus*); river bulrush (*S. fluviatilis*)/burreed (*Sparganium* spp.); arrowhead (*Sagittaria* spp.)/water plantain (*Alisma* spp.); spikerush (*Eleocharis* spp.); and smartweed (*Polygonum* spp.). Percent of the basin filled with water, percent bare shoreline, and mean height of emersed vegetation were estimated visually. Basin size and surface water area were determined by planimeter from aerial

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Table 1. Means and range in data for habitat variables which were significantly ($\alpha \leq 0.05$) different between 1977 and 1978.

Variable	1977 $\bar{x}$	1977 range	1978 $\bar{x}$	1978 range
pH	8.52	7.1 - 9.3	8.83	7.7 - 9.9
Index of submersed vegetation in 0- to 61- depth zone	161	18 - 300	240	12 - 492
Percent smartweed	9.3	1.0 - 39.0	35.1	1.0 - 99.0
VOR's of shoreline vegetation	1.27	0.03 - 4.07	2.38	0.14 - 6.35
Hectares of corn, milo, or sorghum	28.8	6.8 - 71.9	16.0	2.1 - 36.9

photographs (1:4132). Shoreline development was determined according to Lind (1974). Distance to the nearest road, distance to the nearest stock pond, the number of stock ponds within a 1.6-km radius, and the number of natural pond basins within a 1.6-km radius were obtained from the aerial photographs. Land use categories of small grain (wheat); corn, milo or sorghum; pasture; idle; and hay on the adjacent section of upland were mapped on aerial photographs and acreages determined with a planimeter. Estimates of submersed vegetation in the 0- to 61-cm depth zone were made by multiplying frequency of occurrence in 40, 60-X 60-cm quadrats spaced equidistance around the pond, by the mean vegetation coverage rating (Rumble 1979). Percent of the pond 0- to 61-cm deep, percent of the pond 0- to 61-cm deep with emersed vegetation, and percent of the shoreline with trees along it were estimated. Shoreline vegetation data were obtained by the visual obstruction reading (VOR) method (Robel et al. 1970) from 12, 20-m transects, spaced equidistance around the pond and at right angles to the shoreline. Presence of livestock in adjacent pastures or fields was recorded.

Analyis of variance was used to show which habitat variables were different between 1977 and 1978. All possible combinations (32!) of the variables were evaluated in multiple regression equations. The combination of variables with the highest R^2 was interpreted for analyses and discussion herein. July data were used for the analyses because of the larger number of waterfowl broods present. Separate regression analyses of data from the 2 years would provide insight into the habitat variables waterfowl broods responded to during 2 different years. However, long-term habitat management plans for waterfowl usually cannot be drastically changed from year to year. Therefore, data from both years were used for regression analyses. Multiple regression equations were developed for total broods, mallard (*Anas platyrhynchos*) broods, and blue-winged teal (*A. discors*) broods. In addition to mallard and blue-winged teal broods, total broods included pintail (*A. acuta*), gadwall (*A. strepera*), northern shoveler (*A. clypeata*), and American wigeon (*A. americana*) broods. All variables and relationships discussed were significant at $\alpha \leq 0.05$.

Results and Discussion

Brood Utilization

Blue-winged teal were the most common waterfowl broods utilizing study ponds, composing 44 and 37% of the total number of broods in 1977 and 1978, respectively. Mallard broods were the next most common in both years, accounting for 27 and 24% of the total number of broods, respectively. Therefore, management of stock ponds to include habitat characteristics for these 2 species would benefit the majority of waterfowl being produced on stock ponds in this area of the northern high plains.

Year Differences

In terms of habitat and duck production, 1977 and 1978 were quite different. The spring of 1977 was dry following drought conditions in 1976, and ponds did not fill until May or June. The rest of 1977 and the following year had average or above-average precipitation; ponds were full and many fields had standing water during the 1978 spring migrations of waterfowl. Yellow sweetclover, in its second season of growth on range areas, was in suitable condition to provide good nesting cover during May and June. By July sweetclover in pasture areas was commonly over 1 m high. The VOR measurements of shoreline vegetation around study ponds during 1978 were significantly higher (Table 1) than during the previous year (2.38 ± 0.31 vs. 1.28 ± 0.17) ($\bar{x} \pm$ SE). In 1978 significantly ($\alpha \leq 0.001$) more broods (232) were seen on study ponds than in 1977 (85). Submersed vegetation in the 0–61 cm depth zone and percent smartweed significantly increased in 1978 ($\alpha \leq 0.05$). Submersed vegetation increased following drawdown from previous drought conditions and subsequent reflooding. Smartweed also were expanding into areas that were dry 2 years previous. The amount of land planted to corn decreased significantly in 1978 and there were increases in land planted to wheat and alfalfa in 1978. However, statistically, the latter 2 were not signifi-

Table 2. Habitat variables associated with waterfowl brood use of stock ponds as indicated by stepwise forward multiple regression.

Species and habitat variables[a]	Standardized partial regression coefficient[b]	Coefficient of determination R^2	Simple correlation coefficient (r)
Blue-winged teal broods			
Pond size	+0.42	0.19	0.43
Number of natural pond basins within a 1.6-km radius	+0.29	0.28	0.28
Percent river bulrush/burreed	–0.25	0.34	–0.32
Mallard broods			
Submersed vegetation in 0- to 61-cm depth zone	+0.29	0.16	0.40
Pond size	+0.28	0.28	0.28
Hectares of small grain (wheat)	+0.34	0.36	0.22
Percent of shoreline with trees	–0.38	0.40	–0.26
VOR's of shoreline vegetation	+0.26	0.46	0.28
Percent arrowhead/water plantain	–0.21	0.50	–0.25
Total broods[c]			
Pond size	+0.34	0.15	0.39
Submersed vegetation in 0- to 61-cm depth zone	+0.24	0.23	0.21
Number of natural pond basins within a 1.6-km radius	+0.24	0.29	0.20
Percent smartweed	+0.31	0.34	0.33
Percent spikerush	+0.27	0.40	0.24

[a]Variables are listed in the order they were entered into the equation.
[b]Sign of the standardized partial regression coefficient indicates the association of variable in this set of variables, absolute value indicates the relative importance.
[c]All species of waterfowl seen during this study.

cant increases.

Regression Analyses

Of the 32 habitat variables considered, only 10 were significantly associated with mallard brood, blue-winged teal brood, or total brood use of study ponds (Table 2). Pond size was entered into all equations despite the selection of ponds within a narrow size range (0.6 to 3.0 ha). In all cases pond size had a positive simple correlation (r) with numbers of broods. Size of ponds or impoundments was found to be important to waterfowl brood production in studies by Smith (1953), Berg (1956), and Lokemoen (1973). Lokemoen (1973) recommended the minimum pond size be at least 1.5 acres (0.6 ha) and that the maximum size be dictated by topography and economics. Pond size was also correlated to shoreline length, which was important in determining brood use in studies by Mack and Flake (1980). Some other habitat variables showed significant changes between years similar to those observed for numbers of broods; however, broods were most closely associated with pond size.

The number of natural pond basins within a 1.6-km radius of a study pond was positively associated to both blue-winged teal broods and total broods. The study ponds had between 3 and 17 natural pond basins within this proximity. These pond basins generally contain water only during spring and early summer months anad are important to the breeding physiology of nesting waterfowl hens (Krapu 1974, Krapu and Swanson 1975). They also tend to attract breeding pairs (Schroeder et al. 1976), which should result in more broods. Lokemoen (1973) recommended construction of stock ponds near other wetlands. Broods utilizing shallow basins will move to more permanent sources of water when these water sources dry as summer progresses (Evans et al. 1952:43; Mack and Flake 1980).

Submersed vegetation in the 0- to 61-cm depth zones of ponds was associated with mallard broods and total broods. Submersed vegetation provides habitat for aquatic organisms (Krull 1970) which, in turn, are an important food item for waterfowl broods (Swanson and Sargeant 1972, Swanson and Meyer 1973, Sugden 1973). The majority of submersed vegetation on study ponds was composed of *Potomogeton* spp. and *Myriophyllum* spp. Submersed and floating leaved hydrophytes were the most important factors affecting use of flood control structures by waterfowl in Texas (Hobaugh 1977:59).

Visual obstruction readings (VOR's) of shoreline vegetation were positively associated with use of study ponds by mallard broods. Shoreline vegetation provides loafing and escape cover for broods. Greater numbers of broods used ponds with brushy or grassy shorelines (Bue et al. 1952, Lokemoen 1973) or residual vegetation (Gjersing 1975) as opposed to bare shorelines.

Percent of emersed vegetation composed of spikerush and smartweed were positively associated with blue-winged teal broods and total broods. These types of emersed vegetation also provide secure cover for waterfowl broods for hiding or loafing. Lokemoem (1973) reported optimum brood cover appeared to be flooded brush or emersed vegetation. Both spikerush and smartweed comprised between 1 and 99% of the emersed vegetation on various study ponds. Ponds which had more spikerush and smartweed also had more broods.

Arrowhead/water plantain and river bulrush/burreed were negatively associated with blue-winged teal broods and mallard broods, respectively. Biologically, there is probably no negative effect of arrowhead/water plantain or river bulrush/burreed. However, ponds which had these types of emersed vegetation in abundance had little brood use as indicated by negative simple correlations.

The occurrence of trees along the pond edge was associated with reduced use of ponds by broods in this study. Ponds with many trees around the shoreline had fewer waterfowl broods. Trees on the Northern Great Plains have many positive values, and this relationship warrants further research.

Hectares of small grain in the surrounding section of land were positively associated with the occurrence of mallard broods on study ponds. Two successions of wheat farming were included in this variable—fields with a current crop growing and fields in which the stubble was left from the previous fall. The nesting cover provided by dense stands of wheat stubble 10-15 cm in height may have attracted mallard hens. Further, flooded stubble may have provided waste grain and invertebrates for feeding adult pairs. Duck production in areas of tilled lands was more successful if fall stubble was not plowed until mid July and if there was standing water in fields through the nesting season (Higgins 1977). Both conditions existed in this study to some degree. Small grain fields occupied an average of 8% (not more than 41%) of the upland section of land surrounding study ponds. Large scale conversion of uplands to small grain would likely lead to a reduction in overall brood production on associated stock ponds (Higgins 1977).

Management Suggestions

Although these ponds were developed to increase utilization of forage resources by livestock, prudent managers and ranch operators could obtain increased hunting, aesthetic, and in some cases, positive economic values (through hunting fees) by including habitat characteristics in pond construction and management that will enhance waterfowl production. The following features of pond construction are recommended: (1) build larger ponds where possible; (2) maximize the amount of shallow water area and shallow inlets for the production of submersed and emersed vegetation; (3) distribute livestock and maintain grazing levels to allow continued growth and existence of shoreline and emersed vegetation; (4) leave grain stubble in fields until after the peak nesting period to provide nesting cover; and (5) do not drain natural pond basins in adjacent areas.

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Effect of Time of Seeding on Emergence and Long-term Survival of Crested Wheatgrass in British Columbia

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Abstract

The study showed that fall was the best time to seed crested wheatgrass *(Agropyron desertorum)* in the dry belt of British Columbia. With fall seedings, if emergence did not take place in the fall, it did so the following spring; there was very little plant kill over winter. Among the spring seedings, germination took place if the soil moisture content was adequate, usually above 10%. Soil moisture content was the most important single factor in determining establishment of seedlings. Late May and June seedings often germinated and died before seedlings became established. Rains in June, July, and August were ineffective in promoting emergence but may have been a factor in assuring establishment of the early-spring seedlings. By 1981, fall seedings no longer retained their advantage but the poor performance of the June seedings was still evident.

The question of the best time to seed crested wheatgrass has been addressed in a number of locations with varying results. In the northern Great Plains of Saskatchewan (Kilcher 1961), crested wheatgrass established well over a wide range of seeding dates although fall seedings tended to be best. Stands seeded in late spring fared poorly. Fall and spring seedings usually established and survived equally well on the Intermountain Valley region of Montana (Gomm 1974). However, in the Intermountain region of Utah (Frischknecht 1951), early fall seedings resulted in higher emergence than those in late fall or spring but because of high mortality on the fall seeded plots, the number of surviving plants was similar for all seeding dates. Superior survival of fall seedings has been observed on big sagebrush-cheatgrass range in southern Idaho (Klomp and Hull 1972), the pinyon-juniper type in Arizona (Lavin et al. 1973), and in ponderosa pine forest in Montana (Gomm 1970).

In some cases spring seeding of crested wheatgrass may prove most reliable. At one trial in central Montana (Gomm 1974) there was no advantage to either spring or fall seedings; yet in another trial at the same location, spring seedings produced superior stands both initially and after 7 years. In the central Great Plains of Colorado, McGinnies (1960a) seeded crested wheatgrass from April to November for 5 years. There was great yearly variation and April was the only seeding month to produce satisfactory stands for each seeding year. Fall seedings were successful providing the seeds did not germinate until spring. McGinnies (1973) later examined spring seeding dates in greater detail and again found great year to year variation. Mid-April seedings proved most reliable for establishment but May seedings also usually performed well.

Success in establishing stands on grassland range seedings in southern British Columbia has been very erratic. The climate of the grasslands is dry and precipitation patterns are irregular. Timing of range seeding, therefore, is crucial to success. It is important to determine the limiting climatic factor in seedling establishment and the conditions under which successful stands can be obtained. The study reported here discusses the success of seed germination and establishment of seedlings of crested wheatgrass relative to weather factors operating in southern British Columbia.

Methods

Trials to determine the best date to seed crested wheatgrass in grassland ranges in British Columbia were conducted at 4 locations in the Kamloops area. The sites were located in the 3 major grassland zones (van Ryswyk et al. 1966) and one in the ponderosa *(Pinus ponderosa)* savannah. The Tranquille site (395m) was in the big sagebrush *(Artemisia tridentata)* - bluebunch wheatgrass *(Agropyron spicatum)* habitat type (h.t.). The soil, an Orthic Brown Chernozem in the Canadian system of soil classification (Aridic Boroll, U.S. Classification) (Canadian Survey Committee 1978), had a 15-cm layer of fine sandy loam overlaying loam to gravelly sandy loam till with sand lenses. This was the hottest and driest site. West Mara site (640m) was in the ponderosa pine-bluebunch wheatgrass h.t. on an Orthic Brown Chernozem that intergraded to a Dark Brown Chernozem (Typic Boroll) with 30 cm of fine sandy loam to loam lacustrine deposit. Pruden site (700 m) was in the bluebunch wheatgrass - Sandberg bluegrass *(Poa*

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sandbergii) h.t. on a moderately stony Orthic Dark Brown Chernozem with 15 cm of fine sandy loam loess over gravelly sandy loam to loam till. West Mara and Pruden sites had similar climates which were intermediate between the others. East Mara site (853 m) was in the rough fescue *(Festuca scabrella)* - bluebunch wheatgrass h.t. on an Orthic Black Chernozem (Udic Boroll) with 20 cm of fine sandy loam loess over sandy clay loam to loam till. East Mara was the coolest of the sites and had the most favorable moisture regime. The 3-year average April-to-October precipitation for the 4 sites was 104, 117, 130, and 140 mm respectively.

The existing vegetation was lightly rototilled during the fall, prior to seeding. Immediately before each sowing the plots were hand cultivated to remove any remaining plants. The plots were seeded to crested wheatgrass, variety Summit, at a rate of 20 kg/ha, which was equivalent to approximately 720 viable seeds per m^2. The seed was covered to a depth of 1.5 to 2 cm, and the plots rolled lightly with a weighted lawn roller. Seeding was done at 2-week intervals starting April 1 to mid June, and again in September and October for a total of 12 treatments. Exclosures were erected at all sites. The trial was repeated for 3 consecutive years. Tranquille and Pruden were started in 1970, and the East and West Mara sites in 1971. At the East Mara site snow cover prevented seeding on the first two dates in 1971 and the first date in 1972. At all sites a randomized block design was used, replicated 4 times, with a plot size of 1.2 $\times$ 3.0 m.

Daily air temperatures (Stevenson screen at 1.22 m), soil temperatures (3 cm depth) and weekly precipitation were recorded at all sites. Weekly soil moisture determinations were made on samples from the 2-, 5-, 10-, and 15-cm depth by the gravimetric method. The 2-cm sample was not collected if the surface soil was at air-dry conditions. A composite sample of soil, taken from the 2 cm depth, was collected at each seeding site. Soil water retention curves were developed for each composite to calculate soil water storage capacity of the sites.

Seedlings were counted at 2-week intervals following seeding for the first season and once a year, in late May, until 1975. Also, counts and yields were taken on all plots in 1981. Crested wheatgrass density was determined by counting plants on 4 permanent 0.1-m^2 sub-plots within each plot. The sub-plot counts were totalled and converted to number of plants per square meter. Forage yields were taken on 2 0.5-m samples from each plot. Crested wheatgrass was separated from the remaining vegetation (weeds) and oven-dry weights recorded from each component. Yields from the 2 plots were summed to give yield per square meter. Seedling emergence was used as a measure of germination.

Results and Discussions

Seedling establishment the year after seeding varied greatly among seeding years and sites. Fall seedings, however, produced significantly ($P<.05$) better stands the following spring than did spring seedings when the results from the 4 sites and 3 years were pooled in a Duncan's multiple range test (Table 1). Among the spring seedings, those of mid and late April resulted in the best establishment; earlier or later spring seedings were less successful, particularly those in June. With all fall seedings, if germination and establishment did not take place in the fall, it did so the following spring. In contrast to stands from fall seedings, those from spring seedings did not improve the following spring.

Moisture Effects

Examination of the data indicated that the 2-cm soil moisture measurement was most closely correlated with germination and therefore is the only value reported. Soil moisture is expressed as percent of available water storage capacity (by volume) in addition to percent by weight (Table 2) to allow for direct comparison of the 4 sites.

Soil moisture content was the most important factor affecting germination in the present study. Soil moisture (Table 2) and precipitation (Table 3) patterns varied widely between years and sites. Spring germination took place following snow melt if winter moisture reserves remained until the soil temperature increased sufficiently to permit germination. In some years germination followed rains in May. Spring seedings done after late May could not be depended upon to germinate even at East Mara, where soil moisture was adequate and soil temperatures remained in the 15 to 20° C range until mid-July.

Late June seedings were particularly unsuccessful. An average of 80% of the seedlings which emerged from these seedings during the summer died before fall. In addition to this loss, many seeds never emerged. Hassanyar and Wilson (1979) reported greater susceptibility of seeds to injury at late stages of germination than at the beginning. Presumably in the present study, the moisture supply was sufficient to initiate germination but did not persist long enough for seedling emergence and thus seed mortality resulted.

In our study, precipitation values did not relate as well to germination and establishment as did soil moisture values. Because of weekly sampling, soil moisture values did not always correspond to precipitation which may have fallen anytime during the week. The length of time that precipitation remained effective was dependent upon the precipitation pattern and prevailing temperatures. For example, at Tranquille in 1972, 1.9 cm of rain raised the soil moisture content at 2 cm to 22% in the week of June 12, whereas 2.3 cm in the week of August 21 raised the level to only 12%. Previous week soil moisture contents at the above sites were 4 and 5% respectively. However, the limitations placed on the interpretation of both precipitation and soil moisture data when only weekly values are obtained are recognized.

No seedlings emerged when soil moisture content (by weight) was less than 6% and emergence occurred on at least some of the replications when soil moisture exceeded 21%. However emergence was unpredictable when soil moisture content fell in the range of intermediate values between 6 and 21%. For example, at one counting date on the Pruden site when soil moisture was 9.7%, emerged seedlings were present on all replications of one treatment (seeding date) but were absent on all replications of another. Apparently factors other than soil moisture (as measured in this study) were affecting emergence.

Moisture stress frequently has been cited as a major factor impairing crested wheatgrass germination. McGinnies (1960b) found that as moisture stress increased, germination was delayed and the rate was reduced. Nelson et al. (1970) considered moisture the primary cause of differences in seed germination and metabolism since soil moisture fluctuated greatly while soil temperatures remained fairly constant. Drilled seeds experienced delayed ger-

Table 1a. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding, and in 1981; average of 4 sites and 3 years. Values are expressed as the average number of plants per square meter.

	Average of all sites and all years		
Date seeded	Fall	Spring	1981
Apr 1	96*ab*[1,2]	61*ef*[2]	28*abc*[2]
15	136*ab*[2]	97*cde*[2]	33*ab*[2]
29	137*a*	107*cd*	33*ab*
May 13	111*ab*	68*def*	27*abc*
27	115*ab*	70*cdef*	26*abc*
Jun 10	62*bcd*	41*ef*	23*bc*
24	19*cd*	33*f*	17*e*
Sep 1	109*ab*	171*ab*	35*a*
15	70*bc*	171*ab*	33*ab*
29	25*cd*	188*a*	35*a*
Oct 13	0*d*	175*ab*	34*ab*
29	0*d*	127*bc*	29*ab*
Avg	73	109	29

[1]*a-f*Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.
[2]Means adjusted for missing seeding dates.

Table 1b. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding and in 1981; on two Orthic Brown Chernozems over 3 years. Values are expressed as the average number of plants per square meter.

	Tranquille								
	Year seeded								
	1970			1971			1972		
	Year counted								
Date seeded	Fall 1970	Spring 1971	Summer 1981	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981
Apr 1	4b[1]	12c	28	83ab	66cd	27	77b	90abc	21
15	4b	11c	26	139a	84c	23	92b	70bcd	21
29	4b	20c	18	126a	83c	18	101ab	64bcd	12
May 13	6b	17c	30	96ab	73c	22	100ab	66bcd	14
27	4b	25c	19	121a	86c	21	129a	71cd	23
Jun 10	4b	21c	28	47bc	27cd	19	107ab	37cd	18
24	11b	40c	28	3c	8d	19	0c	4d	16
Sep 1	151a	234b	34	0c	171b	9	0c	89abc	31
15	8b	240b	26	0c	240a	11	0c	136a	29
29	3b	333a	30	0c	274a	26	0c	143a	18
Oct 13	0b	184b	26	0c	270a	20	0c	124ab	20
29	0b	206b	25	0c	272a	18	0c	61bcd	18
Avg	17	112	27	51	138	19	50	80	20

	West Mara								
	Year seeded								
	1971			1972			1973		
	Year counted								
Date Seeded	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981	Fall 1973	Spring 1974	Summer 1981
Apr 1	159b	70d	29b	148b	113abc	34a	8f	24e	24c
15	155b	70d	32b	189a	56cd	31a	241c	263c	53a
29	189b	75cd	33b	137b	83bc	32a	286b	271c	62a
May 13	266a	103bcd	50a	160ab	86bc	33a	36f	52e	23c
27	271a	137b	50a	142b	84bc	27ab	47f	72e	28bc
Jun 10	154b	73d	38ab	19d	9d	9c	107e	141d	43abc
24	0c	3e	9c	0d	3d	14bc	161d	171d	49a
Sep 1	41c	89bcd	29b	73c	161a	28ab	379a	344ab	63a
15	7c	131b	43ab	6d	133ab	26ab	357a	308bc	53a
29	0c	122bc	41ab	0d	126abc	25ab	226c	371a	58a
Oct 13	0c	208a	35ab	0d	126abc	24ab	0	309bc	50a
29	0c	109bcd	36ab	0d	59cd	16bc	0	173d	47ab
Avg	104	99	35	73	87	25	185	208	46

[1]*a-f* Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.

mination from low soil temperatures when moisture was favourable, but broadcast seeds were probably most influenced by generally unfavourable and rapidly fluctuating soil moisture content (Wilson et al. 1970).

Soil water retention curves in our study revealed widely differing volumes of soil occupied by water at field capacity (1/3 bar) and permanent wilting point (15 bars) at the 4 seeding sites (Table 4). However the available water storage capacity of the sites were remarkably similar.

Temperature Effects

Values and trends of soil and air temperatures followed similar patterns from year to year in contrast to precipitation patterns. In general, temperature did not appear to be limiting except at times when soil moisture was favourable such as late fall and in some cases early spring. High summer temperatures which coincided with low soil moisture contents probably contributed to the lack of germination.

Other studies have demonstrated that crested wheatgrass and other grasses can germinate at low temperatures following prolonged cold treatment (Wilson et al. 1970, Frischknecht 1951). Bleak (1959) noted germination of smooth brome and tall oatgrass in thawed soil and soil under heavy snow cover. It is probable in the present study that seed planted in the fall germinated very early in the spring and became established before the winter moisture reserves were exhausted. In laboratory trials, McGinnies (1960b) obtained slower germination of crested wheatgrass at 10° C than at 20 or 30° C. Ellern and Tadmor (1966), who similarly reported retardation of onset and completion of germination at low temperatures, remarked on the importance of rapid germination and establishment in a drying seedbed. They suggested that low temperatures may delay germination so that seedlings are unable to establish prior to soil moisture depletion. However, Wilson (1973) found that germination was hastened in field trials when seeds experienced periods of low temperatures with adequate moisture. He remarked that seeds planted in fall and early spring make significant gains in germination hastening after the soil thaws while those seeds planted in late spring when soil temperatures are warmer may have inadequate time for seedling growth. Stratification (exposure to cold and moist conditions for a period of time) may have improved germination in the present and other field studies (Frischknecht 1951, Kilcher 1961) where fall seedings of crested wheatgrass (which germinated under cool conditions) proved most successful. Neither of the laboratory studies (McGinnies 1960b; Ellern and Tadmor 1966) indicated seed stratification prior to planting.

Table 1c. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding and in 1981; on a Orthic Dark Brown (Pruden) and Orthic Black (East Mara) Chernozem over 3 years. Values are expressed as the average number of plants per square meter.

	Pruden								
	Year seeded								
	1970			1971			1972		
	Year counted								
Date seeded	Fall 1970	Spring 1971	Summer 1981	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981
Apr 1	29c[1]	23d	12b	131c	103cd	47a	217a	181a	55ab
15	9c	9d	11b	121c	83d	44a	201a	180a	64a
29	7c	7d	9b	205b	131bcd	51a	102b	141ab	64a
May 13	3c	4d	3b	194b	131bcd	46a	74c	82bc	43bc
27	7c	5d	4b	254a	166ab	54a	73c	48cd	24cd
Jun 10	8c	9d	6b	119c	90d	41a	23d	7d	9d
24	17c	18d	8b	0d	6e	4b	0e	11d	9d
Sep 1	333a	244b	51a	30d	97d	45a	39d	78bc	24cd
15	302b	259b	56a	11d	106cd	41a	0e	96bc	29c
29	18c	323a	48a	0d	122bcd	43a	0e	99bc	31c
Oct 13	0c	286ab	61a	0d	186a	56a	0e	93bc	29c
29	0c	125c	16b	0d	158abc	51a	0e	92bc	31c
Avg	61	109	24	89	115	44	61	92	34
	East Mara								
	Year seeded								
	1971			1972			1973		
	Year counted								
Date seeded	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981	Fall 1973	Spring 1974	Summer 1981
Apr 1	—	—	—	—	—	—	26e	29f	24ef
15	—	—	—	191a	138a	23	129c	141de	46bcd
29	143b	134a	15	202a	133a	36	129c	139de	41bcdef
May 13	224a	128a	20	83c	47b	20	8e	23f	22f
27	108bc	104ab	17	123b	19cd	19	16e	26f	26def
Jun 10	23d	9d	8	68cd	12d	18	36e	54f	35cdef
24	3d	3d	1	0e	6d	11	88cd	123e	39bcdef
Sep 1	59d	86abc	19	51d	119a	23	383a	338a	67a
15	21d	64bc	10	11e	33bcd	13	406a	302ab	55abc
29	0d	51cd	14	0e	43bc	23	203b	246bc	57ab
Oct 13	0d	95abc	16	0e	30bcd	20	0f	190cd	45bcde
29	0d	48cd	21	0e	9d	14	0f	207c	59ab
Avg	58	72	14	66	54	20	119	152	43

[1]a-f Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.

Table 2a. Biweekly percent soil moisture by weight (% by wt) and percent of available water storage capacity (% of AWSC) at 2-cm depth from April to November on two Orthic Brown Chernozems during the years of study.

	Tranquille						West Mara					
	1970		1971		1972		1971		1972		1973	
	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC
Apr 1	—	—	23	49	20	36	—	—	28	73	9	0
15	7	0	11	0	15	7	33	96	20	32	7	0
May 1	7	0	6	0	11	0	13	2	11	0	4	0
15	4	0	5	0	9	0	4	0	7	0	—	0
June 1	—	0	19	27	6	0	15	12	3	0	10	0
15	10	0	13	0	22	43	17	20	27	68	5	0
July 1	7	0	10	0	17	17	11	0	22	45	5	0
15	—	0	8	0	14	2	5	0	13	0	—	0
Aug 1	—	0	—	0	5	0	—	0	4	0	—	0
15	5	0	—	0	4	0	—	0	—	0	—	0
Sep 1	8	0	15	4	6	0	21	39	—	—	4	0
15	9	0	6	0	6	0	5	0	8	0	4	0
Oct 1	6	0	12	0	4	0	12	0	6	0	17	20
15	17	20	8	0	4	0	15	8	3	0	14	5
Nov 1	10	0	7	0	21	41	11	0	23	48	24	55

Table 2b. Biweekly percent soil moisture by weight (% by wt) and percent of available water storage capacity (% of AWSC) at 2 cm depth from April to November on an Orthic Dark Brown (Pruden) and Orthic Black (East Mara) Chernozem during the years of study.

	Pruden						East Mara					
	1970		1971		1972		1971		1972		1973	
	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC
Apr 1	30	95	—	—	—	—	—	—	—	—	47	96
15	17	31	30	95	31	100	—	—	—	—	27	20
May 1	7	0	12	7	20	49	50	100	29	25	14	0
15	6	0	11	0	18	39	24	6	27	20	—	0
June 1	5	0	16	30	3	0	27	20	9	0	26	15
15	8	0	16	30	19	42	29	25	40	66	12	0
July 1	—	0	8	0	16	30	12	0	33	41	10	0
15	—	0	8	0	18	37	11	0	36	55	—	0
Aug 1	—	0	—	0	6	0	—	0	10	0	—	0
15	—	0	—	0	3	0	—	0	4	0	—	0
Sep 1	9	0	17	31	3	0	35	49	33	41	10	0
15	8	0	5	0	6	0	8	0	17	0	10	0
Oct 1	11	0	7	0	5	0	26	15	11	0	26	15
15	17	31	14	19	2	0	29	25	7	0	28	22
Nov 1	12	7	8	0	21	50	18	0	31	33	37	55

Table 3. April to October monthly total precipitation (mm) at the seeding locations during the years of seeding.

	Tranquille				West Mara			
	1970	1971	1972	Avg	1971	1972	1973	Avg
Apr	10	2	6	6	4	10	2	5
May	13	22	16	17	28	14	18	20
Jun	25	33	33	30	36	43	17	32
Jul	4	19	15	13	17	26	8	17
Aug	19	9	24	17	13	32	8	17
Sep	9	8	18	12	9	17	17	14
Oct	16	5	7	9	10	6	16	11
Apr-Oct	96	97	118	104	117	148	86	117
	Pruden				East Mara			
	1970	1971	1972	Avg	1971	1972	1973	Avg
Apr	9	3	6	6	3	9	25	12
May	19	33	25	26	33	24	20	26
Jun	35	32	40	36	39	45	21	35
Jul	3	17	29	16	21	29	12	21
Aug	22	8	22	17	10	32	9	17
Sep	24	10	17	17	13	19	21	18
Oct	13	15	8	12	11	8	15	11
Apr-Oct	125	118	147	130	130	166	124	140

Location Effects

Time and degree of seedling establishment varied greatly from year to year and from site to site, largely because of differences in the climate between locations. Tranquille was the hottest and driest location, while East Mara was the least dry, not only because of higher precipitation but also because of lower evaporation rates resulting from lower temperatures. West Mara and Pruden had similar climates which were intermediate between the others.

In some years the period for successful germination in the year of seeding can be very short (within 2 weeks), especially on the drier drier sites. For example, at Tranquille in 1970, only the September 1 seeding produced a stand during the year of seeding. In 1970, the soil-moisture levels remained low throughout the growing season until 1.3 cm of rain fell in the first week of September. This rain raised the soil moisture level above 10% for 10 days before it dropped again to below 8% by mid-September, where it remained until mid-October. At Pruden, which is 273 m higher in elevation, the same rain shower dropped 1.9 cm of rain and the soil moisture remained between 22 and 11% until mid-October. At this location, germination took place in the September 15 seeding also. The mean soil temperature dropped below 10°C by October 10, preventing further germination.

East Mara was located at the highest elevation of the 4 sites. In 2 of the 3 years snow covered the site on the early seeding dates. Despite the late start for the East Mara site, late-spring seedings were no more successful there than at the lower-elevation sites

Table 4. Water content* at field capacity (0.3 bar) and permanent wilting point (15 bars) and available water capacity* of seeding site soils (1-3 cm depth).

Site	Field capacity	Permanent wilting point	Available water storage capacity
Tranquille	37.5	16.6	20.9
West Mara	37.2	14.3	22.9
Pruden	31.0	10.1	20.9
East Mara	46.1	20.9	25.1

*All values expressed as percent water by volume

Table 5. Effect of date of seeding on crested wheatgrass dry matter yield (g/m^2) in 1981.

Year seeded	Tranquille			West Mara		
Date seeded	1970	1971	1972	1971	1972	1973
Apr 1	41.2	41.5*abc*[1]	56.0*ab*	31.8	39.0*ab*	40.9
15	41.9	40.6*abc*	53.9*abc*	42.7	52.7*a*	60.2
29	34.1	49.9*ab*	70.9*a*	48.2	49.4*a*	77.6
May 13	43.0	52.5*a*	45.4*bc*	45.3	54.6*a*	50.5
27	46.7	49.0*ab*	48.1*abc*	52.6	47.9*a*	47.2
Jun 10	30.7	42.7*abc*	57.7*ab*	50.3	18.2*b*	55.9
24	40.0	31.6*abcd*	31.5*c*	16.3	12.1*b*	58.8
Sep 1	49.5	16.4*d*	41.5*bc*	43.1	57.9*a*	70.3
15	48.6	26.5*cd*	52.6*abc*	38.6	53.8*a*	61.8
29	42.7	47.0*abc*	37.2*bc*	38.5	54.5*a*	57.9
Oct 13	39.5	44.0*abc*	44.0*bc*	45.5	65.7*a*	60.6
29	40.4	29.6*bcd*	52.7*abc*	51.3	66.2*a*	53.3
Avg	41.5	39.3	49.3	42.1	47.7	57.9

Year seeded	Pruden			East Mara		
Date seeded	1970	1971	1972	1971	1972	1973
Apr 1	38.9*cde*	56.2	52.9	—	—	67.0
15	45.4*bcd*	58.7	52.6	—	46.1	84.1
29	20.8*ef*	72.3	68.4	46.2	50.7	68.7
May 13	12.9*f*	48.6	63.0	37.8	25.2	85.5
27	11.7*f*	69.2	60.0	35.5	51.8	50.0
Jun 10	26.8*def*	60.5	31.0	12.3	19.1	92.4
24	28.1*def*	32.9	29.7	19.2	26.7	84.7
Sep 1	63.9*ab*	57.2	54.1	57.2	66.6	93.0
15	52.0*bc*	47.1	66.6	35.1	51.5	83.5
29	61.0*ab*	68.0	71.7	61.7	49.9	68.2
Oct 13	74.8*a*	62.5	50.3	21.6	40.7	102.0
29	46.9*bcd*	61.9	51.5	51.3	35.9	84.1
Avg.	40.3	57.9	54.3	37.8	42.2	80.2

[1]*a-f* Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.

since the soil moisture level dropped about as quickly in early summer as it did at the other sites. In 1972, the April 15 and 27 seedings appeared to respond to rains in late May. In 1971, the late spring seedings germinated quickly, but many seedlings died in late July and August. Similar results were obtained the same year with the late-spring seedings at other locations.

Subsequent Year Effect

Nine to 12 years after seeding, crested wheatgrass populations continued to vary among seeding sites and years. When the 1981 counts were pooled, the advantage of fall versus spring seeding virtually had disappeared since the initial counts, but the populations of the mid-June seedings remained low (Table 1). Yields likewise indicated a disadvantage in many of the June seedings (Table 5). Most populations declined from the initial counts, the exceptions being plants with low starting densities which either remained constant or improved. The 1981 weed yields had very limited interpretive value because of the great variation among plots. There was a tendency for an inverse relationship between weed and crested wheatgrass yield so that total plot yields were often relatively consistent among dates within a seeding year.

At the Tranquille site (driest), crested wheatgrass populations apparently reached equilibrium for each year of seeding. Analysis of yields indicated minor differences among dates in the 1971 and 1972 seedings, but there were no sharp distinctions.

Counts differed significantly among dates at West Mara. Plant populations tended to remain low on those stands with poor initial establishment but plots which originally differed with moderate or good early establishment showed no difference by 1981. Despite count differences among seeding dates, there is no statistical difference in yields except for the 1972 seedings. Low crested wheatgrass productivity for the June 1972 seedings will likely continue as these plots now support moderate to dense stands of big sagebrush, pasture sage *(Artemisia frigida)*, and bluebunch wheatgrass.

Analysis of the Pruden counts also indicated differences among treatment dates. All seeding years shared low mid-June seeding counts but otherwise the years were dissimilar. Early spring seeded plots were favoured over fall seeded in the 1972 seeding, while the reverse was true for the 1970 seeding. There was no difference between fall and spring dates in the 1971 seeding. Diffuse knapweed *(Centaurea diffusa)* has invaded the Pruden site since completion of the seedings. It has become well established where crested wheatgrass density is low but strong wheatgrass populations have impeded knapweed invasion.

East Mara populations have declined greatly from the initial counts, likely as a result of intense competition from Kentucky bluegrass *(Poa pratensis)* and other perennial grasses. No statistical count differences were detected for the 1971 and 1972 seedings, although the average plant densities varied widely among dates. The lack of significance likely resulted from great variation between replicates. Fall seeded plots continued to be favored in the 1973 seeding. The initial advantage enjoyed by the fall 1973 seedings, of germinating in a moist spring following a drought year, is still evident. There was no statistical difference in 1981 crested wheatgrass yields among dates for any of the 3 years, although the 1971 and 1972 June seeding yields appeared low. Again, great variation between plots may have masked seeding date differences.

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Sod-Seeding Alfalfa into Cool-season Grasses and Grass-Alfalfa Mixtures Using Glyphosate or Paraquat

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Abstract

Sod-seeding alfalfa into swards of smooth and meadow bromegrass, tall and intermediate wheatgrass, and orchardgrass and mixtures of these grasses with alfalfa using glyphosate or paraquat to suppress the existing vegetation was evaluated. Glyphosate (1.7 kg/ha) or paraquat (0.6 kg/ha) was applied 12 days prior to sod-seeding alfalfa (645 PLS/m²). Glyphosate completely suppressed or killed all the grasses and as a result, excellent stands of alfalfa were obtained producing 5.8 to 6.4 Mg/ha the establishment year at Mead, Neb., without irrigation. The grass-alfalfa mixtures were also converted into pure stands of alfalfa by using glyphosate. Glyphosate suppressed but did not kill the existing alfalfa. Sod-seeding in pure stands of grasses following paraquat application produced stands that were approximately 50% grass and 50% alfalfa. Paraquat had a limited suppressive effect on alfalfa and sod-seeded alfalfa did not become established in plots containing old alfalfa.

Hayfields and pastures of cool-season grasses and alfalfa (*Medicago sativa* L.) are important forages on many ranches and farms. Cool-season grasses need nitrogen fertilization to maintain maximum productivity. Seeding legumes into grass pastures and hayfields could reduce nitrogen fertilizer requirements. Sod-seeding legumes may reduce tillage needs for establishing legumes or grass-legume mixtures but competition from existing vegetation must be suppressed for the seeded legume to become established.

Recent research on the use of glyphosate [N-(phosphonomethyl) glycine] and paraquat [1,1′-dimethyl-4,4′-bipyridinim ion] to kill or suppress existing vegetation when seeding legumes into grass sod has shown that glyphosate almost completely suppresses perennial grasses and results in almost pure stands of legumes but that paraquat only temporarily suppresses the grasses and mixed stands of grasses and legumes are obtained (Groya and Sheaffer 1981, Muller-Warrant and Koch 1980, Olsen et al. 1981, Sheaffer and Swanson 1982, and Welty et al. 1981).

Previous research on the use of glyphosate or paraquat in sod-seeding has been on grass swards. However, it may often be desirable to renovate old pastures or hayfields that already have some legumes in them. This research evaluated the effectiveness of sod-seeding alfalfa into smooth bromegrass (*Bromus inermis* Leyss.), meadow bromegrass (*B. biebersteinii* Roem and Schult.), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), tall wheatgrass (*A. elongatum* (Host) Beauv.), and orchardgrass (*Dactylis glomerata* L.) swards and mixed swards of these grasses with alfalfa using glyphosate or paraquat to suppress the existing vegetation. Intermediate and tall wheatgrasses and meadow bromegrass are important forage components of many western livestock operations and the effectiveness of glyphosate and paraquat in suppressing these grasses during sod-seeding has not been reported.

Materials and Methods

The research was conducted at the Mead Field Laboratory of the Nebraska Agricultural Experiment Station, located about 32 km west of Omaha. Two adjacent experimental areas on a Sharpsburg silty clay loam (Typic Argiudoll) were used. Both areas were seeded in 1977, one in the spring and the other in the fall, to replicated plots of 'Lincoln' and 'Rebound' smooth bromegrass, 'Regar' meadow bromegrass, 'Slate' intermediate wheatgrass, 'Platte' tall wheatgrass, 'Sterling' orchardgrass, 50-50 mixtures of each grass with 'Dawson' alfalfa, and Dawson alfalfa. Procedures for both experimental areas were the same except for the date of seeding.

Good stands were obtained on all plots. However, in the fall-seeded experiment, orchardgrass winter killed the first winter so the plots originally seeded to orchardgrass were roto-tilled and seeded to alfalfa in the spring of 1978. The experimental design was

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a randomized complete block with 6 replications. The plots were 4.3 m long and 1.2 m wide and were separated on the ends by 1.2-m wide alleys that were seeded to tall fescue (*Festuca arundinacea* Schreb.) in the spring-seeded experiment and to crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) in the fall-seeded experiment.

In 1978, 1979, and 1980 these experiments were maintained as high production irrigated hayland and were harvested on a 4-cut alfalfa schedule. In the early spring of 1981 there were excellent stands in all plots of both experimental areas.

On April 9, 1981, the spring-seeded area was broadcast sprayed with 1.7 kg/ha of glyphosate and the fall seeded area was broadcast sprayed with 0.6 kg ion/ha of paraquat. The surfactant, X-77, was used with the paraquat and 21.4 l/ha H_2O was used as the carrier for both herbicides. Hereafter in this paper the 2 areas will be referred to by their respective herbicide treatments, i.e., glyphosate or paraquat treated area. All grasses and the alfalfa had initiated vegetative growth at the time of spraying. Alfalfa was sod-seeded into both areas on April 21, 1981, at the rate of 645 PLS/m² using a John Deere[1] power-till drill perpendicular to the direction seeded in 1977.

On July 7, August 18, and October 21, 1981, both areas were harvested for forage yield using a flail-type plot harvester that harvested a 0.9 m wide swath out of the center of each plot. The third cut was harvested following a frost (0° C) on October 19, 1981. The cutting height for all harvests was 10 cm. The percentage of harvested forage that was perennial grass or legume was determined for each cut by visual estimation of the standing forage at harvest. The percentage of alfalfa that was from the newly seeded (new) or from established plants (old) was also visually evaluated for the first harvest for both areas. This was possible because the old alfalfa was past full bloom and the new alfalfa had not flowered. It was also possible to differentiate between old and new alfalfa at second harvest on the paraquat area. Visual estimates were made to quantify botanical changes in the swards following treatment with herbicides.

Stand counts were made during the last week of April 1982. Alfalfa stand counts were determined by frame counts. A metal grid containing 25 squares, each 15 cm × 15 cm was placed on each plot and the number of squares containing an alfalfa plant were counted. This procedure was repeated on a different area of the same plot. Since 50 squares were read, stand percentage was calculated as 2 × the total number of squares that contained an alfalfa plant. Grass stands were obtained using the same procedure. Stand counts of 50% for both grass and alfalfa would indicate that 25 of the 50 squares that were read contained at least one alfalfa plant and 25 squares (but not necessarily the same squares as for alfalfa) contained at least 1 grass plant. The experimental areas did not receive any irrigation in 1981 or 1982.

Table 1. Establishment year productivity of alfalfa sod-seeded into established swards of cool-season grasses, alfalfa, and cool-season grass-alfalfa mixtures with preseeding applications of glyphosate and paraquat and the resulting grass and alfalfa stands.

	Means								Stands	
	Harvest 1			Harvest 2			Harvest 3		April 1982	
					Alfalfa[2]					
Entry (previous sward)	Yield[1] (Mgha^{-1})	Old alfalfa[2] (%)	New alfalfa[2] (%)	Yield[1] (Mgha^{-1})	old (%)	new (%)	Yield[1] (Mgha^{-1})	Alfalfa[2,3] (%)	Grass (%)	Alfalfa (%)
				Glyphosate Treated Plots						
Lincoln smooth brome	1.12	0	100	2.98	100[3]		1.72	100	17	100
Regar meadow brome	0.99	0	100	2.89	100		1.88	100	5	99
Rebound smooth brome	1.16	0	100	2.98	100		1.86	100	1	99
Slate intermediate wheatgrass	1.25	0	100	3.14	100		2.11	100	3	99
Platte tall wheatgrass	1.12	0	100	3.00	100		1.88	100	10	98
Sterling orchardgrass	1.41	0	100	3.00	100		1.97	100	4	98
Lincoln + alfalfa	2.64	37	63	3.56	100		1.88	100	3	98
Regar + alfalfa	2.73	22	78	3.58	100		2.06	100	5	99
Rebound + alfalfa	3.11	33	67	3.54	100		1.99	100	0	96
Slate + alfalfa	3.07	28	72	3.65	100		1.90	100	4	98
Platte + alfalfa	3.14	38	62	3.67	100		1.88	100	3	96
Sterling + alfalfa	2.71	28	72	3.32	100		1.94	100	3	97
Dawson alfalfa	3.76	60	40	3.54	100		1.88	100	1	98
LSD .05	0.23	14	14	0.17			0.07		3	8
				Paraquat Treated Plots						
Lincoln	0.96	3	0	1.68	3	43	1.07	50	99	91
Regar	0.94	3	0	1.75	8	28	1.30	50	98	85
Rebound	1.05	3	0	1.99	2	45	1.34	60	88	96
Slate	2.02	7	0	1.86	0	55	1.43	63	92	97
Platte	1.90	0	0	1.75	0	55	1.23	62	91	75
Lincoln + alfalfa	4.97	72	0	4.03	50	10	1.88	63	87	69
Regar + alfalfa	4.90	82	0	4.02	55	12	2.08	73	73	60
Rebound + alfalfa	4.79	75	0	3.81	48	10	1.90	78	60	77
Slate + alfalfa	5.24	75	0	3.67	58	13	1.95	72	85	68
Platte + alfalfa	5.60	80	0	3.83	70	10	1.93	70	80	55
Dawson alfalfa	5.44	100	0	4.19	90	10	2.02	100	10	76
LSD .05	0.48	11		0.19	10	14	0.10	15	14	14

[1]Yields are reported on a dry weight basis. Mgha-1 = megagrams/hectare = metric tons/hectare = 0.446 U.S. tons/acre.
[2]Estimate of the composition of the harvested forage that was alfalfa. % grass = 100 – % alfalfa.
[3]Old and new alfalfa were undistinguishable.

Results and Discussion

Glyphosate Treatment

Excellent initial stands of sod-seeded alfalfa were obtained in the glyphosate area. The 12-day interval between spray and seeding allowed the glyphosate to completely suppress the grasses. At the first harvest in July the old alfalfa, i.e., that seeded in 1977, was in the green pod stage while newly seeded alfalfa was 20 cm tall. The newly seeded alfalfa comprised 100% of the forage harvested from what had previously been pure stands of grasses (Table 1). Glyphosate temporarily stunted but did not kill the old alfalfa plants. At first harvest the old alfalfa had recovered from the glyphosate treatment, and it provided 22 to 38% of the harvested forage on what had previously been grass-alfalfa plots and 60% of the forage in the pure alfalfa plots. By the second harvest at one-tenth bloom, it was difficult to distinguish between the old and new alfalfa, and the entire area looked like a solid stand of alfalfa. No grass was harvested from any of the plots because the grass foliage of surviving plants was shorter than the 10 cm harvest height. In the spring of 1982 alfalfa ranged from 96 to 100% (Table 1). Lincoln smooth bromegrass survived better than all other grasses, demonstrating both within and between species differences for tolerance to glyphosate.

Paraquat Treatment

Excellent initial stands of sod-seeded alfalfa were also obtained in plots treated with paraquat. Paraquat, however, only temporarily suppressed the grasses and its effect on the old alfalfa was minimal. The 1.68 mg/ha more forage produced at first harvest from Dawson alfalfa plots treated with paraquat compared to plots treated with glyphosate illustrates the differences in suppressive effect of the herbicides (Table 1). At first harvest, the old alfalfa in the paraquat area was in the green pod stage and the new alfalfa was 8 cm tall. Since the new alfalfa was below the 10-cm cutting height, it was not a component of the harvested yield for any of the plots at first harvest (Table 1). At second harvest, the old alfalfa was at full bloom while the new alfalfa was at one-tenth bloom. In plots that had previously been grass-alfalfa mixtures or pure stands of alfalfa, it was estimated that 13% or less of the harvested forage was new alfalfa but it comprised about 45% of the harvested forage in plots that previously had been pure stands of grasses (Table 1). At third harvest we could not distinguish between old and new alfalfa plants. Grasses were an important component of the forage yield for all 3 harvests for those plots previously containing grasses (Table 1).

In plots that had previously been pure stands of grasses, nearly equal stands of grasses and alfalfa were obtained by sod-seeding with paraquat. Grass stands in plots that had previously been grass-alfalfa mixtures were slightly higher in most instances than alfalfa stands in the same plots. Alfalfa stands in plots that had previously been grass-alfalfa mixtures were lower than alfalfa stands in what had been pure stands of grasses. In the paraquat area in the spring of 1982, all alfalfa in plots that previously contained alfalfa (1977 seeding) were old alfalfa plants. These alfalfa plants were large randomly distributed plants while those in plots that were previously had been all grass were much smaller and in rows. Apparently sod-seeded alfalfa did not become established in plots containing old alfalfa in the paraquat area because of either excessive competition or alleopathic effects of the old alfalfa. Newly seeded alfalfa did emerge and could be seen in rows in plots that contained old alfalfa but these seedlings did not survive the first year.

Although stand counts were not taken prior to spraying with glyphosate or paraquat, the excellent stands that were present in both sets of plots prior to spraying can be shown by surviving grass and old alfalfa stands in the paraquat plots in the spring of 1982. As pointed out previously, alfalfa plants in the original grass-alfalfa plots in the paraquat study were all old plants. By the time of this study some of the pure stands of Dawson alfalfa had been invaded by some grasses (primarily Kentucky bluegrass *(Poa pratensis* L.)), which accounts for the grass stands listed in Table 1 for Dawson alfalfa. Also, a few old alfalfa plants occurred in some of the grass plots.

Conclusions

The first year yields of 5.8 to 6.4 Mg/ha of alfalfa obtained by sod-seeding alfalfa using glyphosate could be obtained in many regions of the U.S., particularly if supplemental irrigation was used. These results demonstrate that sod-seeding with glyphosate could convert grass and grass-alfalfa stands into essentially solid stands of alfalfa. Glyphosate should not be used, however, if a grass-alfalfa mixture is desired.

Sod-seeding alfalfa using paraquat in pure stands of cool-season grasses could be used to establish mixed stands of grass and alfalfa. Because paraquat has only a limited suppressive effect on alfalfa, its usefulness in seeding alfalfa into mixed stands of grass and alfalfa is questionable.

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Genetic Variability for Characters Affecting Stand Establishment in Crested Wheatgrass

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Abstract

Experiments were conducted in the laboratory (growth chamber) and field to determine the: (1) magnitude of genetic differences in crested wheatgrass [*Agropyron cristatum* (L.) Gaertn. and *A. desertorum* (Fisch. ex Link) Schult.] for characteristics related to seedling establishment on semiarid range and (2) effectiveness of laboratory procedures to estimate relative performance of breeding lines in the field. Significant differences were found among 175 crested wheatgrass progeny lines for seedling emergence, seedling height, seedling dry weight, and fall stand in the analyses of data combined over 2 field locations. The soil at both study sites was a Xerallic Calciorthids. The genetic variance among progenies comprised over 50% of the total phenotypic variance for most traits in the combined analyses of variance. Seedling emergence in the spring was positively related to fall stands ($r = 0.54^{**}$ to 0.61^{**}). In growth chamber experiments involving 168 progeny lines, significant genetic variation was detected in seedling recovery after exposure to drought stress in 3 of 4 experiments. The genetic variance comprised over 50% of the total phenotypic variance in 5 of 6 instances in the combined analyses of the field data and in 3 of the 4 laboratory experiments. In general, laboratory determinations of seedling emergence under drought stress and seedling recovery after drought were not significantly related to seedling establishment in the field. A relatively close correlation between seed weight and all plant responses measured in the field ($r = 0.46^{**}$ to 0.57^{**} in the pooled data) suggests that preliminary screening on the basis of seed weight appears promising.

Crested wheatgrass [*Agropyron cristatum* (L.) Gaertn., and *A. desertorum* (Fisch. ex Link) Schult.] has been widely used for revegetating depleted rangelands in Western United States and Canada. The species complex, which was first introduced to North America from Russia in 1898, was particularly instrumental in reclaiming abandoned wheat land during the dry years of the middle 1930's (Dillman 1946, Westover and Rogler 1947). Crested wheatgrass is a good source of early spring forage, although it becomes dormant during hot, dry periods (Rogler 1973).

Failure of seedling establishment especially under conditions of drought stress has been a major deterrent to revegetation programs on western rangelands. The development of crested wheatgrass cultivars with improved seedling vigor has received limited attention (Rogler 1954b). The cultivar 'Nordan' developed at the USDA Northern Great Plains Research Center (Mandan, N. Dak.), represented a significant improvement in seedling performance and has been grown widely in the semiarid rangelands of the West (Rogler 1954a).

Most selection programs aimed at improving the vigor or drought resistance of grass seedlings are based on total plant responses in lieu of specific characteristics. Seedling responses of range grasses to artificially imposed drought stress have been evaluated (Wright 1965, Wright and Jordan 1970). Voigt and Brown (1969) made substantial improvements in the seedling vigor of sideoats grama, *Bouteloua curtipendula* (Michx.) Torr., after 3 cycles of selection in the field. Asay and Johnson (1980) found significant differences among 134 Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] progeny lines in seedling vigor, seedling recovery after drought stress, and seedling emergence under drought.

A positive correlation between seed size and seedling vigor of forage grasses has been reported by several workers (Asay and Johnson 1980, Lawrence 1963, Kneebone and Cremer 1955, Rogler 1954b, Tossell 1960, Trupp and Carlson 1971). Recurrent selection for seed weight effectively improved the seedling vigor of smooth bromegrass, *Bromus inermis* Leyss. (Trupp and Carlson 1971). In view of the positive relationships observed in his studies, Rogler (1954b) suggested that selection for larger seeds would be a useful criterion for improving seedling vigor in crested wheatgrass.

A major goal of the USDA-ARS plant improvement program at Logan, Utah, is to develop cultivars of grasses that establish readily on semiarid rangelands. Significant genetic differences were found among 120 crested wheatgrass progenies in emergence under drought stress (Johnson and Asay 1978) and among 134 Russian wildrye progenies in seedling emergence and vigor from deep seedings, seedling recovery after drought stress, and seedling emergence during drought (Asay and Johnson 1980). The objectives of this research were to: (1) determine the amount of genetic variation in crested wheatgrass for laboratory determinations of seedling recovery after drought stress and for seedling emergence, seedling vigor, and stand establishment under semiarid conditions in the field and (2) study the relationships between laboratory and field evaluations of characters related to seedling establishment.

Materials and Methods

Plant materials included in the laboratory and field experiments consisted of open-pollinated progenies (entries) of 170 clonal lines of crested wheatgrass. The clones were selected from a 20,000-plant source nursery on the basis of vegetative vigor, leafiness, and resistance to insects and diseases. The parental lines were derived primarily from genetically diverse sources of induced and natural tetraploid forms of crested wheatgrass as well as from hybrids between induced and natural tetraploids. Five seedlots of commercial cultivars were harvested from the same nursery and were included as checks. All seedlots were harvested at the same phenological stage of development and were of uniform quality.

Laboratory Experiments

Data for seedling emergence under controlled drought stress, which were used in laboratory-field correlations, were determined by Johnson and Asay (1978). Seeds were germinated in soil that was separated from a polyethylene glycol-6,000 osmoticum with a cellulose acetate membrane. The amount of water moving across this semipermeable membrane, and hence the water potential of the soil, was controlled by the water potential of the osmotic solution. Two levels of soil water potential (−3.5 and −5.5 bars)

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were employed.

The procedures used to screen the crested wheatgrass progenies for seedling recovery after drought stress were similar to those described by Asay and Johnson (1980). Three seedlings were started in each of 28 plastic containers per entry. The cone-shaped containers were 3.8 cm in diameter at the top and tapered over the 21-cm length to a 2.5-cm diameter at the bottom. After 3 weeks in the greenhouse, the plants were transferred to a growth chamber programmed for 12-hr daylength, 30/10°C day/night temperatures, 20/60% day/night relative humidity, and 900 $\mu E/m^2/sec$ quantum flux density between 400 and 700 nm. Trays with containers were arranged in the chamber as a randomized complete block with 7 containers per entry-replication combination and 4 replications. After a 1-week equilibration period in the growth chamber, water was withheld from the plants for 17 days. The trays were then returned to the greenhouse and watered daily for 3 weeks. Each group of 7 containers was then rated for degree of recovery by 3 independent observers using a scale of 1 to 9 (1 = no living plants and 9 = maximum recovery based on number of living tillers and amount of green leaf area). Four experiments, each comprising 42 entries, were conducted. Two check seedlots were included in each trial.

Two 100-seed samples of each entry were used to estimate seed weight.

Field Experiments

Characters associated with seedling establishment were evaluated on 2 representative rangeland areas near Park Valley, Utah, (site 1) and near Malta, Idaho (site 2). Site 1 receives an average annual precipitation of 24.4 cm and site 2 receives an average of 28.5 cm. The soil in both areas was a Xerallic Calciorthids. Plots were seeded 9 November and 10 November 1976 on sites 1 and 2, respectively, and germination did not occur until the following spring. Each plot consisted of a 3-m row in which 500 seeds were planted 3.5 cm deep with a cone seeder equipped with a double-disc furrow opener. Data were taken from the center 1.8-m section of the plot to allow for border effects. Plots were arranged as randomized complete blocks with 3 replications at site 1 and 2 replications at site 2. Although 336 entries were included in the trials on site 1 and 175 at site 2, data are presented only for those 175 entries seeded at both locations.

Emergence and seedling height were recorded during mid-May. The second emergence and seedling height data were obtained during the third week of June. Shoot dry weight of the seedlings in the 1.8 m of row was determined at the 2 locations during the last week of July and stand percentage during the last week in October. Percentage stand was computed as the ratio of the number of 10 cm sections with plant cover to the total number of 10 cm sections in the 1.8 m row.

Table 1. Seedling recovery of crested wheatgrass progeny lines after exposure to drought stress in the growth chamber.

Parameter	Experiment[1] 1	2	3	4
			Ratings[2]	
Min.	1.0	0.8	0.2	0
Max.	7.2	7.2	7.2	6.3
$S_{\bar{x}}$	0.88	1.00	1.41	1.05
F (prog)	2.94**	2.16**	1.14	2.41**
Gen. Var. (%)	66	54	12	59

[1]Each trial included 42 lines and was replicated 3 times.
[2]Ratings were made by 3 observers on a 1 to 9 scale.
(1 = complete mortality, 9 = maximum recovery based on number of living tillers and amount of green leaf area).
**Significant at the 0.01 level of probability.

Statistical Analyses

All data were subjected to analyses of variance. Percent genetic variability was computed on a phenotypic mean basis as the ratio of $\sigma^2_p/\sigma^2_{\overline{ph}}$, where σ^2_p was the variance component due to differences among progenies and $\sigma^2_{\overline{ph}}$ was the total phenotypic variance among progeny lines or the variance of a progeny mean. In the computation of the variance components, progenies were considered as random variables and locations (sites) as fixed. Simple correlations were computed to study the relationship between laboratory and field data. Only 118 entries were in common in all laboratory and field studies. Consequently, the correlation matrix was restricted to these lines (116 df).

Results and Discussion

Laboratory Experiments

In earlier studies (Johnson and Asay 1978), significant differences were found among the crested wheatgrass progenies for

Table 2. Seedling vigor and stand establishment of 175 crested wheatgrass progeny lines on two rangeland areas.

Location	Parameter	Emergence (No.) May	Emergence (No.) June	Height (cm) May	Height (cm) June	DM Yield (g/plot)	Stand (%)
1	Max.	82	68	5.0	12.3	7.6	88
	Min.	13	9	1.7	4.3	0.1	41
	$\bar{x}$	43	38	3.6	9.1	2.0	72
	$S_{\bar{x}}$	9.0	8.2	0.39	1.16	1.06	6.5
	F (prog.)	1.85**	1.70**	2.62**	1.51**	1.91**	1.58**
	Gen. Var. (%)	46	41	62	34	48	37
2	Max.	70	123	10.0	23.0	31.3	95
	Min.	9	15	2.0	6.0	1.3	44
	$\bar{x}$	33	59	5.6	13.2	10.7	70
	$S_{\bar{x}}$	8.9	17.9	1.03	2.33	4.28	8.2
	F (prog.)	1.56**	1.34*	1.97**	1.47*	1.36*	1.19
	Gen. var. (%)	36	25	49	32	27	16
Pooled Data	Max.	66	84	6.6	15.8	14.8	87
	Min.	12	18	1.8	6.0	0.5	44
	$\bar{x}$	39	46	4.4	10.7	5.5	71
	$S_{\bar{x}}$	6.5	8.3	0.45	1.12	1.70	5.1
	F Prog (P)	2.10**	2.06**	3.31**	2.18**	2.13**	1.79**
	Loc (L)	108**	271**	800**	562**	1102**	8.73**
	PxL	1.14	1.38*	2.01**	1.32*	1.76**	1.01
	Gen. Var. (%)	52	52	70	54	53	44

*,** Significant at 0.05 and 0.01 probability level, respectively.

seedling emergence under 2 levels of controlled drought stress. Although a significant progeny × stress level interaction was encountered, ample genetic variation was available to facilitate selection for this component of stand establishment.

The entries also differed significantly ($P<0.01$) in seedling recovery after exposure to drought in 3 of the 4 experiments conducted (Table 1). The genetic variance comprised over 50% of the total phenotypic variance in the 3 experiments where significant differences were obtained. It is evident that laboratory procedures can detect differences in seedling recovery and that sufficient genetic variability is available for selection. The duration of the stress period imposed on the seedlings has a profound effect on the results. A difference of just a few hours in which the trays are removed from the chamber can mean the difference between complete seedling recovery to complete mortality. Also, to compensate for temperature variation within the chamber, trays of seedlings should be removed individually over a period of a day or more. A check entry probably should be included in each tray and removal of the tray then should be based on the appearance of the check. The containers in our experiments may have limited root growth and therefore may not have adequately evaluated the effect of the root system on seedling survival. For determinations of drought avoidance capacity afforded by early and extensive root development at the seedling stage, a less restrictive soil environment would have to be used.

Field Experiments

Significant differences were found among the progeny lines for all traits measured at field location 1 and for all but percentage stand at location 2 (Table 2). In the analyses of the data pooled over locations, differences among the progenies were significant ($P<0.01$) for all traits evaluated. This range in phenotypic variation along with the relative magnitudes of the genetic variances offers considerable promise to the breeder working to improve stand establishment characteristics in crested wheatgrass. The genetic variability for seedling emergence and fall stand is especially encouraging. Seedling emergence averaged over locations ranged from 18 to 84% in June and the mean percentage stand ranged from 44 to 87%. The genetic variance comprised 52 and 44% of the phenotypic variance for emergence and stand, respectively, in the combined analyses. A positive relationship was also found between seedling emergence and fall stand, suggesting that seedling survival and possibly rate of tillering of the progenies was relatively consistent during the summer. Correlation coefficients between emergence 1 and 2 and fall stand were 0.54 and 0.59 at location 1 and 0.64 and 0.61 at location 2 (critical r, $P<0.01$, 116 df, = 0.24).

As would be expected, location effects were highly significant for all plant responses measured. The progeny X location interaction was significant in most instances; however, the correlations between locations were positive and significant in all cases ($r = 0.24$ to 0.44). Differences among progenies in emergence and fall stand were relatively consistent over locations, as was indicated by the nonsignificant progeny X location interactions.

Field-laboratory Relationships

In most instances, correlations between laboratory determinations of emergence under stress and seedling recovery after stress were not significantly correlated with plant responses measured in the field (Table 3). The poor relationship between seedling emergence under drought stress in the laboratory and field emergence was particularly disappointing. However, the field plantings were made in the late fall and soil moisture was not a major limiting factor until after emergence had occurred the following spring. Apparently emergence from a deep seeding with no attempt to impose drought stress may give a more realistic prediction of field emergence in the early spring. Earlier work with Russian wildrye (Asay and Johnson 1980, Lawrence 1963) would support this approach.

After emergence, stand establishment depends largely on the complex factors influencing seedling survival and tillering under extended or intermittent stress. Seedling recovery after drought stress measured in the laboratory failed to provide a consistent estimate of seedling establishment in the field, although a significant but low correlation ($r = 0.22$) with stand was detected in the pooled field data. However, the significant correlation between emergence and stand observed in our field trials would indicate that differences in seedling recovery after drought were not determinant factors of fall stand.

Seed size was significantly ($P<0.01$) and positively correlated with all characters evaluated in the field. Correlation coefficients between seed size and field data averaged over the 2 locations ranged from 0.46 to 0.57. This represents a significant relationship considering the complex interactions of environmental and genetic factors involved in the establishment of stands on semiarid range. In addition, seed weight was significantly correlated ($P<0.05$) with

Table 3. Correlations (r) of data from laboratory and field evaluations of seedling vigor in 118 crested wheatgrass progeny lines.

Laboratory criteria	Field criteria: Emergence May	Emergence June	Height May	Height June	D.M. yield	Stand
			Location 1			
Emergence:						
−3.5 bars	−.09	−.17	−.03	.07	.09	−.08
−5.5 bars	−.11	−.12	−.09	.09	.12	−.09
Seedling recovery	.10	.18*	.15	.09	.17	.17
Seed wt.	.45**	.45**	.59**	.36**	.45**	.45**
			Location 2			
Emergence:						
−3.5 bars	.07	.19*	.06	.13	.24**	.10
−5.5 bars	−.04	.08	.01	.08	.08	.02
Seedling recovery	−.11	−.03	−.10	.08	.10	.14
Seed wt.	.27**	.33**	.43**	.43**	.39**	.37**
			Field Data Pool			
Emergence:						
−3.5 bars	−.02	.02	.03	.12	.23	−.01
−5.5 bars	−.08	−.01	−.03	.11	.12	−.04
Seedling recovery	.05	.10	.01	.09	.15	.22*
Seed wt.	.48**	.49**	.57**	.46**	.49**	.51**

*,**Significant at 0.05 and 0.01 probability level, respectively (116 df).

recovery after drought (r = 0.19). No correlation was found between seed weight and germination under controlled drought stress in the laboratory.

Summary

Our data confirmed earlier findings that seed weight was a useful criterion in a crested wheatgrass breeding program to develop germplasm with improved stand establishment characteristics. Screening in the laboratory for emergence under drought stress and seedling recovery after exposure to drought would be less likely to lead to enhanced stand establishment. Seedling emergence in the field was indicative of ultimate stand establishment. Seedling emergence from deep seedings in the laboratory has demonstrated promise as a selection criterion in Russian wildrye and should be evaluated in crested wheatgrass. Until a better understanding of plant responses to environmental stresses during stand establishment are developed, preliminary screening on the basis of seed weight appears most promising. This should be followed by evaluation of stand estabishment under semiarid conditions in the field.

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Big Sagebrush Control with Tebuthiuron

C.M. BRITTON AND F.A. SNEVA

Abstract

Tebuthiuron (20% a.i. pellets) was applied in 2 years at rates of 0.25, 0.5, 1.0, and 2.0 kg a.i./ha on sagebrush-grass range. Mortality of big sagebrush *(Artemisia tridentata)* and herbaceous yield was measured at the end of the second growing season, post-treatment. Mean mortality increased with increasing herbicide rate to 93.9% at 2 kg a.i./ha. Herbaceous yield decreased with increasing herbicide rate to a mean of 177.3 kg/ha at the 2 kg a.i./ha rate contrasted to a mean of 423.9 kg/ha for the control.

Big sagebrush *(Artemisia tridentata)* is easily controlled with 2,4-D at rates of 1.0 to 2.0 kg a.i./ha (Hyder and Sneva 1955). Tebuthiuron[1] [1-(5-tert-butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea] can effectively control sagebrush at rates of 2 kg a.i./ha (Britton and Sneva 1981). The objectives of this study were to evaluate the effectiveness of tebuthiuron at rates of 2 kg a.i./ha and less in controlling big sagebrush and subsequent effects on herbaceous yield.

Study Area and Methods

The study area was on the Squaw Butte Experiment Station Range Unit about 65 km west of Burns, Ore. This high desert range, elevation 1,370 m, receives mean annual precipitation of about 30 cm. About 60% of this precipitation occurs during fall and winter, generally as snow, with 25% as rain during May and June. Soil on the study area is a fine-loamy, mixed frigid *Aridic Durixerolls* (G. Simonson, pers. comm.).

Shrub-layer vegetation consisted primarily of big sagebrush with scattered green rabbitbrush *(Chrysothamnus viscidiflorus)* and infrequent horsebrush *(Tetradymia canescens)* plants. Dominant grasses were bluebunch wheatgrass *(Agropyron spicatum)*, Thurber needlegrass *(Stipa thurberiana)*, bottlebrush squirreltail *(Sitanion hystrix)*, Idaho fescue *(Festuca idahoensis)*, and cheatgrass *(Bromus tectorum)*. Forbs were present, but constituted less than 10% of total herbaceous yield.

Plots were established in uniform stands of sagebrush (ca. 7395 plants/ha). Infestations of the sagebrush defoliator *(Aroga websterii)* from 1962 to 1965 resulted in some residual dead-standing sagebrush plants. Tebuthiuron (20% a.i. pellets) was hand applied with a cyclone seeder at rates of 0.25, 0.5, 1.0, and 2.0 kg a.i./ha to 10 × 30-m plots. Herbicide pellets were thoroughly mixed with blank pellets to a constant weight of 1,000 g of material per plot. Herbicide was applied in mid-October 1977 and mid-March 1979. Experimental design was a split-plot in time arrangement of a completely random design with 4 replicates per treatment.

Mortality of sagebrush was determined by counting live and dead plants within a belt established by sweeping a 1-m width around a 20-m line transect. Two belt transects were evaluated per plot. Herbaceous yield was obtained in July by clipping 10, 1-m^2 circular quadrats per plot to a stubble height of 1 cm. Herbage samples were oven dried at 60° C for 48 hr and weighed to the nearest gram. Mortality and yield measurements were made at the end of the second growing season post treatment.

Results and Discussion

High sagebrush mortality rates were obtained with 1 and 2 kg a.i./ha rates of tebuthiuron (Table 1). These rates of tebuthiuron produced results similar to the approximate 1 and 2 kg a.i./ha rates of 2,4-D reported by Hyder and Sneva (1955). There was no treatment difference between years except for the 0.5 kg/ha rate, which resulted in a 51.8% mortality rate for the 1977 fall application compared to 70.9% for the spring 1979 treatment.

Mean herbaceous yield was significantly decreased with each increasing rate of herbicide (Table 1). This effect at the 1 and 2 kg/ha rates was similar to that reported by Britton and Sneva (1981). The inverse incremental herbicide rate-yield relation at rates below 1 kg/ha and overall herbaceous sensitivity was less pronounced following spring than fall applied herbicide. That difference does not appear to be associated with total cropyear (Sept.–June) precipitation for the years involved, as totals were near or above normal. Greatest precipitation differences existed in the first growing season post-application when amounts following spring treatments were subnormal, whereas amounts following fall treatments were above normal. However, the lack of acceptable sagebrush mortality from rates less than 1 kg/ha suggest that the

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[1]This paper reports the results of research only. Mention of a pesticide in this paper does not constitute a recommendation by the USDA nor does it imply registration under FIFRA.

Table 1. Mean big sagebrush mortality (%) and herbaceous yield (kg/ha) in 1979 and 1980 for control and 4 rates of tebuthiuron applied in eastern Oregon in fall 1977 and spring 1979.

	Treatment (kg a.i./ha)				
Response	Control	0.25	0.50	1.0	2.0
1979 Mortality (%)[1]	19.4^{a}	36.0^{b}	51.8^{c}	78.2^{de}	91.6^{f}
1980 Mortality (%)	22.1^{a}	26.1^{ab}	70.9^{d}	89.3^{ef}	96.3^{f}
Mean Mortality (%)[2]	20.7^{v}	31.0^{vw}	61.3^{w}	83.7^{x}	93.9^{y}
1979 Yield (kg/ha)	427.8^{d}	255.9^{c}	206.1^{cd}	126.0^{ab}	21.8^{a}
1980 Yield (kg/ha)	420.0^{d}	426.7^{d}	426.7^{d}	319.2^{cd}	212.8^{bc}
Mean Yield (kg/ha)	423.9^{z}	341.3^{a}	316.4^{x}	222.6^{w}	117.3^{v}

[1]Within rows and for both years, means for each response separated by letters are different ($P<0.05$) according to Duncan's multiple range test.
[2]Mean values over years for each response separated by letters are different ($P<0.05$) according to Duncan's multiple range test.

question of herbaceous sensitivity to those rates is not paramount in eastern Oregon.

Tebuthiuron is an effective herbicide on big sagebrush. However, at rates necessary to be comparable to 2,4-D, herbaceous yields were depressed. At the second year post treatment with 2,4-D, yields are generally 3-fold greater on treated areas compared with pretreatment levels (Sneva 1972). Although herbaceous yields are depressed for at least 2 years, the residual tebuthiuron in the soil (Bjerregaard 1977) may effectively control sagebrush seedlings for several years. This would be a positive factor in the longevity of sagebrush control.

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Effects of Soil Moisture on Burned and Clipped Idaho Fescue

C.M. BRITTON, R.G. CLARK, AND F.A. SNEVA

Abstract

Idaho fescue *(Festuca idahoensis)* plants were burned and clipped under 2 soil water regimes. Treatments were applied to plants in late August and mid-October located in eastern Oregon. Results indicated that watering plants either before or after burning produced no beneficial effects as measured by changes in basal area or yield. Regardless of treatment, plant damage was greater with late August as contrasted to mid-October treatment dates. These data do not support the opinion that high soil moisture is necessary prior to fall burning of sagebrush-bunchgrass communities.

A widely accepted philosophy is to burn rangeland when the soil is moist. In his comprehensive review on range burning, Wright (1974) stated, "Ideally, a prescribed burn should be conducted during the dormant season when the soil is wet." Beardall and Sylvester (1976) listed 4 factors necessary for successful spring burning of sagebrush (*Artemisia* spp.) range. The first factor listed was that the soil must be wet. The wet-soil philosophy is universally accepted and has not been challenged in the literature for bunchgrass communities.

Opportunities for fall burning of Great Basin sagebrush communities may be extremely limited if wet soil is a requisite. Objectives of this study were to evaluate the effects of dormant season burning and clipping of Idaho fescue *(Festuca idahoensis)* under 2 soil water regimes and 2 dates.

Methods

The study area was located on the Squaw Butte Experiment Station Range Unit about 65 km west of Burns, Ore. Elevation is 1,370 m and average annual precipitation is about 30 cm. Approximately 60% of the precipitation occurs during fall and winter, generally as snow, with 25% during May and June as rain. Soil on the study aea is a fine-loamy, mixed frigid *Aridic Durixerolls.*

A 0.5-ha area was fenced to exclude livestock, and 200 Idaho fescue plants were marked with wire stakes. Groups of 20 plants were randomly assigned to 1 of 5 treatments which were applied on August 31 and October 17, 1978. Treatments were clip to 1-cm stubble height, clip then water, burn, burn then water, and water then burn. Water treatments consisted of applying a 5-cm depth of water as a gentle spray to a 72-cm diameter area around each plant. Water was confined to this area with a circular metal ring.

Burns were applied with a portable plant burner similar to that described by Britton and Wright (1979). Time-temperature curves peaked at 200°C at 30 sec. The water-then-burn plants were allowed to equilibrate for 24 hr after irrigation before being burned.

Relative humidity, air temperature, and wind speed were measured with a belt weather kit (Fischer and Hardy 1972) at the time of burning (Table 1). Soil water contents were determined gravimetrically from 10 surface samples (0-5 cm) adjacent to dry and watered plants.

Treatment effects were measured as changes in basal area and yield. After treatment, each plant was photographed to determine initial base area. A wire grid (2.5 by 2.5 cm) was placed over each plant prior to photographing to provide a permanent record of basal area. One growing season after treatment, each plant was rephotographed and percentage change in basal area calculated. Also, after one growing season, aerial biomass was clipped from each plant. Yield was expressed as g/dm^2 of basal area to adjust for different size plants. Mean separation was accomplished using Duncan's new multiple range test ($\alpha = 0.05$).

Table 1. Weather and soil water contents for 2 treatment dates in 1978 for burning and clipping Idaho fescue in eastern Oregon.

	Weather			Soil water contents	
Treatment dates	Relative humidity (%)	Air temperature (2‡ C)	Wind (km/hr)	Dry (%)	Watered (%)
August 31	31	25	3-9	2.4	16.2
October 17	29	23	3-8	2.4	16.0

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Table 2. Mean response over treatment date for Idaho fescue observed in eastern Oregon.

Response	Treatments[1]					Means	
	Clip	Clip + water	Burn	Water + burn	Burn + water	Aug.	Oct.
Basal area reduction (%)	32.8^{b}	31.3^{b}	42.0^{b}	57.1^{a}	59.8^{a}	51.2	38.0
Yield (g/dm²)	2.9^{b}	4.0^{a}	2.4^{bc}	1.6^{cd}	1.3^{d}	2.1	2.8

[1]Means within rows with similar letters are not different ($\alpha = 0.05$).

Results

Regardless of treatment, Idaho fescue was damaged less following treatment in October than in August (Table 2). Basal area reduction was about 35% less and yield was about 33% more after treatments applied in October. Based on the means taken over treatment dates, clipping was less damaging to Idaho fescue than was burning. Plants watered before or after burning produced the least regrowth and basal area reduction was greatest. Response of dry burned plants was intermediate to the wet burned and clipped treatments.

There was no difference in the basal area response of plants which were burned dry or clipped in August (Fig. 1). The clip-then-water treatment resulted in the smallest basal-area reduction (27%). The water-then-burn treatment was the most damaging and resulted in a 75% reduction in basal area. Because of large variation in plant responses, the burn-then-water treatment response was intermediate to the water-then-burn and clip or dry-burn treatments, and these treatments could not be statistically separated. In August, most plants watered either before or after burning initiated growth. These sprouts showed freezing damage by the first week of October.

Basal-area reduction of Idaho fescue following treatments in October was less than after August treatments, except the clip-then-water treatment which increased slightly. The burn-then-water was the most damaging treatment with a 54% basal area reduction of Idaho fescue. Clipping was least damaging, causing a basal-area reduction of 26%. The other treatments resulted in similar responses and were not statistically different.

Yield of treated plants illustrated the greater damage associated with the August than the October treatments (Fig. 2). The exception was clip-then-water, which resulted in the greatest yield regardless of treatment date. There was no difference in yields of plants which were clipped or burned in August. Lowest yields were from plants watered and burned.

Yields of more than 3 g/dm² were recorded where plants were clipped, clipped-then-watered, or burned in October. These yields were not significantly different one from the other, but were greater than the lower yields of plants watered and then burned.

Discussion

Results of this study clearly illustrate that burning in late summer will be more damaging to Idaho fescue than similar burns in the fall. Moreover, delaying prescribed burns until high soil water contents are available is not necessary or desirable for fall burns.

The marked response to date of burn was not anticipated since at the respective burn dates, plants were essentially quiescent. A period of dormancy generally is the best time to burn (Wright 1974). However, Wright (1971) found increasing resistance to burn damage for bunchgrasses in Idaho from late July through late September. This was attributed to low energy reserves and high respiration demands during late summer (Wright 1971). This trend was reversed during early fall.

The negative effect of high soil water content on plant response was suspected. Burning in the spring with high soil water status gives a positive plant response because the growing season is just starting. Burning in the late summer with high soil water contents also stimulates a growth response. However, in the Great Basin freezing night-time temperatures usually occur in late September or early October. Therefore, this winter induced growth response was terminated by the end of the growing season. By October, weather conditions were not favorable for a growth initiation response although soil moisture was available.

A possible factor contributing to the negative response of high soil water content is thermal conductivity. As soil water content increases, thermal conductivity increases. Therefore, when soil moisture is high at the time of burning, the heat pulse can reach the grass meristematic tissue faster and can remain at lethal temperatures longer (Aston and Gill 1976, Wright 1964).

Working with bunchgrasses in Idaho, Wright (1964) found watering plants prior to burning prevented deep burning into the crown and reduced percent mortality. However, dry burned plants

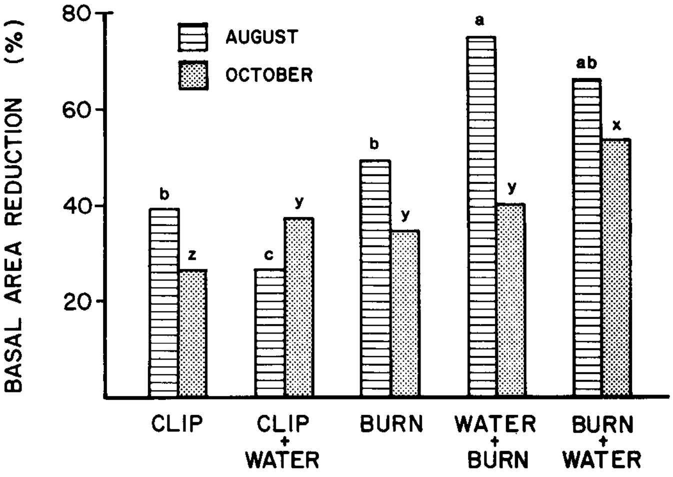

Fig. 1. *Basal area reduction expressed as a percentage of the initial basal area. Within month, means separated by letters are different ($\alpha = 0.05$).*

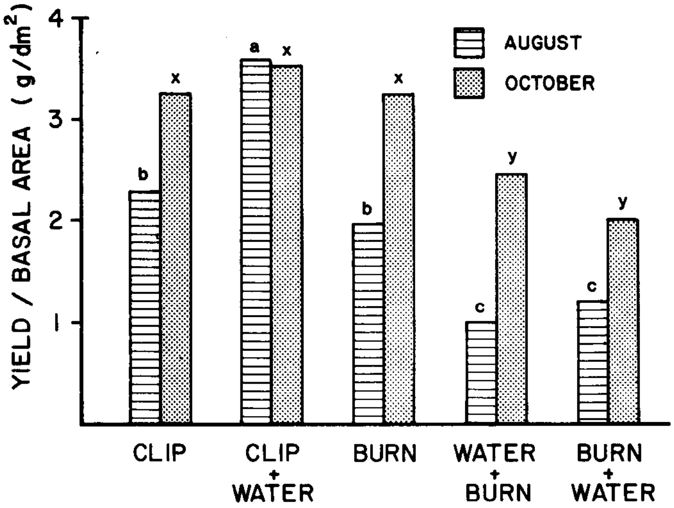

Fig. 2. *Yield of treated plants in grams per square decimeter of live basal area. Within month, means separated by letters are different ($\alpha = 0.05$).*

yielded more herbage compared with watered plants. No mortality of Idaho fescue was observed in this study regardless of treatment. Future research is needed to document the point at which soil water content ceases to be important and evaluate the impact of different depths to meristematic tissue for various grass species.

From a management standpoint, this work suggests that in the Great Basin high soil water content is not necessary for fall burns where Idaho fescue is a dominant species and is probably undesirable. However, this information cannot be extrapolated to spring burning in the Great Basin as high soil water contents at growth initiation is desirable.

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Annual Broomweed [*Gutierrezia dracunculoides* (DC.) Blake] Response to Burning and Mulch Addition

GENE TOWNE AND CLENTON OWENSBY

Abstract

The influence of artificial mulch additions and mulch removal with fall, winter, and spring burning on annual broomweed [*Gutierrezia dracunculoides* (DC.) Blake] density in the Kansas Flint Hills was studied. Removing mulch, either by fall and winter burning or by fall mowing, significantly increased ($P<.03$) annual broomweed density compared to untreated plots. As mulch thickness increased, the number of emerging broomweed plants decreased. Cyclic infestations of annual broomweed appear to be favored by the lack of an overwintering mulch in closely grazed or denuded areas.

Annual broomweed [*Gutierrezia dracunculoides* (DC.) Blake][1] populations fluctuate widely from year to year in Kansas rangelands. Whether real or imagined, dense broomweed stands are usually considered to have a detrimental effect upon forage production and are esthetically undesirable. Although herbicides have controlled broomweed in Texas (Scifres et al. 1971), they are not generally recommended and infrequently applied to stands in the Kansas Flint Hills. An alternative measure is mowing broomweed prior to seed formation, but that practice is impractical for large scale areas and is detrimental to carbohydrate reserve storage in the perennial grasses (Owensby et al. 1970).

Cyclic infestations of broomweed have usually been attributed to climatical factors, primarily drought or mild winters. Heitschmidt (1979) reported that broomweed abundance in Texas was closely correlated with above-average precipitation in May and below-average temperature in April. However, in the Kansas Flint Hills, dense broomweed stands are commonly observed adjacent to pastures devoid of broomweed, suggesting nonclimatic influences.

Since broomweed infestations often persist in heavily grazed or physically disturbed areas, we believed that denuded soil may play a role in broomweed establishment. The objective of this study was to investigate the response of annual broomweed to different rates of artificial mulch additions, and to mulch removal with fall, winter, and spring burning.

Study Area and Methods

A heavily infested broomweed pasture in the northern Kansas Flint Hills 10 miles southeast of Manhattan was selected for the study area. Soil on the loamy upland range site was a Typic Argiudoll formed in material weathered from noncalcareous micaceous shale. The pasture had been annually burned in mid-April and moderately grazed by steers from May through October. In addition to broomweed being the aspect dominant, vegetation was primarily big bluestem (*Andropogon gerardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], tall dropseed [*Sporobolus asper* (Michx.) Kunth var. *asper*], and little bluestem (*A. scoparius* Michx.).

To study the effects of mulch removal with fire, the site was partitioned into 6 m × 6 m plots separated by 1-m alleys. Dates of burning were 19 October 1981, 13 November 1981, 19 January 1982, and 20 April 1982. There were 3 replications for each burning treatment and 4 unburned control plots in the completely randomized design.

An area adjacent to the burned plots was subdivided into 3 m × 3 m plots separated by 1-m alleys to study the effects of mulch additions on broomweed density. Treatments consisted of applying 2,240, 3,360, 4,480, 5,600, or 6,720 kg/ha wheat straw uniformly over each plot in mid-October 1981. In addition to untreated control plots with residual herbage, another treatment consisted of mowing and removing all plant material. The completely randomized design had 3 replications for each of the 7 treatments.

Broomweed density in all mulched and burned plots was determined at the beginning of the study in September 1981 and at the end of the study in July 1982 by averaging the number of plants in 4 0.4-m^2 quadrats. Both sets of data were statistically analyzed by standard analysis of variance and treatment means segregated by Duncan's multiple range test ($P<.05$).

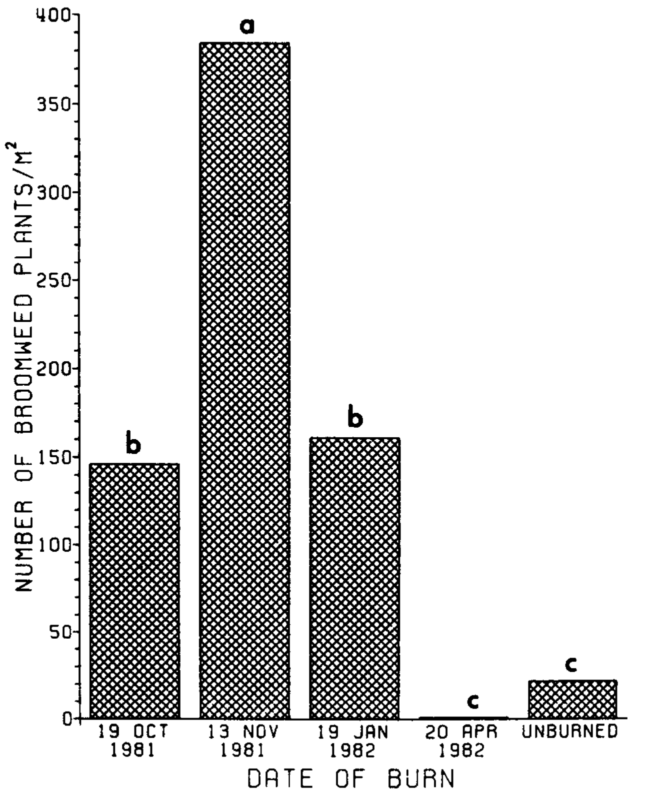

Fig. 1. *Effects of burning on annual broomweed density. Plots burned on indicated dates and plants counted in July 1982. Means with the same letter are not significantly different (P<.05).*

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[1]Scientific names follow McGregor and Barkley (1977).

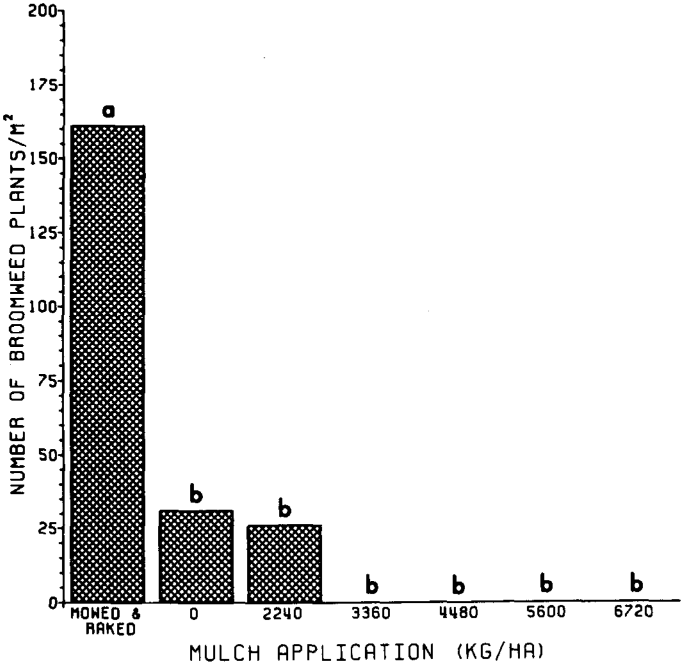

Fig. 2. *Effects of artificial mulch accumulations on annual broomweed density. Mulch added in October 1981 and plants counted in July 1982. Means with the same letter are not significantly different (P<.05).*

Results and Discussion

Fall and winter burning significantly increased ($P<.03$) the number of broomweed plants compared to unburned plots (Fig. 1). Removing the protective ground cover with fire, particularly in mid-November, apparently produced favorable conditions for broomweed establishment. Plots burned in April had significantly lower ($P<.02$) density than fall or winter burned plots. The April fire, however, did not kill broomweed seedlings because they had not yet germinated. Unburned plots were not significantly different ($P = .68$) from plots burned in April, indicating that an overwintering mulch layer was a critical factor in impeding broomweed establishment.

The presence of any mulch significantly reduced ($P=.0001$) broomweed density compared to denuded plots (Fig. 2). Although untreated plots with residual mulch were not significantly different from heavily mulched plots ($P = .15$), the number of emerging broomweed plants decreased as the thickness of artificial mulch increased. No broomweed plants emerged in plots covered with more than 3,360 kg/ha mulch.

In retrospect, 1980 was a hot, dry year with below-average herbage production. By season's end, most of the study pasture had been closely grazed, and the absence of an overwintering mulch layer provided a favorable habitat for broomweed infestations the following year. In 1981, highest ever herbage yields for the Kansas Flint Hills were recorded, producing a heavy mulch at the end of the growing season. Broomweed occurrence in 1982 was localized to grazed-out spots and disturbed areas. Thus, the ephemeral nature of broomweed seems to be influenced, at least in part, by the amount of litter and standing dead remaining from the previous year.

Livestock management schemes in the Kansas Flint Hills could be manipulated to passively reduce broomweed infestations. Intensive-early stocking (Smith and Owensby 1978) allows for removing steers in mid-season after stocking at twice the normal rate. Uniform regrowth would eliminate denuded heavily grazed spots and leave an overwintering mulch unfavorable for broomweed establishment.

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Establishment of Blue Grama and Fourwing Saltbush on Coal Mine Spoils Using Saline Ground Water

GREG WEILER AND WALTER L. GOULD

Abstract

This study was conducted in the greenhouse to determine the effect of limited irrigation of topsoiled sodic shaley spoil with water of various salinities on the emergence and growth of 2 native plant species and on the infiltration rate and salinity buildup of the topsoil. Columns containing 20 cm of sandy loam soil over sodic shaley spoil were seeded to blue grama *(Bouteloua gracilis)* or fourwing saltbush *(Atriplex canescens)*. The columns were irrigated with water having 4 levels of salinity ranging from 750 to 12,890 μmhos/cm and sodium adsorption ratios ranging from 2 to 68. The emergence and growth of blue grama was reduced as the salinity of the water increased; no plants survived the most saline treatment. The most saline water reduced the emergence of fourwing saltbush, but the saltbush grew well after the seedling stage. The infiltration rate was lowered as the sodicity of the irrigation water increased, and the electrical conductivity of the soil increased as the amount and salinity of the water increased. The study indicates that moderately saline water (EC≤4230 μmhos) will probably be suitable for revegetating mine spoils using blue grama and fourwing saltbush.

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The largest reserves of coal in New Mexico at depths that are economically feasible for surface mining are found in the Fruitland Formation in the San Juan Basin in the northwestern part of the state (Shomaker et al. 1971). The climate of the San Juan Basin is semiarid continental with high diurnal temperatures and infrequent precipitation. The average annual precipitation along the western and southern exposures of the Fruitland Formation varies from about 13 to 25 cm. The evaporation during the growing season (May–September) is about 125 cm; so a water deficit occurs most of the time (USDC 1972). Water from the San Juan River has been used for irrigation by 2 mines located near the river to establish vegetation. Mines that are farther from the river may need to utilize groundwater for irrigation to revegetate strip-mined lands. Groundwater from many aquifers in the area is saline, the soluble salt content ranging from 3,200 to over 10,000 ppm. This study was conducted to determine the effect of saline water on the germination and growth of fourwing saltbush [*Atriplex canescens* (Pursh) Nutt.] and blue grama [*Bouteloua gracilis* (H.B.K.) Lag.] when applied in amounts normally used by mines in the San Juan Basin.

Information on the establishment of native range species with saline water is limited. Stewart (1967) reported good to excellent growth of 2 shrub and 6 grass species in the Tularosa Basin of southern New Mexico, using water containing up to 16,000 ppm salt. Fourwing saltbush made good growth in well-drained soils when sufficient water was applied to provide leaching of soluble salts. To successfully establish plant using saline water, leaching of soluble salts was necessary. The saline water did not reduce plant growth in species with high salt tolerance once the plants had grown past the seedling stage.

Jensen et al. (1965) demonstrated that establishment of tall fescue (*Festuca arundinacae* Schreb) and tall wheatgrass [*Agropyron elongatum* (Host) Beav.] was possible on saline-sodic soils of Nevada using waters with low salt content. (The salinity of the irrigation water used was not given). Applications on alternate dates was better for plant survival than irrigations at 4- or 8-day intervals. Their results were similar to findings by Stewart. The most critical stage of growth proved to be establishment.

Blue grama and fourwing saltbush are 2 native range species of wide distribution throughout southwestern rangelands and are valuable forage species for livestock and wildlife (Lamb 1971, Gould 1973, Bell 1973). Bernstein (1958) listed blue grama as having the ability to survive in soils having an electrical conductivity (EC) of up to 6,000 μmhos/cm. Knipe (1968) simulated moisture tension levels of 0 to 16 atmospheres, using aqueous mannitol solutions, and found the germination percentage of blue grama was not significantly reduced until moisture tensions of 10 atmospheres (EC = 27,800 μmhos/cm) were reached. The germination percentage at 16 atmospheres (EC = 44,400 μmhos/cm) was significantly lower than at 13 atmospheres (EC = 36,100 μmhos/cm), being 42.2 and 72.7%, respectively. Vigor of blue grama seedlings was noticeably reduced when moisture tensions exceeded 1 atmosphere (EC = 2770 μmhos/cm).

Fourwing saltbush has been noted for its good salt tolerance (Jones 1969, U.S. Forest Serv. 1937). Welch (1978) reported healthy fourwing plants growing in soil having an electrical conductivity of 7,800 μmhos/cm or greater. Springfield (1966) induced moisture stress in fourwing saltbush using various concentrations of mannitol. As moisture stress increased, total germination was delayed and decreased. In recent years, fourwing saltbush has shown potential for use in the revegetation of western rangelands strip-mined for coal (Aldon 1978; Alson and Springfield 1973, Gould et al. 1975, McKell 1978, Thornburg and Fuchs 1978).

Table 1. Characteristics of Doak topsoil and shaley spoil used in columns in the greenhouse.

	Doak soil	Spoil
Cations (meq/l)		
Calcium	5.0	13.4
Magnesium	1.7	4.3
Potassium	0.3	0.2
Sodium	0.3	152.0
Anions (meq/l)		
Bicarbonate	3.5	3.2
Chloride	2.8	34.7
Sulfate	1.1	132.2
Sodium adsorption ratio	0.2	51.0
Electrical conductivity (μmhos/cm)	700	10,400
ph	7.0	7.8
CEC (meq/100gm)	13.9	34.8
Saturation percentage	22	81
Particle size distribution (%)		
Sand	63	24
Silt	27	38
Clay	10	38

Methods and Materials

This study was conducted in the greenhouse at New Mexico State University. Columns were constructed of 45.7-cm (18-inch) long sections of 16.7-cm outside diameter polyvinyl chloride pipe having 0.5-cm wall thickness glued to a 20-cm square piece of 0.5 thick sheet plastic which served as a base for the columns. Four 0.5-cm diameter holes were drilled in the base of each column for drainage. The columns were filled by layers from the bottom with 7.6 cm of sandy soil, 15 cm of shaley spoil, and 20 cm of the A-horizon of Doak soil, a fine, loamy, mixed, mesic, Typic Haplargid. The columns were filled in this manner to simulate topsoiled surface mine spoils. The shaley spoil was obtained from the San Juan Mine located about 24 k west of Farmington, N. Mex. Doak soil is a major soil type found along the exposure of the having 0.5-cm wall thickness glued to a 20-cm square piece of 0.5 cm thick sheet plastic which served as a base for the columns. Four 0.5-cm diameter holes were drilled in the base of each column for drainage. The columns were filled by layers from the bottom with 7.6 cm of sandy soil, 15 cm of shaley spoil, and 20 cm of the

Table 2. Chemical analyses of groundwater from 2 strata in the San Juan Basin, 3 synthesized solutions, and tap water used in the greenhouse.

	Strata		Synthetic Water No.			
	Westwater Canyon	Entrada	1	2	3	Tap water
pH	7.9	7.9	7.9	8.1	9.2	7.5
Ec (μmhos/cm)	4255	12500	4230	8700	12890	730
SAR*	12	74	10	30	68	2.5
Cations (meq/l)						
Sodium	34.8	137.0	30.2	89.7	144.7	3.8
Potassium	0	6.1	2.1	4.5	7.1	0.7
Calcium	16.6	6.0	17.4	13.0	3.4	3.3
Magnesium	0.7	0.9	0.1	5.4	5.6	1.3
Anions (meq/l)						
Chloride	0.4	14.2	1.3	7.9	4.4	2.8
Sulfate	50.6	137.4	46.8	92.6	145.7	2.6
Bicarbonate	1.0	2.2	1.4	2.1	1.7	3.2
Carbonate	0.0	0.0	0.0	0.0	0.0	0.0

*Sodium adsorption ratio

Fruitland Formation in San Juan County, and the Doak soil used in this study was obtained approximately 30 km southeast of Farmington. The sandy soil used as a filler material was obtained about 25 km northeast of Las Cruces. The analyses of the Doak soil and spoil are presented in Table 1.

Eighty-eight columns were used in the study. Salinity sensors manufactured by Soil Moisture Incorporated were buried at a depth of 15 cm in 16 of the columns to monitor the salinity level of the topsoil 24 hours after each irrigation. A salinity bridge was attached to the sensors to determine EC of the soil solution. Half of the columns were seeded to blue grama (var. Lovington) and the remainder to fourwing saltbush at a rate of 40 seeds per column. The columns without salinity sensors were arranged in the greenhouse in 3 blocks with each block containing 12 columns seeded to blue grama and 12 seeded to fourwing saltbush. Eight of the columns with salinity sensors were placed randomly among the columns in block one, and the other 8 columns were randomly placed in block two. Within a block the same number of columns were seeded to blue grama or fourwing saltbush. These species are common on the exposure of the Fruitland Formation and show medium and high tolerance, respectively, to salinity.

The columns were irrigated with tap water from the greenhouse, which had an EC of 730 μmhos/cm, or 1 of 3 synthesized saline waters with ECs of 4,230, 8,700 or 12,890 μmhos/cm. The latter 3 solutions were mixed in the laboratory using distilled water and reagent grade chemicals, to simulate water from 2 aquifers underlying the coal exposure of the Fruitland Formation and a mixture of waters from these aquifers. The analyses of the various waters are presented in Table 2. Irrigations began with an initial application of 5.1 cm of water followed by 1.27-cm applications every fourth day or when the topsoil in 75% of the columns was dry to a depth of 0.5 cm. After 15 cm of water had been applied, the quantity of water per application was changed to 2.54 cm weekly. In each block, a total of 25, 32.5, or 37.5 cm of the various waters were applied to each of 8 columns with no sensors. These rates were chosen to represent the amount of water applied under different dates of seeding if irrigated throughout the growing season. The columns with sensors received 37.5 cm of water. The rate and frequency of irrigations in this study were intended to simulate actual practice at mines in the San Juan Basin, which allows sufficient water for plant establishment and good growth but is not intended for deep percolation and leaching of salts.

Infiltration time for each column was recorded at each irrigation as the number of minutes between application and disappearance of water from the soil surface. To reduce the effects of soil cracks on the apparent infiltration rate, the soil surface along the edge of the columns was tapped gently and other surface cracks were closed. Infiltration time was converted to infiltration rate in centimeters per hour.

The columns were arranged in blocks in the greenhouse with all combinations of plant species, salinity levels, and irrigation levels randomized in each block.

Plant counts were made daily from the initiation of emergence (6th day after seeding) for 15 days and emergence percentage was calculated on the basis of the number of seeds planted. The number of plants in each column receiving the same quality of water was used to evaluate emergence from the salinity treatment. Thus, average emergence percentage of each species in a particular salinity treatment was based on the emergence percentage from 9 columns. One month after seeding, plants were thinned to 6 blue grama or 4 saltbush per column. Plant height measurements were recorded weekly thereafter. Six days after final irrigations, plants were clipped at the soil surface. Top growth was oven dried for 48 hours at 110°C and dry weight was recorded.

The data were initially analyzed as a complete factorial using analysis of variance procedures. Because of significant differences between species and significant interactions in comparisons with species, the data for each species was analyzed separately for ease of interpretation. The data for emergence were analyzed as a simple randomized complete block because all columns had received the same amount of water at each date of data collection and each column was seeded to a single species. The data for plant size and water and infiltration were analyzed as a split block with irrigation levels as blocks.

Results and Discussion

To facilitate discussion of results, the irrigation waters will be identified as follows:

Tap water — EC = 730 mhos/cm, SAR = 2.5
Water #1 — EC = 4230 mhos/cm, SAR = 10
Water #2 — EC = 8700 mhos/cm, SAR = 30
Water #3 — EC = 12890 mhos/cm, SAR = 68

Plant Emergence

Data for accumulative emergence of fourwing saltbush and blue grama from the sixth through the twentieth day after initiation of irrigation are presented in Figure 1. Seedlings of both species were first observed on the sixth day after the first irrigation. Emergence of fourwing saltbush was nearly complete by 8 days after irrigation began in columns irrigated with tap water and waters #1 and #2, with averages of 24, 21, and 21%, respectively. Twenty days after the first irrigation, emergence percentages with these waters were not significantly different (25, 21, and 24%, respectively). Emergence in columns irrigated with water #3 was significantly lower

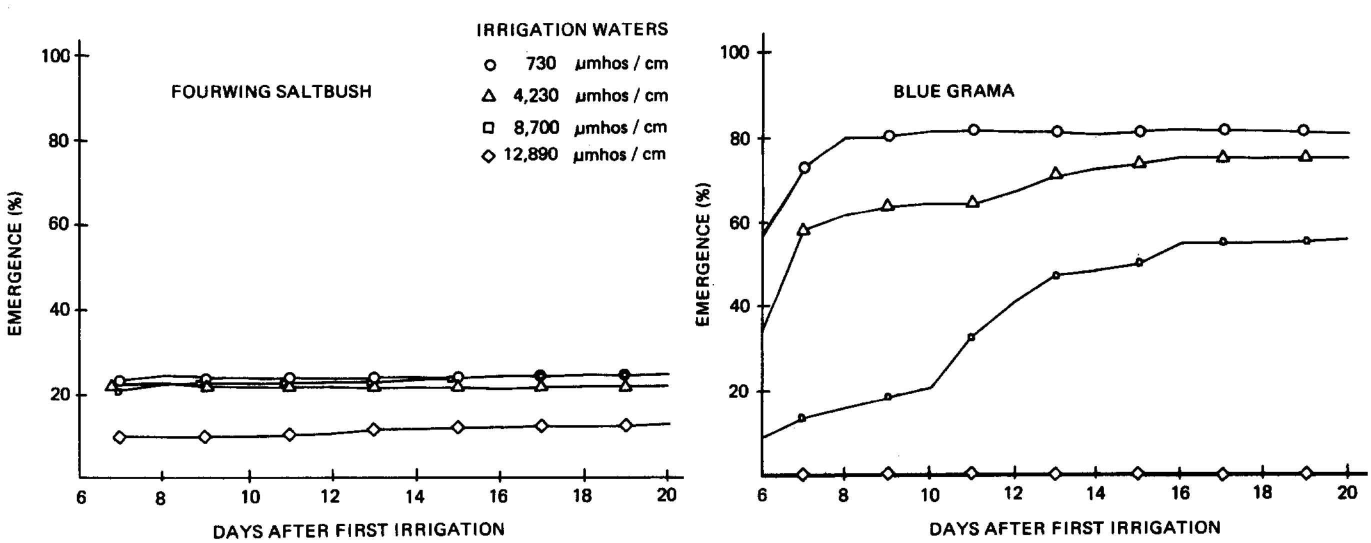

Fig. 1. *Accumulative emergence of fourwing saltbush and blue grama irrigated with four waters of different salinity*

Table 3. Average dry weight (g) of fourwing saltbush and blue grama top growth at 3 levels of irrigation using water with 4 salinity levels.

EC of the irrigation water µmhos/cm)	Level of irrigation					
	Fourwing saltbush			Blue grama		
	25 cm	32.5 cm	37.5 cm	25 cm	32.5 cm	37.5 cm
	c	b	a	b	a	a
730	5.60A	8.71A	11.01A	5.34A	8.08A	8.82A
	c	b	a	b	a	a
4,230	4.23B	8.13A	9.35B	4.12AB	7.19A	6.57B
	c	b	a	b	a	a
8,700	4.60AB	7.55A	9.57B	1.89BC	6.00A	6.80AB
	b	a	a	a	a	a
12,890	2.52C	8.25A	8.47B	0 C	0 B	0 C

Note: For each species and salinity level of water, numbers with the same lower case letter above them are not significantly different at the 5% level of probability using Duncan's multiple range test. Similarly, numbers in a column followed by the same upper case letter are not significantly different.

than with tap water, being 9 and 12% at 8 and 20 days, respectively, after the first irrigation.

The germination percentage of blue grama was much greater than for fourwing saltbush, but blue grama showed greater sensitivity to saline treatments. On the sixth day after the first irrigation the emergence in columns receiving waters #1 and #2 was 61% and 16%, respectively, of the emergence in columns receiving tap water. The emergence with tap water was virtually complete 8 days after irrigation began, while emergence continued until the sixteenth day with waters #1 and #2. At the 5% level of probability, the total emergence of blue grama in columns irrigated with tap water and water #1 did not differ, but emergence with water #2 was significantly less than for tap water or water #1. Only one seedling emerged in columns irrigated with water #3, and that seedling died after 15 cm of water had been applied.

Plant Height and Dry Weight of Plant Top Growth

Accumulative heights of fourwing saltbush and bluegrama with each increment of irrigation water shown in Figure 2 are averages of data from 9 columns for the 10- to 25-cm levels of irrigation, 6 columns for the 25- to 32.5-cm levels, and 3 columns for the 32.5- to 37.5-cm levels. The average height of fourwing saltbush at a given level of irrigation, as indicated by analysis of data at the 25-, 32.5-, and 37.5-cm levels of irrigation, did not differ for the 4 irrigation waters. Generally, plants irrigated with tap water tended to be taller than plants in columns receiving saline water. The increase of soil salinity associated with the application of additional amounts of the various saline waters had little, if any effect on the growth rate of fourwing saltbush. The dry weight of fourwing saltbush top growth increased significantly with time in all irrigation treatments (Table 3) except with water #3. In contrast to the weights of plants harvested after 25 or 37.5 cm of water #3 were applied, the weight of plants after application of 32.5 cm was unexplainably high.

Fourwing saltbush plants in columns irrigated with tap water were not significantly taller than plants in columns receiving more saline water, but they were heavier at the final irrigation.

The tendency toward smaller plants as the salinity of the water

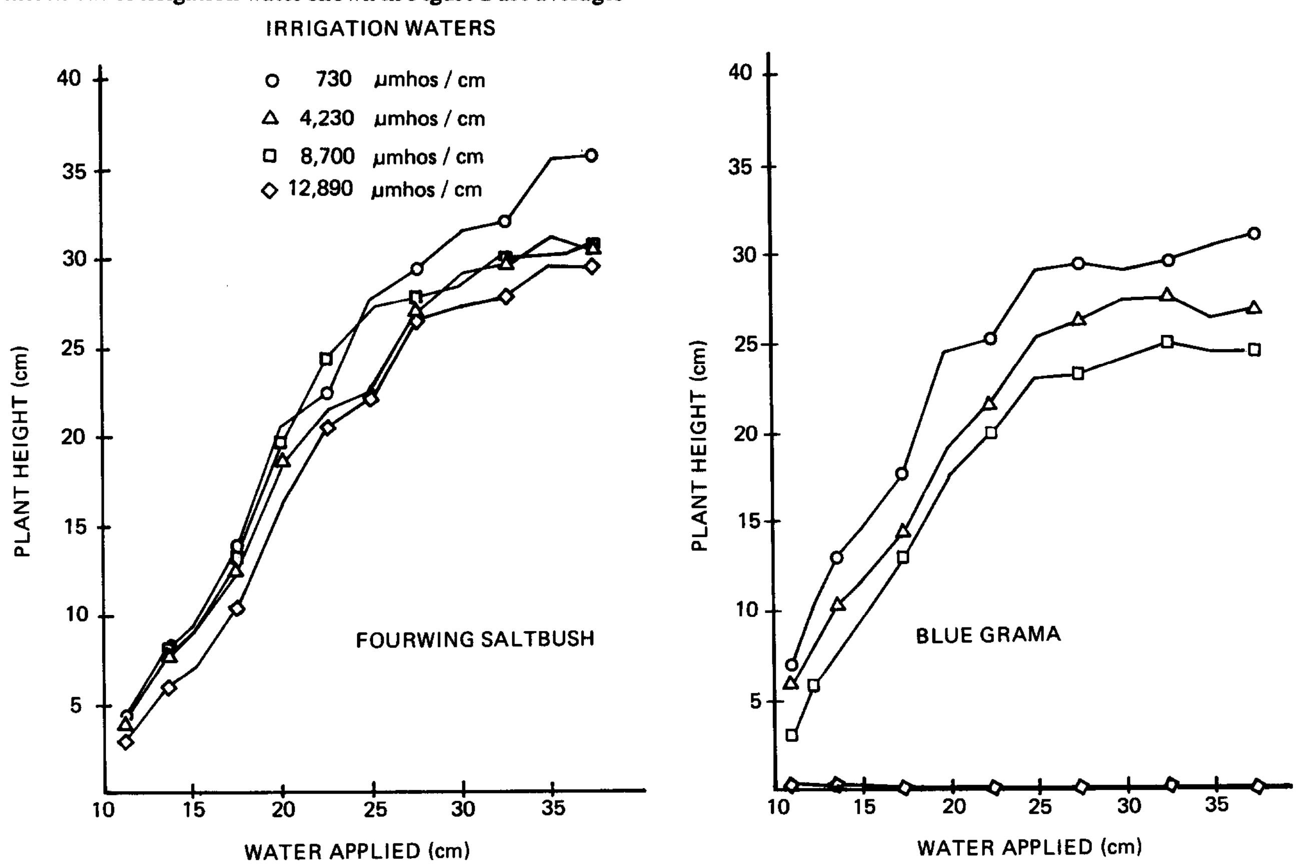

Fig. 2. *Accumulative growth of fourwing saltbush and blue grama after application of various quantities of saline water ranging EC from 730 to 12,890 µmhos/cm.*

increased may be partly attributable to the slower germination and initial growth of fourwing saltbush. The height and weight of plants irrigated with the various saline waters were quite similar after the final irrigation, which indicates a high salt tolerance for this species.

The delay in germination of blue grama (Figure 1) caused by increases in salinity of the irrigation water resulted in differences in plant height at the time of the first height measurements (Figure 2). The rate of growth thereafter appeared to be similar with tap water and waters #1 and #2. Analyses after application of 25 cm of water showed the height of plants irrigated with tap water was significantly greater than plants irrigated with waters #1 and #2, which did not differ. After the last irrigation the plants receiving tap water were taller than those receiving water #2 but were not taller than plants in columns irrigated with water #1.

The weight of blue grama plants was quite variable and a significant increase in weight did not occur during the period between the last 2 harvests (Table 3). There was a tendency for plants irrigated with tap water to be heavier than plants in columns irrigated with more saline water. No plants survived in columns irrigated with highly saline water (EC = 12,890 μmhos/cm). Apparently, blue grama is only moderately tolerant to salinity, which is in agreement with Bernstein's report (1958).

Water Infiltration Rate

The average infiltration rate for the various irrigation waters, at each irrigation after the initial application, are presented for the 2 species in Figure 3. The infiltration rates for 9 columns in each block are averaged at the 5- to 25-cm levels of irrigation, 6 columns are averaged for the 27.5- to 32.5-cm applications, and 3 columns are averaged for the 35- and 37.5-cm applications.

Infiltration rates for all waters declined rapidly from the 5- to 12-cm level of application, and at a slower rate until 22.5 cm had been applied. A reduction in the rate of infiltration with repeated applications of water is to be expected (Musgrave 1955). The rapid decline in infiltration rates after 5 cm of water were applied is because initially dry pores were partially filled with water before additional applications were made (Taylor and Ashcroft 1972). Except for water #4 in blue grama columns, infiltration rates increased with all waters after 22.5 cm were applied. These increases may be attributed to more rapid use of water by the increasing volume of plant foliage and higher evapotranspiration associated with higher temperatures in the greenhouse. Infiltration rates were calculated from the time the water was applied until it had disappeared from the soil surface. Because of greater evaporation and transpiration, the soil became dry and more water was needed to saturate the upper few centimeters of soil. Infiltration rates probably would have been lower if the upper centimeter of soil had been wetted before the regular application of water.

In columns with fourwing saltbush, the infiltration rates were highly variable within water treatments, resulting in nonsignificant differences between treatments after applying 25, 32.5, or 37.5 cm of water. The infiltration in columns with blue grama was somewhat different than in the saltbush columns. There was a greater increase in the infiltration rate for tap water in the blue grama columns than in the saltbush columns, but only a slight increase occurred with water #1. The infiltration rate for water #2 was similar for both species. The infiltration rate with water #3 dropped to a lower level in the columns with blue grama, and the rate continued to decline as more applications of water were applied. No blue grama plants grew in columns receiving water #3, so the only loss of water was from evaporation or deep drainage. Consequently, a saturated-flow condition probably occurred more quickly with treatment, and the infiltration rate was less variable. At the 25-, 32.5-, and 37.5-cm levels of irrigation the infiltration rate with tap water was significantly greater than with water #3, while rates with waters #1 and #2 did not differ significantly from rates with tap water or water #3.

Electrical Conductivity

The electrical conductivity measurements obtained with salinity sensors at the 15-cm depth in the columns are shown in Figure 4. The electrical conductivity began to rise after application of 7.5 cm of waters #1, #2, and #3. After application of 12.5 cm of water the electrical conductivity at the 15-cm level was greater than that of the applied water. The electrical conductivity increased as more water was applied except in the columns with fourwing saltbush that received tap water. With waters #2 and #3 the electrical conductivity was quite similar at each level of applied water in the columns containing blue grama or fourwing saltbush. Under irrigation with water #1 the electrical conductivity increased slightly faster in the columns with blue grama than with fourwing saltbush. After the 27.5-cm level of irrigation with water #1, there was an abrupt increase in salinity in columns with both species.

The growth rate of fourwing saltbush began to level off after application of 25 cm of waters #1, #2, and #3. The infiltration rate for water #1 increased sharply, which indicates the soil was becoming increasingly drier between irrigations, so moisture stress may have caused a reduction in growth rate, and the lower water content of the soil caused an increase in electrical conductivity. The infiltration rate for waters #2 and #3 in the saltbush columns increased only slightly and then declined. Possibly, the osmotic

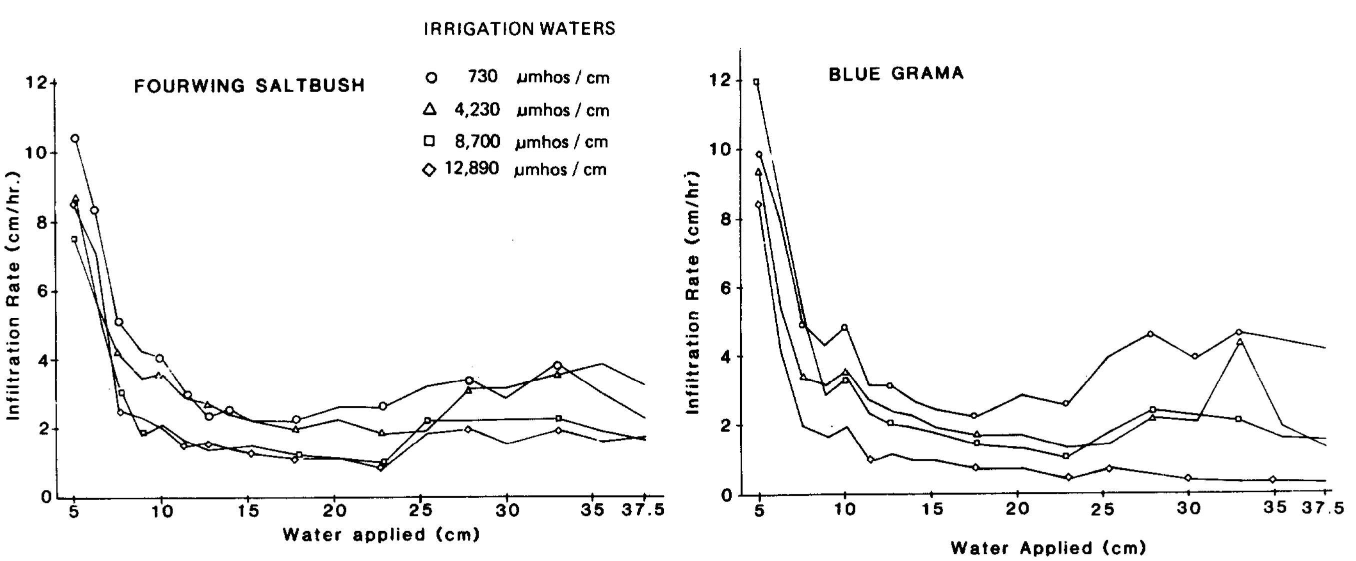

Fig. 3. *Water infiltration rate of columns seeded to fourwing saltbush and blue grama over 37.5 cm of applied irrigation with waters ranging in EC from 730 to 12,890* μmhos/cm.

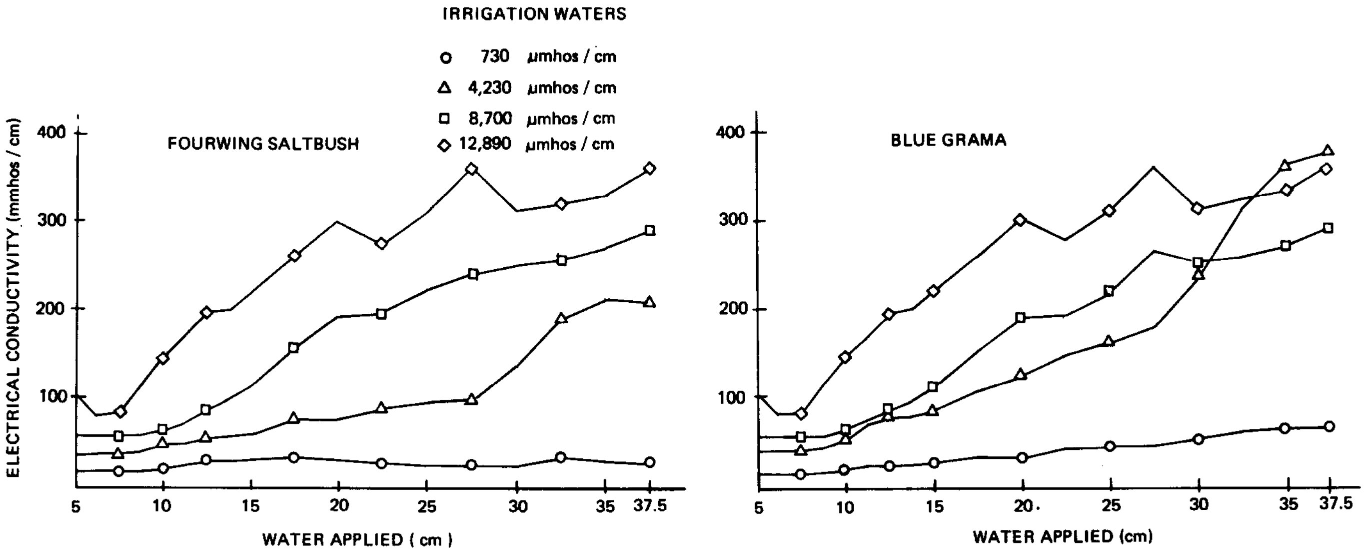

Fig. 4. *Changes in electrical conductivity with additions of saline waters as determined by salinity sensors buried at 15 cm in columns in the greenhouse.*

pressure created by the increasing salt level became inhibitory to plant growth, thus a reduced growth rate. At the same time, the plants were unable to remove as much water from the soil, so the electrical conductivity increased at a somewhat constant rate because the water level in the soil water was nearly constant at each reading.

The growth rate of blue grama tended to level off after application of 25 cm of tap water and waters #1 and #2 (Fig. 2). This reduction in leaf growth is partly attributable to stage of growth, as the plants started to produce flowering stalks. However, the increase of infiltration rate with tap water, and to a lower extent with waters #1 and #2 (Fig. 3), suggests a moisture stress may have developed between irrigations, and this also contributed to a reduction in growth. The electrical conductivity obtained with the salinity sensors was much higher than would be obtained by the saturation extract method, because the concentration of salt would be much lower in the latter method.

The data indicate that the quality of water from the Westwater Canyon Formation will probably be acceptable for use in revegetation on mine spoils but water from the Entrada Formation would be toxic to some species. The amount of water applied in this study did not permit leaching so all the salt applied remained in the soil. The electrical conductivity of the spoil material was greater than the EC of waters #1 and #2 so the salinity of the topsoil would increase with additional applications of saline water until a downward gradient of salinity from soil to spoil is achieved. The sodium level of waters #1, #2, and #3 caused a slight to significant reduction in the infiltration rate in the greenhouse. Further testing would be desirable under field conditions to determine whether the infiltration rate would be reduced sufficiently to increase runoff during a rainfall event.

To reduce the hazard for plant establishment and growth and for a reduction of the infiltration rate, field seeding should be made immediately prior to the period of maximum anticipated rainfall so that a minimal amount of ground water is used for plant establishment.

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Baseline Elemental Concentrations for Big Sagebrush from Western U.S.A.

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Abstract

The analysis of samples of big sagebrush from 190 sites in 8 western physiographic provinces resulted in measurable concentrations of 30 elements. Except for Sb, U, and V, whose concentrations were generally below the analytical detection limits, the expected (baseline) concentration range of each element was defined. The variability in the concentration of Ba, Ca, Li, Pb, Se, Sr, and Zn among the 8 provinces was found to be nonsignificant and therefore a mean and deviation (for all provinces combined) for these elements was used to define their baseline. For concentrations of 20 of the elements (including the environmentally important metals As, Cd, Cr, Co, Cu, Hg, and Mo), significant variability was found among province populations so that baseline values are reported for each province or group of provinces. Physiographic provinces were incorporated in the study design as a convenient natural unit in presenting the element baselines and we anticipate that these data may be useful in assessing biogeochemical changes brought about by the activities of energy development, mineral processing, and other anthropogenic disturbances.

The major goal of this study is to establish baselines for the elemental composition of big sagebrush (*Artemisia tridentata* Nutt.) throughout the western U.S.A. Big sagebrush is one of the most widely distributed and easily recognized shrubs of this vast region and of southern British Columbia, Canada. The importance of this species as a component in natural ecosystems and in regions dominated by livestock production was the subject of a recent symposium (Utah State Univ., 1979).

At the beginning of this study, baseline elemental composition data were seen as being useful primarily in assessing the consequences of energy development in the western U.S.A. Such activities include the surface-mining of coal and the attendant geochemical and biogeochemical changes following land reclamation (e.g., Munshower and Neuman 1980) as well as point-source contamination from coal-fired power plants and mineral processing facilities (e.g., Connor et al. 1976, Severson and Gough 1976). Elemental composition data, however, may be equally useful in evaluating contamination from natural events (e.g., the Mount St. Helens eruption) or assessing the value of sagebrush as a browse plant for livestock or for wildlife (e.g., Alvarez-Cordero and McKell 1979, Welch and McArthur 1979). In addition, big sagebrush has had limited use as a sampling medium for geochemical exploration (Warren et al. 1949, Cannon 1952, Anderson and Kurtz 1956, and Erdman and Harrach 1981) and the data in the present report should be useful in helping to identify anomalous samples from potentially mineralized areas. The use of big sagebrush as a biogeochemical exploration medium is attractive not only because of its wide distribution but also because it grows in vast regions where alluvial and colluvial surfaces (as in the Basin and Range province) may cover blind ore deposits (Lovering and McCarthy 1978).

Sampling Methods and Study Design

In the fall of 1975, big sagebrush samples were collected from 190 sites that were located in 8 western physiographic provinces (Fig. 1). All samples were collected between the end of August and the end of October when vegetative growth has generally ceased (DePuit and Caldwell 1973). Variation in the element concentrations of young big sagebrush tissue can be large (Gough and Erdman 1980). We showed that some differences in element concentration are likely due to intrinsic factors, such as a plant's genetic make-up, coupled with seasonal and climatic changes in element availability, and may not necessarily reflect environmental disturbance or underlying mineralization. In order to minimize these problems samples of sagebrush should represent a given plant part and be collected within a reasonably short period of time.

Each sample consisted of about 300 g of the current year's leaves and stems (approximately the terminal 20–30 cm of branches). A composite of this material was made from several shrubs within a

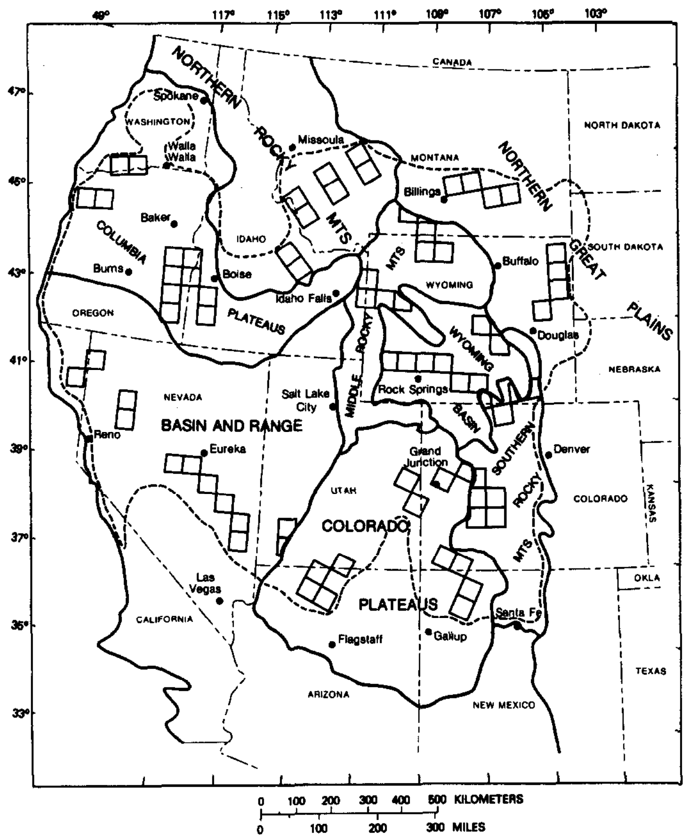

Fig. 1. *Position of sampling locations 50 km on a side and the general distribution of big sagebrush (bold dashed lines, modified from Beetle, 1960) within 8 western physiographic provinces (province boundaries after Fenneman 1931).*

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Table 1. The symmetrically nested, analysis-of-variance sampling designs.

Level	Two 200-km cells per province: Number of samples representing level	Two 200-km cells per province: Degrees of freedom	Three 200-km cells per province: Number of samples representing level	Three 200-km cells per province: Degrees of freedom
1. Province	5	4	3	2
2. 200-km cell	10	5	9	6
3. 100-km cell	20	10	18	9
4. 50-km cell	40	20	36	18
5. 25-km cell	60	20	54	18
6. 5-km cell	80	20	72	18
7. 0.1-km cell	100	20	90	18
8. Duplicate analyses	115	15	110	20
		Total = 114		Total = 109

small area (about 25 m²). Samples were a mixture of the 3 common subspecies: *tridentata* (basin big sagebrush), *wyomingensis* (Wyoming big sagebrush), and *vaseyana* (mountain big sagebrush).

Samples were collected according to a one-way, nested, analysis-of-variance (AoV) design (Table 1) similar to the ones diagrammed by Bainbridge (1963) and described in mathematical detail by Miesch (1976). The design had 8 levels and was unbalanced below the fourth level. The unbalancing meant that dichotomous branching was allowed on 1 of 2 possible legs resulting in the actual use of one-half of the total number of possible sampling sites. The unbalancing stabilized, to an acceptable number, the degrees of freedom used in the AoV (Table 1) and served to economize on field and laboratory time and expense without appreciably affecting the estimates of the variance components (Table 2).

The purpose of the design was to partition the variability in the concentration values of an element in plant tissue among distance increments (natural variance) and analytical procedures (error variance). A proportion of the total variance (s^2_t) was measured at each AoV level as follows: s^2_p, among provinces; s^2_{200}, among cells 200-km on a side; s^2_{100}, between cells 100-km on a side; s^2_{50}, between cells 50-km on a side; s^2_{25}, between cells 25-km on a side; s^2_5, between cells 5-km on a side; $s^2_{0.1}$, between samples 0.1 km apart; and s^2_a, between duplicate analyses of the same sample.

Because of the immense area occupied by the Columbia Plateaus (CbP), Colorado Plateaus (ClP), and Basin and Range (B&R) provinces, and because these 3 provinces contain a large proportion of the total big sagebrush distribution, an additional 200-km cell per province was included in the AoV design (Table 1). This addition increased the number of samples collected in these 3 provinces by one-third; therefore, 30 samples were collected in each of these 3 provinces, whereas 20 samples were collected in each of the other 5 Northern Rocky Mountains (NMR), Northern

Table 2. Distribution of variance in the concentration of elements in big sagebrush from eight western Physiographic Provinces.

Element or Ash	Total $\log_{10}$ variance	Percentage of total variance[1]: Among provinces	Among 200-km cells	Between 100-km cells	Between 50-km cells	Between 25-km cells	Between 5-km cells	Between 0.1-km cells	Between duplicate analyses
Ash	0.0041	*32	9	*12	3	2	22	*16	4
Aluminum	.0897	*34	<1	<1	22	<1	*24	*13	7
Arsenic	.1582	*49	5	*18	8	<1	2	*12	6
Barium	.0562	<1	9	10	<1	2	11	*55	14
Boron	.0365	*20	2	<1	12	<1	*27	*25	15
Cadmium	.1436	*26	2	*15	<1	15	8	*30	4
Calcium	.0090	<1	<1	*14	<1	24	8	*49	5
Chromium	.1160	*23	<1	3	*24	1	14	*19	16
Cobalt	.1020	*28	<1	*22	7	<1	*17	3	22
Copper	.0297	*15	<1	*17	<1	17	<1	*45	6
Fluorine	.0352	*99	<1	<1	<1	<1	<1	<1	<1
Iron	.1265	*44	1	<1	*23	<1	*15	*9	7
Lead	.0540	9	19	*20	10	<1	<1	*31	11
Lithium	.1251	11	4	*10	*33	<1	*29	*7	5
Magnesium	.0131	*23	7	*12	1	<1	13	*32	11
Manganese	.0500	*12	<1	6	17	<1	23	*30	12
Mercury	.0193	*21	4	<1	<1	<1	14	4	56
Molybdenum	.0684	*26	<1	3	1	*23	2	17	28
Nickel	.0891	*22	<1	4	11	4	16	*30	11
Phosphorus	.0162	*99	<1	<1	<1	<1	<1	<1	<1
Potassium	.0036	*13	3	<1	6	3	20	*35	18
Selenium	.2714	17	14	*14	17	6	9	*18	5
Sodium	.1566	*26	12	*11	<1	10	*23	*16	1
Strontium	.0909	<1	*17	<1	*18	<1	23	*22	20
Sulfur (total)	.0086	*34	2	*17	<1	12	4	*17	13
Titanium	.0922	*98	<1	<1	1	<1	1	<1	<1
Zinc	.0329	2	<1	<1	*31	<1	15	*50	2
Zirconium	.0804	*24	<1	8	*14	<1	*27	<1	26

*Significant at the 0.05 probability level.
[1]Values are rounded to the nearest whole number.

Great Plains (NGP), Middle Rocky Mountains (MRM), Wyoming Basin (WB), and Southern Rocky Mountains (SRM).

The geographical position of sampling sites was determined by first superimposing the nested cells on base maps (scale of 1:250,000) and then randomly selecting cells, of successively smaller size, until a point was defined. Figure 1 shows the location of the randomly positioned 50-km cells.

Some restrictions as to the location of cells were imposed by the areal distribution of big sagebrush. Before going to the field, we also superimposed the cells on a map of sagebrush distribution in such a manner as to include as much of the distribution as possible. It is for this reason that the cells shown in Figure 1 appear in various orientations. Further, the random location of cells explains their truncated appearance when they occur near or on province boundaries.

Laboratory Methods

The unwashed samples from the 190 sites were dried at 38-40° C and ground to pass a 1.3-mm screen. Thirty-five random samples were split for the s^2_a measurement and the entire suite of 225 was submitted for analysis. The homogenized ground material was either ashed by dry ignition at about 500° C for 24 hr or subjected to acid digestion (Harms 1976) for the determination of As, F, Hg, Sb, Se, and S. Aluminum, B, Ba, Cr, Fe, Mn, Ni, Pb, Sr, Ti, V, and Zr were determined by semiquantitative d-c arc emission spectrography; As, Ca, Cd, Co, Cu, K, Li, Mg, Na, Sb, and Zn by flame absorption spectroscopy; Hg by flameless atomic-absorption spectroscopy; Mo and P colorimetrically; F by selective ion electrode; Se and U fluorometrically; and total S turbidimetrically.

Data Analysis

All concentration data are presented on a dry matter basis. These values were converted to logarithms because the frequency distributions of the transformed data were more symmetrical than those of the raw data. All statistical tests were performed on log-transformed data.

Some of the concentrations for As, Cd, Cr, Co, Li, Ni, Pb, Sb, U, V, and Zr were censored; that is, below (less than) the lower limit of determination (LLD) for the analytical method used, or not detected at all. Three of these elements (Sb, U, and V) had such a large proportion (>50%) of the values below the LLD that no statistical analyses were performed. The conversion of an LLD value, reported on an ash-weight basis, to a dry-weight equivalent, results in variable LLD values because of differences in the ash yield among samples. For this study we chose to handle the data as follows: (a) after dry-weight conversion, an average of the variable LLD values for each element was calculated; and (b) the censored values were then replaced with a value equal to 0.7 times the average LLD value. If censoring exceeds about one-third of the total number of values then our experience is that a substitution of some fraction of the LLD (in this case 0.7) will produce statistical tests that are compromised and uninterpretable. If substitutions with 0.7 times the LLD are made for censoring that occurs in less than about one-third of the values, then the statistical results can be used if they are interpreted with caution. Calculated average LLD concentrations (ppm) for those elements with censored values follows: As, .05; Cd, .019; Cr, .10; Co, .044; Li, .17; Ni, .48; Pb, .77; and Zr, .64.

Because our data were transformed to logarithms, our measure of the average is reported as the geometric mean (GM) and the spread (or scatter) as the geometric deviation (GD). The GM and GD are simply the antilogarithms of the mean and standard deviation, respectively, of the logarithms. A GD value of 1.0 means that there is no variability in the data. A "baseline," as first proposed by Tidball and Ebens (1976), was calculated and is defined as a concentration range bracketed by the GM/GD^2 to the $GM \times GD^2$. Element means for each province were compared using the Duncan test (1955) as modified by Natrella (1966) for means based on variable numbers of samples.

Results and Discussion

Biogeochemical Variability Among Individual Provinces

Table 2 lists the distribution of the variance as a percentage of the total among the 8 levels of the AoV design for 27 elements and ash yield. The GD for each element (where n=225 samples) can be calculated by taking the antilog of the square root of the total $\log_{10}$ variance. A GD value calculated in this manner includes the variability associated with the 35 analytical splits (duplicate analyses).

We will confine our discussion to the 2 most important levels as defined by the distribution of the variance among the AoV levels (Table 2): the s^2_p level (broad regional component or variability among provinces) and the $s^2_{0.1}$ level (local component or variability at a distance of less than 100 m). Fourteen of the 28 constituents have more than 50% of their total variance at these 2 levels and an additional 10 have more than 40%.

In addition, the distribution of the variance in Table 2, for the concentration of an element in big sagebrush, shows that 78% of the constituents have a significant proportion of their variance at the s^2_p level and also at the $s^2_{0.1}$ level. This means that the concentration of most elements in big sagebrush differs among provinces but that within each province sagebrush individuals separated by about 0.1–5 km are likely to be as different chemically as are individuals separated by about 200 km. Sagebrush samples from the 3 Rocky Mountain provinces were mixtures of the 2 subspecies *vaseyana* and *wyomingensis* and samples from the other 5 provinces were uniformly composed of either *tridentata* or *wyomingensis*. We assume, therefore, that a real but undefinable contribution to the variability in sagebrush chemistry among provinces may be attributed to subspecies differences. A study was conducted in 1978 of the 3 recognized subspecies of *A. tridentata* at a uniform garden plot at the U.S. Department of Agriculture Gordan Creek Field Station near Helper, Utah. The results (J.A. Erdman, unpublished data) indicate that significant differences in concentrations of some elements, in unwashed leaf samples, do exist among the subspecies but that they seem to be minor compared with those differences among provinces observed in this study.

The distribution of the total variance at the s^2_a level (between analytical splits) is also of interest. If this value is large, then the observed scatter in the data measures mainly analytical error rather than natural variability. In our judgement, Hg is the only element with excessive analytical error (56%). Caution should be used, therefore, when interpreting the importance of the distribution of the variance of this element.

The elements Ba, Ca, Li, Pb, Se, Sr, and Zn do not show significant among-province differences. For these 7 elements, a grand geometric mean and deviation (calculated for samples from all of the provinces) is an appropriate measure of central tendency and spread (Table 3). These statistics may be used to assess the degree of uniqueness of a newly collected sample regardless of the province from which it was collected. For example, if a sample of sagebrush were collected in Nevada and had a Pb concentration of

Table 3. Summary statistics (n=190) for the concentration of seven elements in big sagebrush samples not having a significant regional variance component.

Element	Geometric mean	Geometric deviation	Expected 95 % range[1]
	ppm, dry material		
Barium	19	1.73	6.4 – 57
Calcium	5,000	1.21	3,400 – 7,300
Lead	1.1	1.77	.35 – 3.5
Lithium	.44	2.26	.086 – 2.3
Selenium	.11	3.23	.011 – 1.1
Strontium	58	1.85	17 – 200
Zinc	19	1.49	8.6 – 42

[1]"Baseline" as proposed by Tidball and Ebens (1976).

2.6 ppm, it could be compared with the expected 95% range for all 190 samples of this study. A value of 2.6 ppm would be considered large but perhaps not unusual. A value greater than 3.5 ppm is unusual and probably represents an individual belonging to a population other than the baseline population.

Data for Sb, U, and V are not given in Table 2 because of excesive censoring. For these elements the number of values below the LLD was so great that statistical analyses would have had little meaning. Because of the importance of these elements in environmental and biogeochemical prospecting studies, however, we present the observed range of concentration values (ppm) for 190 samples as follows: Sb, <0.02–.25; U, <0.012–.25; and V, <0.42–7.9.

Biogeochemical Variability Among Province Groups

For the 20 elements and ash yield that did show significant regional trends (Table 2), a comparison test was performed in order to identify groups of similar means. Table 4 lists these groups. The last column in Table 4 uses symbols for each of the 8 physiographic provinces in order to illustrate these groupings. This display serves two basic functions: (a) it shows which of the provinces have sagebrush with concentrations of an element that are large or small (when compared to other provinces), (b) it allows for the presentation of summary statistics (GM, GD, and expected 95% range) based on the new province groupings, and (c) it lends itself to the construction of assemblages of elements with similar patterns in province groupings. Table 4 is divided into 3 arbitrary sections based on these element assemblages.

Summary statistics based on these groupings are illustrated by the data for Cr. Because the sagebrush samples from the Columbia Plateaus (CbP) had a GM for Cr significantly larger than the other 7 provinces, the CbP samples make up their own individual group and the summary statistics are based on 30 samples. The second grouping consists of samples from both the Wyoming Basin (WB) and the Middle Rocky Mountains (MRM) and the summary statistics were calculated based on a total of 40 samples. The last grouping consists of the remaining 5 provinces (n=120).

Each of the 3 sections in Table 4 is composed of an assemblage of constituents that have similar province groupings when ordered from largest concentrations to smallest. In general, Section I constituents show the following province order: CbP > WB > Basin and Range (B&R) > Colorado Plateaus (ClP) and MRM > Northern Rocky Mountains (NRM) > Northern Great Plains (NGP) and Southern Rocky Mountains (SRM). The constituents in this section may be classified as the ash-forming elements and include the major-essential and the soil-resistate elements. The variables in Section II have the following general province order: CbP > WB > B&R and ClP > NRM > NGP, MRM, and SRM. Except for B, these elements are heavy metals; however, this assemblage does not appear to have any characteristics that make it particularly unique when compared with the 5 elements in Section III. This latter section has the following general province order: NRM > CbP and NGP > the remaining 5 provinces. The province order of Sections II and III differ most importantly in the position of the NRM province. In Section II (as in Section I) this province is usually in the fifth position (from left to right) whereas in Section III it is always first. This alteration in the position of the NRM province in Section III is due to the influence of a group of samples collected in the vicinity of Butte, Mont., and probably represents either the mineralization of the region or possible contamination related to ore processing.

Table 4. Summary statistics for the concentration of twenty elements (and ash yield) in big sagebrush samples with a significant regional (among provinces) variance component. Concentrations are in parts per million, dry matter basis, except ash yield and K which are in parts per hundred. Elements with similar patterns in province groupings are segregated into sections. The following symbols represent provinces: ● Columbia Plateaus; ▲ Basin and Range; ◒ Colorado Plateaus; ◩ Northern Rocky Mountains; ■ Wyoming Basin; ○ Northern Great Plains; △ Middle Rocky Mountains; □ Southern Rocky Mountains.

Parameter	GM	GD	95% Expected Range	Provinces (overlap of symbols on sucessive lines indicates similarity of means)
Section I				
Ash	5.6	1.17	4.1 - 7.7	●
	4.8	1.09	4.0 - 5.7	■ ▲ ◒
	4.6	1.11	3.7 - 5.7	▲ ◒ ◩ ○ □ △
	4.3	1.16	3.2 - 5.8	□ △
Al	1,600	1.74	530 - 4,800	●
	860	1.51	380 - 2,000	■ ▲
	580	1.73	190 - 1,700	△ ◩ ○ ◒
	520	1.78	160 - 1,600	○ ◒ □
Fe	600	1.82	180 - 2,000	●
	260	1.74	86 - 790	■
	210	1.78	66 - 660	▲
	140	1.72	47 - 410	△ ◩ ○ ◒ □
Mg	1,600	1.20	1,100 - 2,300	○ ■
	1,500	1.20	1,000 - 2,200	● ◒ ◩ ▲
	1,100	1.29	660 - 1,800	□ △
P	1,800	1.17	1,300 - 2,500	● ■
	1,500	1.20	1,000 - 2,200	▲ ◒ ◩ ○
	1,400	1.21	960 - 2,000	△ □
K	1.4	1.14	1.1 - 1.8	● ■ ▲ ◒ ◩ ○ □
	1.2	1.16	.90 - 1.6	△
Na	120	1.54	51 - 280	●
	78	2.68	11 - 560	■ ▲
	50	2.07	12 - 210	○ △
	30	1.78	9.5 - 95	◩ ◒ □
S	1,600	1.15	1,200 - 2,100	● ▲
	1,500	1.18	1,100 - 2,100	◒ ■
	1,300	1.19	920 - 1,800	■ ◩ ○ □
	1,200	1.19	850 - 1,700	□ △
Ti	84	1.80	26 - 270	●
	30	1.62	11 - 79	■ ▲
	24	1.74	7.9 - 73	△ ◩ ○ ◒ □
Zr	2.5	1.80	.77 - 8.1	●
	1.5	1.81	.46 - 4.9	■ △
	.99	1.72	.33 - 2.9	▲ ◩ ○ ◒ □

Parameter	GM	GD	95% Expected Range	Provinces (overlap of symbols on sucessive lines indicates similarity of means)
Section II				
B	26	1.41	13 - 52	● ▲ ○ ◒
	22	1.40	11 - 43	○ ◒ ◩ △ ■
	14	1.35	7.7 - 25	□
Cr	.66	1.71	.23 - 1.9	●
	.46	1.81	.14 - 1.5	■ △
	.26	1.92	.071 - .96	▲ ◩ ○ □ ◒
Co	.16	1.78	.050 - .51	●
	.11	2.08	.025 - .48	■ ○
	.086	1.49	.039 - .19	▲
	.069	1.64	.026 - .19	◩
	.054	1.64	.020 - .14	□ △ ◒
Hg	.030	1.34	.017 - .054	● ▲
	.025	1.31	.015 - .043	◒ ○ ◩ ■
	.022	1.28	.013 - .036	◩ ■ △ □
Mo	.88	1.66	.32 - 2.4	● ■ ▲ ◒
	.54	1.68	.19 - 1.5	◩ ○ □
	.43	1.85	.13 - 1.5	△
Ni	1.9	1.58	.76 - 4.7	●
	1.4	2.31	.26 - 7.5	○
	.93	1.78	.29 - 2.9	▲ □ ◩ ◒ △
	.75	1.75	.24 - 2.3	■
Section III				
As	.97	3.38	.085 - 11	◩
	.17	1.56	.070 - .41	● ○ ■
	.10	1.73	.033 - .30	△ ▲
	.081	1.57	.033 - .20	◒ □
Cd	.28	2.66	.040 - 2.0	◩
	.15	2.00	.038 - .60	○ □ △
	.098	1.73	.033 - .29	■ ●
	.063	1.96	.016 - .24	▲ ◒
Cu	9.2	1.54	3.9 - 22	◩ ○
	8.4	1.32	4.8 - 15	○ ● ■
	6.6	1.41	3.3 - 13	◒ △ □
	5.8	1.40	3.0 - 11	▲
F	10	1.35	5.5 - 18	◩ ●
	8.8	1.17	6.4 - 12	△ ■ ▲
	8.1	1.23	5.3 - 12	□ ○ ◒
Mn	58	2.03	14 - 240	◩
	48	1.31	28 - 82	●
	36	1.58	14 - 90	▲ ■ □ ○ ◒
	31	1.58	12 - 77	◒ △

This type of data display also is useful when comparing the concentration of an element in a newly collected sagebrush sample with the proposed summary statistics for sagebrush from a given province. If, for instance, a sagebrush sample from the ClP province was found to have 1.0 ppm Cr, the conclusion would be that this value is unusually large when compared with the Cr summary statistics calculated from samples that included sagebrush from the ClP and 4 other provinces (Table 4). This is because 1.0 ppm is greater than the upper limit of the 95% expected range for samples from the group of provinces.

The means of groups of provinces were not always significantly different and some overlap occurred. The data for Cu (Section III, Table 4) are an example. A concentration value for Cu in sagebrush collected in the NGP could be compared with the summary statistics that include samples from the NMR or with statistics that include samples from the WB and the CbP. As a result, there are two sets of summary statistics that could be used to assess the degree of uniqueness of the Cu concentration in the new sample. A simplified approach would be to combine the 2 expected ranges from the 2 overlapping groups so that a somewhat larger data spread would result (3.9–15 ppm). The comparison of the Cu value from the new sample with the new range could then be made.

Conclusions

The alteration of the geochemical environment through natural (e.g., the eruption of the Mount St. Helens volcano) and anthropogenic sources (e.g., surface-mining and mineral-processing operations) can be anticipated over sections of the western U.S.A. energy regions. The degree to which these changes occur can be monitored only if reliable background or baseline biogeochemical estimates are known. Based on the distribution in the spatially related variability in the data we present baseline elemental concentrations for 27 elements (and concentration ranges for Sb, U, and V) in the young tissue (leaves and stems) of big sagebrush.

Concentrations of Ba, Ca, Li, Pb, Se, Sr, and Zn were found to possess an insignificant amount of the variability in their data at a regional scale (among the 8 western physiographic provinces). This meant that the variability in the data was distributed among samples more closely spaced and resulted in baselines for these elements that were calculated using samples from all 190 sites in the study. Concentrations of the 20 additional elements, however, were significantly different among the province sagebrush populations and baseline determinations for these elements were determined on samples from individual provinces or groups of provinces.

The manner in which the element baselines ordered themselves in relation to province groupings is interpreted as reflecting the basic geochemistry of these broad areas.

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Water Properties of Caliche

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Abstract

Water absorption and retention by hard caliche nodules (rocks) collected from soils in southern New Mexico were determined. The rate of water uptake by the caliche rocks was rapid and water content at saturation was 13.0% by weight (24.7% by volume). At a matrix potential of -0.7 MPa, the rocks retained 10.6% water by weight, an 18% loss from saturation. Water loss from saturated rocks to a dry atmosphere was slow, but most of the absorbed water was released. The rocks contained only 0.6% water by weight (1.1% by volume) after 34 days in a desiccator. Both laboratory and field trials indicated that, although indurated caliche layers will absorb large amounts of water, the water does not pass through the layers to the soil below.

Caliche is commonly found in soils in the arid and semiarid southwestern United States. Although the chemical composition of caliche varies spatially, calcium carbonate ($CaCO_3$) is always the major constituent. Deposits of caliche often limit the downward extension of plant roots and the volume of soil from which plants can extract water. Thus, an understanding of plant distributions on arid rangelands is often dependent upon a knowledge of how caliche deposits influence the availability of soil water.

The dissolving and leaching of $CaCO_3$ by rainwater, followed by the evaporation and rapid removal of soil water by plants, leads to precipitation of $CaCO_3$ and the development of caliche deposits in soils (Gile et al. 1966, Shreve and Mallery 1932, Stuart and Dixon 1973, Stuart et al. 1961). Deposits of caliche often form along and below contacts between coarse-textured soil layers or between coarse- and fine-textured interfaces (Stuart and Dixon 1973). These carbonate deposits may be in the form of indurated or "hard" caliche—which does not slake when an air-dried portion is placed in water—or in the form of nonindurated "soft" caliche—which does slake when an air-dried portion is placed in water (Gile 1961). Both types of caliche often exist together. Caliche deposits may be in the form of either nodules or layers. In either form, the material is usually parallel to the soil surface in either continuous or discontinuous layers. Depth of the deposits varies from near the surface to a depth of a meter or more. With maturity, whole deposits may become hardened and strongly indurated, especially if they contain high amounts of calcium or aluminum silicates (Stuart et al. 1961). Where soil horizons are so strongly impregnated with carbonate that their morphology is determined by the carbonate, a petrocalcic or Bkm horizon may be designated (USDA Soil Conserv. Serv. 1981). Since hardened deposits are not easily weathered, the layer, upon exposure, can form a caprock (Lattman 1977). The development of carbonate horizons is a useful indicator in determining soil age (Gile 1970).

In calcareous soils, those with caliche layers and those with enough $CaCO_3$ to potentially form caliche, water penetrability and soil sorptivity decrease as the $CaCO_3$ content in the sand fraction increases. Precipitates in such soils can block pore spaces and increase the length of passages available for soil water movement. As a result, both the water storage-capacity and the rate of water advancement (hydraulic conductivity) in the soil are decreased (Tayel 1975, Verplancke et al. 1976). Removal of $CaCO_3$ from a soil increased soil porosity and soil water retention at all suction levels tested by Stakman and Bishay (1976). Calcareous soils were also found to be more susceptible to compaction damage and clogging of micropores by cementation (Talha et al. 1978). Gile (1961) found that infiltration rates of carbonate horizons ranged from 0.13 to 14.99 cm per hour and that infiltration rates decreased exponentially as carbonate content increased.

Caliche is highly insoluble in soil water except when the soil water contains abundant CO_2 (Shreve and Mallery 1932). The insolubility of caliche in water has lead to the assumption that most caliche is highly impermeable to water (Lattman 1977). However, Shreve and Mallery (1932) found that "hard" caliche would absorb small amounts of water (3-6% by dry weight) whereas "soft" caliche absorbed up to 17% water. Shreve and Mallory (1932) also found that water transferred slowly through thin (1-cm thick) caliche layers. They concluded that caliche was a deterrent to the penetration of water from the surface to lower depths, and that, once water reached lower depths, caliche effectively retained it.

Caliche often occurs within the rooting zone of plants on arid rangelands (Gile and Grossman 1979). Thus, water properties of caliche may influence the amount of soil water available to plants. The objective of this study was to determine the water absorption, retention, and transfer characteristics of indurated caliche.

Materials and Methods

Caliche samples were obtained from a mesquite (*Prosopis glandulosa* Torr.) duneland site on the Jornada Experimental Range (administered by the U.S. Department of Agriculture, Agricultural Research Service) in Dona Ana County, N. Mex. On-site examination was made by Soil Conservation Service personnel. Interdunal soils were identified as coarse-loamy, mixed, thermic Typic Haplargids of the Onite series and as coarse-loamy, mixed, thermic Typic Calciorthids of the Wink series. Dunes tall enough to qualify as pedons were classified as mixed Typic Torripsamments of the Pintura series. All of the soils contain petrocalcic layers, generally horizontally discontinuous and ranging from the surface to a meter or more in depth. These soils are in an arid area where mean annual rainfall is 230 mm. Mean annual temperature is 15°C. The average temperatures are maximum in June (36°C) and lowest in January (13.3°C).

Hard caliche nodules (rocks) were gathered from the field site. A layer of caliche rocks is typically found just above the solidly indurated caliche layers. Four weight classes, with 5 rocks in each class, were chosen, based on oven-dry weight as follows: (1) 40-70 g; (2) 70-100 g; (3) 100-150 g; and (4) 150-300 g.

Water Absorption

To determine rate of water uptake and water content at saturation, we oven-dried (105°C) the caliche rocks to a constant weight (48 hr) and submerged them in distilled water. The rocks were removed from the water and excess water removed with towels, then immediately weighed and replaced in water. This procedure was performed after 1, 5, and 15 min; 1 hr; 5 hr; and 24 hr of submergence. Weight determinations at 36 hr showed that a constant weight had been reached at 24 hr. Water content (percentage of dry weight) was calculated for each rock at each time interval.

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An analysis of covariance (rock-size classes treatments-time covariate) was used to determine whether differences existed among the absorption curves of the rock-weight classes.

To determine water retention and release, we first saturated the 20 caliche rocks to a constant weight by submerging them in distilled water for about 24 hours. Then we placed them in a pressure plate apparatus on a bed of soil and, using the procedure described by Richards (1965), equilibrated the rocks with matrix potential values of -0.03, -0.1, -0.7 and -1.5 MPa. After each such application, the rocks were weighed, oven-dried, and then resaturated. Water release curves were plotted for each weight class. An analysis of covariance procedure (weight size classes treatments-matrix potential covariate) was used to determine whether differences existed among the water release curves.

Desorption to a Dry Atmosphere

Water release to dry air was determined by saturating the rocks and placing them in desiccating jars with silica gel crystals for 34 days. Periodically, the rocks were removed, weighed, and replaced as quickly as possible. An analysis of covariance (rock-weight classes treatments-time covariate) was used to test for differences among water release curves for the rock-size classes. After the above experiments were completed, densities of the caliche rocks were determined by oven-drying, weighing, and coating each rock with a thin layer of varnish. After the varnish was dry, each rock was placed in a graduated cylinder or beaker, and volume was determined by water displacement.

Water Flow Through Caliche

To determine whether water would flow through a solid caliche layer, we sealed 3 caliche rocks, which appeared to have no cracks through them, in clear, plastic cylinders with silicone caulking. The sides of the rocks were coated with caulking and rolled up in 30 cm squares of flexible sheet plastic. The overlapping edges of the plastic sheets were sealed with caulking to form a water-tight cylinder. The top of each cylinder was filled with distilled water to a depth of 10 cm. The bottom surfaces of the rocks were exposed to air. The rocks were observed periodically for 3 days to determine whether water had passed through them.

A field test for water flow through caliche was made in conjunction with soil hydraulic conductivity measurements (Hennessy 1982). On an interdune area, a 1-m^2 area was cleared of about 15 cm of soil to expose the indurated caliche layers. A neutron probe access tube was passed through the center of the plot to a depth of approximately 1.22 m. A soil water content was determined with a neutron thermilization unit before water was applied. A metal frame 1 m^2 was placed on the plot. Water was ponded within the frame to a height of 15 cm. That water level was maintained for 15 min, and then the level was allowed to drop. Beginning 2 min after the introduction of water, soil water determinations were made at 15–30 min intervals for the first 5 hr and thereafter once a day for 6 consecutive days. The caliche layer at this location was approximately 30.5 cm thick as observed when the access hole was drilled and as confirmed by probe data. At a nearby plot an access tube was placed in an area where about 45 cm of soil existed above the caliche layer. The plot was flooded and measurements were taken as described above, but the soil above the caliche was not removed. The access tubes fit tightly in the holes. If water seepage occurred between the tubes and surrounding caliche it was not in quantities large enough to influence neutron probe readings which remained fairly constant below the caliche layers.

Results and Discussion

The mean density of the 20 caliche rocks was 1.9 g/cm^3. The range of means among size classes was 1.8 to 2.0 g/cm^3. Examination of rocks under a microscope revealed that density may vary considerably among rocks as both coarse and finely packed layers were usually present. The bulk density of the caliche (1.9 g/cm^3) was much greater than the bulk density of soils on the site. (1.4 g/cm^3).

Water Absorption

The laboratory measurement indicated that all of the caliche rocks had become saturated 24 hr after submersion, and several rocks were at or near saturation after 5 hr of submergence. The absorption curves of the rock-weight classes did not differ significantly ($P>0.05$), so the overall mean (all weight classes combined) was used to illustrate water absorption (Fig. 1). The rate of water uptake was rapid; after 1 min, the mean water content was 3.3% by weight (6.3% by volume); after 5 min, 6.1% by weight (11.6% by volume); after 1 hr, 11.5% by weight (21.9% by volume). The mean of percentage of water content for all the rocks at saturation was 13.0% by weight (24.7% by volume).

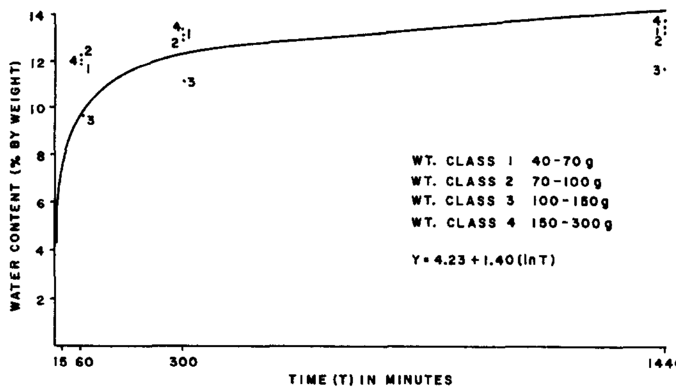

Fig. 1. *Absorption curve of mean water content (% by weight) over time of 20 caliche rocks (all weight classes combined) submersed in water. Observed values at 60, 300, and 1440 minutes are shown for each weight class. The absorption curves of the different weight classes did not differ significantly (P>0.05).*

Desorption at Various Matrix Potentials

The caliche examined appeared to retain water very well. The water lost at various matrix potentials was influenced to some degree by the weight or size (more specifically, no doubt, the surface to pore volume ratios) of the caliche rocks (Fig. 2). The desorption curves for the various rock-weight classes differed significantly ($P<0.05$). The desorption curve for weight-class 3 was somewhat anomalous (Fig. 2), largely because one rock absorbed much less water than the others. The water retention values at -1.5 MPa were erratic, perhaps because the increased pressure disrupted the continuity of water films at the rock-soil interface. Also, the repeated saturation, pressurization, and oven-drying may have

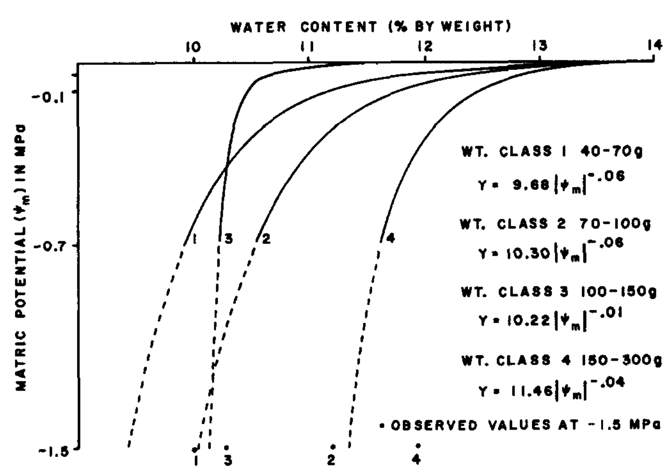

Fig. 2. *Desorption curves for caliche rocks subjected to various levels of maxtrix potential. The curves are based on -0.03, -0.1, and -0.7 MPa values and extrapolated (dashed portion) to -1.5 MPa. Observed values at -1.5 MPa are shown. The curves for the different weight classes differed significantly (P<0.05).*

influenced results.

The largest rocks (weight-class 4), which would be expected to have the smallest surface to pore volume ratios, retained the most water at all matric potentials (Fig. 2). The amount of water retained appeared to be correlated with rock weight, except for weight-class 3 (Fig. 2). Probably the internal pore structure of individual rocks, as well as their surface to pore volume ratios, is an important factor in water retention.

For all size classes combined, the mean (% by weight) of water retained at -0.03 MPa matric potential was 12%, a 6% loss from saturation. At -0.1 MPa matric potential, 11.4% water by weight was retained, a 12% loss from saturation. At -0.7 MPa matric potential, 10.6% water by weight remained, an 18% loss from saturation. Both calculated and observed values indicate that little additional water was lost between -0.7 and -1.5 MPa.

Desorption in Dry Atmosphere

When the 20 caliche rocks were placed in desiccators, weight loss continued for 34 days. The desorption curves for the rock-weight classes did not differ significantly ($P>0.05$), so the overall mean (all weight classes combined) was used to portray water loss (Fig. 3). The mass of the rocks apparently has little influence on the rate of water loss to a dry atmosphere, at least over the time intervals used. The rate of water loss was relatively slow, but most of the water contained in the rocks was released. Only 0.6% by weight (1.1% by volume) remained after 34 days.

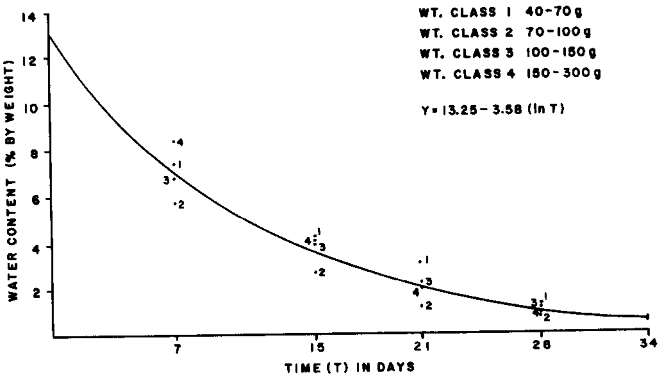

Fig. 3. *Water loss, over time, for 20 caliche rocks (all weight classes combined) after the saturated rocks were placed in a dry environment. Observed values at 7, 15, 21, and 28 days are shown for each weight class. At 34 days the water content ranged from 0.6 to 0.7% among the weight classes. The desorption curves for the various weight classes did not differ significantly (P>0.05).*

Water Flow Through Caliche

In the laboratory tests for determining whether water would flow through caliche, none passed through, although water was absorbed by the rocks. Flooding of the 1-m² field plots confirmed that finding. In the field tests, considerable water was absorbed by the caliche on the plot where caliche was exposed before flooding, but no water passed through to underlying soil layers. Measurements of water content in the caliche layer indicated that it increased during the first 2.15 hr (Table 1). Thereafter, water content remained fairly constant until 72.52 hr. At the end of 6 days, water content in the caliche layer had decreased, perhaps due to lateral flow within the caliche layer. The probe sampling zone at a depth of 30.5 cm was at the lower extreme of the caliche layer, and the reduced amount of caliche at that depth probably accounted for the smaller increase in water content at that depth that at the 15-cm depth (Table 1). At a depth of 45 cm, water content did not change.

On the plot where soil was left in place over the caliche layer, results similar to those shown in Table 1 were found after flooding. On that plot the caliche layer extended from about 45 cm to 61 cm below the soil surface. After the plot was flooded, water content of the soil at depths of 15 and 30.5 cm increased for 3 hr, and then declined. Water content at depths of 45 and 61 cm, where caliche was present, increased steadily for 6 days, indicating that water was accumulating in the caliche layer. Below the caliche layer, at a depth of 76 cm, water content did not change during the 6 days of measurement.

Table 1. Volumetric water content (as a decimal fraction) at 3 depths over time after flooding of a 1 m² plot where the caliche layer was at the surface and extended to a depth of 30.5 cm.

Time (hours)	Volumetric water content at depths of: 15 cm	30.5 cm	45 cm
	Before flooding		
	0.19	0.18	0.18
	After flooding		
.32	0.27	0.18	
.48	0.28	0.18	
.90	0.32	0.18	
1.15	0.32	0.19	0.18
1.40	0.34	0.19	
1.65	0.35	0.20	
2.15	0.36	0.20	
2.40	0.36	0.20	
2.65	0.36	0.20	0.18
2.90	0.36	0.21	
3.40	0.36	0.20	
3.83	0.35	0.20	
4.40	0.36	0.20	
4.90	0.36	0.21	0.18
29.03	0.34	0.22	
72.52	0.36	0.22	
[1]144.23	0.33	0.22	0.18

[1]6 days

Conclusions

Results of both the laboratory and field experiments indicated that caliche can absorb appreciable quantities of water at a rapid rate. It also retains water for extended periods. Hence, in field soils where a caliche layer is present near the surface, a potential exists for a fairly high percentage of rainfall to be absorbed in the caliche layer and rendered unavailable to plants. Although a solid caliche layer prevents water passage to soil below the caliche, some water does reach that soil, probably passing through discontinuities in the caliche layer. That water is generally unavailable to plants unless the discontinuities in the layer are large enough for roots to pass through.

This study has raised a question that needs further investigation. Will the caliche, through vapor transfer and condensation, release absorbed water in sufficient quantities to be beneficial to plants? In view of the large amounts of water (25% by volume) that caliche can absorb, the ultimate fate of the absorbed water is of prime importance in arid regions. Studies of grass cover on the Jornada Experimental Range have indicated that survival of grasses during droughts is better on soils underlain by caliche at shallow depths than on deeper soils (Herbel et al. 1972). That finding indicates that, when caliche is within the rooting zone of plants, it does influence soil water relationships in some manner. The morphological development of caliche layers indicates that thin zones of free water are present, at times, on top of caliche layers (Gile et al. 1966). The longevity of such films and their influence on plant survival in drought periods is not known.

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The Initial Growth of Two Range Grasses on Nonfertilized and Fertilized Soils Collected from Creosotebush Communities in the Southwestern United States

JERRY R. COX, HENRY A. SCHREIBER, AND HOWARD L. MORTON

Abstract

A glasshouse study was conducted to determine how nonfertilized and fertilized soils collected in creosotebush [*Larrea tridentata* (DC.) Cov.] communities would influence seedling leaf growth and shoot production of Lehmann lovegrass (*Eragrostis lehmanniana* Nees) and blue panicgrass (*Panicum antidotale* Ritz.). Soils were collected at 3 locations around creosotebush plants: (1) at the crown base (Basal), (2) along the outer canopy edge (Drip), and (3) in areas between plants (Open). Leaf lengths and shoot production were greatest on nonfertilized soils collected at the plant base, intermediate at the canopy edge, and least in open areas. Leaf lengths and shoot production significantly increased on fertilized soils collected in open areas.

The area from South Central California eastward to the Trans-Pecos in Texas and southward from Central Arizona and New Mexico to Central Mexico is a vast region of basins, valleys, and parallel but discontinuous mountain chains (Mabry et al. 1977). Historically, creosotebush [*Larrea tridentata* (DC.) Cov.] occupied rocky upland sites at lower elevations (Gardner 1951, Buffington and Herbel 1965, Mehrhoff 1955), but has recently invaded grassland and mesquite [*Prosopis juliflora* (Schwartz.) DC.] sites (Humphrey 1958, Chew and Chew 1965, York and Dick-Peddie 1969).

It is desirable to replace creosotebush with perennial grasses to reduce erosion, increase infiltration and provide a reliable forage crop for livestock. However, a successful stand of seeded perennial grasses can be expected in only 1 of 10 planting years (Cox et al. 1982). Stand failures have been attributed to precipitation distribution, reduced surface litter, infiltration, competition and possibly allelopathy (Bridges 1941, Glendening 1942, Anderson et al. 1957, Knipe and Herbel 1966, Jordan 1970).

Tiedemann and Klemmedson (1973) and Ryan et al. (1975) have demonstrated the importance of macro and micronutrients on range grass production at mesquite and creosotebush sites in Southeastern Arizona. Tiedemann (1970) showed that perennial grass production under mesquite canopies exceeded that of open areas between plants by 5 times. Soil moisture, soil temperature, and shading between areas under mesquite and open areas were not sufficient to account for the differences (Tiedemann et al. 1971).

On the basis of knowledge gathered on creosotebush and inference from other shrubs, we expect lateral root absorption of soil moisture to be accompanied by absorption of soil nutrients. Nutrients are translocated, incorporated in plant biomass and eventually returned to the soil directly beneath the creosotebush canopy. This process, in time, would result in a depleted nutrient area between plants and an accumulation area under plants. When soil moisture and temperature are ideal, perennial grass seedling growth should be greater under creosotebush canopies and less in open areas between plants.

This study was conducted to determine (1) perennial grass seedling growth on soils collected under creosotebush and in open areas between plants at 5 sites in the Southwestern United States and (2) if a fertilizer complement containing both macro and micronutrients would increase plant growth when added to depleted soils collected at the canopy drip zone or in open areas between plants.

Study Sites and Methods

The study sites are located (1) 24 km north of Carlsbad, N. Mex., along Rocky Arroyo; (2) 26 km south of Las Cruces, N. Mex., and

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east of I-10 near Mesquite, N. Mex.; (3) 20 km east of San Simon, Ariz. and south of I-10 on Cavet Road; (4) 40 km south of Tucson, Ariz., in Pasture 15 on the Santa Rita Experimental Range (SRER); and (5) 16 km east of Barstow, Calif., and south of I-10 near Daggett, Calif.

The Carlsbad site is near the Pecos River on a narrow alluvial fan with 1 to 3% slopes on a west-east axis; soils are Ector stony loam-loamy, skeletal carbonatic, thermic Lithic Calciustolls (Chugg et a. 1971). Mesquite is above the Rio Grande flood plain and below a series of arroyo-dissected rocky hillsides with 1 to 5% slopes on a east-west axis; soils are Yturbide loamy sand, mixed thermic Typic Torripsamments (personal communications USDA-SCS). San Simon is on a large alluvial plain above active arroyos with 4 to 6% slopes on a north-south axis; soils are Tres Hermonos gravelly loam, fine loamy, mixed, thermic Typic Haplargids (Vogt 1980). Santa Rita Experimental Range is on a terrace above the Santa Cruz River with 2 to 6% slopes on a east-west axis; soils are an Anthony variant, loamy sand, mixed, calcareous, thermic Typic Torrifluvents (Richardson et al. 1979). Daggett is on a broad alluvial fan with 1 to 2% slopes on a south-north axis; soils are Cajon gravelly sand, mixed, thermic Typic Torripsamments (personal communications USDA-SCS).

We arbitrarily selected 10 creosotebush plants of approximately the same height and canopy area at each study site. A sample of soil from the 0 to 15-cm depth was taken at 3 locations around each creosotebush: (1) at the crown base (Basal), (2) along the outer canopy edge (Drip), and (3) in areas between plants (Open). Equal soil volumes were collected at each location in the cardinal directions around each plant. Soils from each location (Basal, Drip, and Open), along each cardinal direction, from the 10 plants at each site were composited and stored in plastic bags.

Because of the distance between study sites and limitations of greenhouse space, soils were collected at Mesquite, San Simon, and SRER in fall 1981; and collected at SRER, Carlsbad, and Daggett in spring 1980. Differences in plant growth based on season were anticipated. Therefore, soils from the SRER were collected twice and included in the fall and spring experiments.

Soil Analysis

One-kilogram soil samples from each composite soil collection (3 total) within each community (5 total) were oven-dried at 40°C for 120 h, and passed through a 2-mm sieve. Triplicate samples from each composite were analyzed for nitrates (Jackson 1958).

Greenhouse Procedure

The 3 composite soil collections from each community plus the spring repeat from the SRER constituted 18 composite soil samples. Each sample was individually mixed to simulate mechanical soil disturbance, screened to 2 mm, and divided into 16 lots each weighing 1.6 kg. Lots were placed into 15-cm tapered plastic pots. Pots 1 to 8 were seeded with 50 seeds of Lehmann lovegrass (A-68) and pots 9 to 16 were seeded with 50 seeds of blue panicgrass (A-130). The small-seeded Lehmann lovegrass was planted at 0.1 cm and the large-seeded blue panicgrass planted at 0.5 cm.

Odd-numbered pots received no fertilizers. Even-numbered pots received a single 10 ml aqueous solution containing 300 mg $Ca(H_2PO_4)_2 \cdot H_2O$ and 1 mg $(NH_4)_6Mo_7O_{24} \cdot H_2O$ was added after seeding to even-numbered pots. A 10-ml aqueous solution containing: (1) 520 mg NH_4NO_{33}, (2) 80 mg $MgSO_4 \cdot 7H_2O$, (3) 80 mg K_2SO_4, (4) 17.50 mg FeEDDHA, (5) 2.00 mg $NaB_4O_7 \cdot 10H_2O$, (6) 1.75 mg MnEDTA, (7) 0.50 mg ZnEDTA, and (8) 0.25 mg CuEDTA was added weekly to even-numbered pots for 5 weeks. All pots were watered daily with 100 mg of distilled water. Excess water was collected in dishes under each pot and readded to the pot.

Relative humidity in the greenhouse varied from 45 to 55% and photoperiod was constant at 15 h. Temperature ranged from 29 to 32°C in the fall and 30 to 35°C in the spring.

Seedlings were thinned to 20 per pot at 1 week, 10 at 2 weeks, and 5 at 3 weeks to reduce competition. Thinned seedlings were readded to the soil surface to reduce nutrient losses.

Leaf heights were measured to the nearest 0.5 cm from the soil surface to the extended leaf tip for the 5 plants at 6 weeks after emergence. Shoots were clipped at the soil surface, dried at 40°C for 48 h, and weighed to the nearest 0.1 g.

A stratified randomized block design was used to determine pot arrangement in the greenhouse. Analysis of variance was used for the statistical evaluation of data. Tukey's (hsd)-w-procedure was used for comparison of treatment means (Steel and Torrie 1960). There were 2 experiments and each was analyzed separately.

Results and Discussion

Mean creosotebush heights ranged between 1.0 and 1.5 m and canopy areas between 2.0 and 3.0 m^2 at Mesquite, SRER, and Daggett. Mean heights were less than 0.5 m and canopy areas less 0.5 m^2 at Carlsbad and San Simon. Hummocks, or areas under creosotebush where litter accumulates, extended 0.1 m from the plant base at Carlsbad, 0.4 m at San Simon, and between 1.0 and 1.5 m at the remaining sites.

Nitrate accumulations (Table 1) were greatest in Basal, Drip, and Open soils collected at Carlsbad and Daggett, and significantly less in soils collected at the remaining sites. Once creosotebush dominates a site, open areas between plants actively erode (Hallmark and Allen 1975), windblown soil and organic matter accumulate (Muller 1953), and nitrate levels under the plant exceed levels found in open areas between plants (Garcia-Moya and McKell 1970, Romney et al. 1980). Nitrates decreased with distance from the plant base at all sites. However, similarities in Basal and Drip or Drip and Open collections are site specific and likely influenced by plant density, height, and climate.

Table 1. Nitrates (ppm) in surface soils collected at 3 locations around creosotebush plants at 5 sites.

	Nitrates[1]		
Soil source	Basal	Drip	Open
Mesquite	18.42^b	2.33^d	0.42^d
San Simon	4.33^c	2.60^d	0.08^e
SRER	6.25^{bc}	2.67^d	1.25^d
Carlsbad	45.42^d	16.80^d	20.17^b
Daggett	52.17^a	51.28^a	25.83^b
$\bar{X}$	25.32	15.14	9.55

[1]Means followed by the same superscript are not significantly different ($P \leq 0.05$) according to Tukey's (hsd) test.

Lehmann lovegrass seedlings began to emerge 6 days after planting and blue panicgrass seedlings at 3 days. Emergence was complete after 14 days for both species.

Lehmann Lovegrass

Lehmann lovegrass leaf lengths varied between 0.5 and 1.0 cm at week 1, 3.5 to 15.5 cm at week 3, and 40 to 65.5 cm at week 6. Small, stunted plants grew on nonfertilized Open soil collections and occasionally on Drip collections. Greenhouse temperature differences during the fall and spring had an effect on Lehmann lovegrass leaf growth (Table 2). Leaves of plants grown in soils collected at SRER were one-third to one-half greater than on soils collected in fall. Although absolute numbers widely separated, trends in leaf growth were similar on SRER soils for both experiments.

Lehmann lovegrass leaf lengths on nonfertilized soil were influenced by soil source and location (Table 2). Nitrate accumulations (Table 1) were greatest in Carlsbad and Daggett soils, and leaf lengths were greatest. Nitrate accumulations were least on Open soils collected at Mesquite, San Simon, and SRER, and leaf lengths were correspondingly low.

The addition of fertilizer significantly increased leaf lengths on Drip and Open soils, with the exception of soils collected at Carlsbad and Daggett (Table 2). Mean leaf lengths were 27, 40, and 66%

Table 2. Leaf lengths (cm) of Lehmann lovegrass seedlings grown for 6 weeks on nonfertilized and fertilized soils collected in fall and spring. Soils were collected at 3 locations in 5 creosotebush communities.

		Nonfertilized			Fertilized		
Collection season[1]	Soil source	Basal	Drip	Open	Basal	Drip	Open
Fall	Mesquite	26.7^{b}	20.7^{c}	11.2^{de}	38.7^{e}	30.7^{ab}	27.2^{b}
	San Simon	20.5^{bc}	12.0^{c}	5.2^{e}	27.7^{b}	27.5^{b}	18.3^{c}
	SRER	23.2^{bc}	15.0^{d}	7.2^{e}	32.5^{e}	27.2^{b}	25.2^{b}
	$\overline{X}$	24.3	17.3	6.8	30.0	24.7	
Spring	SRER	34.0^{cd}	27.6^{d}	15.4^{e}	43.4^{b}	36.1^{c}	38.4^{c}
	Carlsbad	46.7^{b}	35.6^{c}	33.5^{cd}	47.2^{b}	45.2^{b}	45.5^{b}
	Daggett	60.7^{a}	52.9^{a}	24.1^{d}	61.7^{a}	56.6^{a}	46.5^{a}
	$\overline{X}$	47.1	38.7	24.3	50.8	46.0	43.5

[1]Means for individual collection seasons followed by the same superscript are not significantly different ($P \leq 0.05$) according to Tukey's (hsd) test.

Table 3. Shoot production (g) of Lehmann lovegrass seedlings grown for 6 weeks on nonfertilized and fertilized soils collected in fall and spring. Soils were collected at 3 locations in 5 creosotebush communities.

		Nonfertilized			Fertilized		
Collection season[1]	Soil source	Basal	Drip	Open	Basal	Drip	Open
Fall	Mesquite	2.4^{a}	1.7^{b}	1.7^{b}	3.3^{a}	2.8^{a}	2.3^{a}
	San Simon	2.0^{a}	1.1^{b}	1.3^{b}	2.3^{a}	2.1^{ab}	1.4^{b}
	SRER	3.0^{a}	2.4^{a}	1.8^{b}	3.0^{a}	3.0^{a}	2.9^{a}
	$\overline{X}$	2.5	1.7	1.6	2.9	2.6	2.2
Spring	SRER	1.5^{c}	1.1^{c}	0.3^{d}	3.3^{ab}	2.8^{b}	2.1^{b}
	Carlsbad	3.7^{a}	2.1^{bc}	1.4^{c}	4.2^{a}	4.0^{a}	2.8^{b}
	Daggett	4.6^{a}	3.6^{a}	1.4^{c}	4.7a	4.3^{a}	3.1^{ab}
	$\overline{X}$	3.3	2.3	1.0	4.1	3.7	2.7

[1]Means for individual collection seasons followed by the same superscripts are not significantly different ($P \leq 0.05$) according to Tukey's (hsd) test.

Table 4. Leaf lengths (cm) of blue panicgrass seedlings grown for 6 weeks on nonfertilized and fertilized soils collected in fall and spring. Soils were collected at 3 locations in 5 creosotebush communities.

		Nonfertilized			Fertilized		
Collection season[1]	Soil source	Basal	Drip	Open	Basal	Drip	Open
Fall	Mesquite	18.5^{bc}	16.0^{c}	11.0^{cd}	23.7^{b}c	20.5^{b}	21.5^{b}
	San Simon	23.3^{b}	10.7^{d}	7.0^{d}	32.5^{a}	17.2^{c}	16.0^{c}
	SRER	15.5^{c}d	8.2^{d}	6.0^{d}	21.5^{b}	17.5^{c}	17.2^{c}
	$\overline{X}$	19.2	12.5	7.3	25.3	18.8	17.9
Spring	SRER	16.9^{d}	12.9^{d}	8.2^{e}	23.4^{c}	20.0^{cd}	17.1^{d}
	Carlsbad	20.9^{cd}	18.2^{cd}	14.0^{d}	28.6^{bc}	25.0^{c}	23.0^{c}
	Daggett	45.9^{a}	32.4^{b}	11.1^{d}	48.1^{a}	38.4^{ab}	20.5^{c}
	$\overline{X}$	27.9	23.2	11.1	33.4	25.8	20.2

[1]Means for individual collection seasons followed by the same superscripts are not significantly different ($P \leq 0.05$) according to Tukey's (hsd) test.

Table 5. Shoot production (g) of blue panicgrass seedlings grown for 6 weeks on nonfertilized and fertilized soils collected in fall and spring. Soils were collected at 3 locations in 5 creosotebush communities.

		Nonfertilized			Fertilized		
Collection season[1]	Soil source	Basal	Drip	Open	Basal	Drip	Open
Fall	Mesquite	1.3^{bc}	1.1^{c}	1.1^{c}	2.6^{a}	2.3^{a}	2.3^{a}
	San Simon	0.8^{d}	0.4^{d}	0.6^{d}	1.9^{ab}	1.6^{b}	1.3^{bc}
	SRER	1.4^{c}	1.0^{c}	0.8^{d}	3.3^{a}	2.6^{a}	2.8^{a}
	$\overline{X}$	1.2	0.8	0.8	2.6	2.2	2.1
Spring	SRER	1.6^{de}	1.4^{e}	1.2^{e}	3.3^{cd}	3.2^{cd}	2.3^{d}
	Carlsbad	2.7^{d}	1.8^{d}	1.3^{e}	4.1^{bd}	3.7^{c}	3.4^{c}
	Daggett	6.9^{a}	4.2^{bc}	1.5^{de}	7.3^{a}	5.8^{ab}	2.8^{d}
	$\overline{X}$	3.7	2.5	1.3	4.9	4.2	2.8

[1]Means for individual collection seasons followed by the same superscripts are not significantly different ($P \leq 0.05$) according to Tukey's (hsd) test.

greater, respectively, on fertilized Basal, Drip, and Open soils collected at Mesquite, San Simon, and SRER (fall and spring) than on nonfertilized soils.

Accumulated nitrates (Table 1) and increases in leaf lengths (Table 2) are reflected in shoot production increases on nonfertilized soils (Table 3). Fertilization of Basal soils generally increased shoot production, but a significant incease occurred only on the SRER spring collection. Fertilization had a significant effect on shoot production on Open soils; with the exception of San Simon.

Collection season means suggest that nutrient additions will overcome reductions in shoot production; however, deviations do occur among sites.

Blue Panicgrass

Blue panicgrass leaf lengths varied between 3.0 to 5.0 cm at week 1, 5.5 to 54.5 cm at week 3, and were unchanged between weeks 3 and 6. Stunted and chlorotic plants grew on nonfertilized Open and Drip soil collections. Greenhouse temperature differences during fall and spring on SRER soils had a minor effect on blue panicgrass leaf lengths (Table 4).

Leaf lengths on nonfertilized soils were greatest on Basal, intermediate on Drip, and least on Open, but differences were not always significant (Table 4). Fertilization significantly increased leaf lengths on all Open soil collections. Mean leaf lengths were 27, 37, and 55% greater, respectively, on fertilized Basal, Drip, and Open soils collected at Mesquite, San Simon, and SRER (fall and spring) than on nonfertilized soils. Fertilization had a marginal effect on plants grown in Basal and in Drip soils collected at Carlsbad and Daggett.

Blue panicgrass shoot production (Table 5) is generally related to leaf lengths (Table 4) and accumulated nitrates (Table 1) on nonfertilized soils; with the exception of Basal soils collected at San Simon. Nonfertilized plants grown on Basal soils from San Simon were not stunted, but chlorotic and prostrate between weeks 4 and 6. Shoot production under these conditions was not related to leaf lengths. Plants grown on fertilized soils at San Simon and the remaining sites were neither chlorotic nor prostrate, but were stunted on Open soils collected at San Simon.

Shoot production was similar on fertilized Basal, Drip, and Open soil collections made in fall (Table 5). A similar trend was apparent on soil collections made in spring but increases were not significant at Daggett.

Conclusions

Creosotebush and other shrubs in arid regions accumulate nutrients under the canopy at the expense of open areas between plants (Tiedemann and Klemmedson 1973, Romney et al. 1980). If germination occurs, perennial grasses seeded under the plant canopy have a greater probability of becoming established than those seeded in open areas between shrubs.

The stunted appearance of Lehmann lovegrass and chlorotic appearance of blue panicgrass on soils collected from open areas between creosotebush plants and adequate soil moisture implies that even if seeds did germinate, the seedling would probably not survive. The lack of chloroses and increased shoot production with fertilization on Drip and Open soils indicates that seedling establishment should increase because of a more favorable nutrient regime (Tiedemann and Klemmedson 1973).

The difficulty associated with perennial grass establishment in existing creosotebush stands has been attributed to a growth inhibitor produced by creosotebush. Our results suggest that nutrient limitations have a greater impact on seedling growth and eventual establishment than a possible inhibitor.

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Correcting for Differential Digestibility in Microhistological Analyses Involving Common Coastal Forages of the Pacific Northwest

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Abstract

The accuracy of microhistological techniques to describe herbivore diets can be affected by differential digestibility of ingested forages. Correction factors were developed to adjust for those effects in 17 common forages of coastal, forested ranges of the Pacific Northwest. Two ferns, a moss and a sedge were overestimated by microhistological analysis in all seasons, while most shrubs, forbs and a grass were underestimated. Trees were not consistently over- or underestimated. Phenology significantly affected the degree of over- or underestimation of most forages. Failure to correct for differential digestibility will significantly bias results of microhistological techniques such as fecal analyses.

Microtechniques for determining food habits of large herbivores can be biased by differential digestibility of ingested plant species (Holechek et al. 1982). For example, the accuracy of fecal analysis can be affected by the extent of digestion of plant epidermis as it passes through the alimentary tract of a ruminant (Steward 1970, Slater and Jones 1971, McInnis et al. 1983) and by sample preparation techniques (Vavra and Holechek 1980). Yet, fecal analysis is used widely for describing diets of wild and domestic herbivores (e.g., Free et al. 1970, Stewart and Stewart 1980, Hansen and Martin 1973, Hansen et al. 1973, Todd and Hansen 1973, Anthony and Smith 1974). Frequently, it is the only practical method available (Vavra et al. 1978), particularly when dense vegetation and wariness of study animals preclude direct feeding observations and when protection from hunting of some wild and/or rare herbivores eliminates the possibility of collecting ruminal samples. Also, fecal material usually is readily available, which enables the collection of an adequate number of samples at any time of the year.

Results from fecal analyses can be improved by species-specific correction factors that compensate for differential digestibility of ingested forages (Voth and Black 1973, Dearden et al. 1975, Fitzgerald and Waddington 1979, Pulliam and Nelson 1979, Vavra and Holechek 1980). Forbs are usually highly digestible and as a result, underestimated by fecal analyses (Vavra et al. 1978, Vavra and Holechek 1980, McInnis et al. 1983). Some grass and browse species are overestimated by fecal analyses, while others are underestimated (Dearden et al. 1975, Vavra and Holechek 1980). Phenology affects digestibility of most forages (Laycock and Price 1980) and thus, season-specific correction factors may be necessary for individual plant species in the diet (Pulliam and Nelson 1979). Unfortunately, these relationships have been described for relatively few forages.

This report provides correction factors for common forages of coastal, forested ranges of the Pacific Northwest that are important to both wild and domestic ungulates.

Methods

Plant samples were collected as part of a study on the nutritional ecology of Roosevelt elk *(Cervus elaphus roosevelti)* and Columbian black-tailed deer *(Odocoileus hemionus columbianus)* in the Hoh Valley (47°50′ N, 124°′ W) of Olympic National Park, Washington (Leslie 1983). Plant communities of the Hoh Valley were described by Fonda (1974) and are comprised of many forage species typical of coastal, forested ranges of the Pacific Northwest (Franklin and Dryness 1973). For each plant species, a composite sample of approximately 25 grams (dry weight) was collected at random throughout their respective distributions in the study area. Samples of plant parts that were thought to be consumed by cervids were collected in summer (15 July–15 August), fall (15 October–15 November), winter (15 January–February), and spring (15 April–15 May), 1980-1981.

Correction factors were determined by modifying the approach of Dearden et al. (1975) to include a standard forage of known properties in microhistological analyses. Each plant species was part of 5 hand-mixed diets and occurred in various known relative densities (i.e., percentages by weight) in those mixtures. A known percentage of Idaho fescue *(Festuca idahoensis)* was included in each mix as a standard; based on our laboratory observations, it is neither over- or underestimated by microtechniques after digestion. Each mix was digested in vitro (Tilley and Terry 1963) for 48 hours using inoculum from a steer maintained on an orchard grass/alfalfa diet (~10% crude protein, 55% digestible), and analyzed microscopically (Vavra and Holechek 1980). The observed density of each plant species (X_i) was calculated from frequency tabulations of identifiable epidermis (Sparks and Malechek 1968). The actual density (Y_i) was calculated from relative weights and the observed density of the standard (Table 1), assuming the latter equalled its relative weight in the hand-mixed diet. The observed and actual densities were then correlated using a least squares regression forced through the origin (Neter and Wasserman 1974:156). The estimate of β was

$$b = \frac{\Sigma X_i Y_i}{\Sigma X_i^2},$$

where b represented the degree of overestimation ($b<1.0$) or underestimation ($b>1.0$) of a plant species by microhistological analyses. This approach was analogous to Dearden et al. (1975) and provided the same correction factor for a given set of data. However, the actual density in this study was calculated from the relative weights of each species in the hand-mixed diets and then correlated with the observed density (Table 1). Dearden et al.

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Table 1. Procedure for obtaining actual density (Y_i) and observed density (X_i) in determining correction factors for common forages of the Pacific Northwest.

Plant species	Relative weight in hand-mixed diets	Observed density from slides[1] (X_i)	Actual density[2] (Y_i)
Species A	% W_a	$D_{a\text{-obs}}$	$(\%W_a / \%W_{std}) \times D_{std\text{-obx}}$
Species B	% W_b	$D_{b\text{-obs}}$	$(\%W_b / \%W_{std}) \times D_{std\text{-obs}}$
Species C	% W_c	$D_{c\text{-obs}}$	$(\%W_c / \%W_{std}) \times D_{std\text{-obs}}$
Standard[3]	% W_{std}	$D_{std\text{-obs}}$	$D_{std\text{-obs}}$

[1]Calculated from frequency after Sparks and Malechek (1968).
[2]Note that if actual density is made relative to 100 percent, it will equal relative weight in hand-mixed diets.
[3]The standard is neither over- or underestimated (i.e., b = 1.0) in microtechnique after digestion; therefore, observed density from slides equals actual density.

(1975) calculated an observed *relative* density and correlated it with the relative weight in the hand-mixed diets.

Results and Discussion

A total of 29 correction factors was determined for 17 forages (Table 2). Two ferns, a moss and a sedge were overestimated by the microtechnique in all seasons, while most shrubs, forbs, and a grass were consistently underestimated. Trees were less consistent, but only 4 determinations were made. The degree of correction for salmonberry (*Rubus spectabilis)* and bluegrass (*Poa* spp.) was highest in spring and decreased through summer and fall. Other species, such as swordfern *(Polystichum munitum)* and wood-sorrel *(Oxalis oregana),* displayed the opposite trend. Strong inter-seasonal variability of correction factors of some shrubs, forbs, and grasses, suggested that they should be determined for each phenological period in which a diet is being estimated.

The range of correction factors was noticeably greater in our study than those previously reported. Those reported by Dearden et al. (1975) ranged from 0.75 for cotton grass *(Eriophorum vaginatum)* to 1.30 for willow *(Salix pulchra)* and lichen *(Stereocaulon alpinum).* In our study, the lowest factor was 0.20 for fern moss *(Hylocomium splendens)* (Table 2). Similarly, Dearden et al. (1975) noted that mosses were highly overestimated because epidermal tissue fragmented easily in the digestive progress; mosses also are very low in dry matter digestibility (Dearden et al. 1975, Leslie 1983). The highest factor in this study was 6.12 for youth-on-age *(Tolmeia menziesii)* (Table 2). The disparity in ranges in the 2 studies was probably a result of when plant samples were collected relative to phenology. Sampling dates were not reported by Dearden et al. (1975), but if all forages were collected at the same time, correction factors could be less variable than if collections were made during different seasons. Our results and those of Pulliam and Nelson (1979) indicated that phenology of ingested plants significantly affects their degree of over- or underestimation.

The overall effect of these factors on results of fecal analyses, for example, would depend on the relative proportions of each forage species in a given diet. However, one generally would expect uncorrected fecal analyses to overestimate mosses and ferns and underestimate shrubs and forbs. Application of these factors should improve the accuracy of fecal analysis in determining food habits of wild and domestic ruminants in coastal, forested ranges of the Pacific Northwest. Ideally, correction factors should be determined for specific study areas and seasons. Additional research is required to examine the variability of correction factors

Table 2. Seasonal correction factors (≥95% confidence intervals) for common forages in the Pacific Northwest to improve estimates of relative density in fecal analyses.

	Correction factors[1]			
	Spring	Summer	Fall	Winter
Trees:				
Red alder *(Alnus rubra)*	—	—	1.359 (0.311)[6]	—
Western hemlock *(Tsuga heterophylla)*	0.854 (0.152)	—	—	0.759 (0.130)
Western redcedar *(Thuja plicata)*	—	—	—	2.780 (0.431)
Shrubs:				
Huckleberry (*Vaccinium* spp.)[3]	—	1.702 (0.392)	—	—
Salmonberry *(Rubus spectabilis)*	4.263 (1.773)[6]	2.687 (0.816)	—	—
Trailing blackberry *(Rubus ursinus)*	—	—	2.131 (0.426)	—
Vine maple *(Acer circinatum)*	—	1.921 (0.256)	—	—
Willow (*Salix* spp.)[4]	—	1.070 (0.206)	—	—
Ferns:				
Deer fern *(Blechnum spicant)*	—	—	0.684 (0.136)	0.664 (0.295)
Sword fern *(Polystichum munitum)*	0.293 (0.038)	0.664 (0.068)	—	0.663 (0.113)
Forbs:				
Coolwort *(Tiarella trifoliata)*	—	—	1.418 (0.572)	—
Wild strawberry *(Fragaria vesca)*	—	—	1.012 (0.370)	—
Wood-sorrel *(Oxalis oregana)*	1.086 (0.120)	—	2.161 (0.397)	—
Youth-on-age *(Tolmeia menziesii)*	—	—	6.120 (2.690)	—
Grass:				
Bluegrass (*Poa* spp.)[5]	3.720 (0.557)[6]	1.232 (0.214)	1.124 (0.182)	2.264 (0.471)[6]
Sedge:				
Dewey's sedge *(Carex deweyana)*	0.782 (0.171)[6]	—	—	0.602 (0.044)[6]
Moss:				
Fern moss *(Hylocomium splendens)*	0.240 (0.030)	0.208 (0.039)	—	0.200 (0.065)

[1]Each correction factor is the estimate of the slope, *b*, in the regression model Y=bX; all regressions significant at $P<0.05$.
[2]Botanical nomenclature follows Hitchcock and Cronquist (1973).
[3]A composite of *V. parvifolium* and *V. ovalifolium.*
[4]A composite of *S. scouleriana* and *S. sitchensis.*
[5]A composite of mainly *P. pratensis* and *P. trivialis.*
[6]Leaves only.

as they depend on inoculum source (i.e., ruminant species and donor diet). Nevertheless, failure to correct for differential digestibility will significantly bias results of microhistological analyses.

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Evaluating Management Alternatives with a Beef Production Systems Model

M.M. KOTHMANN AND GERALD M. SMITH

Abstract

Simulation techniques were utilized to study alternative management practices for cow-calf operations in the Coastal Prairie of Texas. Data obtained over a 6-year period from a cooperating ranch were used to validate a beef production model successfully. Management practices evaluated with the model included fall, winter, spring, and split (fall-spring) calving seasons, July 1 and October 1 weaning dates, and two levels of nutrition. Eight combinations of these practices were simulated. Winter calving increased death losses of calves compared to fall and spring at the base nutritional level. Fall calving increased weaning weights, whereas spring calving increased the present calf crop. Fall calving with improved nutrtion resulted in the highest level of calf production. Resource limitations frequently prevent screening many management combinations by field research techniques. Simulation can be a valuable aid for integrating and extending experimental data and for selecting the most promising combinations of practices for field testing.

Range livestock production in the Coastal Prairie of Texas is characterized by high potential, but also by many difficulties. High rainfall and long growing seasons result in high potential forage production, but environmental and nutritional stresses on livestock are great during winter months. Cow-calf producers must cope with the effects of low levels of digestible energy and protein in the forage during the winter that result in low calf crop percentages, high death losses of young calves and severe weight losses by cows. Management alternatives such as dates of calving and weaning and kinds and amounts of supplements all have significant impact on the productivity of a ranch. However, evaluation of all possible management combinations in a field research program is not possible.

Computer simulation is a tool which makes possible the evaluation of many combinations of management practices. A Beef Cattle Production Systems Model developed at Texas A&M University (Sanders and Cartwright 1979a, b) was used to evaluate several combinations of management practices for cow-calf operation. Forage and cattle production data obtained over a 6-year period from a cooperating ranch in the Coastal Prairie of Texas were used to estimate base parameters as well as to validate the model. The objectives of this study were to simulate accurately, production from a cow-calf operation and to demonstrate the value of simulation as a research tool.

Materials and Methods

Study Area

Livestock and forage data for the simulations were obtained from a cooperating ranch in northern Calhoun County. The average frost-free period is from mid-February to mid-December and the average annual rainfall is about 114 cm (45 in). Native vegetation is typical of Tall Grass prairie, but has been invaded by Macartney rose *(Rosa bracteata).* Little bluestem *(Schizachyrium scoparium)* is the dominant grass species with yellow indiangrass *(Sorghastrum nutans)* and various species of paspalum (*Paspalum* spp.) as subdominants. Durham and Kothmann (1977) gave a more detailed description of the vegetation on the study area.

Elevation is about 6 m above sea level and drainage is poor. Soils are heavy dark clays of the Lake Charles and Victoria series. Following heavy rains, water stands on much of the soil surface for several days. During January and early February there was generally standing water on much of this ranch.

The ranch was operated as a cow-calf operation with calves sold or moved to other locations at weaning. The herd of approximately 2000 grade Santa Gertrudis cows was rotated between rangeland and Coastal bermudagrass but generally spent the entire period from November to April on rangeland. Yearling replacement heifers were grazed on oat pasture from November to April, with the stocking rate set at a level which restricted forage availability to the point that intake was limited. The primary winter supplement was Coastal bermudagrass hay which averaged about 6% crude protein (CP) and 45% digestible organic matter. Mineral blocks containing 12% P and 12% Ca plus trace minerals were provided free choice throughout the year.

Simulation

Simulation was conducted using a dynamic computer model (Sanders 1974, 1979; Sanders and Cartwright 1979a,b) that was modified to keep account of individual animals (Baker 1982). The model predicts growth rates, condition, milk production, fertility, and deaths from the genetic potential of the cattle interacting with the quality and availability of feed resources. Breedtype for size, maturing pattern, and milk production potential plus time and length of calving season, culling and selling policies, supplemental feeding, and forage quality and availability were set in the model.

The model was based on the assumption that genetic potential for three predominant characters of cattle account for a large proportion of the performance or productivity differences on a life-cycle basis: (1) mature size, (2) milk production, and (3) maturing rate. Effects of previous nutrition were accounted for by the deviation of an animal's present weight (W) from its structural size (WM); WM was the weight of an animal in good condition (3% body fat at birth; 25% at maturity). The growth curve for structural size specified the genetic potential for mature size (WMA) and rate of increase in WM. An animal's nutrient intake relative to its requirements could cause its W to deviate from its WM (above or below), and periods of severe nutritional stress could cause some reduction in WM growth (stunting). Present nutritional status of the animal was a function of its nutritional requirements, as determined by age, sex, size, condition, pregnancy, and lactational status and the quality and availability of feed and was reflected by growth of WM and change in W.

Milk production was calculated in a manner analogous to the calculation of growth rate. Genetic potential for milk production was specified for a mature cow in good condition at peak lactation

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receiving abundant feed. The effects of age, stage of lactation, condition, and nutrition determined actual production.

The basic nutritional concepts functioned as follows: (1) feed intake and potential performance were calculated based upon an animal's breedtype, age, WM, W, pregnancy status, and lactational status; (2) if the simulated nutrient intake was not adequate to meet the potential performance, the performance was adjusted downward in a stepwise fashion until intake and mobilized fat were adequate to meet this reduced performance; and (3) energy intake in excess of requirements was deposited as fat. This approach to nutritional effects allowed simulation of compensatory growth and storage of excess intake for later use.

The model was modified to allow for increased maintenance energy requirements due to cold stress. Maintenance requirements (M) were increased using an adjustment factor for cold stress (CSA) as follows:

$$M = M(1.0 + CSA)$$

$$CSA = CS(T) \left(\frac{FATP}{FAT}\right)^{4} \left(\frac{WMA}{WM}\right)^{15} \left(\frac{W}{W + FW}\right)^{10}$$

The base cold stress correction (CS) was set at .03 for December, .10 for January, .5 for February, and .00 for other months. This factor was increased when body fat (FAT) was less than that of an animal in good condition (FATP) and decreased for the opposite case of animals that were excessively fat. CS was also increased for immature animals, based on degree of maturity (ratio of WM to WMA). CS was decreased in pregnant animals by the ratio of weight (W) to W plus fetal weight (FW) to account for heat production associated with pregnancy. The coefficients for these adjustments were, by necessity, somewhat arbitrarily chosen; however, the adjustments were in the right direction and appeared to be of proper magnitude when compared to other methods of adjusting for cold stress (Young 1971).

The modification for cold stress was included because cow weights and calf weights simulated for January and February exceeded actual weights. This Coastal Prairie range generally had standing water on the ground during winter and little or no windbreak. Cows were thin, had low energy intake, had little or no chance to become acclimatized to cold, and had to lie on wet ground. These conditions resulted in considerable cold stress reflected in increased maintenance requirements. Inclusion of this modification resulted in better agreement between simulated and observed values of W.

A key component of the model was simulation of the effects of previous and present nutritional status on cow fertility (Sanders and Cartwright 1979a,b). This was done by setting maximum levels for the probability that (1) a female will begin to cycle (2) a cycling female will continue, and (3) a cycling female will conceive if mated. These maximum probability levels were adjusted downward for the following effects:degree of maturity (heifers only), condition, weight change, lactation, and postpartum interval for initiation of cycling; condition and weight change for the continuation of cycling; and condition, weight change, postpartum interval and adequacy of bulls for conception.

Death rates were predicted based upon time of year, condition, age, and parturition effects (cows and calves). In addition, death rates were increased in calves up to 4 mo of age that had reduced WM growth.

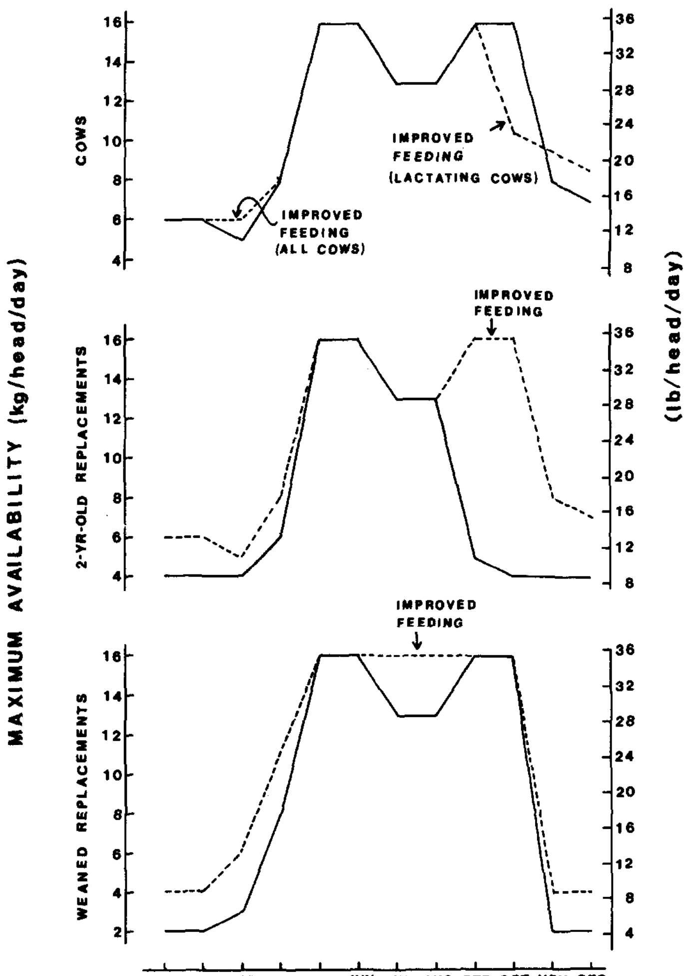

Fig. 1. *Maximum availability of forage by month and class of stock for base (———) and improved (----) nutritional treatments.*

Forage Parameters

Nutritional management was simulated at two levels designated as

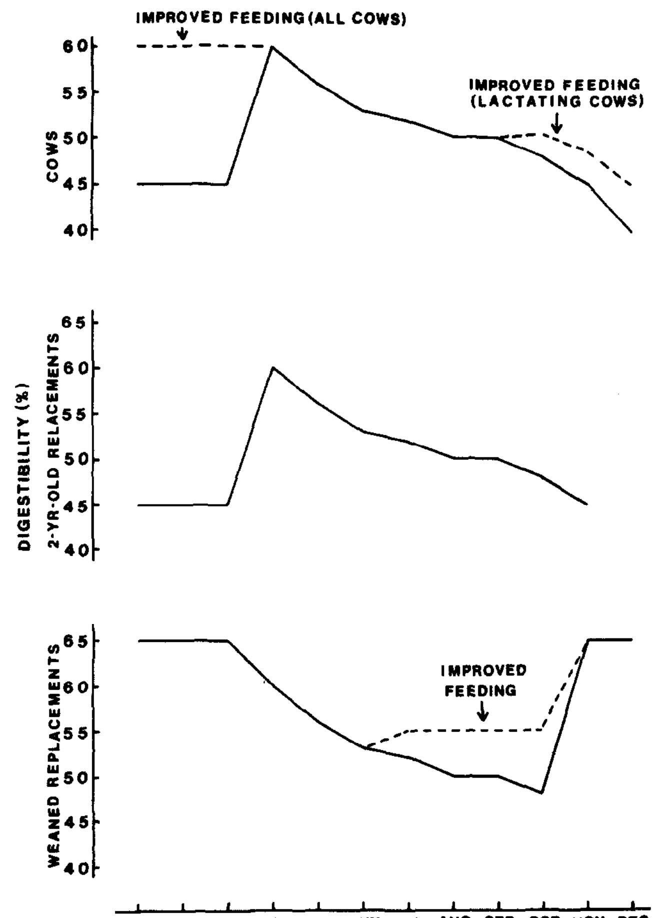

Fig. 2. *Organic matter digestibility of forage by month and class of stock for base (———) and improved (----) nutritional treatments.*

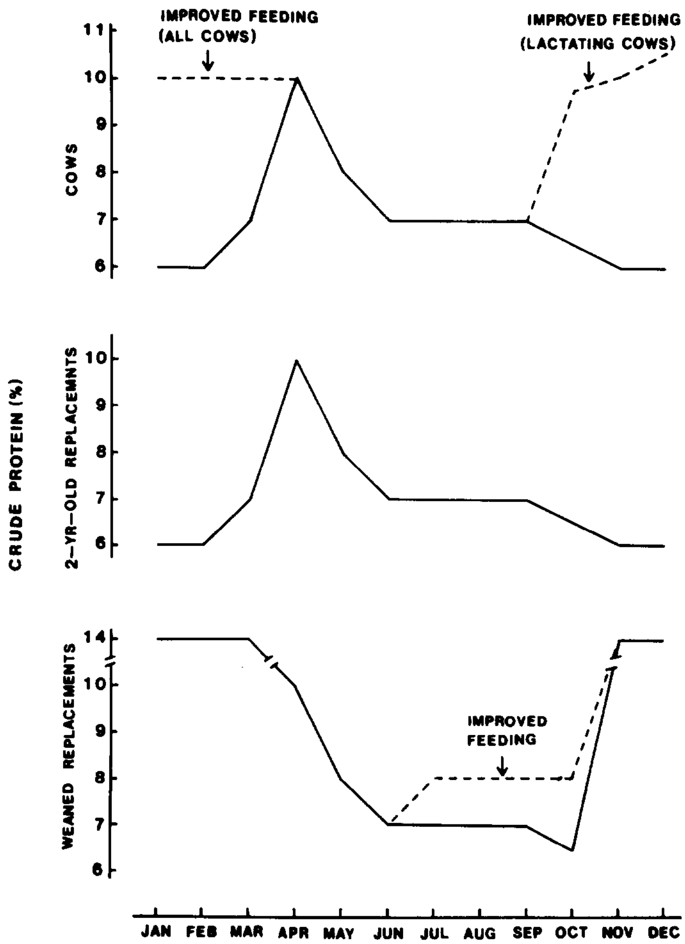

Fig. 3. *Crude protein percentages of forage by month and class of stock for base (———) and improved (----) nutritional treatments.*

base and improved. Stocking rate was held constant for this study; therefore, all treatment comparisons were made on herds of equal size and not on an area basis. Availability, CP content, and digestibility of forage were specified on a monthly time step for weaned replacement heifers, 2-year-old heifers, and cows (Fig. 1, 2, 3). When the simulated intake of forage exceeded the specified availability, intake was set equal to availability.

The values for availability, digestibility, and CP contents of forages (Fig. 1, 2, 3) were derived from published and unpublished research conducted on the ranch from 1974 to 1979 (Durham 1975, Kothmann and Hinnant 1976, Durham and Kothmann 1977, Kothmann unpublished data). Many of the forage values were based on clipped forage analyses with only limited data from samples collected by esophageally fistulated animals (Durham 1975). The judgement and experience of the authors were used to extrapolate from clipped forage analyses to estimated values for consumed forage. In the process of validation, simulated animal production was compared with actual animal production, and areas where there was significant lack of fit were evaluated to determine if changes in forage parameters might be justified.

Base nutritional management for weaned replacements consisted of range forage from weaning through October, then oat pasture from November through March, shifting to range forage in April. Availability of oat pasture was restricted to adjust simulated heifer gains to actual gains. The oat pasture was not fertilized and was heavily stocked so that forage availability was the primary factor limiting gains. The improved nutritional management consisted of increased availability of oat pasture that allowed up to 4 kg D.M./head/day intake, with CP and digestibility unchanged.

For weaned replacements, improved nutritional management also included grazing on tame pasture from weaning through October. Availability of tame pasture and range were high enough not to limit intake during summer and early fall, but digestiblity and CP were higher for tame pasture than for range. This improvement was partially confounded with the times of calving and weaning since fall calves weaned in July were on tame pasture longest. Winter and spring calves weaned October 1 had only 1 month on tame pasture prior to entering the oat pasture.

Weaned replacements were transferred to the 2-year-old category in July and remained in that category for 1 year. On the base nutritional level, Coastal bermuda hay was fed during January and February to the 2-year-old replacements at the rate of 4 kg D.M./head/day with range forage providing the total diet for the remaining months. There was some difficulty in simulating actual gains of 2-year-old heifers until availability was restricted during the periods of September to December and March to April. The model calculated animal gains on the basis of energy intake, and during these periods protein availability probably limited animal growth. Another possible reason that actual gains were lower than simulated gains was reduced intake because of teeth shedding. Improved feeding of 2-year-olds consisted of increasing the level of Coastal bermudagrass hay from 4 to 6 kg D.M./head/day in January and February and increasing the availability of range forage to the same levels allowed for the cows on base nutrition.

Base nutritional level for the cows (3 to 10 years of age) consisted of Coastal bermudagrass hay fed at the rate of 6 kg D.M./head/day in January and February with grazed forage for the remainder of the year. Availability was set at levels which potentially restricted intake during March, April, November, and December. These restrictions were based on the assumption that availability of forage of the designated digestibility and CP content was limited, although additional forage of lower nutrient content was available. Improved nutrition of cows consisted of sorghum hay for the three months of January, February, and March at the rate of 6 kg D.M./head/day (Fig. 1). Digestibility of the sorghum hay was 60% and CP content was 10% (Fig. 2,3). Under improved nutrition, urea-molasses was fed at the rate of 1.5 kg/head/day to all fall-calving cows during October, November, and December and to winter-calving cows during December. The model did not provide for direct specification of separate supplement and forage parameters. For this reason, the urea-molasses supplementation was simulated by externally calculating parameters for a combined diet. Availability was adjusted by first simulating grazed forage intake without supplement, then the 1.5 kg of supplement was added to the simulated dry matter intake of forage and this value was set as the maximum availability.

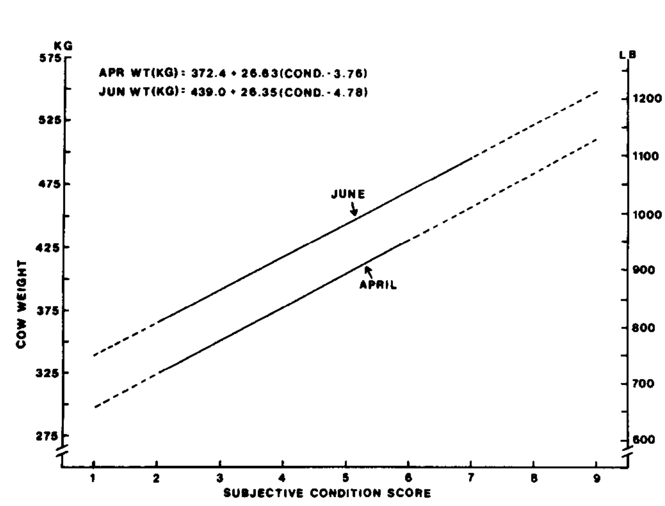

Fig. 4. *Actual cow weights taken in April and June, 1979, regressed on subjective condition scores (——— actual data range, - - - - extrapolated from data).*

Cattle Parameters

Breedtype was specified in terms of genetic potential for mature size, milk production, and maturing rate. The cattle parameters in the present study were chosen to represent a herd of grade Santa Gertrudis, but the results are directly applicable to other adapted breeds of similar size and milking ability.

Mature weight (WMA) was set at 500 kg based on indvidual weights, and condition scores taken on 200 cows in mid-April and again in mid-June, 1979 (Fig. 4). The mean weights and condition scores (scale of 1 to 9) are 372 kg and 3.76 units in April and 439 kg and 4.78 units in June. The relationship between weight and condition for each month was similar. The 67 kg difference between April and June weights at similar condition scores was attributed to increased fill. WMA represented the weight of mature cows in good condition; hence, the weight for a condition score of about 7 was selected.

Milk production potential was set at 11.5 kg/day, which is 15% higher than what has been used in previous simulations for the average of Hereford and Angus cows. This percentage increase was in line with preweaning growth rate differences of about 18% for Santa Gertrudis versus the average of Hereford and Angus calves at the McGregor Research Center (Miquel 1972) when allowance was made for increased growth potential of the Santa Gertrudis calves (U.S. MARC 1977).

In addition to the major specifications associated with breedtype, three other parameters were altered from those normally used for British breedtypes to better reflect the Zebu component. The fraction of mature size at which puberty could first occur was increased from 40 to 50% and the upper limit for this fraction to affect puberty was increased from 60 to 70%. Also, preweaning and postweaning maturing rates were reduced.

Cattle Management Alternatives

Alternatives available to a ranch manager to help synchronize herd feed requirements with feed availability and quality include selection of calving season, weaning age, and heifer development rate. These factors interact with environmental effects, seasonal price fluctuations, and supplemental feeding practices. The cooperating ranch in this study calved from December through March and weaned in late September or early October. Heifers were developed to calve first at 3 years of age and only limited culling of cows was practiced.

Alternatives that were evaluated include winter, spring, fall and split (spring and fall) calving seasons. These were examined for two nutrition programs as outlined in the section on forage parameters. All comparisons were made for herds in equilibrium. That is, the management practices in question were continued until herd composition and productivity stabilized.

Results and Discussion

Validation

Animal performance and forage data from the cooperating ranch were used to verify that the input parameters and model structure closely simulated existing conditions. After the validation run was accepted, it was set as the baseline for comparison of management alternatives.

The correspondence between actual and simulated seasonal weight changes of mature cows is shown in Figure 5. The seasonal patterns of change for simulated and actual cow weights corresponded closely, but the magnitude of annual weight fluctuation was less for simulated data. The greater change for actual weight was attributed to differences in gut fill not accounted for by the model assumption of constant fill and was similar in magnitude to the 67 kg difference observed between April and June for cows in similar condition. The cows were very gaunt in early spring after the low level of winter hay feeding had been discontinued and before adequate spring growth of grass was available. On the other hand, the high availability of low quality forage resulted in near-capacity rumen fill in the fall. In addition, lean tissue loss resulting from protein deficiency was not accounted for in the model and

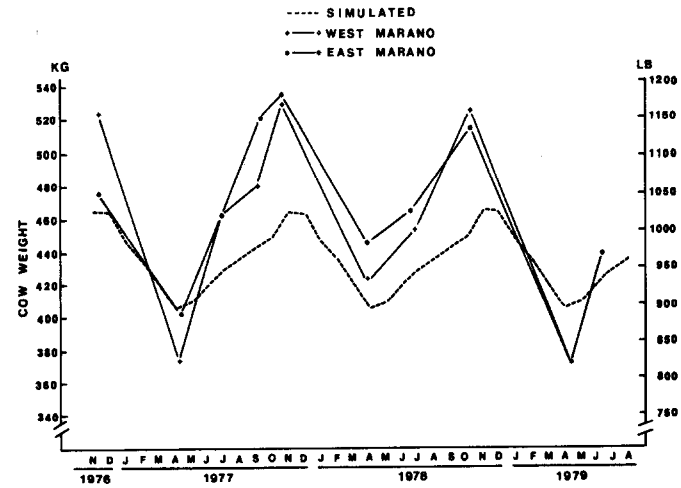

Fig. 5. *Actual and simulated seasonal changes in mature cow weights.*

may further explain why actual weights were less than simulated weights in the spring. The difference in magnitude of fluctuation between actual and simulated cow weights was not considered an important limitation to this study.

Simulated WM and W for replacement females from weaning through maturity along with a number of actual weights are shown in Figure 6. The actual weights were from a number of different pastures and years; hence, the lack of exact correspondence was not surprising. Except for the reduced magnitude of animal fluctuation discussed above, the correspondence between the actual and simulated data was considered good.

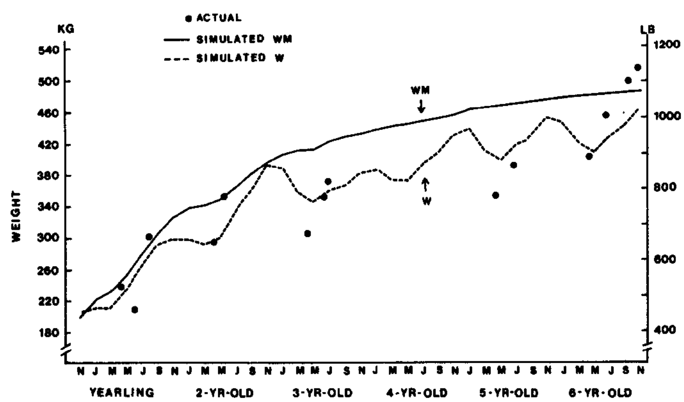

Fig. 6. *Simulated structural size (WM), weight (W) growth curves and actual weights at different ages.*

Comparisons of actual and simulated weights of nursing calves are shown in Figure 7 for birth months combined. Except for some yearly variation, the correspondence of weights near weaning was good. The model over estimated early spring weights, especially for calves born early in the calving season. This over estimation was considerably larger until the model was modified to increase maintenance requirements in young calves due to cold stress. The final simulation of preweaning weights was considered quite adequate.

Table 1. Actual weight (kg) and gain (kg/day) of 1977-born yearling heifers and baseline simulation.

Actual			Simulated		
Date	Weight	ADG	Date	Weight	ADG
4/4/78	240	.55	4/1	215	.54
7/29/78	303		8/1	279	

Table 2. Calf deaths by year and pasture taken from ranch records.

Year	Pasture	Born No.	Died No.	Died %
74-75	E. Marano	202	21	10.2
	W. Marano	220	18	8.2
		422	39	9.2
76-77	E. Marano	86	38	44.2
	W. Marano	56	17	30.4
		142	55	38.7
77-78	E. Marano	140	36	25.7
	W. Marano	129	15	11.6
	E. Big Past.	191	18	9.4
	E. Humble	208	12	6.3
	W. Sq. Tank	142	15	10.6
		810	97	12.0

Simulated postweaning growth rate of yearling heifers was very similar to actual growth rate (Table 1). The heavier actual weights in this table were attributable to the 30 to 40% culling of light heifers; whereas, the simulated weights represented an average of all heifers.

Calf death rates by year and pasture are reported in Table 2 and summarized by birth month in Table 3. Large year and pasture differences resulted from major weather variations, extreme disease problems in one year, and differences in pasture drainage. The much higher death rates of December- and January-born calves (Table 3) reflected the stress of cold, wet winters and inadequate nutrition for lactating cows. The correspondence between actual and simulated death rates by birth month was excellent. Cow death rates were also highly variable among pastures and years but the simulated annual rate of 3.3% is identical to the 1978 ranch average of 3.3% (Table 4).

Simulated pregnancy percentage was somewhat higher than the 1978 palpation records averaged over all cow ages (Table 5). This difference was attributed to a fairly high incidence of brucellosis in the herd that was not accounted for by the model.

The high degree of correspondence between the baseline simulation and actual performance data was encouraging and suggested that useful comparisons of management alternatives can be made.

Simulation of Management Alternatives

Eight simulations of a 4 × 2 factorial design with 4 livestock management schemes and 2 levels of nutrition were evaluated. Only a limited amount of the simulation data generated by the model is reported in this paper. Primary emphasis has been placed on data that relate to calf production.

The percentage of cows becoming pregnant was affected more by changing nutritional level than by changing the time of calving

Table 3. Percentage of calves born by month and death rates by month of birth for actual data for the years 1977-78 and baseline simulation.

Source	Birth month	Born No.	Born T	Died No.	Died %
Actual	Dec.	337	24.5	62	18.4
	Jan.	489	35.6	85	17.4
	Feb.	236	17.2	21	8.9
	Mar.	313	22.7	20	6.4
		1375	100.0	188	13.7
Simulated	Dec.	199	44.2	28	14.1
	Jan.	107	23.8	20	18.7
	Feb.	79	17.6	9	11.4
	Mar.	65	14.4	2	3.1
		450	100.0	59	13.1

Table 4. Actual cow death rates (%) for 4 herds in 1977 and 1978 and for the whole ranch in 1978 and baseline simulation for the whole ranch.

Herd	1977	1978	Simulated
E. Marano	10.8		
	8.5		
W. Marano	18.8		
E. Big Past.	5.9	4.5	
W. Big Past.	12.8	2.6	
Means	12.1	6.0	
Total Ranch[1]		3.3	3.3

[1]Total ranch included a number of other herds.

and weaning (Fig. 8). The percentage of cows pregnant with spring calving and split calving was greater than for fall or winter calving. It should be noted that fall calving was limited to a 3-month period while winter and spring calving were 4-month periods. Split calving consisted of 3-month calving periods during fall and spring with cows allowed to shift from one season to the other. In addition, spring calving cows nursed for 2 months less than fall and winter calving cows. The highest pregnancy rate was 83% for split calving under improved nutrition. No interaction between level of nutrition and calving season was apparent for pregnancy rate.

Level of nutrition interacted strongly with calving season with respect to calf mortality (Fig. 9). Calf mortality was much greater under the base nutrition with winter calving than under any other management alternative. This high mortality rate was reduced by improving nutrition or by changing the calving season. The highest mortality rates always resulted from over-wintering young calves. There appeared to be little opportunity for additional reduction of death losses by further improvement in nutrition.

The number of calves sold per 1000 cows was lowest for winter calving and highest for split calving (Fig. 10). Improved nutrition had a significant effect on calves sold from all management systems, with the greatest effect found in winter calving. The differences among calving and weaning alternatives were greater under base nutrition than under improved nutrition.

Level of nutrition affected weaning weights differently depending on the season of calving (Fig. 11). The younger spring-born calves were lightest under base and improved nutrition and they exhibited the least spread between levels of nutrition. Fall and winter calves had comparable weaning weights on base nutrition, but with improved nutrition fall calves were heavier than winter

Table 5. Actual pregnancy data age class and baseline simulation.

Herd	Age	No.	Pregnancy % 1978
E. Marano	7,8	187	63
W. Marano	6,7	191	58
E. Big Past.	6,7,8	229	52
W. Big Past.	5,6,7,8	225	82[1]
E. Humble	6,7	217	51
W. Humble	4,5,6	223	82[1]
E. Sq. Tank	3,4	201	42
W. Sq. Tank	3,4	216	60
Mean			61.3
		Simulation	
	3		85.3
	4		60.8
	5		64.5
	6		62.4
	7		69.2
	8		63.8
	9		65.3
	10		62.0
Mean			67.0

[1]All cows dry during 1978.

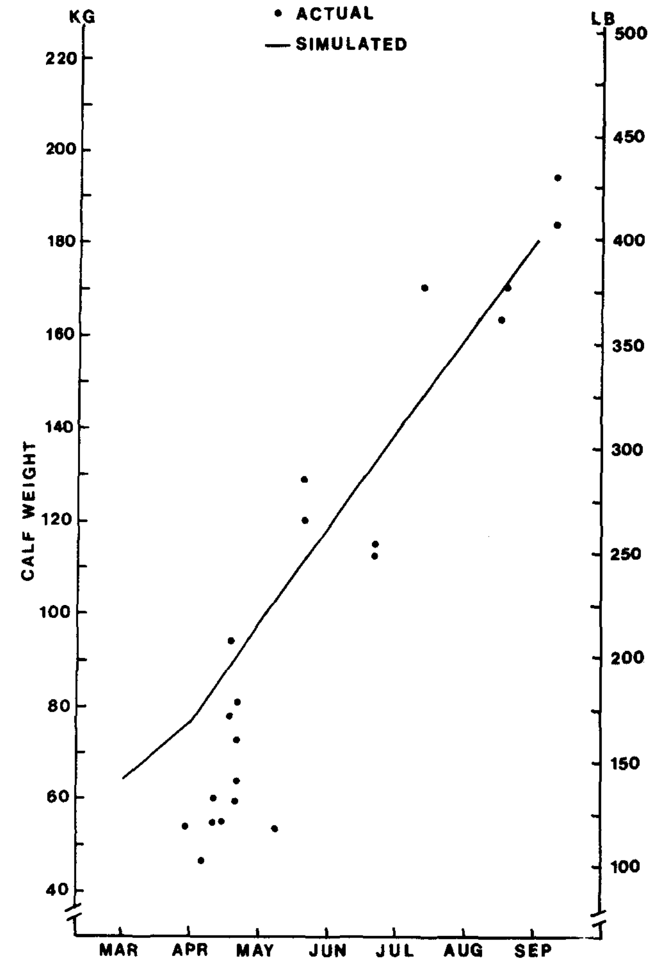

Fig. 7. *Actual and simulated preweaning calf weights averaged across months.*

calves. Spring calves had little opportunity to utilize the higher quality forage available during spring; whereas, fall and winter calves were old enough to utilize this forage. Fall calves received the greatest benefit from improved winter nutrition because of the

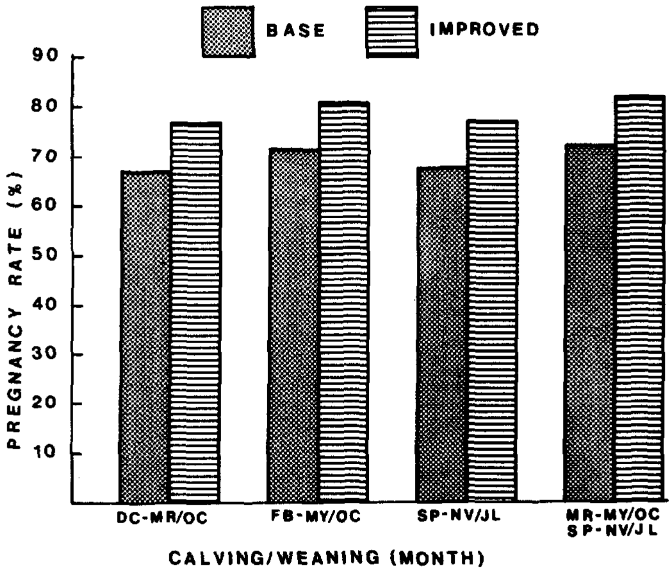

Fig. 8. *Simulated percentages pregnant of cows exposed to breeding for four calving season/weaning age options and 2 levels of supplemental feeding.*

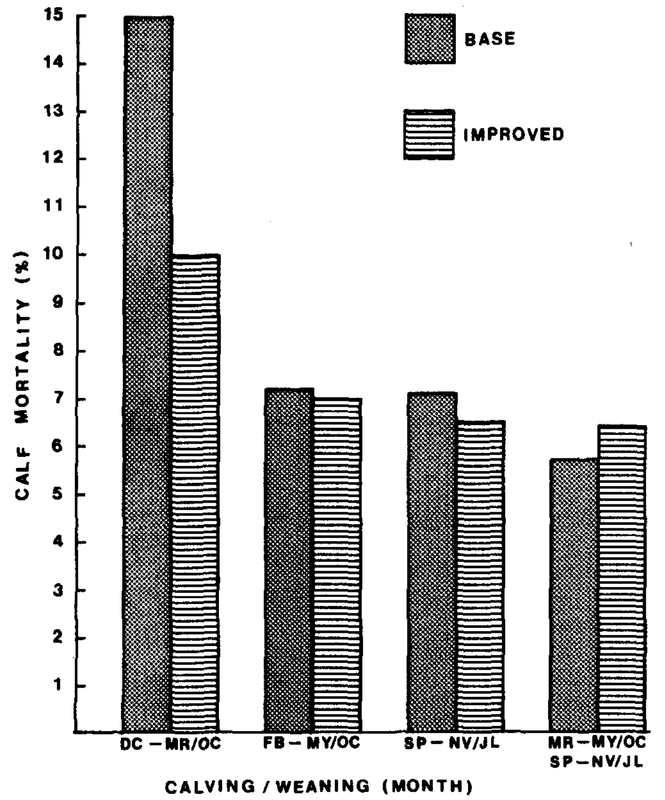

Fig. 9. *Simulated preweaning calf mortality for 4 calving season/weaning age options and two levels of supplemental feeding.*

increased milk production of their dams.

The weight of calves and weight of cull cows sold on a per cow (1 year of age and older) basis was considered to be a significant measure of production from the different management alternatives simulated. The weight of cull cows sold was essentially the same for all management practices (Fig. 12). However, weight of calf sold differed markedly among treatments. Winter calving with base

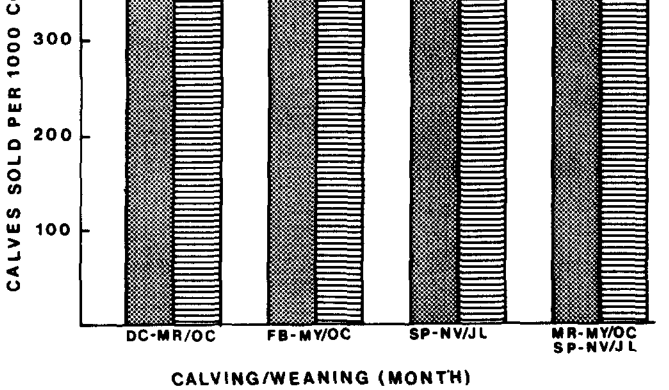

Fig. 10. *Simulated calves sold per 1000 cows (one year of age and older) from 4 calving season/weaning age options and 2 levels of supplemental feeding.*

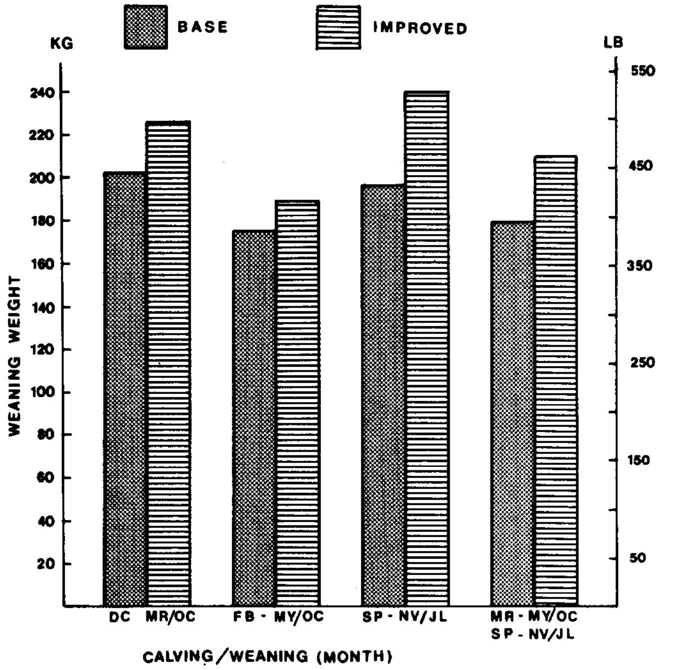

Fig. 11. *Simulated weaning weights of calves for 4 calving season/weaning age options and 2 levels of supplemental feeding.*

nutrition was lowest and fall calving with improved nutrition was highest. Changing calving from winter to fall under base nutrition increased calf sold per cow by 8 kg; under improved nutrition, the increase was 15 kg (Fig. 12). Improved nutrition had a greater effect on calf production than did calving season. The response to improved nutrition varied from 42 kg under fall calving to 22 kg under spring calving with winter and split calving being intermediate (Fig. 12).

Based upon the simulations reported here, different management strategies may be formulated. For a rancher desiring the lowest cash imput with a maximum number of calves produced, spring calving or split calving appear most effective; however, weaning weights would be reduced. Simulations suggested that high levels of supplements had less effect on these management alternatives because weaning weights of spring calves showed little response to improved nutrition. For a rancher desiring to increase calf weights, fall calving appeared to offer the best opportunity, primarily because weaning weight of fall calves responded well to improved nutrition. However, fall calving required greater expenditures for feed, and early fall feeding would be essential to assure good conception rates.

Full interpretation of these data requires that economic aspects of the practices be considered. Simulations were run for numerous different management alternatives. Results of this more extensive study and economic analysis of all the treatments will be reported in subsequent publications.

Research Needs

Field research is very limited for production schemes involving several different management alternatives. Because of limited availability of resources (money, land, personnel, and time) and difficulties in designing such studies, most research has been directed towards comparison of a few management practices involving only one segment of the production scheme. Ranchers must select and combine management practices for all phases of production programs with little guidance from research with respect to possible interactions of these practices when combined in an integrated management program. Systems research may assist both the producer and the researcher by allowing evaluation of integrated production systems. A variety of alternatives can be examined providing a basis for producers to make management decisions.

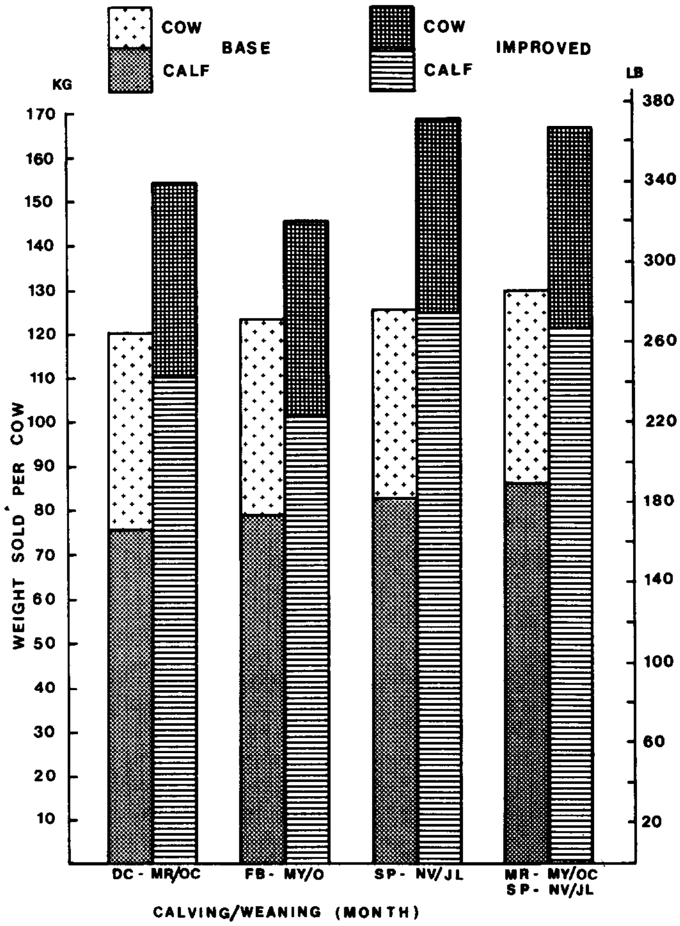

Fig. 12. Simulated calf weight and cow weight sold per cow (1 year of age and older) for 4 calving season/weaning age options and 2 levels of supplemental feeding.

The present cattle model is adequate for evaluating management alternatives when forage quality and availability data are present for the different alternatives. This capability can be used to greatly reduce the cost of grazing management research. Herd productivity can be predicted by simulation rather than by using the large numbers of livestock necessary to measure it directly. However, there is a critical need to develop plant/animal interface models that will accurately predict availability and quality for forage and nutrient intake of grazing animals for different range and livestock management schemes. Efforts to develop these grazing models to link current animal and plant models are underway at some locations (HFRO 1979, Tadmor et al. 1977), but deserve increased attention by others involved in integrated animal and range research.

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The Behaviour of Free-ranging Cattle on an Alpine Range in Australia

H. VAN REES AND G.D. HUTSON

Abstract

The behaviour of free-ranging cattle on the Bogong High Plains, Victoria, was investigated during 2 summer grazing seasons. The main influence on cattle distribution was found to be their preferences for particular vegetation communities. Cattle preferred to graze in grassland and closed heathland and avoided mossbeds. Cattle preferred to rest on grassland, wet grassland, and at cattle camps. The interaction of cattle with mossbeds, the vegetation community most susceptible to disturbance, was investigated in detail. Cattle visited mossbeds primarily to drink, although a small number of animals entered them to graze.

The Bogong High Plains is the largest alpine plateau in Victoria, located 250 km northeast of Melbourne. The High Plains cover an area of some 70 km² above the tree-line and range in elevation from 1,660 m to 1,880 m A.S.L. The vegetation consists primarily of alpine tussock grassland, heathland, and mossbeds. The vegetation of the High Plains has been described by Carr and Turner (1959) and McDougall (1982).

The area is public land managed by the State Electricity Commission (SEC), Soil Conservation Authority (SCA) and the National Parks Service. In economic terms the most important value of the High Plains is a water catchment for the SEC Klewa hydro-electric scheme. The average annual precipitation is 2,555 mm, most of which falls as snow between June and October. Stock have grazed the High Plains during the summer months since 1852. The SCA has control over stock grazing on the High Plains, and today some 20 graziers hold annually renewable licenses to graze 4,000 cows with calves (primarily Hereford and Angus) from mid December until early April. There are no fences on the High Plains and cattle movements are unrestricted.

Previous vegetation studies of Australian alpine areas have indicated that the presence of stock and "burning-off" to improve stock feed have a deleterious effect on the fragile alpine ecosystem (Carr and Turner 1959, Wimbush and Costin 1979). The mossbed com munity, because of its soft, wet soils, appears to be the most sensitive vegetation community and may be more susceptible to disturbances through grazing and trampling by stock. Costin (1958) reported heavy overgrazing of mossbeds by stock on Mt. Kosciusko, and Carr (1977) reported from the High Plains that a mossbed fenced since 1945 had increased in size and wetness, but that comparable mossbeds in grazed areas showed no signs of improvement. Costin et al. (1959) postulate that trampling in mossbeds leads to a breakdown of the internal drainage system, which in turn leads to a lowering of the water table with a consequent general drying out of the moss and peat, eventually reducing the size of the mossbed. It is essential to maintain the mossbeds in good condition to ensure that the optimum water catchment potential of the High Plains is realized.

This paper deals with the behaviour and movements of cattle on the Bogong High Plains, with particular attention given to the interaction of cattle with mossbeds.

Methods

Vegetation of the Study Areas

Two study areas were selected on the criterion that the major vegetation communities present on the High Plains were well represented. The study areas covered about 150 ha at Nelse (37° 51′ s, 147° 20′ E) and about 110 ha at Cope Creek (37° 55′ S, 147° 17′ E). The vegetation of the study areas was sampled using the quadrat method. Each vascular plant species in a 5 × 4-m quadrat was recorded and assigned a quantitative estimate of cover and abundance using a scale similar to that designed by Braun-Blanquet (1932). The locality of each quadrat was plotted on colour aerial photographs.

The quadrat data were analysed by computer using a procedure outlined by Gullan (1978). The result of this analysis was a two-way table which delineated the quadrats and species which formed vegetation communities. With the use of the aerial photographs, vegetation maps of the 2 study areas were prepared, and the percentage area covered by each vegetation community was calculated using a Summagraphics Intelligent Digitizer.

Behaviour of Cattle

The behaviour of free-ranging cattle was observed in the 2 study areas during 2 summer grazing seasons, 1980/81 and 1981/82. Cattle movements and utilization of vegetation communities were recorded using a scan sampling technique (Altmann 1974). Systematic scans of the study area were made every 5 minutes over a 2-hour period until a continuous series of observations from dawn

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till dusk had been accumulated over 2 or 3 consecutive days. At each scan, the activity (grazing, standing head raised, lying, walking, and drinking), the vegetation community occupied, and the distance to the nearest neighbouring cow were recorded for up to 20 individuals. During each season a total of some 27,000 observations of cattle were recorded during 11 dawn till dusk sessions.

The scan data were analysed by computer into cross tabulations of nearest neighbour distance by activity and vegetation community, and activity by vegetation community. In the analysis of time of day data the effect of different day lengths during the season was removed by transforming all times to sun angles, starting at sunrise, for each of the 11 observation sessions. Cattle preferences for particular vegetation communities were determined by comparing the actual number of observations of an activity against the expected number of observations using a 1×2 X^2 test. The expected values were calculated on the hypothesis that if cattle utilized the vegetation communities randomly the occupation of each vegetation community must correspond to the percentage area covered by that community in the study area.

During the 1981/82 season additional detailed observations were made of cattle in mossbeds while the scan data were being collected. Cows entering a mossbed were observed continuously and their behaviour and movements were noted.

On 4 occasions during the 1981/82 season a cow with calf was followed on foot for a 24-hour period starting at sunrise. The location, activity and vegetation community occupied by the cow were continuously recorded. During the night a spotlight was used occasionally to aid observations. Periodic checks of other cattle were also made during the 24-hour period to ensure that the behaviour of the observed cow was similar to that of other animals in the group.

Results

Vegetation of the Study Areas

Five major vegetation communities and 4 minor communities were recognized. The percentage area of the 5 major vegetation communities in each study area is shown in Table 1. The well drained hillsides of the study areas support the grassland community, dominated by the fine-leaved snowgrass tussock *Poa hiemata.* Interspersed between the tussocks grow a variety of herbs which in some areas form the dominant cover. The dominant herbs are the silver snow daisy, *Celmisia asteliifolia* and scaly buttons, *Leptorhynchos squamatus.* Bareground is very common between snowgrass tussocks and none of the grassland quadrats sampled resembled the grassland in climax condition as described by Carr and Turner (1959). Carr (1962) is of the opinion that stock grazing and the wild fires of 1939 have led to an opening up of the grassland, and that shrubs are most efficient in colonizing the resulting bare ground. The increasing shrub cover has led to an increase of the open-heathland community, where the dominant shrubs are alpine grevillea, *Grevillea australis,* and rusty pods, *Hovea longifolia.* On steeper exposed slopes and areas with shallow soils, closed-heathland forms a dense cover of shrubs. Ledge grass, *Poa hothamensis,* is a common component of this community. On more water-logged soils a coarser species of snow grass, *P. costiniana,* and the rush, *Empodisma minus,* are co-dominants of the wet-grassland community. Extensive mossbeds have formed along drainage lines, dominated by the moss, *Sphagnum cristatum,* heath species such as *Epacris glacialis* and the sedge *Carex gaudichaudiana.*

Table 1. Percentage are covered by vegetation communities in the Cope Creek and Nelse study areas.

	% Area	
Vegetation community	Cope Creek	Nelse
Grassland	34.0	21.4
Open heathland	29.4	22.5
Closed heathland	4.6	42.4
Wet grassland	11.0	2.9
Mossbed	18.2	9.0
Other	2.8	1.8

Behaviour of Cattle

Cattle in the study areas grazed in small groups of 6–12 animals. The cattle in these groups were very close together, with individuals less than 5 m apart in 50% of all grazing observations (Fig. 1). Resting behaviour (standing, head raised and lying) was observed in larger groups with greater numbers of individuals close together, and 65% of individuals were less than 5 m apart (Fig. 1).

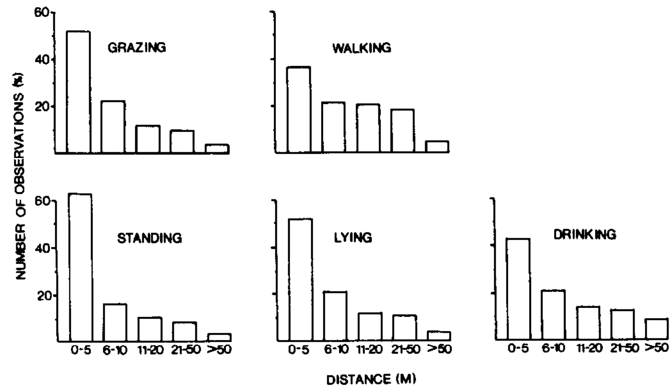

Fig. 1. *Frequency distributions of nearest neighbour distances for different activities.*

Variation in spatial behaviour in the vegetation communities was related to the cattle's activities. In the communities where cattle grazed for a significant part of the day (grassland, open and closed heathlands) the cattle were spaced further apart than in communities such as cattle camps where cattle primarily rested (Fig. 2).

The diurnal activity pattern of the cattle was similar in both years. Around sunrise cattle started an intensive grazing period which lasted 4 to 5 hours. This was followed by a siesta around midday, intermittent grazing in the afternoon, and another intensive grazing period in the late afternoon (Fig. 3). The diurnal activity pattern was not related to the utilization of particular vegetation communities, except for cattle camps, which were used more during the midday hours than during the rest of the day.

The grazing behaviour of cattle in each vegetation community is shown in Table 2. At Cope Creek in both seasons cattle preferred to graze in grassland and closed heathland, while wet grassland and mossbed were not preferred. During the 1981/82 season cattle

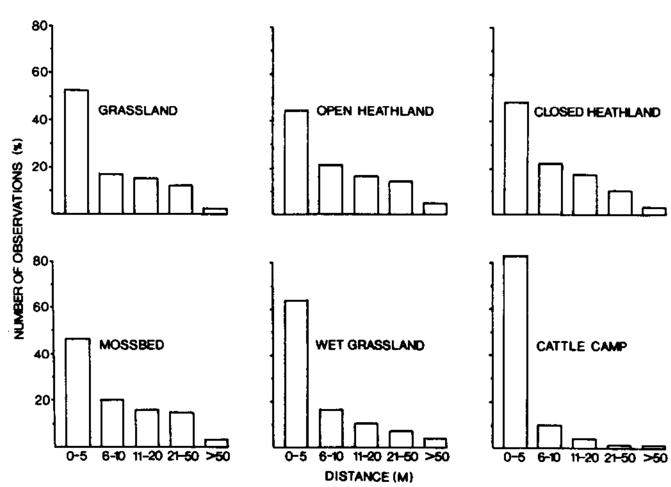

Fig. 2. *Frequency distributions of nearest neighbour distances for different vegetation communities.*

Table 2. Grazing behaviour in the Cope Creek and Nelse study areas during 1980/81 and 1981/82 seasons.

	Cope Creek			Nelse		
	Actual No. observations (%)		Expected No observations	Actual No. observations (%)		Expected No. observations
Vegetation community	1980/81	1981/82	(%)	1980/81	1981/82	(%)
Grassland	56.0**	40.9**	34.0	30.7**	18.4**	21.4
Open heathland	24.3**	30.5*	29.4	24.3**	23.6*	22.5
Closed heathland	6.1**	10.4**	4.6	27.7**	41.8	42.4
Wet grassland	5.9**	6.3**	11.0	8.1**	4.0**	2.9
Mossbed	4.8**	6.2**	18.2	2.4**	3.0**	9.0
Other	2.9**	5.7**	2.8	6.8**	9.2**	1.8

** $P<0.01$, * $P<0.05$, χ^2 test, d.f. = 1

moved into open heathland and closed heathland at the expense of grassland. Grazing behaviour in the Nelse study area was similar to Cope Creek. Cattle showed a marked increase in preference for closed heathland during the 1981/82 season. Mossbed was not preferred for grazing during both seasons.

The resting behaviour of cattle in each vegetation community is shown in Table 3. Similar behaviour was observed in both study areas. Cattle preferred to rest in grassland, wet grassland (except

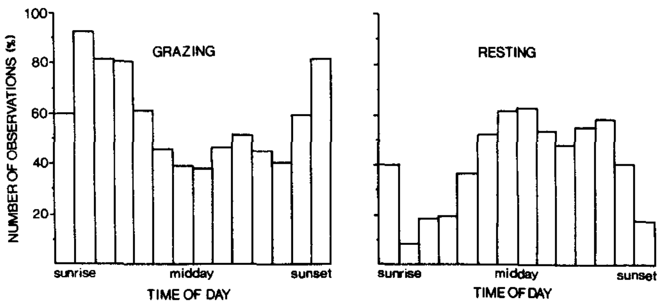

Fig. 3. *Frequency distributions of grazing and resting behaviour during daylight hours.*

Cope Creek in 1980/81), and cattle camps. Open heathland, closed heathland, and mossbed were not preferred for resting.

In both study areas a significant percentage of resting (6–22%) was at cattle camps. These camps were conspicuous rocky outcrops where cattlemen regularly salt their cattle. Even when no salt was given, large numbers (20–40 animals) congregated around these rocks during the midday resting period. The camps were not used as bedding grounds at night.

Ethograms of the behaviour patterns of 2 cows are shown in Figure 4. There was a marked increase in time spent grazing per 24-h day as the season progressed. The cow observed at the start of the season spent 7.3 h grazing, compared with 11.5 h for the cow at the end of the season, of which 3.0 h was spent grazing at night. None of the cows observed spent any significant time in mossbeds, and used mossbeds always for drinking. These data support observations using the scan sampling technique.

The scan data suggest that cattle do not find mossbeds attractive

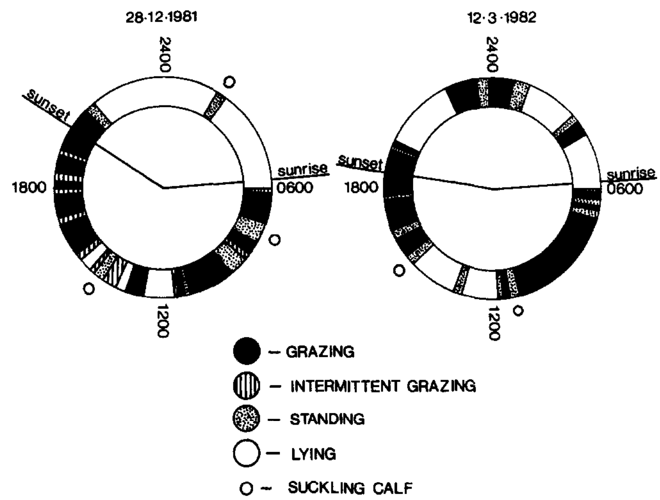

Fig. 4. *Ethograms for behaviour patterns of a cow observed in a 24-hr period at the start of the season (28/12/81) and the end of the season (12/3/82).*

for grazing, but that this community provides the major source of drinking water (Table 4).

On 45 occasions the activities of individual cows in mossbeds were observed during the 1981/82 season (Table 5). The main impression formed from these observations was that cattle entered the mossbed to drink but often grazed on their way in and out. Of the 30 cattle that grazed in mossbeds, 22 also drank. Cattle that grazed and drank tended to graze for shorter periods (median 4.5

Table 3. Resting behaviour in the Cope Creek and Nelse study areas during the 1980/81 and 1981/82 seasons.

	Cope Creek			Nelse		
	Actual No. observations (%)		Expected No observations	Actual No. observations (%)		Expected No. observations
Vegetation community	1980/81	1981/82	(%)	1980/81	1981/82	(%)
Grassland	58.4**	48.8**	34.0	22.6*	27.4**	21.4
Open heathland	13.28**	16.8**	29.4	11.2**	13.9**	22.5
Closed heathland	0.5**	0.5**	4.6	3.7**	6.5**	42.4
Wet grassland	10.0*	15.3**	11.0	25.9**	27.2**	2.9
Mossbed	5.0**	3.6**	18.2	5.6**	4.4**	9.0
Cattle camp	6.7**	6.1**	0.1	22.2**	17.3**	0.2
Other	6.2**	9.9**	2.7	8.8**	3.3**	1.6

** $P\leq0.01$, * $P<0.05$, χ^2 test, df = 1

Table 4. Behaviour of cattle in mossbeds in the Cope Creek and Nelse study areas, during the 1980/81 and 1981/82 seasons.

	Cope Creek		Nelse	
	1980//81	1981/82	1980/81	1981/82
No. of observations in mossbeds (%)	5.3	6.1	4.1	4.2
No. of grazing observations in mossbeds (%)	4.4	6.2	2.4	3.0
No. of drinking observations in mossbeds (%)	89.7	98.6	85.5	96.0

Table 5. Frequency and median duration of activities observed in the visits of 45 cows to mossbeds. Ranges are shown in parentheses.

Activity	Frequency	Duration (min)
Grazing	30	5.5 (1-55)
Standing	18	2.0 (1-8)
Walking	33	1.0 (1-4)
Drinking	33	2.0 (1-6)

min, range 1-31 min) than cattle that grazed and did not drink (median 17.5 min, range 1-55 min, $p = 0.08$, Mann-Whitney U test). Thus, there was a small number of individuals who appeared to enter mossbeds to graze.

Discussion

Previous studies have shown that the distribution of cattle on free-range is influenced by the type of vegetation, steepness of slope, roughness of terrain, and distance from water and salt (Cook 1966, Hodder and Low 1978, Low 1972, and Mueggler 1965). The vegetation of the Bogong High Plains formed a mosaic with all the major vegetation communities easily accessible. Therefore, distance and slope steepness did not affect selection of vegetation communities by cattle. The steepest slope in the study areas was 15°, but even steeper sections outside the study areas were accessible along one of the many cattle tracks which followed contour lines. We found that cattle grazed the preferred vegetation communities extensively regardless of the slope. Distance to water and salt were not restrictive influences as free-flowing water and salting areas were common in both study areas. Thus, the main factor affecting distribution of cattle on the High Plains was the preference of cattle for particular plant communities.

The behaviour of cattle has a strong influence on which vegetation communities were preferred. Cattle preferred to rest on grassland, wet grassland, and during the midday resting period, at cattle camps. Grazing cattle utilized vegetation communities in the 2 study areas to different extents, probably because of differences in availability of the communities rather than differences in plant composition. In both study areas grazing cattle preferred grassland; open heathland was not actively preferred (utilization was similar to availablity) and mossbeds were avoided. Closed heathland was preferred in the Cope Creek area, but although the amount of time cattle grazed in closed heathland in the Nelse study area was high (up to 42%) it was not a preferred community because of its availablity.

The selection of different vegetation communities by grazing cattle is dependent on the availability of palatable plants. Preliminary investigations into the diet of cattle on the High Plains (van Rees 1982) have shown that many of the plants regularly grazed by cattle are those plants common in grassland and closed heathland. Plants common in mossbeds were not regularly grazed by cattle.

Cattle on the High Plains exhibited the same diurnal pattern of behaviour as other grazing cattle (Arnold and Dudzinski 1978). There were 2 main grazing periods, in the morning and afternoon, with a resting period around midday. The 24-hour observations showed that when green feed was abundant at the beginning of the season total grazing time was short and there was no grazing at night. However, as the summer progressed and the vegetation dried out, cattle were grazing for longer periods including a 2- to 3-hour grazing period at night.

The interaction of cattle with mossbeds poses a threat to maintaining optimum water catchment conditions. Cattle primarily used this community for drinking, but a small number of individuals entered mossbeds with the sole intention of grazing. Mossbeds are easily disturbed through trampling, and this community should be closely monitored so that further deterioration does not occur.

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Effect of Water and Nitrogen, and Grazing on Nematodes in a Shortgrass Prairie

JAMES D. SMOLIK AND JERROLD L. DODD

Abstract

Densities of plant feeding nematodes were highest in range receiving additional water and nitrogen (H_2O + N), however, biomass of plant feeders was not significantly increased. Populations of stunt nematodes were highest in the grazed treatment. Maximum numbers of 3 other plant feeding groups, ring, Tylenchidae and Dorylaimida, occurred in the H_2O + N treatment. Predaceous and microbial feeding nematode populations were also highest in the H_2O + N treatment. Populations of plant feeding and predaceous nematodes peaked in early June and remained high throughout the growing season. Populations of microbial feeders also peaked in early June, but fluctuated through the sampling period. It appears the benefits of additional water and nitrogen on plant growth are not offset by large increases in biomass of plant feeding nematodes.

Nematodes are major consumers in the shortgrass prairie (Scott et al. 1979). They are also prevalent in other North American grasslands (Norton and Schmitt 1978, Freckman et al. 1979, Smolik and Lewis 1982). Cattle grazing and wildfire did not affect nematodes in a shrub steppe community (Smolik and Rogers 1976); however, in a mixed prairie in South Dakota plant feeding nematode biomass was decreased by heavy cattle grazing (Smolik and Lewis 1982). The objectives of the present study were to determine the vertical distribution of nematodes and effects of grazing, seasonality, and application of water and nitrogen on nematode populations in the shortgrass prairie. Additionally, results of this and an earlier study in a mixed prairie (Smolik and Lewis 1982) are also discussed.

Materials and Methods

This study was conducted in a shortgrass prairie of northcentral Colorado. Climatic and edaphic characteristics have been described by Dodd and Lauenroth (1979). Vegetation in the study area was dominated by *Bouteloua gracilis, Opuntia polycantha,* and *Artemisia frigida.* In 1973 samples were obtained in mid-August from areas ungrazed since 1939 and from areas grazed heavily (ca. 1 AUM/ha) in summer and from another ungrazed area receiving additional water and nitrogen (Dodd and Lauenroth 1979). The water treatment maintained soil water at field capacity for the entire growing season, and annual spring applications of ammonium nitrate maintained soil mineral nitrogen levels at 100 kg/ha above adjacent nonfertilized areas. Six randomly selected cores were removed from each area to a depth of 60 cm, subdivided into 6 10-cm increments, labeled and placed in plastic bags. Samples were placed under ice in an insulated container and shipped to the senior author for nematode analyses. Nematodes were extracted, counted, and biomass determined as previously described by Smolik and Lewis (1982), except an additional taxonomic group *(Criconemoides)* was included. In 1974 soil cores were removed only from the water plus nitrogen (H_2O + N) treatment on 7 dates in an attempt to measure seasonal effects on nematode populations.

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Results and Discussion

Range Treatments

The taxonomic groupings, genera or species within each group, individual weights, common name, and tropic levels are listed in Table 1. The analyses of variance for 1973 and 1974 data are summarized in Table 2. Significant main effect or interaction means were compared with Fisher's least significant difference (FLSD's) at the .05 level (Carmer and Swanson 1971).

Total plant feeding nematode densities were highest in the H_2O + N treatment (Table 3). The taxonomic groups comprising the plant feeders varied in their response to the range treatments. Highest populations of Tylenchidae and ring nematodes (Table 3) and plant feeding Dorylaimida (Fig. 1) occurred in the H_2O + N treatment, while populations of stunt nematodes were highest in the grazed treatment. Biomass of total plant feeders (Table 3) and populations of the remaining plant feeding groups were not significantly different between treatments (Table 2). The Tylenchidae were primarily responsible for the increase in plant feeder densities in the H_2O + N treatment (Table 3); however, they are comparatively small nematodes (Table 1) and they did not significantly increase biomass estimates. In addition, numbers of the larger stunt nematodes declined in the H_2O + N treatment.

The majority of the plant feeders occurred in the 0–10 and 10–20 cm sampling depths (Table 4 and Fig. 1), which was similar to their distribution in a mixed prairie (Smolik and Lewis 1982). The lack of a significant increase in plant feeding nematode biomass in the H_2O + N treatment (Table 3) would seem to indicate that the treatment benefits are not offset by large increases in the nematode populations. However, nematode biomass estimates fluctuate considerably both between years and among dates within years (Smolik and Lewis 1982). More extensive sampling might have detected consistent differences. In addition, nematodes respond differentially to applications of water and fertilizer as Wallace (1963) indicates and as evidenced by the significant increase in ring nematodes (Table 3). It is possible that a longer duration study would have resulted in certain groups dominating in the H_2O + N treatment.

Highest populations of predaceous and microbial feeding nematodes occurred in the H_2O + N treatment (Fig. 2 and 3). The majority of both groups occurred in the 0–10 cm sampling depth. However, the decline in numbers of predators with increasing sampling depth was less than that for microbial feeders. Similar results were observed in the mixed prairie study (Smolik and Lewis 1982).

Seasonal Dynamics

Maximum populations of total plant feeders occurred in early June and slowly declined during the remainder of the sampling period (Fig. 4). As in 1973 the majority of plant feeders occurred in the 0–10 and 10–20 cm sampling depths (Fig. 4). Peak plant feeding nematode biomass occurred in early July (Fig. 5) and ranged from 108 to 216 mg/m^2 through the sampling period.

Highest populations of stunt nematodes were recorded in late July (Fig. 6). Spiral nematode populations were highest from May through early July (Fig. 7). The majority of stunt nematodes occurred in the 0–10 cm sampling depth (Fig. 6) whereas spiral nematode numbers were highest in 10–20 cm or deeper sampling

Table 1. Trophic levels, taxonomic grouping, and weights used in comparisons of nematode densities and biomass.

Trophic level	Taxonomic group	Common name	Weight	Genera or species within group
Plant feeding	Tylenchorhynchidae	Stunt	.055[a]	*Geocenamus* sp. *Merlinius* sp. *Tylenchorhynchus* sp.
	Hoplolaimidae	Spiral	.054	*Helicotylenchus leiocephalus, H. exallus*
	Paratylenchidae	Pin	.013	*Paratylenchus vexans*
	Tylenchidae		.032	*Tylenchus exiguus, T. parvissimus, T. plattensis, Thada striata, Ditylenchus* sp.
	Longidoridae	Dagger	.893	*Xiphinema americanium, Xiphinema* sp. *Longidorus* sp.
	Pratylenchidae	Lesion	.038	*Pratylenchus* sp. *Pratylenchoides* sp.
	Criconematidae	Ring	.050	*Criconemoides* sp.
	Dorylaimida		.110	*Axonchium* sp. *Diphtherophora* sp. *Dorylaimellus* sp., *Leptonchus* sp., *Pungentus* sp. *Trichodorus* sp., *Triplonchium* spp. *Tylencholaimellus* spp., *Tylencholaimus* spp.
Predaceous	Dorylaimida		.251	*Aporcelaimellus* spp. *Carcharolaimus* sp., *Discolaimus* spp. *Discolaimium* spp., *Ecumenicus* sp. *Eudorylaimus* spp., *Mononchus* spp. *Nygolaimus* spp. *Thonus* sp.
Microbial feeding	Rhabditida/Araeolaimida/ Aphelenchina		.074	*Acrobeles* spp., *Acrobeloides* sp. *Anaplectus* sp. *Aphelenchus* sp. *Aphelenchoides* sp., *Cephalobus* sp., *Cervidellus* sp. *Chiloplacus* sp., *Eucephalobus* sp. *Mesodiplogaster* sp. *Panagrolaimus* sp., *Plectus* sp. *Wilsonema* sp.

[a]Average dry weight (μg) of an adult nematode within taxonomic group.

Table 2. Summary of significance in analyses of variance of nematode density and biomass data, 1973 and 1974.

Date	Source	Stunt	Spiral	Pin	Tylenchidae	Dagger	Lesion	Ring	Dorylaimida (plant feeding excl. Dagger)	Predaceous	Microbial feeding	Plant feeding	Biomass plant feeding
		Probability of F											
1973	Range Treatment	.0322	.0763	.3615	.0407	.4824	.2557	.0049	.0028	.0029	.0012	.0323	.1448
	Depth	.0156	.0536	.0001	.0001	.0201	.0278	.0016	.0001	.0001	.0001	.0001	.0001
	Treat × Depth	.0655	.5179	.9281	.1226	.5274	.0777	.0001	.0016	.0009	.0014	.2365	.2868
1974	Date	.1025	.0016	.0331	.0001	.5614	.0828	.0269	.0430	.0369	.0037	.0001	.0941
	Depth	.0001	.0001	.0001	.0224	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	Date × Depth	.0077	.0002	.1883	.0048	.1478	.0072	.0001	.0314	.0255	.0001	.0001	.0243

Table 3. Effect of range treatments on density of total plant feeders, stunt, Tylenchidae, ring nematodes, and biomass of plant feeders in a shortgrass prairie, N.E. Colorado, 1973.

Treatment	Total plant feeders	Stunt	Tylenchidae	Ring	Biomass, plant feeders
Ungrazed	1,767,000[a]	122,000	410,000	0	138[b]
Grazed	3,480,000	315,000	594,000	0	195
H_2O + N	4,244,000	137,000	1,590,000	128,000	242
FLSD (.05)	251,000	25,000	157,500	12,300	NS

[a]Number of nematodes/m² to 60 cm depth.
[b]Mg/m² to 60 cm depth.

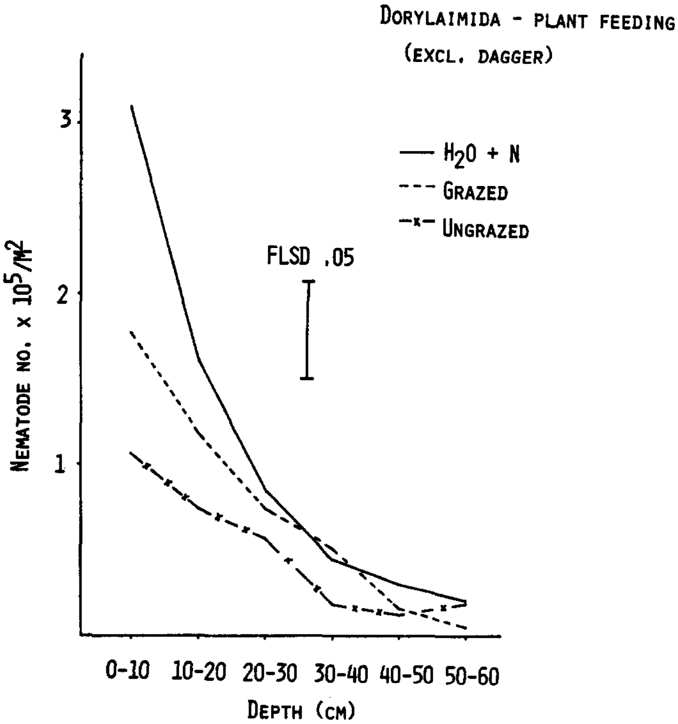

Fig. 1. *Vertical distribution of plant feeding Dorylaimida and effect of range treatments, 1973.*

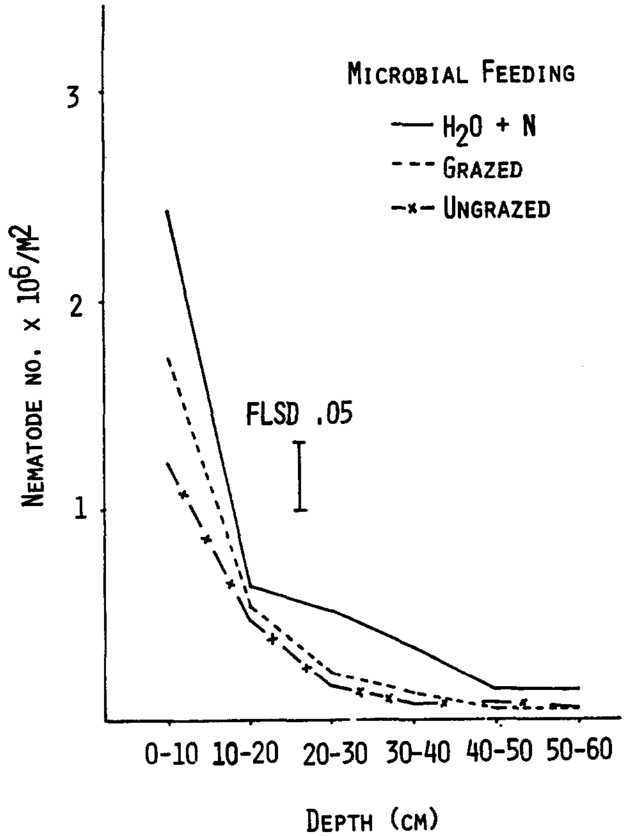

Fig. 3. *Vertical distribution of microbial feeding nematodes and effect of range treatments, 1973.*

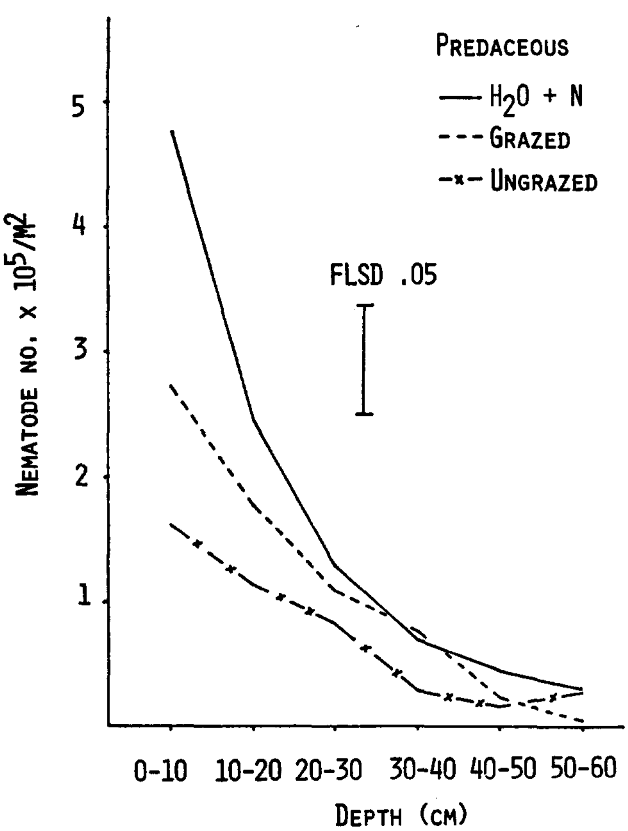

Fig. 2. *Vertical distribution of predaceous nematodes and effect of range treatments, 1973.*

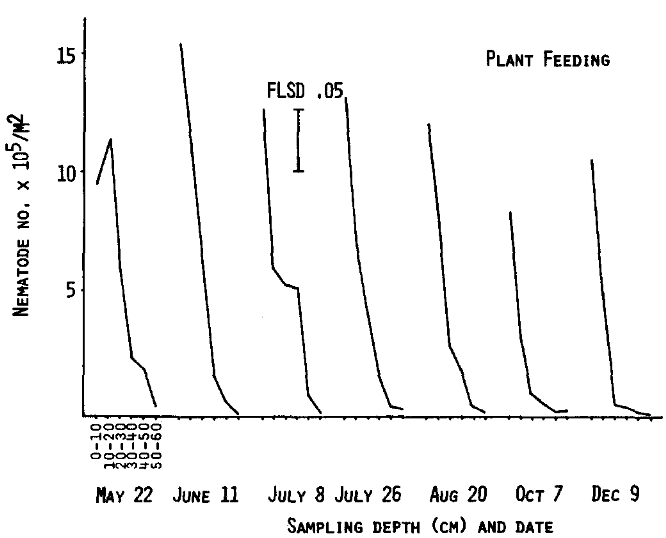

Fig. 4. *Seasonal densities of plant feeding nematodes at 6 sampling depths, 1974.*

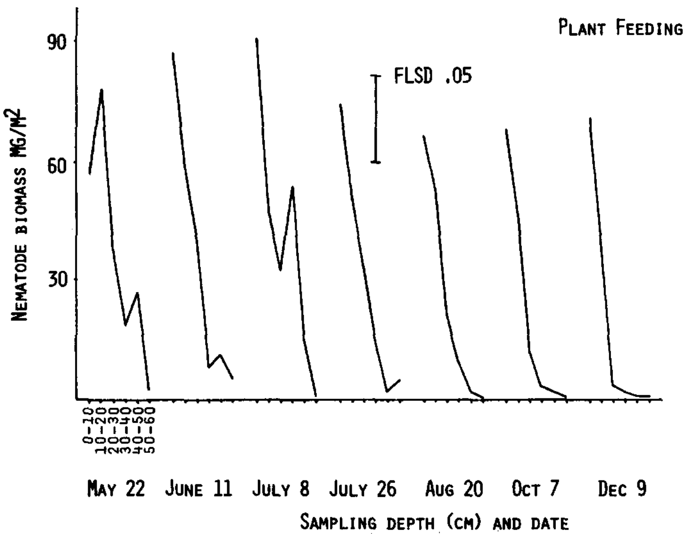

Fig. 5. *Seasonal biomass of plant feeding nematodes at 6 sampling depths, 1974.*

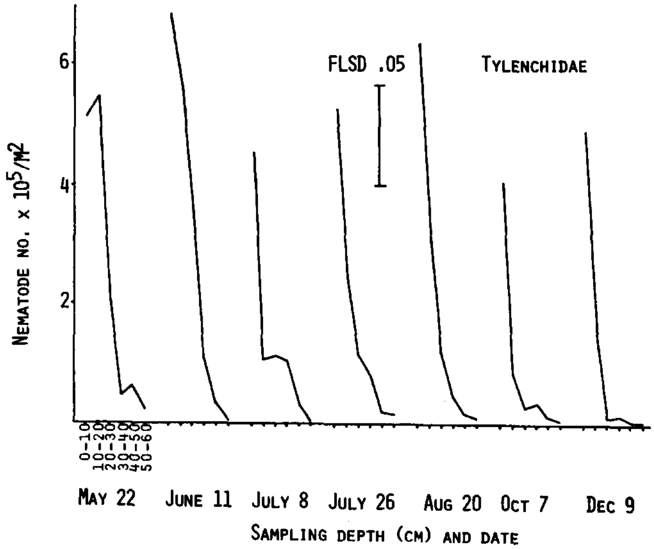

Fig. 8. *Seasonal densities of Tylenchidae at six sampling depths, 1974.*

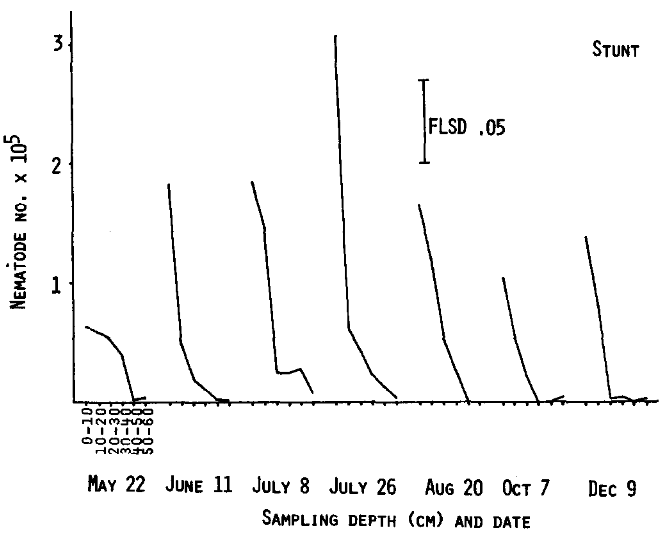

Fig. 6. *Seasonal densities of stunt nematodes populations at 6 sampling depths, 1974.*

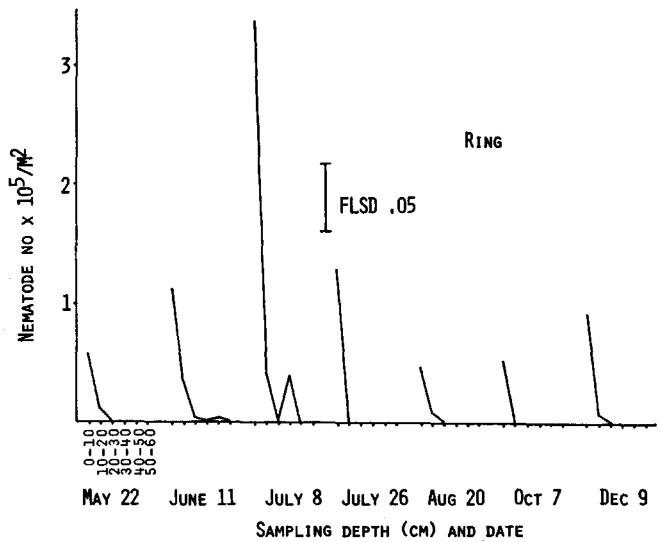

Fig. 9. *Seasonal densities of ring nematode populations at 6 sampling depths, 1974.*

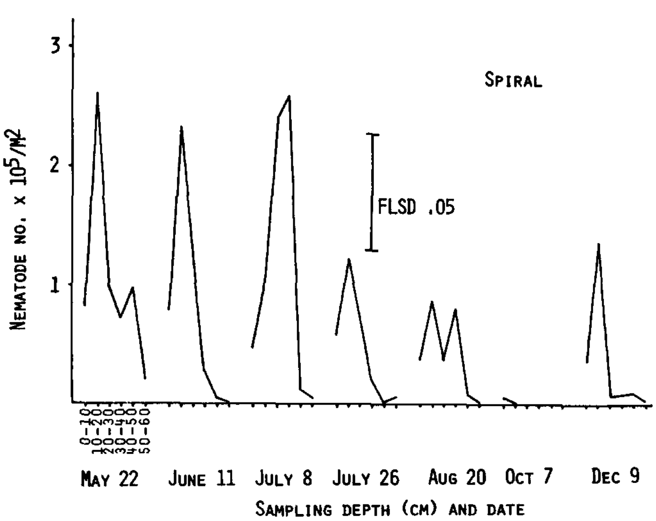

Fig. 7. *Seasonal densities of spiral nematode populations at 6 sampling depths, 1974.*

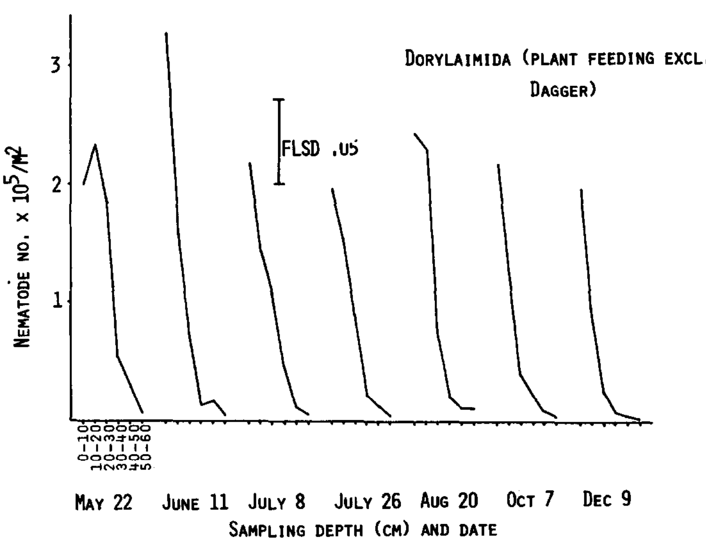

Fig. 10. *Seasonal densities of plant feeding Dorylaimida at 6 sampling depths, 1974.*

Table 4. Vertical distribution of plant feeding nematodes and biomass in a shortgrass prairie, N.E. Colorado, 1973.

Sampling depth (cm)	Total plant feeding	Stunt	Pin	Tylenchidae	Dagger	Ring	Lesion	Biomass, plant feeding
0-10	1,048,600[a]	100,600	138,700	374,800	5,300	35,000	4,300	70[b]
10-20	825,500	30,300	104,100	291,200	19,500	4,300	10,300	52
20-30	525,300	39,600	45,700	126,800	4,300	500	4,000	26
30-40	321,100	9,500	22,600	47,100	4,000	2,900	3,000	16
40-50	169,800	11,800	11,700	13,700	2,700	0	0	5
50-60	81,900	0	7,300	10,200	2,600	0	0	2
FLSD (.05)	198,400	57,200	25,300	138,000	10,500	17,000	6,000	14

[a]Number/m² to indicated depth, average of 3 treatments.
[b]Mg/m² to indicated depth.

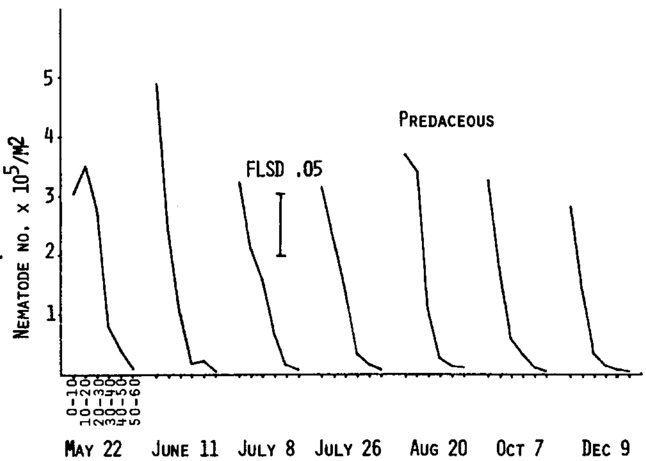

Fig. 11. *Seasonal densities of predaceous nematodes at 6 sampling depths, 1974.*

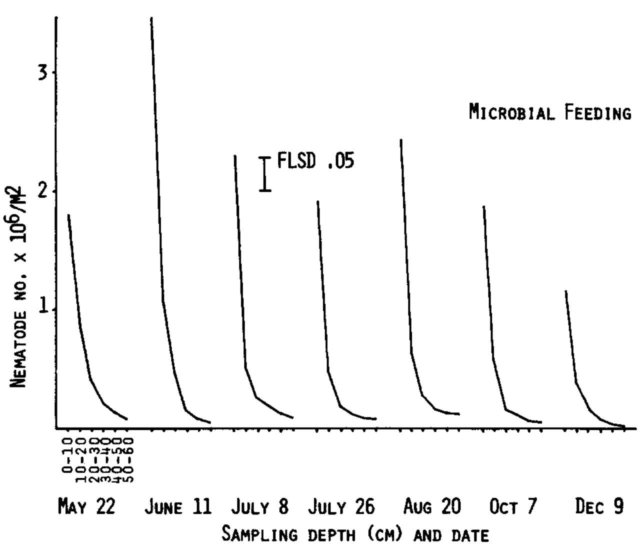

Fig. 12. *Seasonal densities of microbial feeding nematodes at 6 sampling depths, 1974.*

depths (Fig. 7). This segregation by depth was also observed in the mixed prairie (Smolik and Lewis 1982) and may suggest a possible means of control through practices such as interseeding or range ripping that disrupt this spatial distribution.

Densities of Tylenchidae were relatively high throughout the sampling period (Fig. 8) with highest populations in early June. Except in late May, highest populations of Tylenchidae occurred in the 0-10 cm increment (Fig. 8). Pin nematodes reached a peak population of 181,000/m² in early June. The vertical distribution of pin, lesion, and dagger nematodes was similar to that in 1973 (Table 3). Populations of ring nematodes increased slowly from May to June then climbed sharply in early July and decreased in late July (Fig. 9). The majority of ring nematodes occurred in the 0-10 cm increment. The plant feeding Dorylaimida group contained a comparatively large number of genera (Table 1), which may account for the relatively stable populations throughout the sampling period (Fig. 10).

Populations of predators were highest in early June and fluctuated little for the remainder of the sampling period (Fig. 11). The majority of the predaceous forms occurred in the 0-10 and 10-20 cm increments. Densities of microbial feeders increased significantly from late May to early June, declined in both early and late July, increased again in late August and again declined during the remaining sampling periods (Fig. 12). Interestingly, population fluctuations of the microbial feeders corresponded rather closely to fluctuations in the numbers of soil microarthropods (Dodd and Lauenroth 1979). These two groups may share a similar food base or certain of the microarthropods may prey upon microbial feeding nematodes.

In conclusion, nematode populations are lower and appear to be less sensitive to cattle grazing in the shortgrass region of Colorado than in the mixed prairie of South Dakota. However, vertical distribution of members of all trophic categories was similar in both studies. Additional research should be conducted on the influence of nematodes on energy flow and nutrient cycling patterns in range ecosystems to determine if regulation of nematode populations is a viable method for increasing plant production.

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Pronghorn Reactions to Winter Sheep Grazing, Plant Communities, and Topography in the Great Basin

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Abstract

The winter distribution of pronghorn over a 142-km² area on the Desert Experimental Range was significantly related to sheep grazing during the current winter, presence of black sagebrush, and topographic characteristics. Even moderate sheep use during the dormant period left grazing units relatively unfavorable for pronghorn until spring regrowth—at least on ranges where key pronghorn forage plants were in short supply. Winter use areas preferred by pronghorn were above the valley bottoms in rolling to broken topography where black sagebrush communities were evident. Movement characteristics of pronghorn have allowed many of them to readily locate rested grazing units, and, therefore, avoid severe dietary competition with sheep.

The Great Basin and other parts of the Intermountain West contain about 16 million ha of low-shrub cold desert. Most of these lands are publicly owned, and their primary use has traditionally been the grazing of sheep in winter and cattle in various seasons. In the last decade or so land managers have intensified efforts to consider the needs of wild animals, and require specific information to consistently make good management decisions. Information is available on pronghorn diets, water requirements, and predator losses (Beale and Holmgren 1975, Beale and Smith 1970, Beale and Smith 1973), but no intensive study has been accomplished in the Great Basin region to document the effects of livestock grazing systems on pronghorn *(Antilocapra americana)* populations Kindschy et al. 1978). Neither have the impact of other uses of the low-shrub desert on pronghorn been well documented for the Great Basin. A study to probe the effects of winter sheep grazing and certain environmental factors on pronghorn distribution was conducted on the USDA Forest Service Desert Experimental Range near Milford, Utah, during the winters of 1976-81.

Pronghorns thrive best on ranges with a diversity of grass-forb-shrub communities (Autenrieth 1978), but are widely adaptable to different forage conditions across the total range of the species. The severity of competition between pronghorns and domestic livestock appears to vary greatly with differences in species of livestock, season of the year, and plant species available to the foraging ruminants (Salwasser 1980, Yoakum 1980). Although pronghorn habitat has mainly been manipulated by livestock grazing, many proposed energy, mineral, and defense activities threaten severe habitat disruptions. Winter ranges are often especially critical for pronghorn and are of particular concern (Kindschy et al. 1978). When the most important plants in the pronghorn's diet are a minor component of the vegetation, widespread surface disturbances or intensive sheep grazing of all available habitat could result in increased winter mortality for the pronghorn.

The size and stability of pronghorn winter home ranges appear to be important in the animal's ability to adapt to newly created unfavorable habitat situations. Bayless (1969) found the pronghorn's winter home range to average 10–11 km², but one-half of the animals observed shifted home range at least once during the winter. This suggests that pronghorns may be flexible in their selection and use of wintering areas, although Howard et al. (1980) reported pronghorn avoided rough, broken terrain.

Methods

Pronghorn distribution on the Desert Experimental Range was systematically observed during the winters of 1976-77 through 1980-81. Total pronghorn numbers during this period increased from 80 to approximately 230. Observations generally began in November and continued until the pronghorn herds were dispersing in the spring—usually in April. Observations were made by the unaided eye and by use of binoculars and spotting scopes along a vehicular travel route. The observation route included 106 km of observation and about 144 km of total travel. The route was followed twice each week in the winter of 1979-80 and once each week during other winters. Some weeks no observations were made because of severe weather conditions.

The pronghorn counts were summarized for each of 11 grazing units for each observation date. Pronghorn counted on the observation route did not constitute an estimate of the total population, therefore, calculated densities were considered as "relative densities". Relative pronghorn densities were determined by dividing the observed number of animals by the area available in each grazing unit. The area available for pronghorn use on the Desert Experimental Range totaled 142 km².

Herded sheep used the area a portion at a time, spending 1 to 3 weeks on each grazing unit of 500 to 2400 ha. Each year, 2 units were grazed by domestic sheep in early winter, 3 in midwinter, 2 in late winter, 3 were rested, and 1 unit was always ungrazed. The pronghorn count-data were summarized into pregrazing and postgrazing periods for each range unit grazed by sheep. During the short periods of sheep grazing, data were insufficient to allow analysis of pronghorn response to the actual presence of sheep. For those units that were rested during the entire winter, the data were divided at February 1 to represent early and late winter periods. The differences between periods (pregrazing or postgrazing, early or late winter) were analyzed by *t*-test, using pronghorn density per grazing unit per date as the sample unit (Snedecor and Cochran 1967). The number of sample units per situation tested varied from 40 to 114.

Pronghorn observations were plotted on maps of the Desert Experimental Range. Chi-square comparisons were made to determine if pronghorn exhibited pronounced plant community or topographic site preferences during the winter period (Snedecor and Cochran 1967).

Some pronghorns had been collared during previous studies by Utah Division of Wildlife Resources. The collars provided an opportunity to determine movements and area selection of specific animals.

Results and Discussion

Relationship of Pronghorn Distribution to Sheep Grazing

An initial analysis of pronghorn distribution was conducted for the winter of 1979-80 because the frequency of observations had

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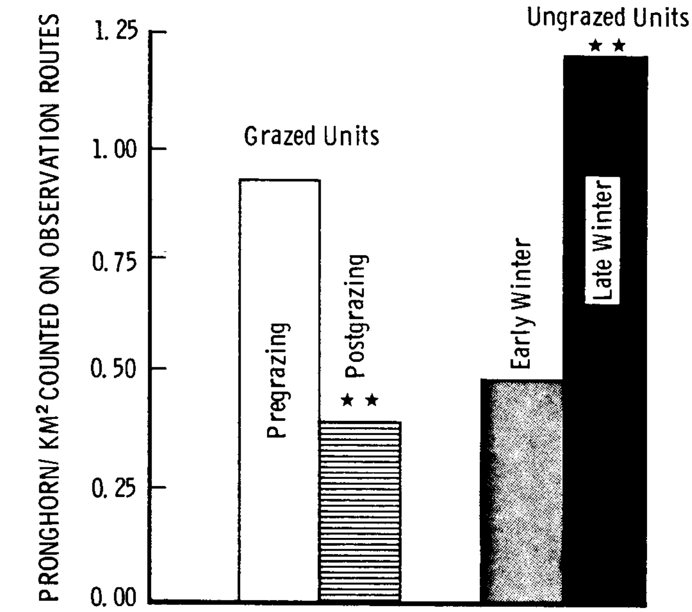

Fig. 1. *Relative pronghorn densities (winter of 1979-80). Double star (**) indicates significance at 0.01 level.*

been doubled during that period. Seven units were grazed by sheep in 1979-80. The relative pronghorn density observed per day was $0.93 \pm .18/\text{km}^2$ ($\pm$ SE) in the pregrazing period (Fig. 1). In comparison, the relative density of pronghorn in these same units after grazing was only $0.32 \pm .04/\text{km}^2$—a significant reduction ($P \leq .01$). The opposite trend occurred on the four grazing units that remained ungrazed the entire winter. The relative pronghorn density was $0.38 \pm .09/\text{km}^2$ in the early portion of the winter, but this increased significantly ($P \leq .01$) to $1.20 \pm .14/\text{km}^2$ on the same ungrazed units in the last half of the winter. The changes in densities on these units strongly suggest that, although sheep grazing was moderate, the pronghorn found the grazed units relatively unfavorable for their use and therefore tended to concentrate in the remaining ungrazed units during the latter part of the winter.

The remaining years of data were examined to determine if their results supported the initial analysis. Three test situations were available.

a. The winters of 1976-77 and 1977-78, which were combined for analysis because of small sample sizes.

b. The winter of 1978-79, during which no sheep grazing occurred and immediately preceded the initial test winter.

c. The winter of 1980-81, which immediately followed the initial test winter.

Data obtained during 1976-77 and 1977-78 supported the previous analysis. Relative pronghorn densities dropped significantly ($P \leq .05$) from $0.46 \pm .07/\text{km}^2$ before grazing to $0.21 \pm .06/\text{km}^2$ after grazing (Fig. 2). Relative densities appeared to increase in the late winter period for ungrazed units, but the change was not significant ($P > .05$).

The Desert Experimental Range was not grazed by sheep the winter of 1978-79, and so provided an opportunity to determine if our observations of pronghorn densities were consistent from early winter to late winter. This appeared to be true as the early winter mean relative density ($0.90 \pm .20/\text{km}^2$) was very similar to the late winter relative density ($0.80 \pm .21/\text{km}^2$). Additional t-tests were made to determine if significant density changes occurred through the winter on those groups of units that showed change during the 1979-80 winter. These tests showed no significant changes ($P > .05$) in pronghorn densities among units when no sheep were on the range.

Observations in the winter of 1980-81, when pronghorns numbered approximately 230, strongly reinforced the earlier results. Relative densities were only about one-fifth as high after grazing as they were during the pregrazing period ($0.53 \pm .11/\text{km}^2$ as opposed to $2.83 \pm .47/\text{km}^2$) on the grazed units (Fig. 2). Likewise, relative densities on ungrazed units showed a strong increase in late winter as compared to early winter ($1.14 \pm .15/\text{km}^2$ as opposed to $0.51 \pm .13/\text{km}^2$). The changes in relative pronghorn densities on both grazed and ungrazed units were highly significant ($P \leq .01$) for 1980-81.

These findings clearly show that even moderate use by sheep (1 ha/sheep month) renders the range less favorable for pronghorn

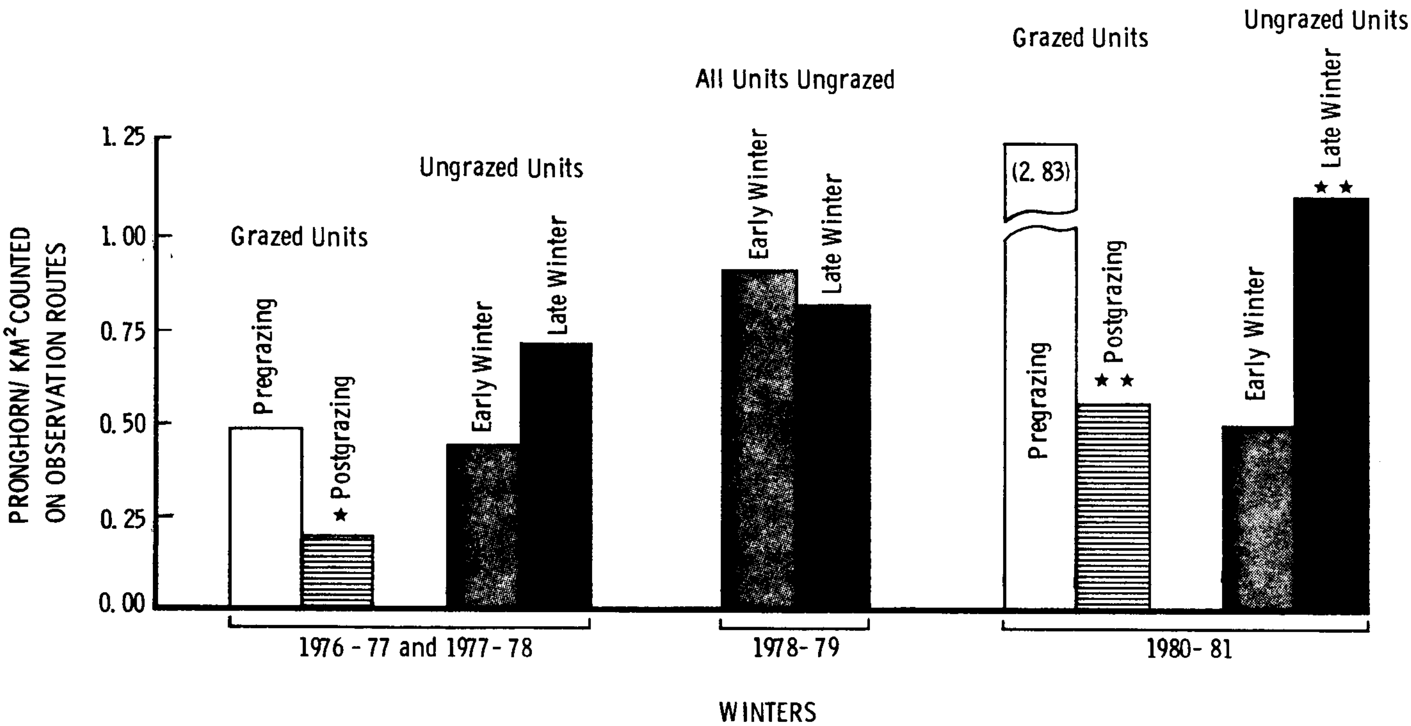

Fig. 2. *Relative pronghorn densities for all winter except 1979-80. Single star (*) indicates significance at 0.05 level, double star (**) indicates significance at 0.01 level.*

Table 1. Comparison of pronghorn and plant community distribution.

Plant community dominant	Pronghorn-days per plant community: Observed	Expected (based on area of community)	Chi-square contribution
Black sagebrush	2176	919	1719.31
Bud sagebrush *(Artemisia spinescens)*	5	15	6.67
Shadscale *(Atriplex confertifolia)*	110	171	21.76
Littleleaf mountain mahogany *(Cercocarpus intricatus)*	84	425	273.60
Winterfat *(Ceratoides lanata)*	396	420	1.37
Narrowleaf low rabbitbrush *(Chrysothamnus viscidiflorus stenophyllus)*	299	131	215.45
Galleta *(Hilaria jamesii)*	115	166	15.67
Utah juniper *(Juniperus osteosperma)*	31	62	15.50
Indian ricegrass *(Oryzopsis hymenoides)*	237	57	568.42
Various warm season grasses *(Sporobolus, Hilaria, Bouteloua)*	1678	2231	137.07
Littleleaf horsebrush *(Tetradymia glabrata)*	2	5	1.80
Broom snakeweed *(Xanthocephalum sarothrae)*	55	36	10.03
Others	2	519	515.00
			3501.66[1]

[1]Greatly exceeds table value ($\alpha = 0.01$) of 26.22.

until the new spring growth begins. At that time, on the Desert Experimental Range, the pronghorn disperse to all units—presumably because new green forage is available and previous dormant-season grazing by sheep no longer has a significant effect.

The prime factor in the avoidance of sheep-grazed units is likely dietary competition for black sagebrush *(Artemisia nova)* (Smith and Beale 1980). This species is a dominant component of pronghorn winter diets on the Desert Experimental Range (Beale and Smith 1970), and also highly preferred by sheep (Hutchings and Stewart 1953). Because in many areas of the Desert Experimental Range production of black sagebrush does not exceed 11 kg/ha, little remains of this preferred plant after sheep have grazed an entire unit.

No statistical evidence was found that pronghorn density or use was related to the previous winter's sheep grazing. Pronghorn density was only related to the current winter's sheep grazing.

Relationship of Pronghorn Distribution to Plant Communities

The distribution of pronghorns was examined in relation to the distribution of plant communities. Vegetation was grouped into 13 broad communities based on the dominant species. Chi-square comparisons were made to determine if the distribution of pronghorn observations among the various community categories was in proportion to the area of the communities (Table 1). Observations for the early and late periods of the winters of 1979-80 and 1980-81 were pooled to examine average winter distributions. A very high calculated chi-square value (X^2=3,502) suggests that few plant communities received pronghorn use proportionate to their area ($P \leq .01$). The largest contribution to the calculated chi-square value was from black sagebrush-dominated communities, which received 2 to 3 times as much pronghorn use as would be expected based on area occupied. Several other communities experienced higher than expected use, for example, those dominated by low rabbitbrush and Indian ricegrass. These small communities occurred in part near watering locations and also had small drainages within them which supported black sagebrush. Pronghorn made little use of communities dominated by summer-growing grasses, gray molly *(Kochia americana)*, and the open playa. Pronghorn also appeared to make little use of littleleaf mountain mahogany, but too much of this community was inaccessible to observers to support a definite conclusion.

Relationship of Pronghorn Distribution to Slope and Aspect

Although pronghorn have a reputation for avoiding rough country, that is not necessarily the case on the Desert Experimental Range. Eleven percent of the area available to pronghorn had slopes in excess of 33%; however, 18% of the animal observations were on these slopes—a significant response ($P \leq .01$). These observations were concentrated on the slopes with black sagebrush communities. Steep slopes dominated by littleleaf mountain mahogany were apparently little used. Therefore, location of plant communities appeared to be more significant to pronghorn distribution than the slope steepness.

Pronghorn also responded significantly ($P \leq .01$) to directional aspect during these winter periods. The proportion of observations was approximately 50% higher on warm aspects (S, SW, and W) than would be expected based on area occupied by these aspects. In addition, observations in late winter on nearly level (ca. 2½% slope) valley floors were about 75% greater than expected as pronghorn dispersed during March and April.

Observation of Marked Animals

Twenty-six pronghorn were individually identifiable because of marked collars placed on them during earlier studies. Movements of individuals observed 6 or more times per winter were mapped and studied. The observations per individual studied varied from

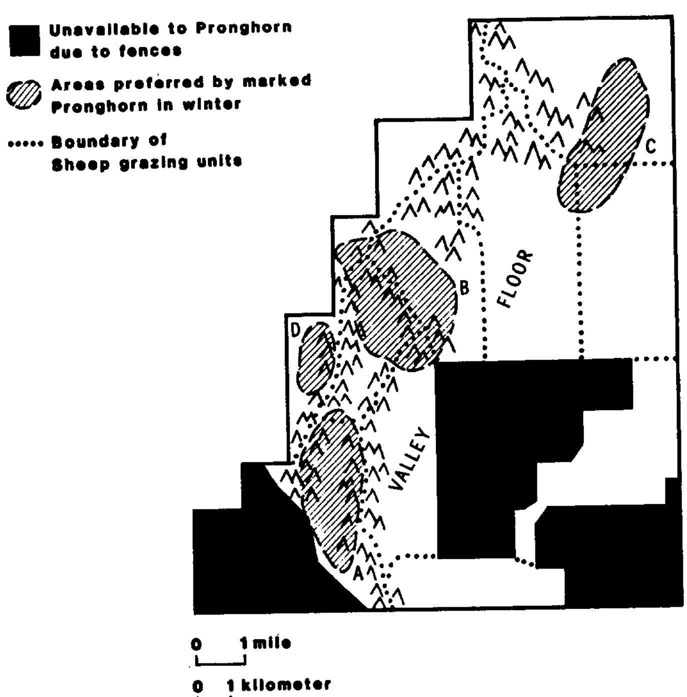

Fig. 3. *Location of areas on the Desert Experimental Range preferred by marked pronghorn in winter.*

6-13 with an average of 9.

In the winter of 1976-77, 14 individually identified females used 3 different areas of the Desert Experimental Range. Two spent the entire winter in about 2-3 km² of area A (Fig. 3), which was rested from sheep grazing. Seven females spent the winter in area B, which had no sheep grazing until March and April when some new green forage was available. The average observed winter use area (calculated by the method of Hayne 1949) for the 7 was 6 km². One female divided her time between areas A and B and had a use area of 16 km². Four females preferred the northeastern portion of the Desert Range (area C). Their winter use area varied from 1½ to 19 km², but they all persisted in their use of area C even though it had been grazed by sheep in midwinter.

Five marked males exhibited similar winter use preference as the females. Two remained the entire winter in area B, 1 made alternate use of A and B, 1 used only C, and 1 was observed in areas A, B, and C. The winter use areas of the males ranged from 5 to 40 km², with a mean of 16 km².

In the winter of 1977-78, 9 individually marked female pronghorn were observed at least 6 times each. Three of these began the winter in area A, but moved to area D for the remainder of the winter after sheep grazing of area A. The average use area for the 3 was 7 km² for the winter, but only about 1 km² when in area D. One other animal occupied area A until it was grazed by sheep, but it was not seen again until March when it was observed at the south edge of area B. It then moved to the valley floor. Five of the 6 remaining animals also spent considerable time in the relatively small area D. Four of these apparently traveled together, moving from the valley floor in November, across area B in December, then remained in area D during midwinter. Two returned to the valley floor in March. The winter use area of these 4 averaged 15 km²; however, about one-half of their observations were within 1 km² of area D. The ninth animal was first seen with the above group shortly before they arrived at area D. It later moved to the valley floor in March.

Only 4 individuals were observed and identified 6 or more times in both winters. Of these 4, 2 individuals used the same area both winters and 2 used different areas.

Relatively few of the moves by marked pronghorn appeared to be directly related to sheep herd movements. Most pronghorn moves were between units ungrazed by sheep. Some individuals seemed to move periodically, but were seldom observed in grazed units. Our interpretation is that the pronghorn, as part of their general movements, may have crossed grazed units, but spent relatively little time on them. Then, when they encountered an ungrazed unit with adequate forage, they perhaps lingered and were more apt to be observed there. This is somewhat different from initial interpretations that pronghorn seemed to remain in a winter grazing unit until sheep grazing competition forced them to move (Clary and Holmgren 1981). Pronghorn were regularly present in ungrazed preferred wintering areas, but based on the movements of individuals, the actual animals present may have changed through time.

Areas A, B, and D all have topography that varies from gently rolling to steep and broken (Fig. 3). Likewise all have substantial areas of black sagebrush-dominated plant communities, and a more varied botanical composition than that available in the more level valley bottoms. Area C differs somewhat from the previous 3 areas in that it has less steep topography and less black sagebrush. There are, however, numerous small ephemeral drainages that contain black sagebrush. The elevation of all 4 preferred areas is predominantly above 1,800 m, which is likely above the boundary of the midwinter cold air inversions.[1] Pronghorn on the Desert Range apparently respond to winter weather conditions because in the previous analysis it was shown they sought the warmer aspects. Protection from wind and the occurrence of warmer nighttime temperatures may have been factors in selection of winter use areas in addition to the relative abundance of their major diet species—black sagebrush.

Conclusions

Winter observations on the Desert Experimental Range show a statistically definable pattern of reduced densities of observed pronghorn on units grazed by sheep and that these densities remained low until spring plant growth had begun. The interpretation is that even moderate sheep use during the dormant period leaves grazing units relatively unfavorable for pronghorn until regrowth occurs—at least on ranges where the key pronghorn forage plants are in short supply.

The winter distribution of pronghorn is strongly affected by plant community distribution. Pronghorn used black sagebrush areas at 2-3 times the amounts expected based on areal coverage even though many of the black sagebrush-dominated communities were on quite steep topography. Pronghorn did not appear to avoid slopes in excess of 33% if black sagebrush communities were present; in fact pronghorn may have preferred broken topography that could attenute severe winter conditions.

The presence of ungrazed areas on the Desert Experimental Range each winter seems to have been important in reducing competitive impacts of sheep grazing (Clary and Holmgren 1981). Periodic movements of pronghorn were a mechanism in their apparent ease in finding areas ungrazed by sheep. If most pronghorn had remained in small specific areas throughout the winter, the presence of rested grazing units available several miles away would have been of little benefit. Likewise, when other uses of the desert affect specific winter range areas, pronghorn can apparently easily relocate if the proper plant communities are available. Permanent destruction of habitat, however, would obviously lead to long-term reduction of pronghorn populations if they are forced to continuously over-concentrate on favorable habitats.

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[1]Ralph C. Holmgren, Provo, Utah, personal communication.

Diethylstilbestrol as a Temporary Chemosterilant to Control Black-tailed Prairie Dog Populations

MONTE G. GARRETT AND WILLIAM L. FRANKLIN

Abstract

Controlling reproduction in pest rodent populations may be preferable to using lethal rodenticides. The effectivenss of diethylstilbestrol (DES), a synthetic estrogen, as a reproductive inhibitor in female black-tailed prairie dogs *(Cynomys ludovicianus)* was examined in a 4-year study at Wind Cave National Park, South Dakota. In 1979 and 1980, a study colony was monitored to determine age structure, reproductive success of individual animals, and rate of colony expansion. In 1981, the colony was divided into control and experimental areas. Application of DES-treated oats (.11% active ingredient) during the breeding season resulted in complete curtailment of reproduction in the experimental group while reproduction in the control group was normal. Results were identical in 1982 when treatment was reversed. There were no obvious effects of DES treatment on subsequent reproductive capability of study animals. In 1981, surface expansion of the study colony was 4X less on the DES-treated side compared with control.

In recent years, research in the use of chemosterilants to control pest rodent populations has been increasing (Howard 1967, Knipling and McGuire 1972, Marsh 1973, Marsh and Howard 1970, 1973, 1976). Chemosterilants reduce the need for lethal rodenticides by concentrating management efforts on reducing natality rather than on increasing mortality. It is more practical to prevent the birth of animals rather than to reduce their numbers after they are fully grown and established in a secure environment (Basler 1964a). Further, chemosterilants are less toxic in baits than rodenticides and pose less hazard of killing humans, pets, or domestic animals (Brooks 1973).

Bennetts et al. (1946) first reported that plant estrogens in subterranean clover *(Trifolium subterranean)* reduced reproductive success in sheep *(Ovis aries)*, and Davis (1961) conducted one of the first experiments in the use of estrogens to control rats *(Rattus norvegicus)*. Howard and Marsh (1969) and Marsh and Howard (1969) reported mestranol (a synthetic estrogen) to be an effective reproductive inhibitor for several rodent species (*R. norvegicus* and *Microtus* spp.). Because such nonsteroidal compounds are inexpensive, highly potent, and effective when taken orally, they are good candidates for chemosterilants.

Although extensively used to increase growth rates in domestic livestock (Trenkle and Burroughs 1978), the antifertility effects of the synthetic estrogen diethylstilbestrol (DES) have been tested with few species. Travis and Schaible (1962) noted reduced embryo counts in mink *(Mustela vison)* treated with DES. Linhart and Enders (1964) reported good bait acceptance and termination of pregnancy in Des-treated captive red foxes *(Vulpes vulpes)*, but field tests indicated insignificant reproductive effects in wild foxes (Allen 1982). The number of female coyotes *(Canis latrans)* successful in breeding was significantly reduced after consuming DES-treated baits in a field trial (Balser 1964b), but no effect was reported in wild skunks *(Mephitis mephitis)* (Storm and Sanderson 1969). Study of antifertility effects of DES in rodents has been mostly limited to lab studies (reviewed by Saunders 1968). However, Pfeiffer (1972) conducted a preliminary study on DES-treated wild populations of black-tailed prairie dogs *(Cynomys ludovicianus)*.

Prairie dogs have been a problem in range management since the western grasslands were first tilled or fenced for the production of crops and livestock (Koford 1958). These herbivorous rodents reduce graminoid standing crop in the vicinity of their colonies and are considered a competitive threat to domestic and other wildlife grazers (Bonham and Lerwick 1976, Hansen and Gold 1977, Klatt and Hein 1978). Although the use of rodenticides has reduced numbers of prairie dogs to a fraction of their original range, this approach has not been altogether satisfactory. In situations in which population reduction is desirable over complete eradication, a temporary chemosterilant may be an effective management tool alone or when used in conjunction with lethal control. As Howard (1967) points out, poisoning large numbers of animals is of little value without some means of preventing or slowing recovery.

Prairie dogs are large, colonial ground squirrels indigenous to the North American shortgrass prairie. Prairie dog colonies are characterized by the presence of burrow mounds and modified vegetation. Colonies are subdivided into socially cooperative family units called *coteries* (King 1955). Individuals of the same coterie restrict their activities within a well-defined *coterie territory,* which they defend against individuals of other coteries. Prairie dogs are polygynous; a coterie typically contains one adult male, 3–4 females, and several yearlings and juveniles of both sexes (Hoogland 1981).

In northern latitudes, prairie dogs breed from late February through March. Gestation is about 34 days, infants remain underground for an additional 5–6 weeks, and weaned juveniles emerge from natal burrows in May and early June (King 1955, Hoogland 1982, Garrett et al. 1982). Individuals of both sexes usually first breed as 2-year-olds, but breeding by yearlings is common in some years (Tileston and Lechleitner 1966, Hoogland 1982, Garrett et al. 1982). Females usually remain in the natal coterie for their entire lives, whereas males generally disperse during their second year (Hoogland 1982, cf. Garrett 1982).

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This publication reports research and recommendations for the use of a chemosterilant to control prairie dogs. It does not imply that uses discussed here have been registered. Chemosterilants must be registered by appropriate state and/or federal agencies before incorporation into a management plan.

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[1]DES was obtained from the Sigma Chemical Company, Box 14508, St. Louis, Mo. Diethylstilbestrol as a Temporary Chemo-sterilant to Control Black-tailed Prairie Dog Populations

Several biological characteristics of prairie dogs make them particularly suited for control with chemosterilant: (1) prairie dogs are monoestrus and therefore would require only one treatment a year to curb population growth; (2) effects on nontarget species would probably be minimal because the prairie dogs' breeding season occurs during winter, when most other small herbivorous mammals are inactive and seed-eating birds are not nesting; (3) prairie dogs usually chase away other small mammals that enter their colony (King 1955), further reducing chances of chemosterilant effect on nontarget species; and (4) prairie dogs are gregarious and populations are sedentary, which makes treatment easy and efficient. In addition, it is possible that reproductive control would be more acceptable to those with strong convictions against the killing of wildlife.

Pfeiffer (1972) reported a smaller percentage of pregnant females sampled from DES-treated colonies in South Dakota. However, he did not find significantly lower juvenile:adult ratios between treated and untreated populations, making these results difficult to interpret. In any given year, reproductive performance may vary greatly among females of different colonies (Garrett et al. 1982). Yearlings produce smaller litters than do adults (Koford 1958) and exhibit estrus later than adults (Foreman 1962), reducing chances for copulating and securing an adequate nest burrow. Thus, a knowledge of female age structure and reproductive histories of colonies tested is required to accurately assess the effects of chemosterilant treatment.

Specific objectives of this study were (1) to test the use of DES as a reproductive inhibitor in prairie dogs, (2) to determine the effects or reduced reproduction on colony surface expansion (i.e., area of modified vegetation), and (3) to examine the effect of DES on the subsequent reproductive success of treated individuals. If DES is an effective temporary chemosterilant, then treated females should be able to produce normally the following year. If treatment results in lower animal density, then colony surface expansion should decrease compared with an untreated area with higher animal density.

Materials and Methods

A *colony* is defined as the physical area inhabited by prairie dogs. The *population* refers to the prairie dogs inhabiting the colony. Thus, colony *expansion* refers to increases in numbers of burrows and area of modified vegetation. Age classes are defined relative to the February breeding season: *juveniles* are individuals ≤7 months postemergence, *yearlings* 8 to 20 months, and *adults* >20 months postemergence.

Field research was conducted in Wind Cave National Park (WCNP), South Dakota. The area is described in detail by King (1955). Prairie dogs in WCNP are protected from shooting, poisoning, and other forms of human disturbance. The study colony was located in sec. 6, T. 6 S., R. 6 E. on an ephemeral watercourse in Wind Cave Canyon. This population has been rapidly growing since its discovery in 1976, and although colony surface expansion occurred at all times of the year, expansion was most rapid during the months of peak animal density following the emergence of juveniles (Garrett 1982). The colony expanded from 0.5 ha in 1979 to 2.5 ha in 1982.

The behavior and reproduction of prairie dogs at the study colony was monitored during 4 reproductive seasons from May 1979 to June 1982. To obtain accurate information on individual animals, all prairie dogs were periodically captured and marked with eartags and fur dye. Juveniles were captured immediately after emerging from natal burrows. Procedures used for livetrapping, handling, and marking prairie dogs are outlined by Hoogland (1977, 1979). Data were recorded by observing the animals from an observation blind.

The colony was mapped at regular time intervals, and a planimeter was used to measure colony expansion. Coterie compositions and territorial boundaries were determined as described by King (1955) and Hoogland (1981).

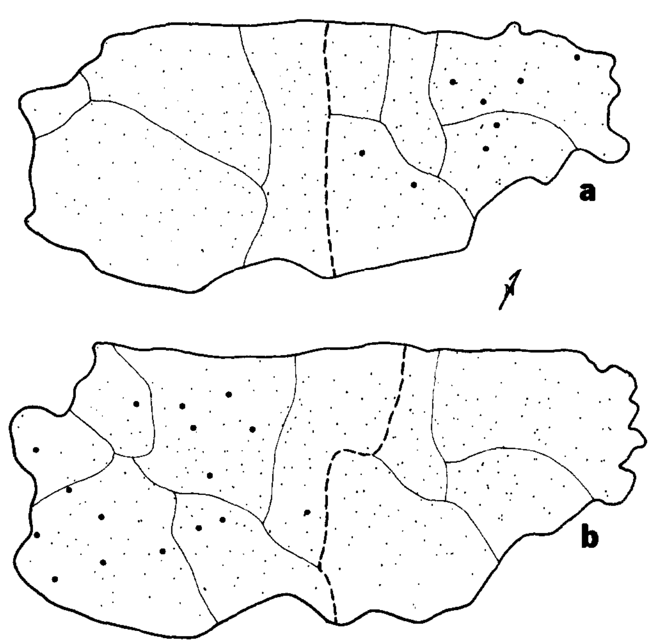

Fig. 1. *Wind Cave Canyon prairie dog colony 1981 (a) and 1982 (b). Area of modified vegetation indicated by heavy solid line. The heavy broken line distinguishes the experimental and control areas. Coterie territory boundaries are delineated by thin solid lines. Burrows (dots) from which litters emerged are circled.*

The study colony was divided into east and west sides, the sides serving as experimental units. In 1981, the west side consisting of 4 coterie territories and 21 females (11 adults, 10 yearlings) was the experimental area; the control area on the east side consisted of 5 coterie territories and 13 females (9 adults, 4 yearlings) (Fig. 1a). Treatment was replicated in 1982: the east side was the experimental area with 20 females (9 adults, 11 yearlings), and the west side was the control with 18 females (all adults) (Fig. 1b). Because of changes in territorial boundaries, the 1982 delineation of experimental and control areas was determined by the residence of females (i.e., females not treated in 1981 received DES in 1982, and vice versa).

Numbers of productive and unproductive females in the pretreatment years (1979 and 1980) were compared to determine differences between east and west sides. The same analysis was used for 1981 and 1982 to determine the effect of DES treatment on control and experimental sides. To account for possible confounding effects of the DES treatment to the west side in 1981, reproductive success of females of the west (control) side in 1982 was compared with that of females in 1979 and 1980.

Twenty-five grams of DES were mixed with 22.7 kg (50 lb) hulled oats, 13 g yellow dye, and 156 g lipoidal (Pfeiffer 1972). Mixing was facilitated by the state bait-mixing station, Pierre, S. Dak. One cup of the DES-oat mixture (.11% active ingredient by weight) was placed at each active burrow (loose dirt, fresh scats) in the experimental side of the colony. A placebo oat mixture identical to the above, but without DES, was administered to the control side. Because prairie dogs confine their activities to their coterie territory (Hoogland 1981), individuals of the same coterie probably ate only the oats in their particular territory.

The colony was treated twice during the first week of March, the period of peak breeding in 1981 and 1982. The placebo mixture was consumed more quickly than the DES mixture, suggesting that DES may impart an unattractive taste to the oats. However, all the bait was eaten within a week, possibly because little alternative foods was available during that time of year. Prairie dogs were the only animals observed feeding on the bait.

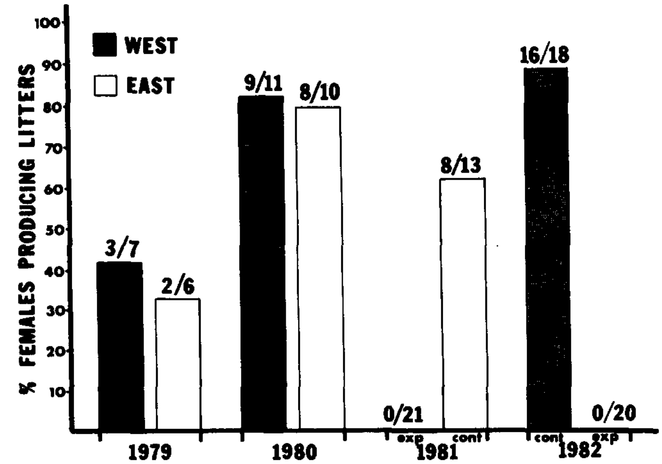

Fig. 2. *Percentage of females producing litters for the 2 sides of the study colony during the 4-year study period. DES was administered during 1981 and 1982: experimental (exp) and control (cont) areas.*

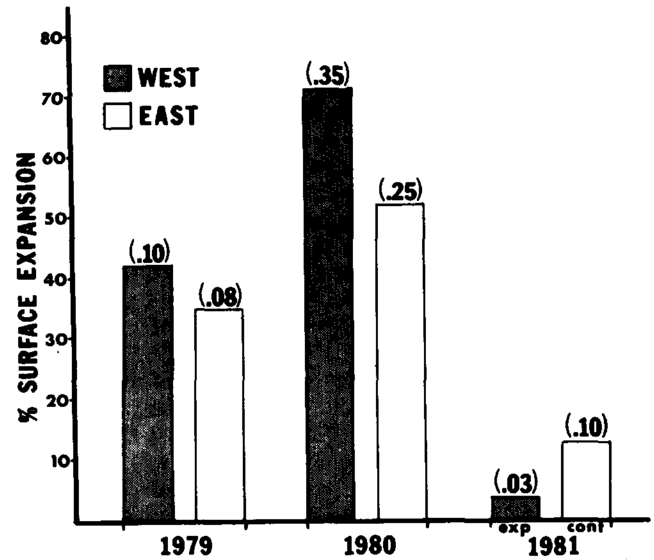

Fig. 3. *Percentage surface expansion for the 2 sides of the study colony. Actual increases in surface area (ha) are indicated in parentheses.*

Results and Discussion

Reproduction was highly variable from one year to the next. For example, only 5 of the 13 (38%) total females of the study colony produced litters in 1979, but 17 of 21 (81%) produced litters in 1980. However, productivity in these years was similar for the east and west sides of the colony (P=.54, Fisher's Exact Test) (Fig. 2). In 1981, 8 of 13 (62%) females not treated with DES produced litters, whereas the treated females (N=21) were entirely unproductive. Pfeiffer (1972) attributed reproductive failure to embryo death and resorption. Results were similar in 1982 when DES treatment was reversed: the 20 treated females did not produce litters, whereas 16 of 18 (89%) females treated with DES in 1981 brought up litters in 1982 (Fig. 1 and 2). For 1981 and 1982, reproduction was significantly less likely in the DES-treated sides of the colony (P=.000, Fisher's Exact Test). Of 7 females that produced litters in 1980, 6 (86%) produced litters in 1982, the year following their treatment with DES. Only 2 females that reproduced in 1979 were present on the west side in 1982; both produced litters.

Because the reproductive characteristics of yearlings can be different than those of adults, the number of yearling females in the population may affect the interpretation of results. The number of yearlings may affect the proportion of females producing litters. In both treatment years, there was a greater proportion of yearling females in the experimental group compared with the control group. Therefore, the control females may have been expected to reproduce more successfully than the experimental females. However, although King (1955) and Hoogland (1982) found that yearlings do not usually breed, reproduction by yearlings was common in this particular colony (Garrett et al. 1982). Indeed, yearlings were more productive than adults of the control group in 1981 (Table 1). Koford (1958) suggested that food abundance was a more important factor in yearling reproduction than body weight or physiological ineptitude. Garrett et al. (1982) concluded that abundant food resulted in rapid development and high reproductive rates of prairie dogs at this colony.

The number of yearling-produced litters may also affect juvenile body weight. The juveniles produced by 16 adult females of the control group in 1982 weighed significantly less than those produced by 8 females of the control group in 1981 (t = 2.69, df = 95, P<.01). Reduced juvenile weight in 1982 may have been a residual effect of the DES treatment to the females of the west side in 1981. However, mean weight of juveniles varied greatly between non-treatment years (Table 1). In addition, mean juvenile weight in litters produced by yearlings was significantly greater than adult-produced litters (1980: t = 56.68, df = 54, P<.001; 1981: t = 3.23, df = 28, P<.005). Because there were no yearling females present in the control group in 1982, mean juvenile weight was expected to be less compared with the control group in 1981 when yearlings were contributing heavier pups.

Litter size varied greatly between years and sides of the study colony, ranging from 2.8 on the east side in 1980 to 4.2 on the west (control) side in 1982 (Table 1). Because yearling litters tend to be

Table 1. Comparison of demographic properties between the two sides of the study colony. Numbers are mean ± SD. Sample sizes are indicated by parentheses. (E) = Experimental Area (C) = Control Area

		% Adult reproduction	% Yearling reproduction	Juvenile weight (g)	Litter size
1979	West	Unk.*	Unk.	226.5 ± 76.7 (10)	3.3 ± 1.5 (3)
	East	Unk.	Unk.	231.5 ± 40.2 (9)	4.0 ± 2.8 (2)
1980	West	100 (7)	50 (4)	138.8 ± 18.1 (33)	3.8 ± 0.7 (9)
	East	100 (5)	60 (5)	138.5 ± 38.0 (23)	2.8 ± 1.2 (8)
1981	West (E)	0 (11)	0 (10)	—	—
	East (C)	56 (9)	75 (4)	166.2 ± 25.2 (30)	3.8 ± 0.9 (8)
1982	West (C)	89 (18)	—**	150.0 ± 28.4 (67)	4.2 ± 1.2 (16)
	East (E)	0 (9)	0 (11)	—	—

*Exact ages of study animals were unknown during the first year of study.
**There were no yearlings in 1982 because no litters were produced on the west side in 1981.

smaller than adult litters, the large litter sizes in 1982 probably were due to lack of yearlings rather than to latent effects of previous DES treatment. In addition, females of the control group in 1982 had not been physiologically stressed with reproduction the previous year and, therefore, were expected to produce larger litters.

King (1955) found no direct relationship between density and colony expansion, perhaps because of the complexity of factors involved. However, he suggested that population pressure may be important influence on expansion. Koford (1958) reported a direct correlation between the appearance of juveniles and the time of major expansion. Before juvenile emergence in 1981, animal density was similar on both sides of the colony. After emergence, density had increased significantly in the control area compared with the DES-treated area (Exp. = 39.7 animals/ha [before and after]; Cont. = 28.1 [before], 66.4 [after]; $X^2 = 7.99$, df = 1, $P < .005$). Although colony expansion on the west side was greater than the east in 1979 and 1980, expansion of the west side (experimental) was 4X less than that of the east (control) following DES treatment in 1981 (Fig. 3). Note that colony expansion in 1979 and 1980 somewhat reflects the proportion of females producing litters (see Fig. 2). These data suggested that expansion is related to animal density, and that control of prairie dogs' reproduction can reduce colony expansion.

Conclusions

Treatment of prairie dogs during the breeding season with DES inhibited production, and lower animal density resulted in reduced colony expansion. There seemed to be no adverse effects of DES the year following treatment. In previously treated individuals, there was no effect on the proportion of females reproducing, size of litters, or weight of juveniles.

Perhaps effective prairie dog management should involve an integrated approach; that is, use of rodenticide for initial reduction and irregular DES treatments thereafter to maintain the population at desirable levels. However, if the use of rodenticide is impossible or objectionable (e.g., national parks, captive populations), population reduction could be achieved with annual treatments of DES alone. This study was conducted on a small scale and under rigorous control. Until the effectiveness and efficiency of using DES on larger areas is confirmed, practical application of this chemosterilant must remain tentative.

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An Indirect Method to Estimate the Aerial Biomass of Small Single-stemmed Woody Plants

R.D. FITZGERALD

Abstract

The above-ground biomass of unbrowsed, and subsequently, browsed plants was estimated from measurements of plant height. Unbrowsed weight was estimated from the quadratic regression of plant weight on plant height. Browsed weight was estimated by inserting coefficients which were appropriate for a given proportion of the original height into the above quadratic equation for unbrowsed weight. Estimation of these coefficients involved 3 steps. (1) Sample plants were cut into sections, dried and weighed. From these data, quadratic relationships between weight and height or portion (%) of height were established. (2) Coefficients from these relationships were then plotted against percent height, and a polynomial regression fitted. (3) The polynomial regression was used to predict coefficients for any given percent height. These predicted coefficients could then be inserted into the original quadratic equation for full height for determination of the weight of any given proportion of the full height. The technique depends on a good relationship between plant height and weight, such as might be expected to occur with the unbranched shoots of suckering aspen *(Populus tremuloides)*. It is useful where nondestructive estimation of the aerial biomass of browsed plants is required, and it avoids the tedious measurement of the diameter of browsed stems.

In an experiment in regenerating aspen forest after burning, the relative preference of cattle for the major woody species was determined by estimating the relative daily consumption of each species (FitzGerald 1982). This approach required a daily estimation of the aboveground biomass of each species.

The most direct method of determining weight of aboveground material is by destructive sampling, drying, and weighing. However, there are numerous research situations in which a nondestructive estimate of aboveground biomass may be required, for example in order to follow the growth of particular plants, or where the destructive sampling of some plants in a population has a measurable impact on the growth of the remainder.

There are a number of established techniques for indirect estimation of the biomass of the aerial portions of trees. These generally involve measurements of the trunk diameter (DBH) and the tree height (Perala 1973, Berry 1973, Bella and De Franceschi 1980). Since tree height is difficult to measure, foresters frequently have opted for quite satisfactory estimations based on DBH (Bartos and Johnston 1978, Koerper and Richardson 1980). However, estimation of browsed plants presents special problems, since the diameter bears different relationships to the biomass of browsed and unbrowsed plants. Measurement of the diameter of browsed stems would give an estimate of the weight of plant material removed (Basile and Hutchings 1966), but such measurement would be prohibitively laborious.

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Height measurements have provided a satisfactory estimate of biomass in circumstances which permitted accurate measurement (Kelly and Walker 1976, Harrington 1979). Height is a convenient measurement for small (<2 m) single-stemmed woody plants, and might give an indication of the extent of browsing if the height of the original unbrowsed plant were known.

Hence a predictive estimation of the dry weight of the 4 major woody species of the regenerating aspen forest was developed from plant height, for unbrowsed and subsequently browsed plants. The relationship between height of browsed plants and their weight involved a special adaptation of the direct regression of height on weight.

Methods

Field Data

Aspen forest which was regenerating after fire was heavily grazed by cattle for about 10 days as part of an experiment reported elsewhere (FitzGerald 1982). In order to estimate daily changes in species biomass in the grazed plant community, the height and density of each of the major woody species was measured daily for the duration of grazing. Measurements were made within fixed 1-m² quadrats. There were 3 replications of each grazed community sampled, and 10 fixed quadrats in each replication.

Height: Weight Relationships

A sample of the aerial portions of 40 plants of each of the major woody species— aspen *(Populus tremuloides)*, rose *(Rosa woodsii)*, raspberry *(Rubus strigosus)*, and snowberry *(Symphoricarpos occidentalis)*—were randomly collected from regenerating forest adjacent to, and treated identically to, the experimental plant community in which biomass estimates were to be made. The samples were taken to the laboratory and cut into 6 sections, oven dried at 65° for 24 hours, and weighed. The sections consisted of the lower 50% of the stem divided into 2 equal portions (25%) each, and 4 equal portions of the upper 50% (12.5% each), which allowed a cumulative determination of the weight of 25% of the height, 50%, 62.5%, 75%, 87.5%, and full height.

The regressions which best fitted the relationship between weight and full height were quadratic polynomials forced through the origin, as follows.

$$W = b_1 H + b_2 H^2 \qquad 1$$

where W = estimated aerial weight
H = total height of plant
b_1 and b_2 are calculated coefficients.

This form of regression was also the best fit for regressions of weight on various portions of height. The coefficients from these quadratic regressions were plotted against proportion of height. Figure 1 illustrates the relationship between one such coefficient

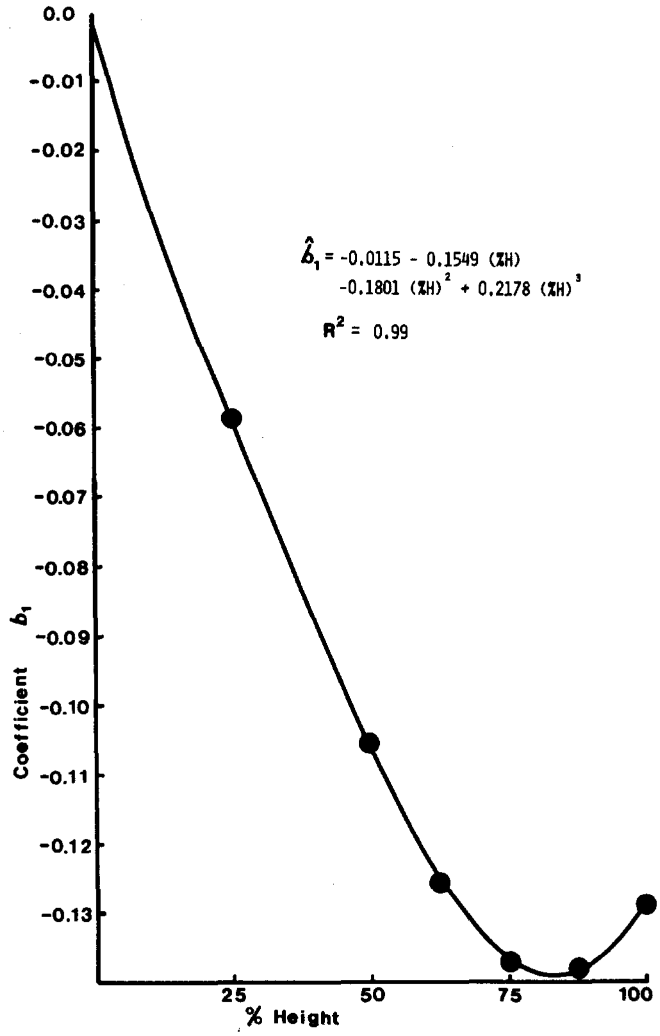

Fig. 1. *Coefficients* b_1 *from quadratic regressions of weight on height or proportion of height plotted against percent height, and showing the fitted third degree polynomial regression curve, for aspen sampled in August 1979.*

(b_1) and proportion of height of aspen suckers in their first season of growth. From this graph (or, more precisely, from a regression fitted to these points) it was possible to determine b_1 for any given %H. In this way, coefficients b_1 and b_2 could be determined for any given browsed height. Coefficients for a given browsed height could then be inserted into the height:weight quadratic regression equation (Equation 1). Hence, providing plant height before (H) and after (%H) browsing was known, the weight of the plant browsed to any given height could be calculated.

Comparison with Direct Harvesting

The calculated weight estimates were verified by comparing them with direct harvesting estimates. The calculated plant weight for each species was multiplied by plant density for that species to give total aboveground biomass per unit area. Biomass estimates for each species in the plant community were summed to give an estimate of total aboveground biomass. This was compared with biomass estimates produced by harvesting all plant material within 0.5-m² quadrats placed in close proximity to the fixed sites in which plant height and density estimates had been made.

Results and Discussion

Sampling of plants adjacent to the experimental population was necessary on every occasion that a series of weight estimates was required. Height: weight relationships from one such sampling (aspen in August 1979) are presented here (Tables 1 and 2) to illustrate the method. The regression coefficients for the model which best fitted the relationship between height and weight of aspen in August 1979 (Equation 1) are presented in Table 1, which showed coefficients and R^2 values.

Table 1. Regression coefficients for quadratic regressions through the origin, for weight on proportion of height (%), for aspen sampled in August 1979.

	Regression coefficients		
Height (%)	b_1	b_2	R^2
100	-.1292	.0035	.96
87.5	-.1380	.0035	.97
75	-.1373	.0033	.97
62.5	-.1271	.0029	.96
50	-.1056	.0024	.96
25	-.0583	.0012	.95

The relationships between each of these coefficients (b_1 and b_2) and percent height (%H) were best described by third degree polynomials as follows.

$$b_i = b_o + b_1(\%H) + b_2(\%H)^2 + b_3(\%H)^3 \qquad (2)$$

where i = 1 or 2.

Coefficients for these equations for aspen are shown in Table 2. The b_1:%H relationship was illustrated diagramatically in Figure 1. The coefficients b_1 and b_2 for any given %H could be read from the diagram or calculated from the polynomials (Equation 2), and inserted into Equation 1. Since unbrowsed plant height (H) was known, browsed or unbrowsed plant weight could be calculated.

Table 2. Polynomial regression coefficients for regressions of b_1 and b_2 values from the quadratic regression (Table 1) on percent height, for aspen sampled in August 1979.

Quadratic	Regression coefficients				
coefficient	b_0	b_1	b_2	b_3	R^2
b_1	-.0115	-.1549	-.1801	.2178	.99
b_2	.0001	.0038	.0037	-.0041	.99

The form of the regression models was the same for all species examined, at all sampling times.

In Table 3 a comparison is made of the estimates of the total biomass of woody species from height/density measurements and the estimate from direct harvesting. In no case are the two approaches significantly different, but the trend of over-estimation by direct harvesting or underestimation by height measurement is apparent. The discrepancy arose primarily because the height/-density technique took no account of branching which, in some species (mainly rose), may have contributed additional weight to tops. The relationships between the estimations at different dates were consistent, and, in most experiments, the comparative aspect of the estimations is more important than the absolute values.

The effectiveness of the technique is dependent on the existence of a good relationship between plant height and plant weight such as occurs with young unbranched aspen suckers. The height:weight

Table 3. Biomass (kg/ha^{-1}) of woody species at four sampling times estimated from height/density and from direct harvest, showing 95% confidence intervals.

Sample	Estimation type			
Time	Height/density	Rank	Direct harvest	Rank
1979 Early	455 ± 91	4	1186 ± 774	4
1979 Late	3103 ± 186	1	4125 ± 1183	1
1980 Early	824 ± 90	3	1242 ± 559	3
1980 Late	1453 ± 147	2	2025 ± 1075	2

relationship for rose, on the other hand, was satisfactory in the first year after the fire ($R^2 = 0.96$), but became poorer in the second year ($R^2 = 0.87$) as rose plants became more branched.

The technique was useful here where the experiment required repeated observations on the same plants as browsing proceeded, and where destructive sampling would have had a marked impact on treatment effects. It may also be useful in range experimentation where the loss of plant material from browsing of small erect species must be estimated but measurement of the diameter of browsed stems is impractical.

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Long-term Effects of Big Sagebrush Control on Vegetation and Soil Water

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Abstract

Herbaceous productivity of mountain big sagebrush *(Artemisia tridentata* spp. *vaseyana)* areas sprayed with 2,4-D (2,4-dichlorophenoxy-acetic acid) was nearly twice that of untreated areas 10 years after spraying, while the number of sagebrush plants on treated areas was 4% of that before spraying. Soil at the Wyoming study site was a Youga loam (Argic Cryoboroll). On treated areas, soil water depletion from the surface 0.9 m of soil slightly exceeded that of untreated areas beginning the third year after spraying when herbaceous vegetation had fully responded to release from sagebrush competition. Water depletion in soil 0.9 m to 1.8 m deep was substantially less on sprayed areas compared to unsprayed areas. Seasonal water depletion in the surface 1.8 m of soil was reduced 31% the year of treatment, and about 7% between 5 and 11 years after treatment. Mathematical relationships were developed to predict the effect of sagebrush control on seasonal water depletion in the surface 1.8 m of soil, the surface 0.9 m of soil, and soil 0.9-1.8 m deep.

Control of big sagebrush *(Artemisia tridentata)* with the herbicide, 2,4-D (2,4-dichlorophenoxyacetic acid) beginning in the late 1940's revolutionized management of sagebrush rangeland. Millions of acres have been sprayed to benefit livestock forage production. The response by vegetation to spraying has been investigated at numerous locations in years immediately after treatment, but information about reestablishment of big sagebrush on treated areas is less common.

Both biotic and abiotic values are affected by spraying. Hydrologic impacts, for example, have received little attention compared to vegetative responses. The soil water regime may be altered when deeply rooting big sagebrush is replaced by shallower rooting herbaceous species and there is speculation that treatment can increase water yields in some locations.

This paper focuses upon the responses by vegetation and soil water to big sagebrush control 6 to 11 years after treatment. Treatment responses in the first 5 years were previously reported (Sturges 1977).

Vegetation Characteristics

Spraying big sagebrush vegetation with 2,4-D commonly increases grass production 2 to 3 times above pretreatment levels, where adequate populations of herbaceous species are present (Hull et al. 1952, Hyder and Sneva 1956, Tabler 1968, Miller et al. 1980). Forb production is suppressed by spraying, but control of big sagebrush by burning does not greatly alter vegetative composition (Harniss and Murray 1973, Nimir and Payne 1978).

Sagebrush control is not a permanent type conversion, but the time required for big sagebrush to return to pretreatment levels is quite variable. Harniss and Murray (1973) found that grass and forb production remained above preburn levels for 12 years after a mountain big sagebrush *(A. tridentata* spp. *vaseyana)* stand was burned, but was below preburn levels 30 years after treatment. The useful life of a spray project in Oregon exceeded 17 years (Sneva 1972). Sagebrush was a minor vegetation component in the first decade after treatment, but sagebrush density was similar to untreated vegetation in the fifteenth year. Big sagebrush reestablishment was investigated by Bartolome and Heady (1978) in another Oregon study. The age of sagebrush plants growing on sprayed areas indicated that treatment seldom killed all plants and that most reestablishment occurred in years immediately following treatment. Thilenius and Brown (1974) and Johnson (1969) investigated the return of big sagebrush to sprayed areas in Wyoming.

Soil Water Withdrawal Characteristics

Changes in the soil water regime that follow control of big sagebrush depend upon rooting depths of sagebrush and replacement herbaceous species and upon the depth of soil water recharge (Sturges 1977). Several studies indicate that water withdrawal in the surface meter of soil decreases slightly the first 2 years after sagebrush control. (Sonder and Alley 1961, Cook and Lewis 1963, Tabler 1968, Shown et al. 1972, Sturges 1977). Thereafter, water use by treated and untreated vegetation is similar.

A substantial reduction in seasonal water withdrawal was detected at 2 Wyoming sites when mountain big sagebrush was sprayed. Tabler (1968) found that seasonal evapotranspiration decreased 14% the second year after spraying based on measurements to a 1.8 m soil depth, while Sturges (1977) detected differences of 19, 15, and 8% in the first, second, and fifth year after treatment, respectively. Treatment differences in seasonal water use were located almost entirely in soil 0.9 m to 1.8 m deep and accrued while vegetation was actively growing. No soil water study extended more than 5 years beyond the treatment year.

Experimental Site

The study was performed 29 km west of Saratoga, Wyo., at an elevation of 2,225 m on the Stratton Sagebrush Hydrology study area. Annual precipitation from 1969 to 1980 averaged 52.2 cm while summer precipitation (June–September) averaged 10.4 cm. About two-thirds of total precipitation fell as snow. A mature stand of mountain big sagebrush inhabited the site at study initiation in 1969. At this time about 20% of the plants were between 21 and 30 years old, 20% were 31 to 40 years old, and 35% of the plants were 41 to 50 years old. Understory vegetation was mainly Idaho fescue *(Festuca idahoensis)* and blue grasses (*Poa* spp.). The site was grazed by sheep until the study began, but then was fenced to exclude livestock grazing.

The study site was located on a north-facing hillside in a moderate snow catchment, and except for 2 winters, snowmelt in the spring was sufficient to fully recharge soil water levels. Soil developed in place from sandstone of the Brown's Park Formation and is an Argic Cryoboroll. The A horizon of the Youga series is 36 cm thick and has a loam texture, while the B horizon is 56 cm thick and has a loam to clay loam texture. The C horizon is a gravelly loam and contains numerous rock fragments; roots, however, freely penetrate the horizon.

The 14 0.4-ha experimental units were arranged in 7 randomized blocks; thus each block contained 2 of the 0.4-ha experimental units. Herbicide was applied to 1 randomly selected experimental unit within each block in 1970 while the other unit remained untreated. Treated units were sprayed with 2,4-D appl··d from a truck-mounted spray rig at the rate of 3.1 kg ai/ha. Re ·ining live

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plants were hand-sprayed the following year, so that sagebrush mortality approached 100%.

Vegetation Measurements

Herbaceous productivity, including the leaves and current year's twig growth of sagebrush, was measured the year before spraying, the year of spraying, and 1, 2, 3, 10 and 11 years after spraying. An electronic capacitance meter was utilized for production measurements on undisturbed experimental units using procedures described by Morris et al. (1976). The capacitance meter was also used on spayed experimental units from 1970-1972, and in 1980. In 1969 production plots on both treatments were clipped and were also clipped on sprayed experimental units in 1973 and 1981. The number of plots that were clipped and that were read with the capacitance meter each year is indicated (Table 1). Clipped and metered plots were 30 by 61 cm in size and were randomly located each year. Measurements were taken in mid-July as grass species matured. Clipped vegetation was separated into sagebrush, grass, and forb components and oven-dried for 24 hours at 105° C before weighing.

Canopy cover of big sagebrush was determined by the line intercept method on all 14 experimental units in 1969. That portion of the sagebrush crown containing live stem or leaf tissue was considered crown intercept; measurements were taken along five randomly located transects within each 0.4 ha experimental unit. Transects were 15.2 m long and two of them were used to determine sagebrush density by counting the number of plants rooted within a belt 1.3 m wide and 7.6 m long (0.001 ha). Canopy cover of sagebrush on unsprayed experimental units was remeasured in 1980 using the same sampling procedures as employed in 1969.

The density of big sagebrush growing on sprayed experimental units 10 years after treatment (1980) was determined by counting the number of plants rooted within circular plots 5.0 m in diameter (0.002 ha). Sagebrush was counted on 5 randomly located plots in each 0.4 ha experimental unit. No attempt was made to distinguish between sagebrush seedlings and older plants. Bartolome and Heady (1978) noted that big sagebrush can persist as a seedling-sized plant for a number of years, so that age determination based on size is not reliable.

Soil Water Measurements

Soil water content was measured with a neutron moisture meter at 4 aluminum access tubes randomly located within each 0.4-ha experimental unit. Six depth measurements, beginning 15 cm below the surface and continuing to a 168 cm depth by 30.5 -cm increments, were made in each access tube. Average plot moisture content at the 6 measurement depths on each sampling date was calculated from data collected in individual access tubes. An initial measurement was made each spring immediately following snowmelt, usually in May. A final measurement was made about October 1, when vegetation growth for the year had been terminated by cold weather.

The change in soil water content between the spring and fall measurement was used to evaluate the effect of sagebrush control on summer water depletion. Water use information was not available in the fourth and sixth year following treatment. Soil water measurements were also taken at 2- to 3-week intervals through the growing season 1, 2, 3, 5, 10, and 11 years after treatment to detect changes in the soil water use pattern in years subsequent to spraying.

Data Analysis

The 14 0.4-ha experimental units (whole units) were arranged in 7 randomized blocks. Soil water data were analyzed statistically utilizing a split-plot design in which the 6 measurement depths served as subunits. This model permitted testing for differences in soil water withdrawal between sprayed and unsprayed experimental units, testing for differences in water use at the 6 measurement depths, and testing for a treatment-depth interaction. A variance analysis was made each year based on the change in soil water content between the first measurement in the spring and the last measurement in the fall. Analyses based on change in soil water content between successive sampling dates were performed in years when data were collected through the growing season. A modified "t" value, calculated for a split-plot experimental design, was used to test treatment differences in water depletion at a given soil depth for significance (Steel and Torrie 1960). Statistical significance in this paper is based on a 0.05 level of probability.

Differences in the composition of vegetation, herbaceous productivity, and canopy cover of sagebrush, between sprayed and unsprayed experimental units were tested for statistical significance within a randomized block design. Analyses were based on the average value of parameters for each 0.4-ha experimental unit as calculated from replicate measurements on a unit. The yearly variance analyses for sagebrush, grass, and forb yields were based on information collected from clipped plots; the analysis for total herbaceous yield was based on information obtained with the capacitance meter for years this instrument was used. An arcsine transformation was made on herbage composition data before performing the analysis of variance.

Results

Composition and Yield of Vegetation

Prior to treatment, experimental units assigned to the spray and nonspray treatments had similar composition (Table 1) and yield characteristics (Fig. 1). Vegetation was dominated by big sagebrush, which contributed about 73% of total yield while grasses and forbs contributed 23% and 4%, respectively, of total yield. Environmental factors influencing growth the first 3 years after spraying were comparable to those experienced 10 and 11 years after spraying. Grass and forb production on untreated experimental units averaged 504 kg/ha the first 3 years after treatment and 497 kg/ha in the tenth and eleventh posttreatment years.

The response of vegetation to treatment was comparable to that reported from other studies following control of big sagebrush with 2,4-D. Grass yields were 2.4 times greater on sprayed experi-

Table 1. The number of herbaceous production plots clipped and read with the capacitance meter in each experimental unit and percentage composition of vegetation for sprayed and untreated experimental units.

	No. plots/exp. unit				Percent composition					
	Spray		Unspray		Sagebrush		Grass		Forb	
Year	Clipped	Meter	Clipped	Meter	Spray	Unspray	Spray	Unspray	Spray	Unspray
1969	10	0	10	0	74	71	22	25	4	4
1970	2	15	2	15	0	63*	92	29*	8	8
1971	5	10	5	10	0	61*	99	35*	1	4*
1972	5	10	5	10	0	67*	98	29*	2	4
1973	10	0	5	10	0	66*	98	29*	2	5*
1980	2	10	2	10	0	48*	96	45*	4	7
1981	6	0	2	10	3	54*	95	45*	2	1

*Significant difference between treatments at the 0.05 level of probability.

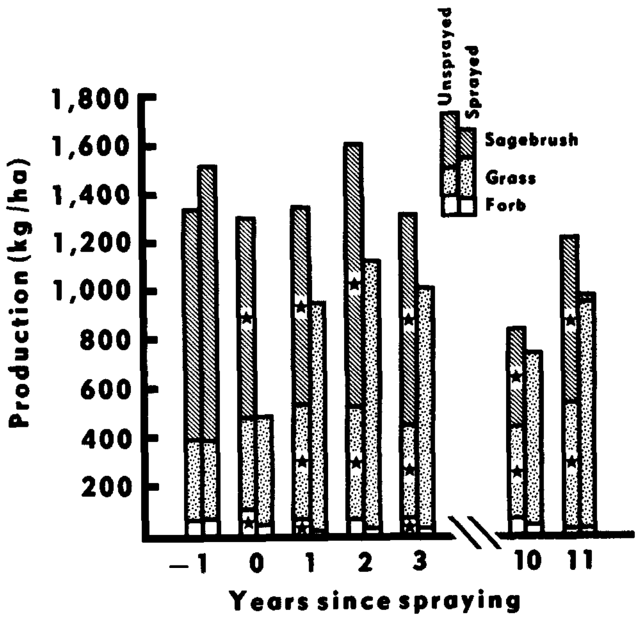

Fig. 1. *Herbaceous productivity of vegetation at sprayed and unsprayed experimental untis through 11 years after treatment. A star indicates that treatment differences for that class of vegetation are significant at a 0.05 level of probability. Total herbaceous yields were significantly reduced by spraying 0, 1, 2, and 3 years after treatment.*

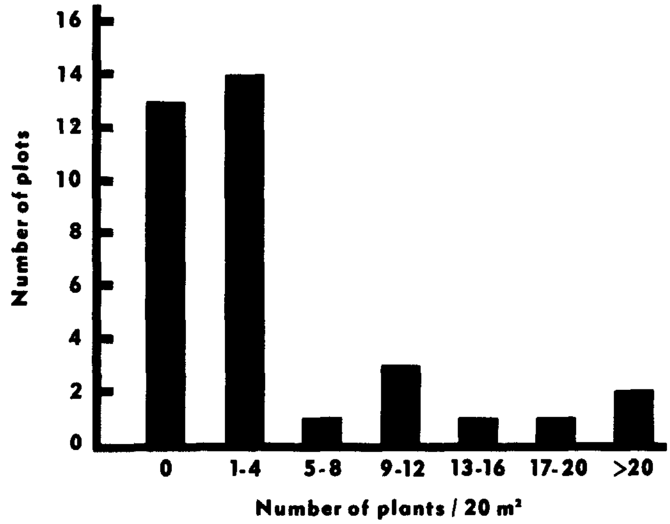

Fig. 2. *Density of big sagebrush on treated experimental units 10 years after spraying with 2,4-D. Five plots that were 20 m² were sampled on each 0.4 ha experimental unit.*

mental units than on unsprayed units in the 3 years after spraying and 1.9 times greater 10 and 11 years after spraying. Thus, there appeared to be some slippage in treatment effect with time. Grass yields of treated experimental units were significantly higher than those of untreated experimental units in all posttreatment years while forb yields were depressed significantly 0, 1, and 3 years after spraying.

The total yield of vegetative matter was significantly reduced by spraying in all but the tenth and eleventh posttreatment years because increased grass yields did not completely compensate for the loss of big sagebrush herbage. This aspect of treatment is not considered when effects of sagebrush control are evaluated only in terms of livestock grazing values. However, the decrease in total production has important hydrologic implications because of the use of soil water by vegetation.

Big Sagebrush Characteristics

Big sagebrush established on sprayed experimental units after treatment despite a high herbaceous productivity level and the absence of livestock grazing. However, it was a minor vegetation component in the first decade following treatment. Sagebrush's density was 50,700 plants/ha before treatment and 2,100 plants/ha 10 years after treatment. The distribution of sagebrush plants was spotty in 1980 and about a third of sample locations were still free of sagebrush (Fig. 2). Small areas of bare soil or disturbed sites such as ground squirrel or badger holes provided favorable locations for seedling establishment.

The importance of big sagebrush on unsprayed experimental units decreased sharply between 1973 and 1980. Canopy cover of sagebrush was 27.5% in 1969 and 18.1% in 1980, a significant reduction. Herbage yields of sagebrush were sharply lower in 1980 and 1981 compared to previous years (Fig. 1) and its contribution to total production also decreased (Table 1). The advanced age of the stand, rodent depredation, but primarily damage inflicted by an unidentified fungus, contributed to the decline of sagebrush. The snowmold fungus was first noticed in 1973 following snowmelt and damage caused by the fungus was readily apparent in subsequent years.[1] In a given year, the fungus only attacked individual branchlets of the sagebrush canopy, but entire plants were sometimes killed after a few years.

Rodents (presumably voles [*Microtus* spp.]) caused localized mortality of big sagebrush by girdling the trunk of plants growing on untreated experimental units during the 1971-72 and 1979-80 winters. A similar phenomenon attributable to voles was noted by Mueggler (1967) and Tabler (1968). Frischknecht and Baker (1972) believed conditions favoring such depredation occur when vole numbers suddenly increase on sagebrush rangelands that have a dense herbaceous understory and that are snow-covered through the winter. Such conditions occur almost every winter at the study site.

Soil Water Depletion

Soil water withdrawal characteristics for experimental units assigned to the spray and nonspray treatments were statistically similar the year before treatment (Table 2) and until herbicide application on June 23, 1970 (Sturges 1973). There was an immediate reduction in water use after treatment; by the end of the season, 31% less water had been withdrawn from the surface 1.8 m of soil on sprayed experimental units compared to the amount withdrawn from undisturbed units. The reduction in water use was attributable to loss of sagebrush, because the combined yield of grasses and forbs was almost identical for both treatments (Fig. 1). Differences in seasonal water use between treated and untreated vegetation decreased the first 3 years after spraying, but then stablized at about a 7% difference in later years of study.

The response in the soil water regime was inversely related to the response in herbaceous production. Depletion was reduced 31% the year of spraying when total herbaceous yields were 37% as large as those by undisturbed vegetation. Total herbaceous productivity of treated experimental units was 77% as large as that by undisturbed experimental units 3 years after spraying and 89% and 80% as large in the tenth and eleventh year, respectively, when there was about a 7% difference in seasonal water withdrawal.

Differences in seasonal water withdrawal between treatments did not accrue uniformly through the 1.8-m deep measurement zone (Fig. 3). In the year of spraying, less water was withdrawn on sprayed experimental units than on unsprayed units at all soil depths (Sturges 1973). After this, water use in the surface 0.9 m of soil was essentially the same for both treatments. Consequently, reductions in soil water depletion after the treatment year were realized almost entirely from soil 0.9 m to 1.8 m deep.

Information collected about the timing of soil water use during the growing season also reflected the reduction in treatment effect with time. The reduction in water withdrawal on sprayed experimental units compared to untreated units the year after spraying

[1]"A Snowmold Disease of Mountain Big Sagebrush *(Artemisia tridentata vaseyana).* D.L. Nelson and D.L. Sturges. Paper presented at the Society for Phytopathology, Salt Lake City, Utah, August, 1982".

Table 2. Yearly measurement interval, precipitation, and seasonal soil water depletion for experimental units sprayed with 2,4-D in 1970, and experimental units that remained in an undisturbed condition.

Year	Treatment	Years after treatment	Measurement interval	Interval precipitation (cm)	Seasonal depletion (cm)	Decrease in depletion (%)
1969	Sprayed	-1	05/13-09/29	11.6	25.5	+4
	Unsprayed				24.6	
1970	Sprayed	0	05/27-09/30	16.1	14.3	[a]31
	Unsprayed				20.8	
1971	Sprayed	1	05/23-09/14	7.7	18.3	[a]17
	Unsprayed				22.0	
1972	Sprayed	2	05/18-10/04	12.1	17.3	[c]15
	Unsprayed				20.4	
1973	Sprayed	3	05/31-10/04	13.7	25.9	[b]11
	Unsprayed				29.1	
1975	Sprayed	5	06/02-09/30	5.8	23.9	8
	Unsprayed				26.0	
1977	Sprayed	7	04/28-10/06	18.9	23.0	9
	Unsprayed				25.3	
1978	Sprayed	8	05/15-10/02	13.1	29.4	3
	Unsprayed				30.4	
1979	Sprayed	9	06/04-10/02	7.1	29.9	[b]10
	Unsprayed				33.2	
1980	Sprayed	10	05/27-10/02	9.0	27.1	[c]7
	Unsprayed				29.2	
1981	Sprayed	11	06/01-10/01	8.6	24.7	[c]6
	Unsprayed				26.2	
Avg.	Sprayed			11.2		
	Unsprayed				26.1	

[a]Significantly different at 0.01 level of probability.
[b]Significantly different at 0.05 level of probability.
[c]Significantly different at 0.10 level of probability.

was significant between June 10, and July 20. Three years after spraying, water use by treated experimental units was significantly less only in the 15-day interval between June 25 and July 10. Late July was the only time water withdrawal on treated experimental units was significantly less 5 and 10 years after spraying. Sagebrush was still actively withdrawing water from deeper soil at this time, but grass-dominated vegetation had largely completed growth for the year.

Seasonal moisture dynamics are indicated for treated and untreated vegetation 2 and 10 years after treatment in soil 0.3- to 0.6-m and 1.2- to 1.5-m deep (Fig. 4). Both treatments utilized water primarily from surface soil early in the growing season and differences in seasonal water use were not significantly different. Water-use shifted to deeper soil in mid-July after surface soil dried. The entire treatment difference at the 1.2- to 1.5-m depth accrued between mid-July and mid-August, when sagebrush roots were actively extracting water. The rate of water use by undisturbed sagebrush vegetation declined sharply after mid-August, which coincided with the time big sagebrush was shedding ephemeral leaves. Seasonal water depletion for sprayed experimental units was significantly less compared to untreated units in soil 1.2- to 1.5-m deep in both the second and tenth year after spraying.

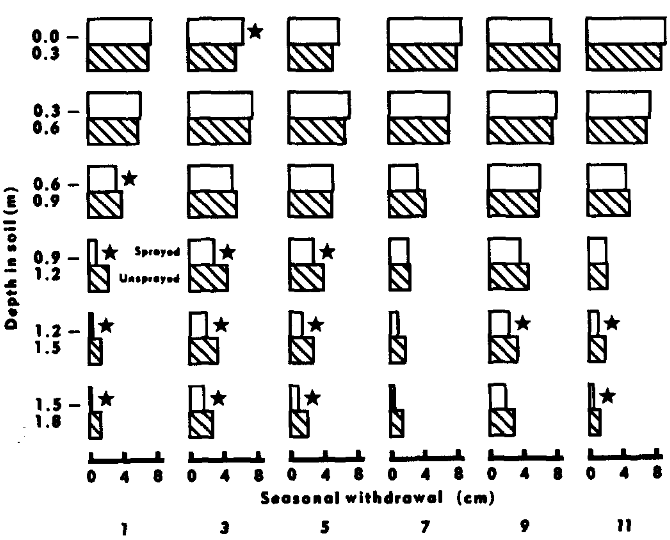

Fig. 3. *Seasonal water depletion for sprayed and unsprayed experimental units at six soil depths. A star indicates that seasonal differences between treatments are significant at a 0.05 level of probability.*

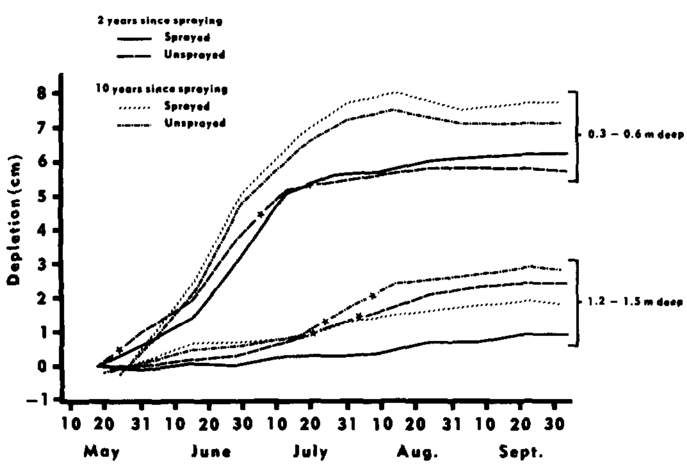

Fig. 4. *Soil water depletion at sprayed and unsprayed experimental units in soil 0.3 m to 0.6 m deep, and 1.2 m to 1.5 m deep, during the second summer and the tenth summer after spraying. A star indicates that the difference in depletion between successive soil water measurement dates attributable to treatment is significant at a 0.05 level of probability. Sagebrush control significantly reduced seasonal water depletion in soil 1.2 m to 1.5 m deep both the second and tenth summer after spraying, but seasonal depletion in soil 0.3 m to 0.6 m deep was unaffected by treatment.*

Predicting Soil Moisture Response to Big Sagebrush Control

Study data were used to derive empirical relationships relating the reduction in seasonal water withdrawal to time since spraying (Fig. 5). The percent reduction in seasonal depletion between stands of sprayed and unsprayed sagebrush vegetation in the surface 1.8 m of soil is expressed by:

$$y = 4.38 + 26.67/(t) \quad (1)$$

where y = percentage reduction in fall recharge requirement
t = number of years +1 since big sagebrush was controlled

Separate relationships were also derived to express treatment effect in the upper 0.9 m of soil and in soil 0.9 m to 1.8 m deep. The percentage reduction in seasonal depletion between sprayed and unsprayed vegetation in the surface 0.9 m of soil is expressed by:

$$y = 7.63 - 5.50 \ln(t) \quad (2)$$

The percent reduction in seasonal depletion for soil 0.9 m to 1.8 m deep is expressed by:

$$y = 66.62 - 14.85 \ln(t) \quad (3)$$

Terms in equation (2) and (3) are defined the same as for equation (1). The coefficient of determination (r^2) for equations (1), (2), and (3) was 0.94, 0.44, and 0.81, respectively.

Prediction equations are based on data collected from a site where soil water is usually recharged completely by snowmelt and where soil was more than 1.8 m deep. A productive herbaceous understory existed at the site prior to treatment. After spraying, grasses quickly responded to release from sagebrush competition and invasion of sagebrush into treated experimental units was negligible through 11 years. The relationships are applicable only to locations having comparable vegetation, soil, and water recharge characteristics.

Discussion and Management Implications

The effects of spraying on vegetation productivity and soil water depletion were evaluated on the basis of differences between treated and undisturbed experimental units. However, it is not possible to precisely evaluate how the soil water regime of undisturbed experimental units was affected by snowmold fungus attacking big sagebrush. Water-use efficiency comparisons were made between the 1969-1972 years (before the fungus was active) and the 1973, 1980, and 1981 years (when the fungus was active), based on big sagebrush production and seasonal water change in soil 0.9-1.8 m deep. Similar calculations based on grass productivity and seasonal depletion in the surface 0.9 m of soil were also made. These depths were selected because big sagebrush is the primary water user from soil below 1 m, while the principal water reservoir for grasses is located in the upper meter of soil.

Big sagebrush productivity (kg/ha) per centimeter of water depletion averaged 115 in years before the fungus was active and 72 in years after the fungus was active. The ratio of grass production per centimeter of water depletion was 22 and 17 for the same 2 intervals. The change in the ratio between time periods was considerably larger for sagebrush than for grasses, suggesting that depletion by undisturbed vegetation was affected by the loss of sagebrush. However, if water use on undisturbed experimental units did decrease, the reduction was not as large as the 34% reduction in sagebrush canopy cover that occurred between 1969 and 1980, because remaining plants used more water to produce a given amount of vegetative matter in later years of the study. Thus, after 1972, the study probably provides a conservative, but reasonable estimate of changes that occur in the soil water regime following control of big sagebrush.

The study clearly demonstrated that the response in the soil water regime following sagebrush control was different in soil above and below a depth of 1 m. Except for the year of spraying, water use in the upper 0.9 m of soil was not materially reduced by spraying. A root-weight study conducted at the same study site supported this conclusion. The weight of roots in the surface 1.2 m of soil under undisturbed sagebrush vegetation was not significantly different from those of vegetation sprayed 3 years previously (Sturges 1980).

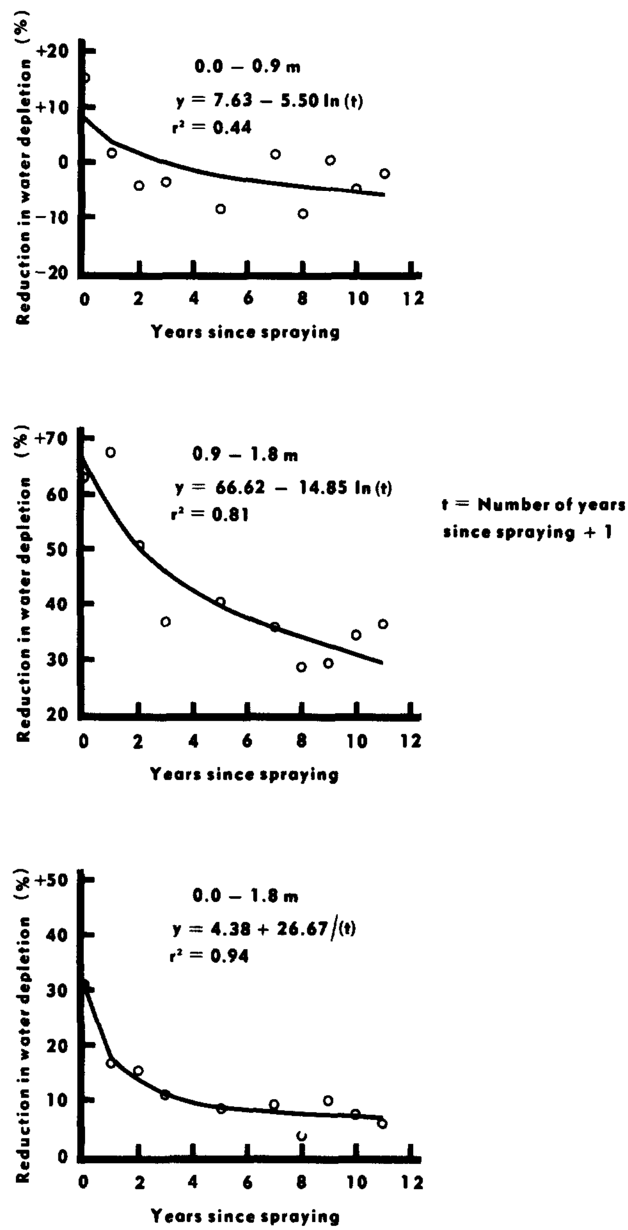

Fig. 5. *Field data points through 11 years after spraying and predictive equations showing the percentage reduction in soil water depletion for soil 0.0 m to 0.9 m deep, 0.9 m to 1.8 deep, and 0.0 m to 1.8 m deep. The top figure indicates that depletion in the surface 0.9 m of soil for sprayed areas exceeds depletion for untreated areas beginning the fourth year after spraying.*

Study findings parallel those of Hyder and Sneva (1956), Cook and Lewis (1963), and Shown et al. (1972), where short-lived reductions in water use were detected in soil up to 0.9 m deep. Tabler (1968) conducted the only other study in which soil water measurements extended below the surface meter of soil, and found a sizeable reduction in depletion in soil 0.9 m to 1.8 m deep. The overall reduction in evapotranspiration for the 1.8-m measurement zone was 14% the second year after spraying compared to a 15% difference in soil water depletion detected by this study.

A relationship based on data collected the first 5 years after spraying was previously developed to relate the reduction in soil water use to time since spraying (Sturges 1977). Field measurements 6 to 11 years after spraying indicate this relationship underestimated the magnitude of treatment effect beyond the fifth year. Equation (1) suggests that there is about a 7% reduction in soil water withdrawal 10 years after spraying, and a 5% difference 30 years after spraying. The exact duration of treatment effect at the study site is, or course, unknown. Additional years of information will alter the form of equation (1) to reflect return of big sagebrush to sprayed experimental units. Sagebrush establishment had a negligible effect on the soil water regime in the first 11 years after treatment.

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Using Precipitation to Predict Range Herbage Production in Southwestern Idaho

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Abstract

Analyses of 9 years of herbage yield and precipitation data from the Reynolds Creek Experimental Watershed in southwest Idaho show that annual herbage yield can be estimated by the Sneva and Hyder procedure (Sneva and Hyder 1962a, 1962b) at locations other than where their procedure was developed. These analyses did indicate that for sites below 1,680 m, their procedure was more useful when the crop-year precipitation index was based on a variable number of winter and spring months, rather than September through June. For sites above 1680 m, using winter and spring separately in a modified form of their basic equation may improve yield predictions.

Stocking rangelands to fully utilize the annual supply of grazeable forage is not only a difficult task, but it is generally impractical, because of the wide variations in annual yield and the inflexibility of grazing herd size and grazing season. In practice, carrying capacity is usually based on "average" annual herbage production. This results in some overgrazing during below-average production years and under-use of the available forage during above-average production years. In the development of grazing management plans, estimates of average annual herbage production are often unavailable. If annual herbage yields can be predicted from precipitation data with reasonable accuracy, then long-term precipitation records can be used to help establish average annual herbage production for range sites associated with the precipitation data.

Yield prediction equations can also be used to forecast current year's forage production and add at least a degree of flexibility to grazing management, enabling managers to make more efficient use of the total forage resource to provide the year-around nutritional needs of the livestock. Sneva and Hyder (1962a) related herbage yield to crop-year precipitation (September–June) and suggested that current year's yields could be forecast as early as April 1, using the September–March precipitation, plus long-term median precipitation values for April, May, and June. These forecasts could be updated monthly, using actual precipitation data up to the date of forecast and monthly median values for the remainder of the crop year.

Attempts to correlate annual herbage yields with annual precipitation have generally been unsuccessful. This is due primarily to precipitation's variable distribution, and to the fact that range plants generally have the greatest rate of growth during the growing season and little, if any, growth during fall and early winter. Use of seasonal or combinations of monthly precipitation have helped account for the distribution effects and, in many situations, have provided reasonably accurate yield estimates. In Canada, Smoliak (1956) found that May and June precipitation provided good estimates of yield (r=0.86). In North Dakota, Rogler and Haas (1947) correlated April–July precipitation with annual herbage yields (r=0.76). Also in the northern Great Plains, Power and Alessi (1970) and Wight (1978) found that May precipitation was the best single month index of annual herbage production. Sneva and Hyder (1962a) reviewed studies in the intermountain region that indicated winter and spring precipitation were closely correlated to annual herbage production.

In most studies, simple or multiple linear regression analyses, using yield as the dependent variable and precipitation as the independent variable, have been used to develop predictive equations. Such equations tend to be site dependent. To overcome this dependency, Sneva and Hyder (1962a, 1962b) and Sneva (1977) expressed herbage yield and precipitation as ratios of long-term medians. Using data from 13 yield-precipitation series from 3 locations in the intermountain region, they developed an herbage-yield response line based on crop-year precipitation that accounted for 77% of the variation in yields. Another significant innovation of this work was the use of median rather than mean values as a more reliable estimate of the long-term expected values.

The purpose of this study is to verify and extend the procedure developed by Sneva and Hyder (1962a, 1962b) to herbage yield and

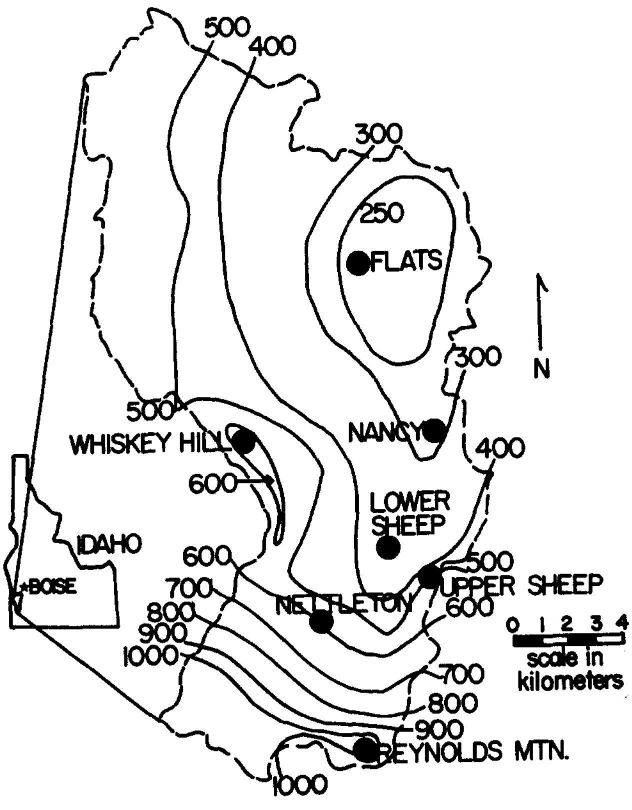

Fig. 1. *Isohyetal map with the locations of the 9 study sites, Reynolds Creek Experimental Watershed, southwest Idaho. Numbers indicate millimeters of precipitation per year.*

Authors are agricultural engineer, hydrologic technician, and range scientist, respectively, Northwest Watershed Research Center, USDA-ARS 1175 South Orchard, Suite 116, Boise, Ida. 83705.

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Table 1. Elevation (m), slope (%), aspect of slope, annual precipitation (mm), vegetative cover (%), and years of record.

Site	Elevation	Slope	Aspect of slope	Precipitation	Vegetation cover	Years of record
Flats	1180	5	N	251	25	8
Nancy Gulch	1400	8	NE	302	25	9
Nettleton	1490	38	W	483	25	9
Lower Sheep Creek	1640	16	NW	347	25	8
Whiskey Hill	1680	15	E	701	50	8
Upper Sheep Creek (South Face)	1860	33	SW	508	25	8
Upper Sheep Creek (North Face)	1860	33	NE	508	50	9
Reynolds Mountain (West)	2090	5	SW	770	25	8
Reynolds Mountain (East)	2070	6	NW	1044	50	9

precipitation data obtained from the Reynolds Creek Experimental Watershed in southwestern Idaho, where herbage yields vary with differences in exposure and elevation.

Methods

Site Description

Nine native range study sites were located on the Reynolds Creek Experimental Watershed in southwestern Idaho (Fig. 1). Site elevation ranged from 1,180 m at Flats to 2,070 m at Reynolds Mountain and the associated average annual precipitation varied from 251 mm to 1,044 mm, respectively (Table 1). Drifting snow accumulations increased plant available water at the Upper Sheep Creek (North Face) and Reynolds Mountain (East) sites. The precipitation distribution was similar for all sites, occurring primarily during winter through early summer (Fig. 2). Soils at the study sites were derived from basalt, granite, or rhyolite; soil textures varied from loam to gravelly loam (Table 2) (Stephenson 1977). The primary plant species at each study site are listed in Table 3. All sites had a dense sagebrush *(Artemisia tridentata* or *Artemisia arbuscula)* cover, except Flats, where shadscale *(Atriplex confertifolia)* was the the major brush species.

Procedure

Annual herbage yields were determined by the double-sampling, weight estimate method described by Wilm et al. (1944). Each year, 2 people estimated the green herbage weight, by species, within 20 randomly located, 9.8-ft^2 circular plots at each site—10 plots inside and 10 plots outside the exclosures. An additional 3 plots inside and 3 plots outside the exclosure were clipped to determine green to dry weight ratios. Sample plots outside the exclosures were caged to protect them from grazing. Yield estimates were made at each site when bottlebrush squirreltail *(Sitanion hystrix)* had reached the seed set stage. Only the nonwoody portion of the brush species was considered annual growth. All yields are reported on an air-dry weight of 12% moisture.

Sneva and Hyder (1962a, 1962b) used precipitation and yield indices as the basic elements in their yield estimations. The precipitation indices were calculated as the individual "crop-year" precipitation (September–June) divided by median crop-year precipita-

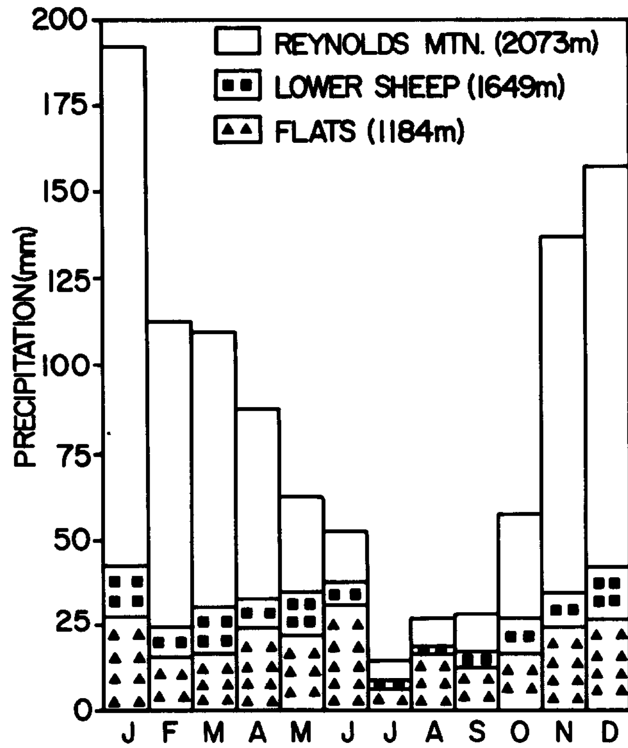

Fig. 2. *Average monthly precipitation at 3 sites.*

Table 2. Geologic material and soil characteristics at study sites.

Site	Geologic material	Soils		
		Subgroup	Family	Series
Flats	Sedimentary	*Typic Haplargids*	Fine loamy mixed, mesic	Nannyton loam
Nancy Gulch	Basalt	*Xerollic Haplargids*	Fine, montmorillonite, mesic	Glasgow loam
Nettleton	Basalt	*Lithic Argixerolls*	Loamy skeletal, mixed, mesic	Reywat-Bakeoven rocky, very stony loam
Lower Sheep Creek	Basalt	*Calcic Argixerolls*	Loamy skeletal, mixed, frigid	Searla gravelly loam
Whiskey Hill	Granite	*Typic Haploxerolls*	Coarse loamy, mixed, frigid	Takeuchi rocky corase sandy loam
Upper Sheep Creek (South Face)	Basalt	*Lithic Argixerolls*	Loamy skeletal mixed, frigid	Gabica very rocky loam
Upper Sheep Creek (North Face)	Basalt	*Argic Pachic Cryoborolls*	Fine loamy, mixed	Harmehl and Demast loam
Reynolds Mountain (West)	Rhyolite	*Pachic Cryoborolls*	Fine loamy, mixed	Bullrey gravelly loam
Reynolds Mountain (East)	Rhyolite	*Pachic Cryoborolls*	Fine loamy, mixed	Bullrey gravelly loam

Table 3. List of primary plant species at study sites.

Plant species	Site 057 Flats	098 Nancy Gulch	135 Nettleton	117 Lower Sheep Creek	092 Whiskey Hill	138 Upper Sheep Creek (South Face)	138 Upper Sheep Creek (North Face)	176 Reynolds Mt. (West)	176 Reynolds Mt. (East)
Grasses and Sedges									
Bearded bluebunch wheatgrass *Agropyron spicatum*		X	X	X	X	X			
Slender wheatgrass *Agropyron trachycaulum*							X		X
Big Mountain brome *Bromus marginatus*							X		X
Cheatgrass brome *Bromus tectorum*	X	X	X		X				
Oniongrass *Melica bulbosa*							X		
Idaho fescue *Festuca idahoensis*					X		X	X	X
Nevada bluegrass *Poa nevadensis*							X		X
Sandberg bluegrass *Poa secunda*	X	X	X	X	X	X	X	X	
Bottlebrush squirreltail[1] *Sitanion hystrix*	X	X	X	X	X	X	X	X	X
Needle-and-thread *Stipa comata*					X		X	X	X
Sedges *Carex* sp.							X	X	X
Forbs									
Western yarrow *Achillea millefolium lanulosa*					X		X	X	X
Low pussytoes *Antennaria dimorpha*		X				X			
Rose pussytoes *Antennaria rosea*								X	
Milkvetch *Astragalus* spp.				X		X			
Arrowleaf balsamroot *Balsamorhiza sagittata*					X				
Indian paintbrush *Castrileja* spp.								X	
Bastard toadflax *Commandra pallida*					X				
Hawksbeard *Crepis* spp.					X				
Sulfur eriogonum *Erigonum umbellatum*					X		X		
Clasping pepperweed *Lepidium perfuriatum*	X								
Lupine *Lupinus*			X		X	X	X	X	X
Phlox *Phlox* spp.		X							
Cinquefoil *Potentilla argula convallaria*							X		
Yellow salsify *Tragopogon dubius*			X						
Violet *Viola* spp.							X		X
Shrubs									
Low sagebrush *Artemisia arbuscuta*				X		X			
Mountain big sagebrush *Artemisia tridentata vaseyana*							X	X	X
Wyoming big sagebrush *Artemisia tridentata wyomingensis*	X	X	X		X				

Table 3. Continued.

Plant species	Site 057 Flats	098 Nancy Gulch	135 Nettleton	117 Lower Sheep Creek	092 Whiskey Hill	138 Upper Sheep Creek (South Face)	138 Upper Sheep Creek (North Face)	176 Reynolds Mt. (West)	176 Reynolds Mt. (East)
Shadscale *Atriplex confertifolia*	X								
Mountain low rabbitbrush *Chrysothamnus viscidiflorus lanceolatus*					X	X	X		
Mountain snowberry *Sumonoricarpos oreophelus oreoprelus*							X		X

[1]Indicator species for harvest.

tion; the herbage yield indices were determined, using the same procedure. A regression of the yield indices on the precipitation indices, using data from 13 yield-precipitation series from 3 locations in the intermountain region, resulted in the following equation:

$$Y = 1.11X - 10.6 \quad r = 0.88 \text{ [Sneva and Hyder (1962 a, 1962b)]} \qquad [1]$$

where Y is the yield index (%) and X is the precipitation index (%).

Because of the short yield record in this study, estimated medians were calculated for both precipitation and yield, and these values were then used to compute the precipitation and yield indices. The estimated medians were calculated by averaging the middle five values from the 9-year records and the middle four values from the 8-year records. Precipitation data from the 3 sites shown in Figure 2 were used to determine how well the estimated median values, and the range of the 9-year series used in this study compared with the 18-year record available at each site. The estimated median values were all within 9% of the 18-year medians. The range of values used in this study included the year with the least precipitation at each site, and the year that was within 1 or 2 values from the highest value in each series. Similar analysis of a 41-year precipitation record from the U.S. Weather Bureau at Boise, Ida., also supported the validity of the estimated medians, using the same 9-year period as used in the study. The estimated median was within 8% of the 41-year median and range of values included both the highest and lowest values of the series. Based on precipitation alone, this analysis would suggest that the yield data used in this study represent the range of yields that can be expected.

Crop-year indices were calculated for various precipitation periods—i.e., November-April, November-May, etc. Regression techniques were used to relate the crop-year precipitation indices to the herbage yield indices. Except at the Flats site, average herbage yields of the plots in the exclosure and outside the exclosure were not significantly different and were averaged together (Table 4). All tests of significance were done at the .05 probability level.

Results and Discussion

Initial regression analyses showed that there was good correlation between a single crop-year index and the herbage yield index for the 4 data sites below 1,680 m (Table 1). Because the individual equations for the 4 sites below 1,680 m were not significantly different, all the data were combined and a single regression equation obtained for the 4 sites below 1,680 m was:

$$Y_1 = 1.03X_1 + 7.09 \quad r = 0.88 \qquad (2)$$

where Y_1 is the yield index (%) and X_1 is the precipitation index (%). The slope of equation [2] was not significantly different from that of Sneva and Hyder (equation [1]), and the residual variances were homogeneous, indicating that the 2 equations were not different. Thus, equation [1] was used throughout the study.

Herbage yield was computed for the low elevation sites using Sneva and Hyder's crop-year precipitation (September–June) and the crop-year precipitation periods selected through regression analysis (Table 4). The results shown in Figure 3 indicate that the best fit crop-year improves yield estimates, but not significantly. Neither of the regression lines shown in Figure 3 was significantly different from the line of equal value, nor were they significantly different from each other.

These analyses indicate that the Sneva and Hyder procedure could be used to estimate yields and that a somewhat improved yield estimate could be made if precipitation data for specific months were available. One reason why the variable length crop-year concept may not have improved the results more was because a preponderance of the precipitation fell during the November through January period; thus, variations in the other monthly amounts do not have the same effect on the computed yields.

Analysis of data from the 5 sites at or above 1,680 m indicated that 2 precipitation-index periods (Table 4) improved herbage yield estimates. The analysis also suggested that each precipitation-index period contributed about 50% to the total yield. Precipita-

Table 4. Average total herbage yield (kg/ha) and crop-year precipitation.

Site	Herbage yield	Harvest dates[1]	Crop-year precipitation period
	Low Elevation Sites		
Flats			
Exclosure	710	May 24	November–April
Grazed	900	May 24	November–April
Nancy Gulch	770	May 29	November–April
Nettleton	1150	June 13	November–May
Lower Sheep Creek	680	June 18	November–May
	High Elevation Sites		
Whiskey Hill	1360	June 30	November-March April–May
Upper Sheep Creek (South Face)	620	June 27	November–March April–May
Upper Sheep Creek (North Face)	1970	July 20	November–March April–June
Reynolds Mountain (West)	730	July 18	November–April May–June
Reynolds Mountain (East)	1550	July 31	November–April May–June

[1]Mean harvest date for years of record.

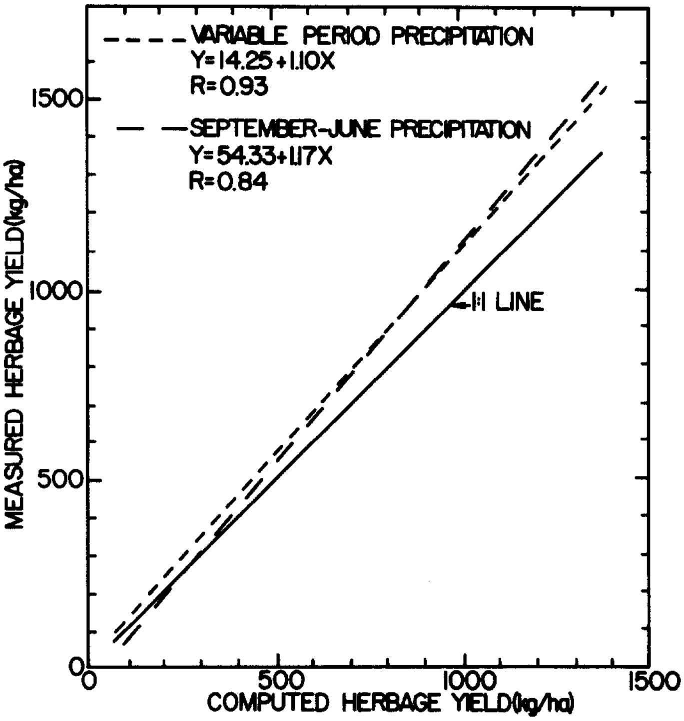

Fig. 3. *Relationship between measured and computed herbage yield using a modified form of the Sneva and Hyder equation where the "crop-year" precipitation varied with location and the Sneva and Hyder equation, for study sites below 1,680 m.*

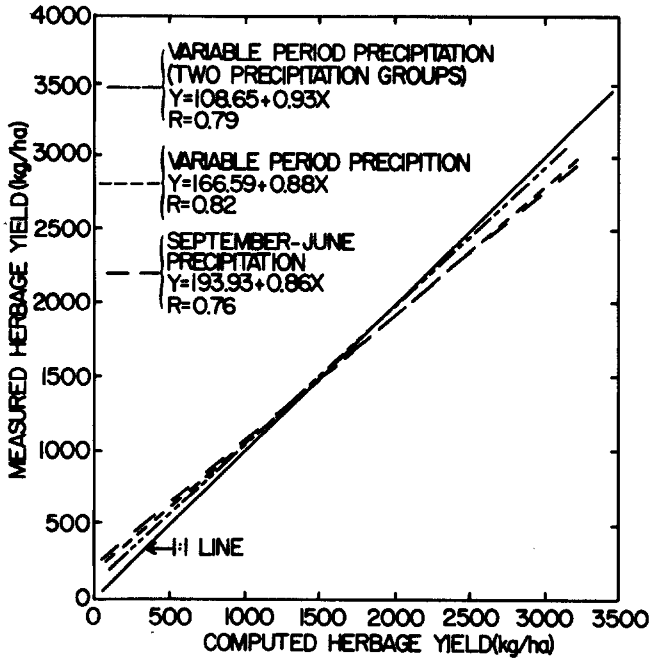

Fig. 4. *Relationship between measured and computed herbage yield to modified forms of the Sneva and Hyder equation, and the Sneva-Hyder procedure for study sites above 1,680 m.*

tion indices were then developed for several precipitation period combinations for each site using a modified form of Equation [1] (see equation [3]). The modified form of equation [1] was then used to determine which precipitation periods best represented each site (Table 4).

This combination of winter and spring precipitation suggests that spring precipitation is more effective for annual growth than winter precipitation, because winter and spring precipitation are given equal weight; but, there was considerably more precipitation during the winter.

The equation developed for the sites at 1,680 m and higher was:

$$Y_h = (X_{h_1} + X_{h_2})\,0.55 - 10.6 \qquad (3)$$

where Y_h is the yield index (%), X_{h_1} is the precipitation index (%) from winter precipitation period, and X_{h_2} is the precipitation index (%) from the spring precipitation. The relationships are shown between measured and computed yields, using equation (3), and equation (1), and equation (1) with the crop-year precipitation periods indicated in Table 4. The slope of the regression lines (Fig. 4) is not significantly different from 1.0 and the intercepts are not significantly different from zero; the regression lines are not different from each other. However, the regression lines shown in Table 4 suggest that a variable length crop-year precipitation index or a 2 crop-year precipitation index (Equation [3]) may improve yield predictions.

As shown in Table 4, the crop-year precipitation periods were November through April, and November through May at the low elevation sites. This difference is most likely associated with the vegetation maturing later in the season as the elevation increases. At the higher elevation sites, such as Upper Sheep Creek, there were 2 precipitation periods that contributed to the herbage yields—one associated with winter precipitation, which was primarily snow, and one associated with spring snow and rain. Precipitation periods at the high elevation sites showed the same trend as those at the low elevation sites with crop-year precipitation extending later into the summer with increasing elevation.

Summary

The results of this study show that the procedure developed by Sneva and Hyder (1962a, 1962b) is effective over a wide range of annual precipitation and vegetation types. Our study also indicated that at lower elevation sites (below 1,680 m), where there was normally an ephemeral snow cover, results may be improved by using a precipitation index obtained from the months of November through April, or November through May; this depended on site location rather than the crop-year precipitation period Sneva and Hyder used, which was September through June. At sites at or above 1,680 m, a modified form of the Sneva and Hyder equation, using 2 crop-year precipitation periods, may represent the field data more accurately than a single crop-year period. The 2 precipitation periods are likely associated with the fact that snow cover at these sites was generally continuous throughout the winter, and that plant growth is also enhanced by spring and summer rain.

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Genetic Differences in Resistance of Range Grasses to the Bluegrass Billbug, *Sphenophorus parvulus* (Coleoptera: Curculionidae)

K.H. ASAY, J.D. HANSEN, B.A. HAWS, AND P.O. CURRIE

Abstract

Significant differences in plant resistance to larvae of the bluegrass billbug, *Sphenophorus parvulus* Gyllenhal (Coleoptera: Curculionidae), were found among and within range grass species and interspecific hybrids in nurseries at the Decker, Mont., surface mine and on a site near Miles City, Mont. Slender wheatgrass *(Elymus trachycaulus)* and related species were particularly susceptible. Crested wheatgrass *(Agropyron cristatum* and *A. desertorum),* thickspike wheatgrass *(E. lanceolatus),* Russian wildrye *(Psathyrostachys juncea),* and salina wildrye *(Leymus salinae)* were among the species with a relatively high degree of resistance to the insect. Clonal lines of the *Et. repens* × *Et. spicata* hybrid differed significantly in resistance. Over 50% of the total phenotypic variation among the hybrid lines was attributed to genetic effects, indicating that selection for resistance would be effective.

Billbugs, *Sphenophorus* spp. (Coleoptera: Curculionidae), are serious pests on many pasture grasses (Satterthwait 1931). Both the bluegrass billbug (*S. parvulus* Gyllenhal) and the hunting billbug (*S. venatus vestitus* Chittenden) begin their development inside the stems of grass plants. After hatching, the early instars feed internally and later the older larvae move to the roots where pupation occurs (Tashiro and Personius 1970, Kamm 1969). Although feeding by adults causes damage, the last instars are the most destructive stage and the cumulative injury to the plant becomes most evident in late summer.

Chemicals have been proposed and tested for controlling billbugs in lawns and in grass seed production fields (Kamm and Every 1969, Brussell and Clark 1968, Tashiro and Personius 1970). However, resistance by the billbugs to cyclodiene insecticides was reported in Ohio (Niemczyk and Frost 1978) and the cost of application is prohibitive on western rangeland. An alternative strategy is to develop cultivars of grasses that are resistant to billbug feeding injury. Resistance to the bluegrass billbug has been observed in Kentucky bluegrass *(Poa pratensis)* (Kindler and Kinbacher 1975). Documentation of genetic factors conditioning resistance to this potentially damaging insect pest would be a major contribution to the development of improved grass cultivars for revegetating disturbed and depleted rangeland.

Methods

As part of a USDA-ARS breeding program to develop grass cultivars for revegetating areas disturbed by surface mining operations (Asay 1979), 2 space planted nurseries (A and B) were established on reclaimed spoils of the Decker, Mont., surface mine. Nursery A consisted of 515 accessions representing 62 species and interspecific hybrids. Plots in this 8,240-plant nursery consisted of 8 plants each. Nursery B comprised 23 entries (Table 1) arranged in plots of 10 plants each. In both nurseries, plants were established on 0.5 × 1.0 m centers and the single row plots were organized as randomized complete blocks with 2 replications.

In cooperation with Utah State University, the USDA-ARS is actively involved in a breeding program to develop fertile and stable cultivars from germplasm generated through interspecific hybridization (Asay et al. 1978). The most promising of these is the hybrid between quackgrass, *Elytrigia repens,* and bluebunch wheatgrass, *Et. spicata,* (Dewey 1976, Asay and Dewey 1981). During May 1, 46 clonal lines of this population (designated as the RS hybrid) were established on a nursery on a semiarid site near Miles City, Mont. Single-plant plots were arranged in the nursery on 1.0-m centers as a randomized complete block with 10 replications. This design permitted the quantification of the relative magnitude of the genetic variation among the clonal lines for resistance to the insect. The percent genetic variability on a mean basis was computed as $\sigma^2_C/\sigma^2_{\bar{Ph}}$, where σ^2_C was the genetic variance among clonal means and $\sigma^2_{\bar{Ph}}$ was the total phenotypic variance among the 46 entries.

The relative amount of damage caused by the billbug was determined in the nurseries at Decker and Miles City as natural infestations occurred. Plants were rated on a 0 to 9 scale, with 0 indicating

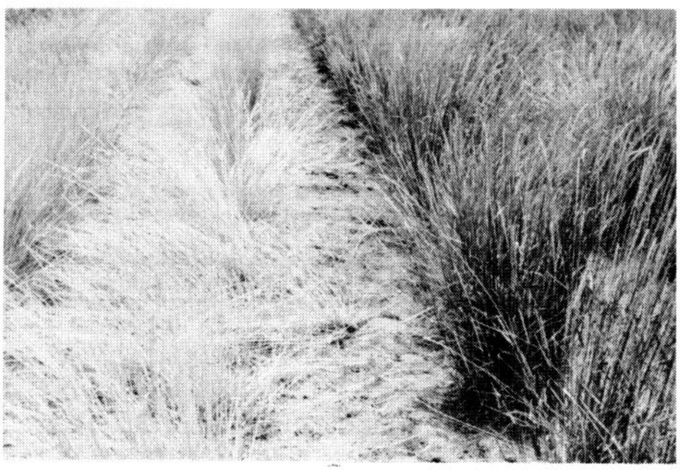

Fig. 1. *Grass breeding nurseries at the Decker, Mont., surface mine. Left, slender wheatgrass severely damaged by the bluegrass billbug; right the* Elytrigia repens × Et. spicata *(RS) hybrid relatively unaffected by the insect.*

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Table 1. **Average rated damage to range grass species and interspecific hybrids inflicted by the bluegrass billbug at the Decker, Montana surface mine.**

Species or hybrid	Injury rating[1]	Species or hybrid	Injury rating
Agropyron cristatum R1	1.7	*L. triticoides*	0.6
A. cristatum R2	2.8	*L. virginicus* M2	8.4
A. cristatum R3	2.8	*Hordeum violaceum*	9.0
Elymus lanceolatus A1	2.3	*Et. repens* × *A. cristatum*F1	0.6
A. desertorum M138	2.3	*Et. repens* × *A. desertorum*	0.6
E. trachycaulus A20	9.0	*Et. repens* × *Et. spicata* 1	2.8
Leymus ambiguus 1	1.7	*Et. repens* × *Et. spicata* 2	3.4
L. ambiguus 2	2.3	*Et. repens* × *Et. spicata* 3	5.1
Psathyrostachys juncea A27	1.1	*Et. repens* × *Et. spicata* 4	3.4
P. juncea V16	0	*E. trachycaulus* × *E. sitanion*	8.4
L. salinae A9	0.6	*E. lanceolatus* × *P. juncea*	0.6
L. salinae A10	1.1	Mean	3.1

LSD (0.05) = 2.45

[1]Ratings: 0 = least and 9 = most damage — detached root system. Data based on 2 replications.

no damage and 9 severe damage (detached root system). The taxonomic nomenclature proposed by Dewey (1983) was used to describe grass species.

Results and Discussion

In the second year after planting (1979), the Decker nurseries were infested by a billbug identified as *Sphenophorus parvulus.*[1] Significant differences in damage caused by the insect were evident among the breeding lines of grass species and hybrids in Nursery A. Larva feeding near the base of the crown severed major portions of the root system and completely devastated the stands of susceptible entries. Slender wheatgrass *(Elymus trachycaulus)* and related species, particularly those with the same genomic constitution (SSHH), were the most severely damaged. These species included *E. donianus, E. fibrosus, E. mutabilus, E. sibiricus,* and *E. virginicus.* Crested wheatgrass *(A. cristatum* and *A. desertorum),* tall wheatgrass *(Et. pontica),* thickspike and streambank wheatgrass *(E. lanceolatus),* western wheatgrass *(Pascopurum smithii),* altai wildrye *(Leymus angustus),* basin wildrye *(L. cinereus),* Russian wildrye *(Psathyrostachys juncea),* salina wildrye *(L. salinae),* and several promising interspecific hybrids were relatively undamaged by the insect.

Initially, a 2,600-plant population of the F_7 generation of the RS hybrid included in Nursery A was relatively undamaged by the insect (Fig. 1). However, moderate injury was observed among the hyrid plants after adjacent plots of slender wheatgrass and other susceptible species had been severely depleted. Genetic variability for resistance to the billbug was evident among breeding lines within the hybrid population, offering some encouragement that selection for resistance would be effective.

Ratings were made during July 1980 to estimate the relative damage to the 23 breeding lines included in nursery B at Decker (Table 1). As was the case in the larger nursery, breeding lines differed significantly ($P<0.01$) in resistance to the billbug. Feeding injury ranged from an average rating of 0 (essentially no damage) for a line of Russian wildrye to 9.0 (detached root system and plant death) for slender wheatgrass.

During August of 1981, the 46 clonal lines of the RS hybrid in the nursery at Miles City were infested with billbugs. Extensive ratings were made and significant ($P<0.01$) differences were found among the clonal lines for resistance to the insect (Table 2). Some lines were essentially undamaged in all 10 replications, while others were moderately to severely affected. The genetic variance for resistance among the clonal lines accounted for 56% of the total phenotypic variance.

Although the data are still somewhat preliminary and parent-progeny relationships are yet to be studied, the opportunities for genetic improvement of resistance to the billbug appear to be excellent. Research is progressing to assess the damage attributable to the insect on western range and to develop laboratory and field procedures to identify resistant plant germplasm.

[1]Identified by C.W. O'Brien, Florida A and M Univ., Tallahassee, Fla.

Table 2. Summary of ratings for billbug damage among 46 *Elytrigia repens* × *Et. spicata* (RS) hybrid clonal lines at Miles City, Montana.

Parameter	Ratings[1]
Range in clonal means	1.3–5.0
Grand mean	3.1
F (clonal lines)	2.4**
$S_{\bar{x}}$	0.59
Gen. Var. (%)	56

[1]Insect damage rated on individual plants from 0 to 9 (0 = no damage, 9 = severe damage — detached root system). Data based on 10 replications.
**Significant at the 0.01 level of probability.

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Residual Effects of Liquid Digested Sludge on the Quality of Broomsedge in a Pine Plantation

L. S. DUNAVIN AND M. C. LUTRICK

Abstract

Broomsedge (*Andropogon virginicus* L.) is generally looked upon with some disfavor as a weed but has been utilized for grazing. Liquid digested sludge (LDS) has been tested as a fertilizer on tree plantations where broomsedge comprises a portion of the understory. Broomsedge samples were collected 4 years after treatment of a slash pine (*Pinus caribaea* More.) plantation with LDS containing 0, 21.6, 40.5, 62.1, 83.7, and 102.6 t/ha of dry solids. Sludge was applied both as a top application and incorporated prior to tree planting. Crude protein (CP) of grass samples was generally increased with an increase in sludge application. In vitro organic matter digestibility (IVOMD) appeared to decrease with increased sludge application under conditions of top application only. The understory at the 0 and 21.6 t/ha-rates of sludge was about 67% broomsedge. At the higher sludge rates, the understory was only 10% broomsedge or less.

Broomsedge bluestem (*Andropogon virginicus* L.) is found throughout most of the eastern U.S. and in several western states (Hitchcock 1935). Considered a pest, it has been called "Autumn's Golden Glow" for its color changes with the weather and the light (Morris 1978). Voigt (1953) found that about 3 months of satisfactory grazing of broomsedge could be expected in southern Illinois. The grass has been accused of destroying the value of millions of acres of grazing land and hay meadows in the South as a result of encroachment (Thurman and Ward 1967). Broomsedge is not relished by livestock and is usually grazed only in the absence of more palatable grasses (Phillips Petroleum 1956). Considerable effort has been directed toward the control of broomsedge. Peters and Lowance (1974) indicated that fertilization of tall fescue (*Festuca arundinacea* Schreb.) and bluegrass (*Poa pratensis* L.) in pastures infested with broomsedge along with mowing of old growth of broomsedge and grazing by cattle resulted in broomsedge control after a period of years. Lowance et al. (1975) indicated the value of certain arsenical herbicides for removing broomsedge from forage grasses. Wolters and Schmidtling (1975) found that intensive culture of pine (*Pinus* spp.) trees which included clearing, plowing, disking, and 3 post-planting diskings each growing season, with fertilization rates as high as 448-224-224 kg/ha of NPK, reduced total broomsedge herbage production in pine plantations.

Land application of sludge has received extensive attention in the last 30 years in the U.S. and England. Anderson (1955) and Bear and Prince (1955) reported beneficial effects from sewage sludge as a fertilizer and soil amendment. Coker (1966) found that liquid digested sludge (LDS) gave as large an increase in grass dry matter as equivalent fertilizers. He found that mean recovery of N applied in LDS was 84% of that recovered from equivalent inorganic fertilizer. Lutrick et al. (1976) obtained data indicating that sun-dried LDS could be fed to cattle at 100 g/head/day for 219 days without detrimental effects to cattle and with carcasses suitable for human consumption.

Various workers have obtained different results concerning the effect of N on grasses with regard to digestibility. Niehaus (1971) found in vitro dry matter disappearance (IVDMD) to be unaffected by N rate on reed canarygrass (*Phalaris arundinacea* L.). Fribourg et al. (1979) found that fertilization with N increased the seasonal mean IVDMD of 'Midland' bermudagrass [*Cynodon dactylon* (L.) Pers.]. Fribourg and Loveland (1978) found that season affected IVDMD of tall fescue more than N fertilization, although the higher or more frequent N rates increased IVDMD indirectly. Minson (1973) found that rhodesgrass (*Chloris gayana* Kunth.), 'Pangola' digitgrass (*Digitaria decumbens* Stent.), and kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) had different responses to N with respect to digestibility and that the effect of additional N was not constant throughout the season. Ruelke and Prine (1971) found a significant increase in in vitro organic matter disappearance (IVOMD) in response to levels of fertility for 6 hybrid bermudagrasses, Pangola digitgrass, and 'Pensacola' bahiagrass (*Paspalum notatum* Flugge).

This study was undertaken to determine the residual effects upon broomsedge of the application of LDS to a pine plantation.

Methods

Samples of broomsedge were taken on 15 September 1978 from 2 separate experiments which had been established on slash pine (*Pinus caribaea* More.) plantations. The broomsedge forage samples were taken at random over the plots. Whole plants were clipped to an 8-cm stubble. These samples were ovendried and ground in a Wiley mill. Pine needles were sampled from 6 trees selected at random in each plot. One lateral branch was selected from the south side of each sample tree in the upper half of the crown. The complete needle bundle from the last fully elongated flush of needles on the terminal portion of a primary branch was utilized, and a composite sample of bundles was formed. These were ovendried and ground in a blender. The soil was a Troup loamy fine sand (Grossarenic Paleudult).

Experiment 1 was planted to pines in February of 1974 and LDS was applied over the trees. Sludge application was completed in November, 1974. In Experiment 2, sludge was applied and incorporated in September, 1974, prior to planting the pine trees on 20 February 1975. Incorporation was done with a rolling chopper. Plots measured 12 m × 37 m. Pine seedlings were planted 1.8 m apart in rows 3.7 m apart. Treatments included 0, 21.6, 40.5, 62.1, 83.7, and 102.6 t/ha of dry solids applied as LDS. Sludge was obtained from the Main Street sludge treatment plant in Pensacola, Fla. Each metric ton of dry solids in the LDS contained 33.8 kg N, 17.3 kg P, 1.8 kg K, 19.0 kg Ca, and 2.0 kg Mg. Four replications in a randomized complete block design were utilized.

Sample crude protein (CP), crude fiber (CF), ether extract (EE), and ash were determined on the dried grass samples and CP was determined on the dried pine needles according to the procedures recommended by the Association of Official Analytical Chemists (1970). In vitro organic matter digestion (IVOMD) was determined at the Agronomy Research Support Laboratory in Gainesville, Fla. on the dried grass samples by the 2-stage technique of Tilley and Terry (1963) as modified by Moore et al. (1972). The

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Table 1. Crude protein, crude fiber, ether extract, ash, and in vitro organic matter digestion of broomsedge sampled 4 years after sludge application to a pine plantation.

Dry solids Applied as LDS t/ha	Top-application Crude Protein	Crude Fiber	Ether Extract %	Ash	IVOMD	Incorporated Crude Protein	Crude Fiber	Ether Extract %	Ash	IVOMD
0	5.5c	34.4	2.1	3.1	24.4a	5.9c	35.0	2.0	2.5	24.4
21.6	6.1bc	35.4	1.7	3.2	24.2a	6.5bc	37.0	2.0	2.3	20.8
40.5	6.3b	35.4	1.9	3.2	20.5b	6.7bc	35.3	1.9	2.7	24.8
62.1	6.6ab	36.3	2.1	2.7	20.0bc	6.7bc	34.7	2.2	2.4	22.7
83.7	6.6ab	36.2	1.9	2.9	17.2c	7.4ab	34.3	2.1	2.3	21.5
102.6	7.1a	35.6	1.9	2.7	18.6bc	7.9a	35.2	2.1	2.3	22.4

Means, in a particular column, followed by the same letter or by no letter are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

data were analyzed statistically by both the analysis of variance and linear regression procedures.

Results and Discussion

Crude protein concentrations of the broomsedge are shown in Table 1. These data indicate a linear increase in protein with an increase in applied sludge and show that even 4 years after the heavy N applications there is a residual response.

Although protein content of broomsedge was higher at the higher sludge levels, the value of these areas for possible forage from broomsedge would have been less because the broomsedge stand on the areas with the higher sludge rates (more than 21.6 t/ha of dry solids) was only 10% or less. Herbage under the pines at the high sludge rates consisted, primarily, of blackberry or dewberry (*Rubus L.* sp.). These are good forages for such game species as deer (Moore 1961).

No differences among sludge treatments were found for IVOMD of broomsedge in the experiment in which sludge was incorporated prior to planting the pine trees; however, in the experiment where sludge was applied over the trees, the IVOMD was significantly ($P<.05$) higher at the sludge levels of 0 and 21.6 t/ha (Table 1). This indicates some decrease in the relative quality of the broomsedge at high levels of sludge under conditions of top-application even though protein content was increased. Of course, these low digestibilities indicate a poor quality forage in all cases.

At the 0-rate of sludge, grass was the major undergrowth herbage component, making up about 70% of the cover of which about 95% was broomsedge. In a few areas, *Panicum spretum* Schult. was abundant.

No differences in CF, EE, or ash content were found for broomsedge among the various levels of sludge (Table 1).

Since the area of the study was a pine plantation, the protein analysis of the pine needles is included and presented in Table 2 and indicates a generally higher protein content with increasing levels of sludge.

These results indicate that N was available from the sludge even 4 years after application. They also indicate that higher rates of sludge tended to reduce the broomsedge stand with replacement by blackberry or dewberry.

Table 2. Protein content of pine needles sampled 4 years after sludge application to a pine plantation.

Dry solids applied as LDS t/ha	Crude Protein % Top-application	Incorporated
0	5.2c	5.1b
21.6	5.4bc	5.2b
40.5	5.8ab	5.1b
62.1	5.9ab	6.0a
83.7	6.3a	6.1a
102.6	6.2a	5.8a

Means, in a particular column, followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

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Relationships of Site Characteristics to Vegetation in Canyon Grasslands of West Central Idaho and Adjacent Areas

E.W. TISDALE AND MARY BRAMBLE-BRODAHL

Abstract

The relation of vegetation types to soil and other site characteristics was examined for 57 sample plots representing the Pacific Northwest Bunchgrass Region. Three series characterized by *Carex* spp., *Festuca idahoensis*, and *Agropyron spicatum* respectively, and 5 habitat types comprised the vegetation units. These were compared to their associated soil taxa (soil families) and to a group of individual soil and other site characteristics. Relationship to soil taxa was relatively weak, with several soil families associated with each of 4 of the habitat types. Strong relationship of vegetation types to 13 individual soil and site factors was shown by means of stepwise discriminant analysis. Reclassification by these site factors resulted in 92% concurrence with habitat types and even higher agreement with vegetation series. Site factors showing the highest degree of relationship with vegetation units were: elevation, radiation index, color (value), and organic matter of the "A" horizon, and lime depth. This method of relating individual site factors to vegetation provides a powerful tool for testing the validity of ecosystems recognized by vegetation, and should be useful also in categorizing sites where plant cover has been disturbed.

The grasslands of the Snake and Salmon River valleys in Idaho and adjacent parts of eastern Oregon and Washington constitute a distinctive section of the Pacific Northwest Bunchgrass Region. These grasslands occur mainly on steep canyon slopes and are closely related to the so-called Palouse grasslands of the Columbia Plateau in northeastern Oregon, eastern Washington, and northwestern Idaho.

A brief description of this canyon area and a preliminary classification of its grassland has been published (Tisdale 1979). Due to a combination of rugged topography, dry climate, and stony soils, most of the grassland remains uncultivated. Despite the influence of heavy use by livestock over much of the area, many examples of relatively undisturbed vegetation remain. From a study of such relict areas, Tisdale (1979) recognized 2 vegetation series and 5 habitat types which constitute most of the grassland vegetation of the area. The *Festuca idahoensis* series includes 3 habitat types: *Festuca idahoensis*/*Koeleria cristata, Festuca idahoensis*/*Agropyron spicatum,* and *Festuca idahoensis*/*Symphoricarpos albus.* The other group, occupying drier sites, is the *Agropyron spicatum* series which includes *Agropyron spicatum*/*Poa sandbergii* and the *Agropyron spicatum*/*Opuntia polyacantha* habitat types.

Subsequent studies indicated the existence of a third vegetational series characterized by the co-dominance of *Carex hoodii, C. geyeri,* and other upland *Carex* species. One habitat type, *Carex hoodii*/*Festuca idahoensis,* has been recognized to date. This type is restricted to the highest elevations of the grasslands, and has not been previously described in the literature. In addition to the dominance of *Carex,* it is characterized by the common occurrence of *Bromus carinatus, Danthonia intermedia, Poa nervosa, Antennaria anaphaloides,* and *Eriogonum flavum,* species often associated with subalpine areas and rare or lacking in grasslands of lower elevation. Data from this habitat type are included in the present study.

The classification approach used here recognizes the "series" as a group of communities characterized by a single dominant climax species. The habitat type is considered to be the "aggregate of all areas that support or can support the same primary climax" (Daubenmire 1970). The habitat type (h.t.) has relatively uniform biotic and abiotic structure and is the primary unit of ecosystem classification. It is recognized by means of its vegetation, but is characterized also by distinctive habitat features.

Following preliminary classification of the vegetation, a second objective was to determine the relationship of habitat factors to the plant communities. We desired to know whether these vegetational groups represented recognizable ecosystems when considered on the basis of site characteristics only.

Methods

The habitat data were confined to topographic and edaphic factors, since climatic records for the study area are too sparse to be of value in a detailed analysis. Topographic information included records of elevation, slope, and aspect. Soil data included type of parent material, depth and stoniness of profile; texture, color, organic matter, structure and pH of the principal horizons; presence and depth of lime accumulation; and amount of surface gravel and stone. The soils were also classified into taxonomic units according to the USDA system (USDA 1975). Classification was made only to soil family, since soil survey information was not sufficient to provide classification to the series level for many soils of the study area. A radiation index, based upon latitude, aspect and slope (Frank and Lee 1966), was calculated for all sites.

The kinds of information listed above were available for 74 sample plots representing 6 habitat types. One of these, the *Festuca idahoensis*/*Symphoricarpos occidentalis* h.t. which occurs marginally in the study area, was represented by only 3 samples and was dropped from the analyses.

Two approaches appeared feasible for investigating vegetation-site relationships with the data available. One was to make a direct comparison of vegetation and soil taxonomic units, the other was to determine the relationship of individual site factors to units of vegetation. The rationale for the first approach is that climax vegetation and soils are considered to be the products of the same set of formative factors (Jenny 1958), hence, some degrees of relationship at the taxonomic level might be expected.

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The second alternative involved examination of the data for individual site characteristics in order to determine their relationship to vegetation units. Graphing of such data, and consideration of group mean values and their variability, indicated that a number of site characters had some degree of relationship to vegetation.

Although marked differences in several of these site factors were evident between some of the habitat types, no one factor was dominant among all of them, and the data showed high variability within and considerable overlap of site values among vegetation units. These results indicated that a multivariate analysis was needed to explore the relationships further.

Of the several methods available, stepwise linear discriminant analysis appeared most suitable for our purposes. Discriminant analysis has been successfully used by several workers studying vegetation and vegetation-site relationships (Mathews 1979, Bunting 1978, Pyott 1971).

Stepwise linear discriminant analysis consists of stepwise multivariate analysis of variance (stepwise MANOVA) for selection of variables, followed by canonical analysis. In our data, classes were defined by habitat types.

The initial discriminant analysis of our data followed the procedure described in SPSS (Nie et al. 1975). The results were then checked by the discriminant analysis procedure described in SAS (Helwig and Council 1979).

For the stepwise linear discriminant analysis (SPSS) procedure, the selection of variables, the calculation of Fisher's Linear Discriminant Functions, and the canonical analysis were performed on the 57 sites (of the 71) which had complete data for 16 site variables. The variables submitted to the program were: depth of the solum, organic matter of the A and the B_1 horizons, color value and chroma of the A horizon, pH of the A, texture of the A (percent silt, percent sand, percent clay), depth of the A and depth of the B_1, percent of the surface covered by coarse fragments, percent coarse fragments (stoniness) in the profile, depth of the $CaCo_3$, radiation index, and elevation. Thirteen of these variables were selected in the initial stepwise multivariate analysis of variance portion of the program.

The discriminant analysis and reclassification of the original sites were then performed using the 13 selected variables.

The linear discriminant (SPSS) procedure assumes approximate equality of within group variances. The SAS procedure was used to test this assumption and to provide an alternate (quadratic) discriminant analysis if unequal group variance was detected. The latter being the case, the SAS quadratic procedure was then used to confirm the linear discriminant results. This method requires that the number of variables in the model be about half the number of sites sampled. The limiting factor in this case was the *Carex/Festuca* h.t. with 9 sites. To meet this restriction we chose 5 variables based on their weights in the first standardized function of the linear analysis (Table 2). These variables were: elevation, radiation index, organic matter and color (value) and pH of the "A" horizon. In a second analysis, logarithmic transformations of pH and organic matter were made to improve normalcy of distribution. Reclassification success was used to evaluate the effectiveness of the 5 variables in the model.

Results

Soil Types and Vegetation

Comparison of soil taxa with vegetation showed great variability in the degree of relationship. The closest correspondence was found for the *Carex Festuca* h.t., which was associated in all cases with a single soil family described as loamy skeletal mixed Typic Cryumbrept. Association with soil taxa was much looser for all other habitat types. The *Festuca/Koeleria* h.t. occurred with 2 soil orders (Mollisols and Inceptisols), although the majority of sites occurred within the former. At the Great Group level, both Argixerolls and Haploxerolls were represented, with a total of 6 soil families within these groups. Nearly as much variability was found in soils of *Festuca/Agropyron* h.t.; all were Mollisols, but 5 soil families occurred. The *Agropyron/Poa* h.t. occurred only in Mollisols, but with 6 soil families included. The *Agropyron/Opuntia* h.t. showed wider variability with Entisols as well as Mollisols at Order level, and 9 soil families included. Two of the latter were Xerorthents, the others divided among Haploxerolls and Argixerolls.

In addition to the occurrence of several soil families for all but 1 of the 5 habitat types, 3 soil families occurred in more than 1 type. Loamy skeletal mixed mesic Ultic Argixerolls were found in the *Agropyron/Opuntia, Agropyron/Poa, Festuca/Agropyron* and *Festuca/Koeleria* habitat types, although in 1 site only for the latter 2 types. Lithic Ultic Argixerolls were found in both the *Agropyron/Opuntia* and *Festuca Agropyron* habitat types and Pachic Ultic Argixerolls occurred in both the *Festuca/Agropyron* and *Festuca/Koeleria* habitat types, although more commonly in the latter type. Some of this overlap might be removed at soil series level, but classification to this category was not available.

These results are not surprising in light of the findings of others who have studied comparable vegetation and soils. Daubenmire (1970) found little relationship between vegetation and soil taxa in grassland and shrub-grass communities of Washington. The *Agropyron/Poa* h.t. occurred with 4 soil families (6 if the "lithic phase" of the *Agropyron/Poa* is included). His *Festuca/Symphoricarpos* h.t. was found with 7 soil families. Conversely, 1 soil series, Ritzville silt loam, supported 5 shrub-grass or grassland habitat types. Hironaka and Fosberg (1979) found 2-5 soil families associated with most habitat types in sagebrush-grass vegetation of southern Idaho. Hugie et al. (1973) concluded from their study of shrub-grass vegetation and soils in the Intermountain Region that "soil classification appeared to be most compatible with vegetation at the soil subgroup level."

Individual Site Factors and Vegetation

Results of analysis by the SPSS procedure for determining the relative influence of individual site factors are summarized in Tables 1-4. The value of the various functions in accounting for the variance among habitat types is shown in Table 1.

Table 1. Eigenvalue and percent of variance accounted for in 4 canonical discriminant functions involving 13 site factors.

Function	Eigenvalue	Variance	Cumulative variance
1	18.30324	85.40	85.40
2	2.14858	10.03	95.43
3	0.75304	3.51	98.94
4	0.22627	1.06	100.00

The data indicate that almost all the influence of the site factors is expressed in functions 1 and 2. This result is pertinent to evaluation of the discriminant function coefficients for the 13 site factors shown in Table 2. These coefficients reflect the magnitude and

Table 2. Standardized canonical discriminant function coefficients (1 + 2) for 13 site factors.

Site Factor	Function 1	Function 2
Solum depth	−0.30889	−0.80339
Depth "B"	−0.09850	0.50535
Lime depth	0.69604	−0.37557
Color (value)	0.89325	0.35938
Color (chroma)	−0.21241	−0.28159
Organic M. "A"	0.72272	−0.50285
Organic M. "B"	−0.53390	0.41550
PH "A"	0.58504	−0.52075
Sand "A"	−0.12554	0.67661
Silt "A"	−0.42171	0.21147
Radiation index	0.97959	0.71423
Elevation	−1.56080	0.21027
Gravel (surface)	0.41521	−0.53258

direction (positive or negative) of the distribution of each dependent variable in that function.

The apparent influence of different site factors evidently varies considerably both within and between functions. Since the data of Function 1 account for 85% of the total variability, those variables counting most heavily in it may be considered the principal habitat factors reflecting the vegetation pattern. These are, in order of magnitude, elevation, radiation index, color (value) and organic matter of the "A" horizon, lime depth, pH of "A" horizon, organic matter of "B", horizon, percent silt in "A" horizon, surface gravel and depth of solum. In Function 2 some of these factors show as less influential, while depth of "B" horizon and percent sand in the "A" horizon become relatively important.

Table 3. Canonical discriminant functions evaluated at group means (group) centroids).

Habitat Type	Function 1	Function 2
Agropyron/Opuntia	5.49837	1.05871
Agropyron/Poa	2.39029	0.57747
Festuca/Agropyron	0.43533	-1.72166
Festuca/Koeleria	-2.25274	-1.44966
Carex/Festuca	-7.21427	2.05309

Other valuable information is provided by the discriminant functions evaluated at group means as shown in Table 3. These data show the relative positioning (ordination) of the 5 types by habitat factors. The arrangement in Function 1 shows a gradient from the values associated with the most xeric community *(Agropyron/Opuntia)* to the most mesic *(Carex/Festuca).* The data in Function 2 show particularly well the affinities within and the separation among the vegetation units at series level. The ultimate test of the analysis, however, is the degree to which the the data from the habitat factors predict the groupings established by vegetation alone. The results of this test are summarized in Table 4.

The data indicate a high degree of concurrence between the group designations by habitat factors and by vegetation, with an overall agreement of 92%. Where differences in site grouping occurred, it was mainly within the series. A subsequent test, using stepwise discriminant analysis and grouping the sites by series rather than habitat types, resulted in agreement of 94, 100, and 100 % for the *Agropyron, Festuca* and *Carex* series, respectively.

A feature of the discriminant data, not shown in Table 4, is that the classification of each site by habitat factors is given in terms of a highest and a second highest group, each with a specific probability rating. This provision of first and second choice with probability ratings is useful in assessing the status of sites which are marginal in regard to their classification. An example occurs in the 4 sites with full habitat information which were classified differently by vegetation versus habitat. In 2 of these cases, the habitat data show relatively low probabilities (0.5164 and 0.5447) for "first choice" in the analysis, while the "second choice" agrees with the vegetation classification with a probability only slightly lower (0.4688 and 0.4553). The vegetational composition of each of these sites falls in the outer range of its class, and the habitat data reflect the same marginal situation. The probability rating for most sites, where classification by vegetation and habitat factors concurred, was in the range of 0.7500 to 1.000.

There were indications in the results of this "all group" analysis (Table 4) that differences between the *Carex/Festuca* h.t. and the other types were greater than those among the latter. The 2 habitat types of the *Agropyron* series seemed particularly similar. The analysis by series gave a high degree of separation (98%) at that level. The *Agropyron* and *Festuca* series also showed a high degree of concurrence (91 and 100% respectively), for site factors and habitat types.

Analysis by the SAS procedure showed that in all cases the hypothesis of equal inter-group variance matrices was rejected, and quadratic discriminent analysis was performed. The results obtained from this analysis are shown in Table 5.

The results show 86% of the sites were classified to concur with the habitat types, and 97% in the "correct" vegetational series. It is evident that the SAS procedure, using only 5 major variables, provided only slightly less agreement overall among vegetation and site factor groupings than did the SPSS procedure using 13 variables. The degree of concurrence was noticeably poorer only in the case of the *Agropyron/Poa* h.t., which was distinguished from the *Agropyron/Opuntia* h.t. in just 66% of the cases. When log transformations for 2 of the 5 variables, pH and organic matter of the "A" horizon were used to improve the normality in distribution, agreement of the vegetation and site classification was improved overall to 93% In the case of the *Agropyron* series, concurrence was increased to 93.7% and 81.2% for the *Agropyron/Opuntia* and *Agropyron/Poa* habitat types, respectively. This still left agreement for the latter lower than for any of the other 4 types. Addition of some of the 8 variables omitted in this test might have resulted in better separation of this type. Direct comparison of group means and their variability suggests that such factors as solum depth, organic matter of the "B" horizon, percent sand in the "A" horizon and percent surface gravel may have value in distin-

Table 4. Results of classifying habitat types by 13 site factors using SpSS discriminant analysis.

	Number of cases	Predicted Group Membership (%)				
		AG/OP	AG/POA	FEST/AG	FEST/KO	CAR/FEST
Agropyron/Opuntia	12	91.7	8.3	0	0	0
Agropyron/Poa	13	15.4	84.6	0	0	0
Festuca/Agropyron	9	0	11.0	89	0	0
Festuca/Koeleria	16	0	0	0	100	0
Carex/Festuca	9	0	0	0		100

Table 5. Results of classifying habitat types by 5 site factors using SAS discriminant analysis.

	Predicted Group				
Group	AG/OP	AG/POA	FEST/AG	FEST/KO	CAR/FEST
Agropyron/Opuntia	88	12	0	0	0
Agropyron/Poa	31.3	62.5	6.2	0	0
Festuca/Agropyron	0	9.1	90.9	0	0
Festuca/Koeleria	0	0	5.5	94.5	0
Carex/Festuca	0	0	0	0	100

guishing between the 2 *Agropyron* habitat types.

Discussions and Conclusions

The apparent lack of strong relationship between most vegetation and soil taxonomic units must be considered in light of the current state of the art and the limitations of the current study. The classification of plant communities was made primarily on the basis of species presence, followed by consideration of frequency and cover data. The soil taxa are determined on the basis of a large number of factors, many of which may not critically affect botanical composition.

The current soil classification appears to recognize finer divisions in the grassland ecosystems under study than does the system of vegetation classification. This may be inherent in the systems, but the fact that the soils classification represents a concerted national effort over several decades is also pertinent. No comparable effort to develop a standard system for the classification of vegetation has been made, at least on this continent. As a consequence, we may have recognized only the broader ecosystem units as reflected in botanical composition, and missed finer subdivisions that might correlate more closely with soil families.

Even in the present situation, certain relationships of soil and vegetation taxa are evident. In the *Agropyron spicatum*/*Opuntia polycantha* h.t., 50% of the sites had Xerolls with lithic profiles, while another 12.5% were Lithic Orthents. Only 1 lithic profile was found in the *Agropyron spicatum*/*Poa sandbergii* h.t., where Ultic or Calcic Argixerolls occupied 43% of the sites and Calcic Haploxerolls another 25%. The *Festuca idahoensis*/*Koeleria cristata* h.t. contained 45% Pachic Ultic or Ultic Argixerolls and 40% Pachic Ultic Haploxerolls, reflecting the depth of mollic epipedon and degree of leaching associated with this more mesic community.

Future studies should include close examination of currently recognized vegetation units which are associated with several soil taxa. Similarly, consideration should be given to recognizing certain groups of soil taxa as essentially equivalent with respect to vegetation. The process of resolving apparent differences calls for joint soil-vegetation studies on a more intensive scale than has generally be practiced in the past.

The effort to relate individual site factors to vegetation units at both series and habitat type levels was highly successful. This was accomplished by multivariate analysis in the form of stepwise discriminant analysis. The method tended to maximize differences "between" groups and to minimize the considerable variability "within" which characterized our data. The analysis confirmed the validity of groups recognized by vegetation only. It also showed the value of the series concept as a basic group in the classification hierarchy, by giving higher agreement with site factors at this level than for habitat types.

The SAS analytical procedure was helpful in corroborating the results obtained with the SPSS approach. It also was attractive in providing a high degree of vegetation-site correlation with use of only a few site factors. It must be remembered, however, that the selection of these 5 site factors was possible only after their relative importance had been shown by the SPSS procedure. Even with the SPSS system, the value of the analysis was definitely affected by number of sites, and the results support the value of obtaining relatively large numbers of samples for this type of study, in order to cope with the great natural variability encountered in both vegetation and site factors.

The rating of site variables provided by the SPSS procedure supports the hypothesis of a topo-edaphic pattern in the distribution of the canyon grassland vegetation. In the case of the 6 leading factors, elevation and radiation index may be considered as representing the topographic influence most directly, while the soil influence is reflected primarily in organic matter, color and pH of the "A" horizon, and in lime depth.

The advantages of this approach for situations such as presented in the current study include the ability to use soil and other site data determined directly on the sample plots. These data can be obtained concurrently with sampling the vegetation and are not dependent on the prior existence of soil survey or local meteorological data.

The results of this analysis of site factors support the idea that vegetation units independently determined can define ecosystems. The method also offers promise for the study of seral vegetation. Except on sites where severe accelerated erosion has occurred, it seems likely that the site factors used in this study would be affected little by the livestock grazing which has altered the vegetation during the past century.

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Effects of Plant Shredding on Nutrient Content of Four South Texas Deer Browse Species

J.H. EVERITT

Abstract

The nutrient content [crude protein (CP), P, Ca, K, and Mg] of the regrowth of shredded and current growth of nonshredded (control) plants was measured for 4 important deer browse species in south Texas. Plants were shredded in February, April, and July of 1980. Plants shredded in February and their controls were sampled for nutrient analyses at 2, 6, and 9 months after shredding. Plants shredded in April and July and their controls were sampled for analyses 2 months after shredding. Two months after shredding, regrowth from plants shredded in February, April, and July generally had higher CP and P than current growth from nonshredded plants. Few differences were detected in CP and P at 6 and 9 months after shredding. These results indicate that CP and P levels could be increased in initial regrowth from plants shredded at various dates during the growing season. Levels of Ca, K, and Mg did not differ between shredded and current growth, or they were slightly lower in the regrowth.

Shredding is one of several techniques that can be used to regenerate stands of browse. The treatment causes shrubs to produce new leader growth which is of enhanced nutrient quality while active growth is occurring (Reynolds and Sampson 1943). Such regenerative treatments should be carefully planned so that large contiguous areas of browse are not shredded at one time. Large treatment areas could cause impacts to the structure of the midstory which might adversely affect wildlife species dependent on this midstory structural component.

The short-term effect of shredding of browse plants is similar to that of clipping of herbaceous plants. Removal of leaves and twigs during the growing season stimulates sprouting and new twig growth (Laycock and Price 1970, Willard and McKell 1978). Powell and Box (1966) thought there was increased use by deer and cattle of brush resprouts after shredding because the resprouts had greater palatability. The present paper reports the changes in concentration of crude protein (CP), P, Ca, K, and Mg in 4 browse plant species from south Texas that were shredded at 3 different seasons.

Materials and Methods

The study was conducted on the H. Yturria Ranch located about 13 km north of Raymondville in Kenedy and Willacy counties, Texas. The ranch has 7,200 ha of native and improved rangeland located in the transition zone between the Coastal Prairies and the South Texas Plains (Gould 1975). The climate, soils, and vegetation of this area were described by Everitt and Gonzalez (1979).

The experimental site was on a tight sandy loam range site with Delfina fine sandy loam soil (Aquic Paleustalfs). The brush had been bulldozed in 1977, but was reinfesting the area. Its regrowth ranged from 1 to 2 m in height. In February 1980, 6 plots, each 30 × 150 m, were established where the vegetation was uniform. These were arranged into 3 pairs, designated A, B, and C. One plot of each pair was shredded with a 1.8-m rotary blade pulled by a tractor and the adjoining plot served as a nonshredded control. The brush was shredded to about a 10-cm stubble height in mid-February for plot pair A, mid-April for pair B, and mid-July for pair C. The site was lightly grazed intermittently by cattle during the study. Deer at a density of 1/7 ha utilized the area throughout the study (Gary Waggerman, Texas Parks and Wildlife Department: personal communication).

Four common browse species were selected for nutrient analyses: bluewood *(Condalia hookeri)*, granjeno *(Celtis pallida)*, lime pricklyash *(Zanthoxylum fagara)*, and lotebush *(Ziziphus obtusifolia)*. These species are important foods of white-tailed deer *(Odocoileus virginianus)* in south Texas (Davis and Winkler 1968, Everitt and Drawe 1974, Everitt and Gonzalez 1979, Arnold and Drawe 1979). For pair A, vegetation samples were collected in 1980 on 3 dates following shredding to determine if nutrient value declined following treatment; mid-monthly in April (2 months after shredding), August (6 months after shredding), and November (9 months after shredding). Lotebush is deciduous, thus November samples were not collected from this species. For plots shredded in mid-April (pair B) and mid-July (pair C), samples were collected 2 months after shredding in mid-June and mid-September, respectively. Vegetation samples were collected only once from these plots to determine if the nutritive content of regrowth of shredded plants varied from current growth of control plants. Plants were handclipped and leaf and stem samples from only the outer 5 cm of new growth were collected. Only unbrowsed plants were sampled for analyses. Ten samples were collected for each species from both nonshredded and shredded plots. Each sample was a composite from at least 4 plants to provide adequate tissue for analyses. Samples were oven dried at 65°C for 48 hours, ground in a Wiley mill through a 1-mm mesh screen, thoroughly mixed, and stored in sealed jars.

Duplicate plant samples were analyzed for CP, P, Ca, K, and Mg, and the results averaged. Total N was determined by the Kjeldahl method (Peech et al. 1947). Percent CP was calculated by N × 6.25. Levels of Ca, K, and Mg were determined by atomic absorption spectrometry (Robison 1966). Lanthanum oxide was added to Ca and Mg samples to reduce interference. Phosphorus was determined by the rapid digestion method (Bolin and Stramberg 1944).

Results

February Shredding

Nutritive content of the 4 browse species from shredded and nonshredded plots on 3 dates during the growing season are given in Table 1. In April, 2 months following shredding, the CP content of granjeno, lime pricklyash, and lotebush regrowth from the

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shredded plants was higher than current growth of plants from the nonshredded plants. In August, 6 months after shredding, only the regrowth from granjeno was higher in CP than that of current growth. There were no differences between treatments in the CP content in November, 9 months after shredding. The P content of regrowth of all species from the shredded plot was significantly higher in April than that of the current growth from the nonshredded plants; however, there were no differences between treatments in August or November, regardless of species.

The Ca content of lotebush samples from the shredded plants was significantly lower in April than that of samples from the nonshredded plants. In August, shredded plants of bluewood, granjeno, and lotebush were lower in Ca than the controls. The Ca content of bluewood, granjeno, and lime pricklyash regrowth from the shredded plants was lower in November than the growth from nonshredded plants.

The K content of bluewood regrowth from the shredded plot was significantly lower than that of control plants on all 3 sampling dates. In November, lime pricklyash from the shredded plot was lower in K than current growth from the nonshredded plot, but no differences were detected on the first 2 sampling dates. The K content of granjeno and lotebush from the shredded and nonshredded plots did not differ on any of the sampling dates.

Magnesium levels of all 4 species from the shredded plot were significantly lower in April than those from the nonshredded plot. In August, the Mg content of shredded plants of bluewood, granjeno, and lime pricklyash was lower than that of nonshredded plants. Bluewood from the shredded plot also had a lower Mg content in November than plants from the nonshredded plot. No differences were detected in the Mg content of the other species in November.

April Shredding

The nutritive content in June (2 months after shredding) of the 4 browse species from shredded and nonshredded plots are presented in Table 2. Treatment differences in the CP and P levels of the 4 species were the same as those of April samples from the February shredding (Table 1). There were no differences in the Ca content of bluewood and granjeno from shredded and nonshredded plots; however, lime pricklyash and lotebush from the shredded plot had lower levels of Ca than plants from the nonshredded plot. Bluewood from the shredded plot had a significantly lower K content than that on the control while other species did not differ between treatments. The Mg content of bluewood, lime pricklyash, and lotebush samples from the shredded plot were lower than those from the nonshredded plot. The Mg content of granjeno was not affected by shredding.

July Shredding

Nutritive content of the leaves and twigs of 4 browse species from shredded and nonshredded plots in September, 2 months following shredding, are presented in Table 3. Regrowth of bluewood, granjeno, and lime pricklyash from the shredded plot was significantly higher in CP than of the current growth of these species on the nonshredded plot. Phosphorus levels of all species from the shredded plot were higher than those from the nonshredded plot; whereas, Ca levels from the shredded plot were lower than those from the control. Bluewood from the shredded plot was lower in K than growth from the nonshredded plot, but there were no differences between treatments in K levels of the other species. All species from the shredded plot had significantly lower levels of Mg than those from the nonshredded plot.

Discussion and Conclusions

Data indicated that CP and P content in regrowth of browse plants shredded on various dates was higher than in current growth from nonshredded plants at 2 months after shredding. As growth matured the CP and P declined and essentially no differences occurred between shredded and nonshredded plants at 6 or 9 months after shredding. Changes in the CP and P content of leaves and stems of woody plants through the growing season have been reported on by several researchers (Price and Laycock 1970, Kozlowski 1971, Kramer and Kozlowski 1979). Their findings indicate that CP and P levels are highest in initial growth in spring or early summer and these nutrients rapidly decline as the foliage matures. Apparently this same cycle occurred in the regrowth from shredded plants. All species from both shredded and nonshredded plots on all sampling dates had levels of CP adequate for the nutrition of white-tailed deer (French et al. 1956, Murphy and Coates 1966). The minimum daily P requirement for white-tailed deer nutrition is in excess of 0.25% of the dry ration (Magruder et al. 1957). At 2

Table 1. Average crude and mineal content of four browse species sampled at three dates during the 1980 growing season from shredded and nonshredded plots on the Yturria Ranch in south Texas. Plots were shredded in February 1980.

Species	Chemical analyses	April		August		November	
		Shredded	Nonshredded	Shredded	Nonshredded	Shredded	Nonshredded
Bluewood	CP[1]	22.39	19.68	17.68	18.94	18.77	17.36
	P	.25*	.15	.15	.17	.18	.17
	Ca	1.48	1.56	.77*	1.25	.97*	1.51
	K	2.66*	3.11	2.46*	3.17	1.95*	2.43
	Mg	.55*	.75	.57*	.82	.66*	.84
Granjeno	CP	28.73*	21.51	27.98*	22.69	22.10	23.32
	P	.26*	.20	.25	.26	.21	.19
	Ca	2.64	2.79	2.47*	3.14	3.11*	3.93
	K	1.91	1.84	2.11	2.14	1.88	1.96
	Mg	.72*	.93	.71*	.99	.88	1.10
Lime pricklyash	CP	22.19*	16.09	16.52	17.42	18.00	16.52
	P	.30*	.19	.19	.21	.20	.18
	Ca	1.01	1.14	1.29	1.37	1.53*	1.94
	K	2.00	1.91	1.71	1.77	1.36*	1.63
	Mg	.30*	.45	.45*	.57	.45	.56
Lotebush	CP	27.20*	19.87	18.34	19.0	—[2]	—
	P	.29*	.19	.22	.21	—	—
	Ca	.66*	.95	.98*	1.32	—	—
	K	2.59	2.85	1.98	1.91	—	—
	Mg	.22*	.25	.40	.41	—	—

*Significantly different from nonshredded at $P<0.05$ level.
[1]CP=Crude protein.
[2]Insufficient plant material for sampling.

Table 2. Average crude protein and mineral content of four browse species sampled from shredded and nonshredded plots on the Yturria Ranch in south Texas. Plots were shredded in april and plant material was collected for analyses in June 1980.

Chemical Analyses	Bluewood		Granjeno		Lime pricklyash		Lotebush	
	Shredded	Nonshredded	Shredded	Nonshredded	Shredded	Nonshredded	Shredded	Nonshredded
CP[1]	19.51	17.28	31.00*	19.42	21.80*	15.68	26.00*	16.98
P	.22*	.16	.31*	.21	.29*	.19	.28*	.17
Ca	1.20	1.23	3.07	3.33	1.01*	1.35	.73*	1.28
K	2.66*	3.58	2.03	2.16	1.70	1.49	2.41	2.42
Mg	.62	.77	.96	1.09	.31*	.52	.35*	.49

*Significantly different from nonshredded at $P<0.05$ level.
[1]CP=Crude Protein.

Table 3. Average crude protein and mineral content of four browse species sampled from shredded and nonshredded plots on the Yturria Ranch in south Texas. Plots were shredded in July and plant material was collected for analyses in September 1980.

Chemical Analyses	Bluewood		Granjeno		Lime pricklyash		Lotebush	
	Shredded	Nonshredded	Shredded	Nonshredded	Shredded	Nonshredded	Shredded	Nonshredded
CP[1]	22.52*	17.30	36.84*	24.60	23.63*	16.14	23.95	22.14
P	.20*	.16	.48*	.26	.34*	.21	.31*	.22
Ca	.73*	1.32	2.43*	3.47	.74*	1.09	.71*	1.23
K	2.56*	3.25	2.00	1.92	2.10	2.07	2.32	2.27
Mg	.44*	.80	.61*	1.04	.29*	.49	.21*	.32

*Significantly different from nonshredded at $P<0.05$ level.
[1]CP=Crude Protein.

months after shredding most of the leaf and twig samples from shredded plants had P levels at or above this minimal level, but as growth matured on shredded and nonshredded plants, P levels were generally inadequate for deer.

Levels of Ca, K, and Mg either did not differ between regrowth from shredded plants and current growth from nonshredded plants or were significantly lower in the regrowth. Similar patterns were observed on all sampling dates. The reason for decreased concentrations of these minerals in some of the regrowth samples is unknown. Everitt and Gonzalez (1981) reported that levels of Ca, K, and Mg remained generally stable from spring through fall in south Texas browse plants. Although these minerals were often lower in the regrowth, they were always above the requirement levels reported for deer and other ruminants (Magruder et al. 1957, Maynard and Loosli 1969).

The study area had droughty conditions during the first 7 months of 1980. The drought was broken in early August by Hurricane Allen when 36 cm of rain fell within 2 days. Prior to this, total rainfall for the year was about 18 cm, 50% below normal. Although droughty conditions prevailed, brush shredded during this period had regrowth. Because rainfall peaks in south Texas occur in May or June and again in Sepember, optimum times for shredding may be in April and July. Shredding in July may have more practical significance than in April, because other deer foods such as forbs and soft mast are not as available in late summer and early fall. Thus, shredding can enhance the probability for providing deer with more succulent nutritious growth.

More deer browsing was noted on the shredded plots than on the nonshredded plots. This observation agrees with that of Powell and Box (1966). Shredding creates nutritious sprouts that are more palatable and readily available because plant height is reduced and restrictions to browsing such as sharp thorns, often prevalent on mature stems, are eliminated.

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Relationship between Selected Factors and Internal Rate of Return from Sagebrush Removal and Seeding Crested Wheatgrass

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Abstract

One alternative in increasing western range forage production is sagebrush removal and seeding crested wheatgrass. Of primary importance when considering such investments is economic profitability. Using internal rate of return (IRR) as a measure of economic profitability, a range improvement computer budget program (RIBPRO) was used to calculate IRR's for a specific ranch example. Factors associated with high IRR's are a constant forage production function over time, agricultural conservation payments, a 30-year or older stand, approximately 80 ha or more of improved range, low initial user cost/ha, and high additional kg of forage/ha.

Western ranch producers, public range managers, as well as others, recently have shown increasing interest in improving forage production on western private and public rangelands. This is reflected in the public sector by increased legal encouragement with respect to range improvements. In the Taylor Grazing Act of 1934, Sec. 10, the only grazing fee funds specifically directed to range improvement were. . . .

> "25 per centum of all monies collected under Section 15 of this Act during any fiscal year when appropriated by the Congress, shall be available until expended solely for the construction, purchase, or maintenance of range improvements. . ."

Section 15 lands are those acreages administered by the Department of Interior outside grazing districts established by the Taylor Grazing Act. The Federal Land Policy and Management Act of 1976 directed that 50% of the collected grazing fees "be used for on-the-ground range rehabilitation, protection, and improvements. . . . ." Half of these funds is returned to the source (usually the BLM district) and the other half is distributed by the Secretary of the Interior. The Public Rangelands Improvement Act of 1978 authorized additional appropriations for range improvement, giving priority to entering cooperative agreements with range users for building and maintenance of ". . .on-the-ground range improvements." Recent amendments to that part of the Code of Federal Regulations concerning administration of public lands gives first priority of permanent additional forage to permittee(s) or lessee(s) in proportion to their contribution or efforts which resulted in the additional forage (Code of Federal Regulations 1982). Previously, allocation of additional forage on the basis of quantity of current grazing preferences was listed first in the priorities (Code of Federal Regulations 1981).

Another stimulus to private land managers has come from possible reductions by the Bureau of Land Management (BLM) in grazing preferences and grazing time periods, with the latter reductions being proposed primarily for spring grazing (Paradise-Denio EIS 1981, Tonopah EIS 1980). Expected future decreases in quantity of grain for livestock feed, decreases in amount of available fossil fuels, and increases in world population seem to support arguments for increasing productivity of forage on public lands for livestock (Holechek 1981). In addition, ranch firms continue to experience what is often called the "cost-price" squeeze—the average annual percentage increase in purchased input prices being greater than the average annual percentage increase in output prices (or appearing to be, given that changes in technology may not be accounted for).

Individuals directly or indirectly concerned with western ranching and range production have reacted to the above changes by searching for management alternatives. One alternative is investment in such ranch improvements as big sagebrush *(Artemisia tridentata)* removal and crested wheatgrass *(Agropyron cristatum)* seeding. An immediate question to be answered, however, is that of project profitability relative to alternative investments.

Alternative Investment Criteria

Three capital budgeting criteria generally used in economic evaluation of range improvement projects are present net worth (PNW), benefit-cost ratio (B/C), and internal rate of return (IRR), (Workman 1981). PNW is the sum of the difference between future benefits and costs over the life of an investment project, discounted to the present. B/C is the present value of project benefits divided by the present value of project costs. IRR is that interest rate of discount which will equate the PNW of a project to zero. When investible funds are unlimited, investment projects are acceptable under the alternative criteria if PNW is greater than zero, if B/C is greater than 1, or if IRR is greater than the interest rate cost of project capital and the interest rate that could be earned in an investment that is similar (length of life, initial investment, benefit stream flow, cost stream flow, risk). With unlimited funds, all 3 criteria will accept or reject the same projects, although one potential problem with IRR may be the existence of multiple roots (IRR's) if the annual net income flows are not monotomically increasing or decreasing (Hirshleifer 1970).

Under conditions of limited investible funds or mutually exclusive projects (it is not physically possible to simultaneously undertake all projects), ranking of projects is necessary. Applying the 3 criteria separately, the decision maker would sequentially allocate funds to projects with the highest PNW values, largest B/C ratios, or highest IRR's. Unfortunately, the 3 investment criteria can yield different project rankings if projects differ in terms of initial investment, in expected life, and benefit and cost stream flows. The problem and proposed adjustments to account for these differences are outlined by Mishan (1976) and are illustrated with range improvement projects by Workman (1981). The purpose of the "adjustment" or "normalization" procedure is to give the same,

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and theoretically correct, project rankings from the 3 investment criteria.

IRR: Advantages and Limitations

IRR is used in this study because (1) investors, especially profit maximizers, can compare calculated IRR's with the interest rate of borrowed capital or rates of return expected from alternative investments, (2) it is not necessary in standard IRR calculations to initially choose an interest rate of discount, and (3) the IRR concept is the conceptual equivalent of the annual compound rate of interest used in money markets (Gardner 1963), and thus may be more readily understood by ranchers and other users as a relative measure of investment project desirability than PNW or B/C.

If the project manager's choice is to accept or reject a single investment project using capital borrowed over the life of the project, then IRR is conceptually valid. A project is acceptable if its IRR is greater than the rate of interest on borrowed capital. However, if the manager can select among 2 or more mutually exclusive projects or is in a limited investible funds situation, then "correct" project ranking may avoid "incorrect" project selection decisions. The appropriateness of adjusting or "normalizing" calculated IRR also applies to sensitivity analysis. Unfortunately, to applying the "normalization" procedure means losing some of the advantages of IRR. IRR values calculated in this study are not normalized, and should be interpreted accordingly.

A Computer Investment Evaluation Program

An additional criticism of IRR is that IRR's are not easy to calculate without computers (Randall 1981), and this criticism could be expanded to include computer programs appropriate for given types of investment projects. One computer range improvement budget program (RIBPRO) has been specifically developed to calculate internal rate of return to dollars invested in sagebrush removal and crested wheatgrass seeding (Lucier et al. 1981).

In this computer program sagebrush removal and native grass stand improvement alternatives include spray and seed, plow and seed, and spray only (Fig. 1). Herbicides to kill sagebrush may be applied using aerial spraying or ground spraying. Additional fencing and water development for grazing cattle are also included as optional management activities. To calculate an internal rate of return from all activities anticipated by the user, detailed information (INPUT DATA) must be provided by the user. A minimum number of assumptions are incorporated into RIBPRO. Annual equipment depreciation costs of equipment owned by the land manager are allocated to the range improvement project in proportion to annual hours devoted to this activity.

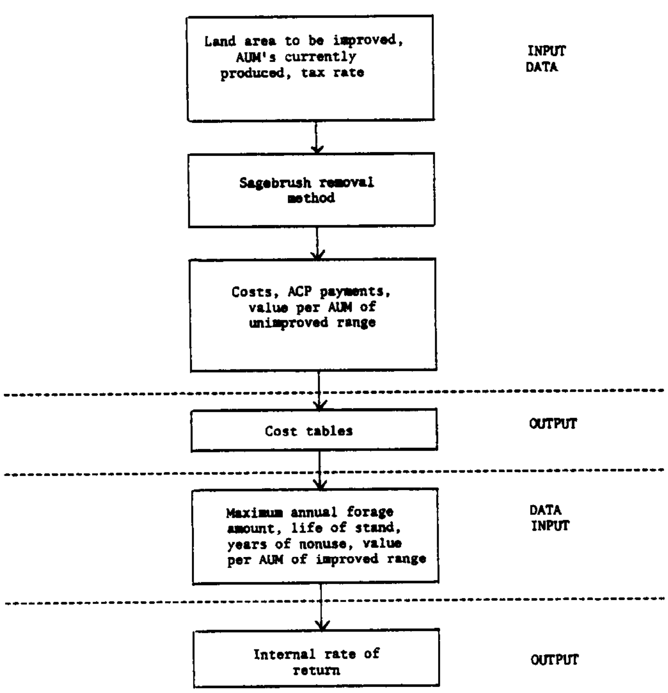

Fig. 1. *Schematic of RIBPRO.*

Application Example

An example with a given set of parameters (Table 1) can best illustrate data input requirements and output results of RIBPRO.

Table 1. Parameters and values used in internal rate of return sensitivity analysis.

Parameter	Value	Units
Area improved	182.1	ha
Area per AUM, unimproved	7.28	ha/AUM
Area per AUM, improved	.84	ha/AUM
Tax rate, unimproved	.311	$/ha
Tax rate, improved	1.04	$/ha
Spray tractor		
Current value	15,000	$
Proportion of life remaining	75	%
Annual use	450	hr.
Annual maintenance and repair costs	675	$
Fuel use	12.1	l/hr.
Fuel cost	.304	$/l
Seeding tractor		
Current value	18,000	$
Proportion of life remaining	90	%
Annual use	385	hr.
Annual maintenance and repair costs	700	$
Fuel use	13.6	l/hr.
Tractor fuel cost	.304	$/l
Sprayer		
Current value	2,000	$
Proportion of life remaining	85	%
Annual use	50	hr.
Annual maintenance and repair costs	120	$
Spray rates	1.295	ha/hr.
Rangeland drill		
Rental cost	850	$
Use rate	1.92	ha/hr.
Seeding rate	6.73	kg/ha
Seed cost	2.49	$/kg
Herbicide		
Cost	3.96	$/l
Application rate	4.68	l/ha
Labor		
Cost	6	$/hr.
Spray time	.52	hr./ha
Seed time	.44	hr./ha
Fencing		
Length	1.6	km
Cost	2,580	$
Annual maintenance cost	45	$
AUM values		
Unimproved	5	$/AUM
Improved	5.35	$/AUM
Forage production		
First-year grazing	448.3	kg/ha
Average harvestable yield over stand life	402.4	kg/ha
Life of stand	30	Years
Non-grazing time	2	Years
Expected inflation rate	8	%
ACP payments	3,500	$

Assume a rancher wants to increase quantity of spring forage available to the ranch operation by increasing the number of deeded acres in crested wheatgrass. The first step is to remove big sagebrush and green rabbitbrush *(Chrysothamnus viscidiflorus)* from 182.1 ha by spraying with low volatile butyl ester of 2,4-dichlorophenoxy acetic acid (2,4-D). The 2,4-D is sprayed at the rate of 4.68 liters/ha in the spring. In the fall of the same year, crested wheatgrass is seeded at the rate of 6.73 kg/ha with a rented standard rangeland drill.

Before improvement, the 182.1 ha produce an average 49.8 kg of consumable forage/ha, or 7.28 ha/animal unit month (AUM), where 362.87 kg of consumable forage is assumed to 1 AUM. As a result of this rangeland investment, average annual consumable forage production during the 30-year life of the crested wheatgrass stand is increased to 402.4 kg/ha (Table 1). Grazing is assumed to start 2 years after the crested wheatgrass is planted, with 448.3 kg/ha of consumable forage available the first year of grazing and 430.4 kg/ha each year thereafter for 27 years.

In this particular situation, no water development on the improved range is undertaken, although 1.6 km of fence is built to improve grazing management. Estimated value of the range in its unimproved state, e.g., rental value minus all management costs, is $5.00/AUM. Given increased forage production, likely increased quality of forage, improved seasonal availability of forage, and increased fencing, the value of improved range is slightly higher at $5.35/AUM. Recall, an AUM is defined as 362.87 kg of consumable forage. In this example, the rancher owns and uses 2 tractors and a ground sprayer in the range improvement investment. A $6.00/hr charge for labor, including owner/operator labor if used, is accounted for in labor cost. In application for decision making, all values provided by the user of RIBPRO are "expected values." Actual per unit costs and returns may be quite different from expected.

Range improvements such as sagebrush removal, crested wheatgrass seeding, and fencing may be eligible for cost-sharing under the U.S. Department of Agriculture, State, and County Agricultural Conservation Programs. Cost sharing maximum percentages for range improvement related practices vary by county (USDA 1981). In this example, the rancher receives $3,500 of Agricultural Conservation Payments (ACP).

Internal rate of return values are calculated assuming a constant rate of inflation over time. All per-unit values of factors and products given by the rancher at the time project costs and returns are estimated are compounded using a selected inflation rate over the 30-year project life. For this example, an inflation rate of 8% is assumed. That is, per unit factor costs and product prices paid or received annually are expected to increase 8% per year until end of the project.

If there is a seeding success the first year of planting, the internal rate of return from the investment is 15.6%. In considering whether to undertake this range improvement project, this internal rate of return is to be compared with the interest cost of money for the investment or other ranch or nonranch investment projects with similar initial investment, risk, length of life, and income and cost flows over time.

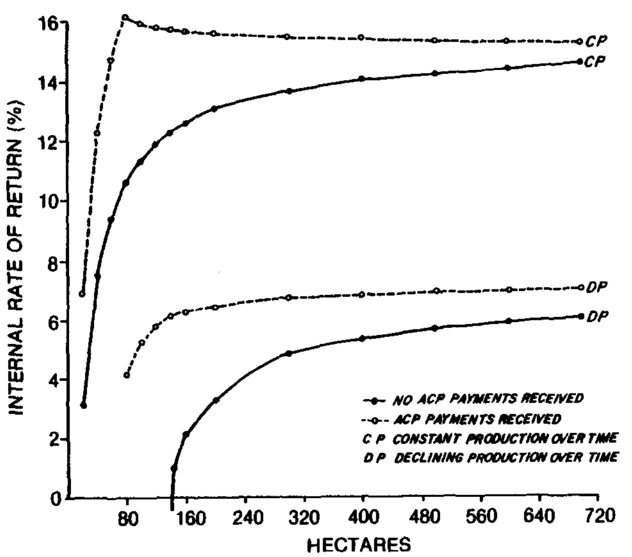

Fig. 2. *Hectares seeded to crested wheatgrass plotted against internal rate of return at constant production and declining production, with and without agricultural conservation payments. (Only items related to improvement size are varied in cost calculations.)*

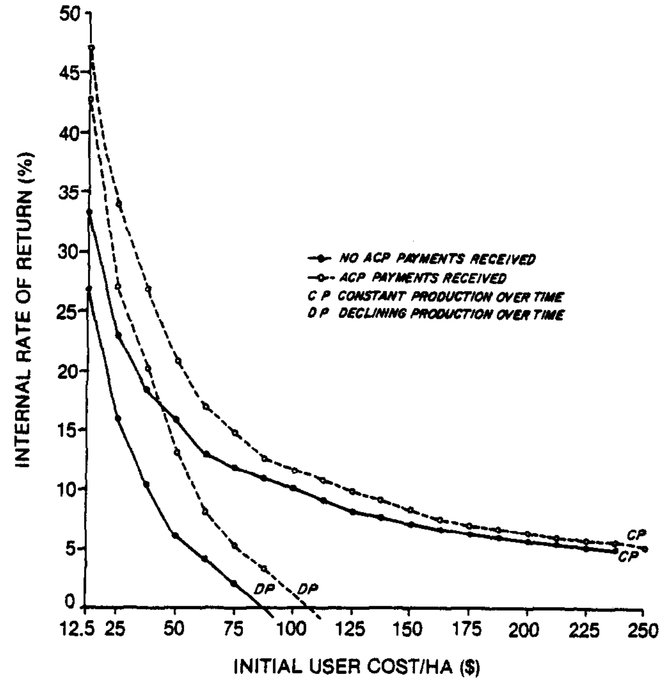

Fig. 3. *Initial cost per hectare for crested wheatgrass seeding plotted against internal rate of return at constant production and declining production, with and without agricultural conservation payments. (Initial user cost is dollar outlay by user in time period zero before any ACP payments are received.)*

IRR Sensitivity Analysis

Procedures

IRR is calculated for 2 crested wheatgrass production functions over time and 2 alternative initial cost situations for a given set of sample parameters (Table 2). Two extreme production function alternatives are shown. The constant production function assumes maximum yield the first year of grazing, with 96% of maximum yield each year thereafter for the life of the stand. The declining production function assumes maximum yield the first year of grazing, and a constant percentage decrease in forage quantity such that at the last year of stand life, production is approximately equal to precrested wheatgrass seeding conditions (49.8 kg/ha). Where ACP payments are assumed, the user receives 50% of initial costs, with a $3,500 maximum (Fig. 2-5). IRR is calculated for varying: (1) hectares seeded to crested wheatgrass, (2) initial cost/ha for sagebrush removal and seeding, (3) stand life of the seeding, and (4) forage production first year of grazing.

Results and Discussion

For any given number of hectares and production function, IRR is greater when ACP payments are received (Fig. 2). However, the absolute difference between IRR's for a given production function narrows as hectares increase. For all sizes, IRR associated with a constant production function is greater than IRR from a declining

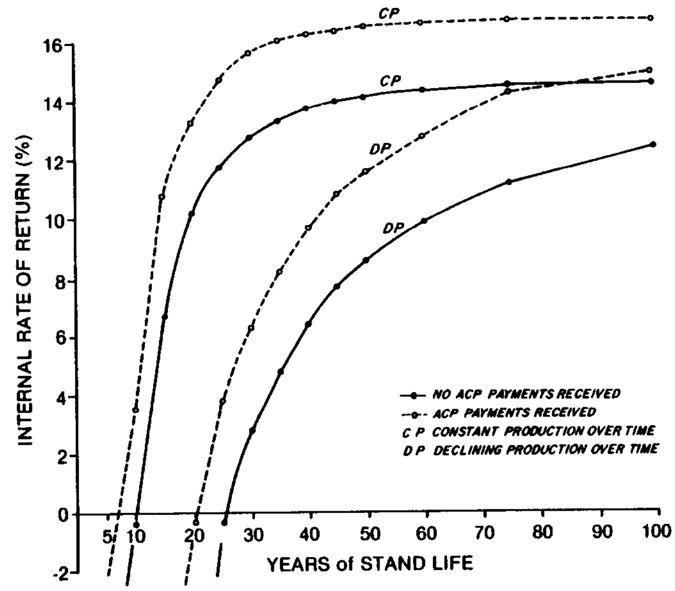

Fig. 4. *Stand life of crested wheatgrass seeding plotted against internal rate of return at constant production and declining production, with and without agricultural conservation payments.*

production. In all 4 cases, the major gains from spreading the fixed costs over more hectares are achieved at relatively small acreages (560 ha or less). In the case of constant production with ACP payments, a maximum IRR is achieved at approximately 80 ha, and the IRR decreases as hectares increase. A factor contributing to the decrease in IRR after reaching a maximum is the increase in initial cost/ha after the $3,500 ACP limit is reached. For any initial user cost/ha, IRR declines as initial dollar investment/ha increases. The rate of decline in IRR is greatest for increases in initial user costs at low cost levels.

For constant production of the wheatgrass stand, IRR does not become positive until approximately 10 years of stand life (Fig. 4). Termination of a constant production function in such a short period would likely be for legal, political, or economic reasons rather than biological. In other words, this situation would occur where initial costs are assumed by a particular user and grazing access by that user is terminated without compensation. The constant production function IRR increases rapidly as years of life increase to approximately 30 to 40 years. The rate of increase in IRR beyond this stand life is small. For the declining production function, IRR continues to increase at a higher rate for longer lived stands.

IRR curves plotted against productivity of the stand are not continuous because of the tax structure assumed in the model (Fig. 5). Lands are assessed in Nevada according to productivity. Breaks in the curves represent a shift to a higher land classification and hence a higher assessment for tax purposes. Unlike increasing hectares of the improvement (Fig. 2) or increasing years of stand life (Fig. 4), the rate of change in IRR does not tend to decrease dramatically at higher levels of forage (holding unimproved forage production level constant). Similar patterns would also be exhibited if dollar value per unit of the improved range (holding dollar value of the unimproved range constant) were used in place of kg/ha. The increase in IRR with increases in kg/ha under declining production function conditions is nearly linear with constant land taxes.

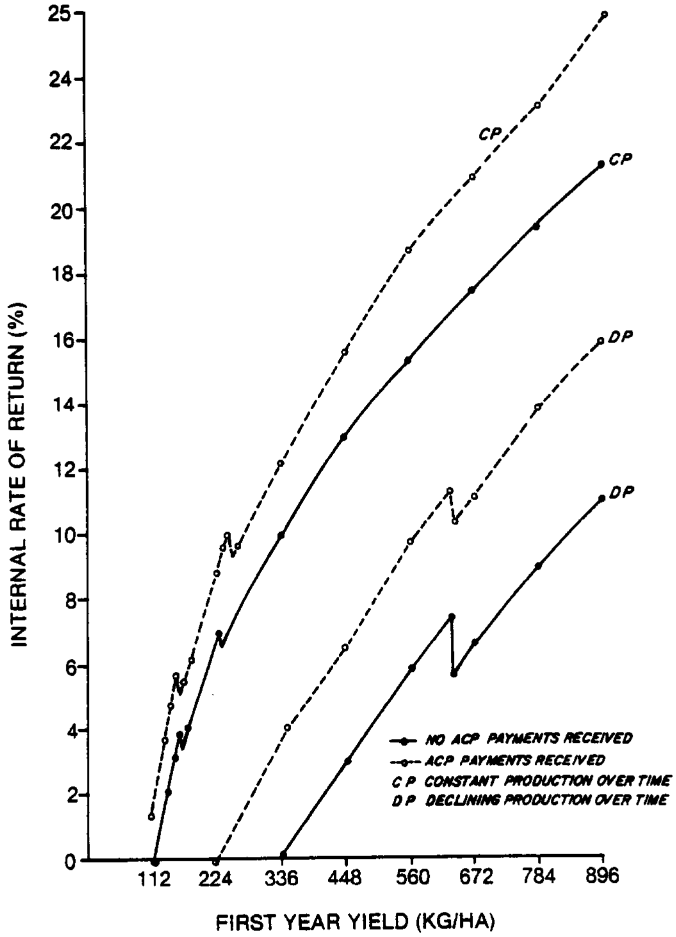

Fig. 5. *Pounds of forage per hectare first year of grazing seeded crested wheatgrass and internal rate of return at constant production and declining production, with and without agricultural conservation payments. (Discontinuous graph portions result from changes in land tax category and hence taxes paid as forage production per acre changes.)*

A sensitivity analysis of IRR to varying parameters for a representative example range improvement of sagebrush removal and crested wheatgrass seeding yields several general implications. Profitability (IRR) is sensitive to whether crested wheatgrass production is constant or declines over time. The economic advantage of constant over declining production decreases as expected years of stand life increase. Most profitability gains associated with increasing land area are achieved rapidly (up to approximately 250 ha) for improvements with proportions of fixed and variable costs similar to that used in this study. IRR is sensitive to: (1) initial user cost/ha, declining rapidly as cost/ha increases from low levels, and (2) additional first year yield or additional dollar value per unit of improved over unimproved forage.

A subsidy to the investor, e.g., ACP payments, will always increase a given range improvement project's profitability, all else constant, but a specific dollar subsidy does not insure economic acceptability. An investment project is acceptable if the IRR is greater than the interest cost of money borrowed to undertake the project, or is greater than IRR's which can be obtained from similar projects available to the investor.

Conclusions and Management Implications

A primary determinant of whether a range investment project should be undertaken is its economic profitability, the weighing of future dollars benefits against future dollar costs. Internal rate of return (IRR) is one investment criterion which can be used to evaluate range investment projects.

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Edaphic Factors Influencing the Control of Wyoming Big Sagebrush and Seedling Establishment of Crested Wheatgrass

GREG J. CLUFF, JAMES A. YOUNG, AND RAYMOND A. EVANS

Abstract

The physiographic position and taxonomic identity of soils of a Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*)/grassland community were determined. Surface soil materials from each identified soil were analyzed for a variety of chemical and physical properties. Areas of each soil were either burned, sprayed with 2,4-D [(2,4-dichlorophenoxy) acetic acid], or plowed for sagebrush control and seeded to crested wheatgrass (*Agropyron desertorum* cultivar Nordan). Spraying and plowing resulted in significantly (p=0.05) different sagebrush mortalities of 75 and 62% averaged over all soils with brush mortality being much higher on some soils than others. Burning resulted in 100% sagebrush mortality on all soils. Seedling establishment of crested wheatgrass was significantly higher on plowed than sprayed soils with 9 and 6 seedlings per meter of row, respectively. Soils of burned areas averaged 5 seedlings per meter of row on a dry year. Most seedlings were established on loamy soils regardless of the method of brush control. Multiple regression analyses of edaphic factors were used to develop equations predicting brush mortality and seedling establishment in sprayed and plowed areas. Soil series descriptions include data which could be used in making such predictions.

The Wyoming big sagebrush *(Artemisia tridentata* spp. *wyomingensis)* grassland community occupies at least 40 million hectares in the western United States (Tisdale et al. 1969). With the introduction of cattle to this community in the 1850's and heavy overgrazing in the 1880's, much of the endemic perennial grass understory was destroyed, leaving degraded, closed stands of sagebrush in many areas (Young et al. 1979a). Rehabilitation of the degraded sagebrush/grasslands began in the 1930's when R.L. Piemeisel demonstrated that one way to restore such lands was to remove the brush and establish perennial grasses (Piemeisel and Chamberlin 1936). Since that time, much research has gone into the development of better and more cost-effective technologies for the improvement of degraded sagebrush/grasslands.

Early recommendations for rangeland improvement were very generalized when addressing the question of what soils should be seeded. The sagebrush/grassland community was considered edaphically rather homogeneous for seeding purposes. Robertson and Kenneth (1943) recommended seeding areas "with annual precipitation in excess of 10 inches, with at least 2 or 3 inches falling during the spring growing season, and where there is good depth of productive soils." Plummer et al. (1955) recommended seeding areas of deep, fertile soils that were well supplied with organic matter. Heavy soils with good moisture-holding capacity were recommended more than lighter textured soils in areas of marginal precipitation. Saline soils were not recommended for seeding. Schwendiman (1955) recommended seeding where soil had good moisture-holding capacity, depth, and fertility to grow grass. Use of available soil surveys and land-use maps was advised.

More recent studies have been concerned with more precisely defining soil characteristics which affect seedling and stand establishment of crested wheatgrass. Eckert et al. (1961) found differences in the stand establishment and herbage yield of crested wheatgrass on 3 adjacent but edaphically, topographically, and vegetationally different areas within the big sagebrush *(Artemisia tridentata)* community. The different productivities of the 3 areas were

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believed to be related to the moisture-holding capacity of the soils. Use of indicator species and general soil classifications was recommended for determining site potential for seeding with crested wheatgrass. Shown et al. (1969) did an extensive study relating crested wheatgrass yield to precipitation, cultural practices, and soil characteristics at 48 sites throughout the western United States. They concluded that success or failure of seeding was the result of complex interactions of climate, soil, treatment methods, and grazing management. Simple correlation coefficients were very small when crested wheatgrass yields were compared with any of the measured soil, natural vegetation, or precipitation values. Their data indicated that moisture-holding capacity was the single soil property best correlated with stand yield. Wood (1976) found that emergence of crested wheatgrass was lower in interspace soils with vesicular crusts between shrub mounds, than in noncrusting coppice soils beneath shrubs. Seedlings emerging in crusted, interspace soils showed a high degree of stress, as measured by morphological characteristics, compared with seedlings emerging in noncrusted, coppice soils. Wood et al. (1982) concluded that descriptive criteria for selecting a successful seeding site in the sagebrush/grassland community include the density, size, and vigor of sagebrush which could be used as an indicator of the percentage of coppice and interspace and therefore the severity of vesicular crusting. Better crested wheatgrass emergence in noncrusted, coppice soils than in interspace soils was thought to be related to more favorable texture, structure, and moisture-holding characteristics.

The United States Department of Agriculture Soil Conservation Service (SCS) has commonly used soil survey data as means of determining land use potential of rangelands (Anonymous 1976). The concept of range site has been developed as a basis of site suitability for seeding based upon a gross summary of precipitation, topography, elevation, native vegetation, and soils (Vallentine 1971). Soil factors used in site determinations include texture of the surface, percentage of coarse fragments, depth to a restrictive layer, depth to an abrupt textural change, electrical conductivity of the top 18 cm, depth of root zone, available water-holding capacity of the top 18 cm, and tendency toward vesicular crusting (Anonymous 1971). However, interpretation of the effects of these soil characteristics on seeding suitability is completely subjective and the relative importance of each factor in determining seeding suitability has not been determined. A site is simply classified as good, fair, poor, or very poor for seeding. Successful seedings can be expected 7 out of 10 years on good sites and 3 years out of 10 on very poor sites. Several species could be planted on good sites, but only the most drought-tolerant species should be planted on poor or very poor sites.

Few studies have been concerned with the effects of specific soil properties on sagebrush control. Recommendations for control have usually been based upon practical considerations such as economics, topography and terrain, effects on desired species, and availability of equipment (Vallentine 1971). However, soil moisture at the time of treatment is one factor which has been related to sagebrush control, either by spraying or plowing. Cook (1963) reported poor sagebrush mortality using 2,4-D when soil in the upper 60 cm of a silty clay loam was below 12%. He interpreted this percentage moisture to be equivalent to 15.5, 13.5, 12.5, 10.5, and 5.5% moisture for clay, loam, clay loam, silt loam, and sandy loam soils, respectively. Soil moisture at the day of herbicide application was not directly correlated with sagebrush mortality. Bleak and Miller (1955) found that summer plowing in Nevada, when the soil was dry and firm, killed more mature sagebrush plants than spring plowing, when the soil was moist and compactible. Pechanec et al. (1954) observed that plowing or disking, correctly done, would kill 70 to 90% of sagebrush; however, on heavy, compact, dry soils, it would probably be necessary to plow twice.

The purpose of this experiment was to compare 3 standard range improvement techniques applied to sites with variable soil features in the same geographical area for their effects on Wyoming big sagebrush mortality and seedling establishment of crested wheatgrass. We believed that there are easily determined soil characteristics that the land manager could use in quantitatively determining the probability of success or failure of a given range improvement technique to control sagebrush and establish seedlings of crested wheatgrass.

Methods

The experimental area was located at the University of Nevada Gund Ranch Research and Demonstration Center in Grass Valley, central Nevada. The ranch contains several thousand hectares of degraded sagebrush/grassland on alluvial fans along the base of the Simpson Park Mountains. Wyoming big sagebrush is the dominant brush species in the experimental area with a sparse understory of Sandberg bluegrass *(Poa secunda),* squirreltail *(Sitanion hystrix),* Indian ricegrass *(Oryzopsis hymenoides),* and downy brome *(Bromus tectorum).* A century of livestock grazing has greatly reduced the native perennial grass portion of the plant community. Thurber's needlegrass *(Stipa thurberiana)* and bluebunch wheatgrass *(Agropyron spicatum)* may have once occurred in specific plant communities on the alluvial fans (Young and Evans 1980). This area was considered poor for rangeland seeding; crested wheatgrass establishment could be expected only 5 years out of 10 (personal communication of R.A. Foster, USDI/BLM, Elko, Nev.). Average annual precipitation ranges from 20 to 36 cm with most moisture occurring in the winter and early spring (Houghton et al. 1975). Precipitation for the 2 years of the study was 26 and 20 cm from July 1 to June 30, 1979 and 1980, with 13 and 18 cm occurring in the winter-spring of 1979 and 1980, respectively.

Aerial photographs of the experimental area were used to delineate landforms which served as the basis for determining boundaries for taxonomic identification of the soils. Soil horizons were described to a depth of 2 m in each landform area and the soils were identified taxonomically (Anonymous 1975). Four soils occupying the major portion (>95%) of the study area were tentatively identified. Soil samples were taken to a depth of 10 cm in the interspace of each of the 4 soils in 5 locations along the 6-km length of the study area. The samples were analyzed for those properties which would best differentiate specific soils in terms of their surface characteristics. The soils were analyzed for percent gravel by sieving through a 2-mm screen, percent sand, silt, and clay using the method of Bouyoucos (1962); percent organic matter using the method of Walkley and Black (Black 1965b); relative infiltration rate of 5 cm of water using a double ring infiltrometer in situ (Black 1965a) with 7.6 and 20 cm inside and outside diameter rings; electrical conductivity of the saturated paste extract using a conductivity meter; nitrate using a digital ion analyzer with a nitrate probe; and relative dry force of penetration using a hand-held force indicator with a 0.5 cm diameter by 0.5 cm long cone-shaped tip. Data were analyzed using discriminate analysis (Nie et al. 1970) in order to statistically separate the soils based on these properties. The 4 soils will be described in detail in the results section of this paper. The percentage area covered by coppice and interspace was determined for each soil along four 50-m transects by the line-intercept method (Phillips 1959).

In the spring and summer of 1979, twelve 16-ha exclosures were established in this area. The fenced areas were placed so as to include portions of the 4 major identified soils plus small inclusions of different soils. Treatments for range improvement involved 3 methods of brush control and 2 methods of seeding. Brush control methods were: (a) spraying with 3.3 kg/ha 2,4-D low volatile ester, (b) brushland plowing in 2 directions, and (c) burning. Seeding methods were: (a) seeding crested wheatgrass cultivar Nordan with a regular rangeland drill, and (b) seeding crested wheatgrass with a deep-furrow rangeland drill. The treatments were located within the fenced areas such that each treatment (method of brush control and seeding) covered at least 1 ha of each of the 4 soils. Herbicidal brush control was done in early May 1979. A modified ground sprayer for sagebrush rangelands (Young et al. 1979b) was used to apply 3.3 kg/ha of 2,4-D low volatile ester to large portions of each soil (minimum of 5 ha). The herbicide was applied in water at 105 liters/ha. Other areas of each soil (minimum of 2.5 ha) were plowed in 2 directions using a brushland plow (Anonymous 1968) at different times from May through August 1979 for sagebrush control. Treated areas were planted with crested wheatgrass at 9 kg/ha in October 1979 using a standard rangeland drill with 30-cm row spacing, and using a modified deep-furrow rangeland drill (Asher and Eckert 1979) with 50-cm row spacing. At least one third of each soil-brush control treatment was seeded using the modified deep-furrow rangeland drill. The prescribed burn treatment was conducted in August 1980. At the time of burning, relative humidity was less than 10%, air temeprature was 35° C, and wind speed was 24 km/hr. The burned treatment was seeded in October 1980 using standard and modified drills. It was only practical to seed 2 of the major soils in the burned treatment.

In May 1980, a second set of surface soil samples (top 10 cm) were taken in 5 locations in each of the 4 major defined soils and in the small inclusions of other soils in the seeded areas. Sampling was stratified by coppice and interspace where such areas could be discerned. Some soils did not have evident coppice and interspace, and plowing destroyed distinguishing evidence of coppice and interspaces in other soils. The samples were analyzed for the same properties and in the same manner as the first set of samples that were used to statistically differentiate the major soils.

In July 1980, percentage brush mortality was determined in 4 randomly placed 2 by 50-m transects for each soil type in each brush control treatment. Seedling establishment of crested wheatgrass was determined by counting the number of seedlings in 10 random samples consisting of 1-m row in each soil, brush control treatment, and drill treatment. Sampling was stratified by coppice and interspace where such areas were discernible. The yield, frequency, and percentage cover of downy brome was determined by clipping 10 plots, 0.1 m^2 in area, by the step-point method (Evans and Love 1957), and estimating ground cover of ten 0.25-m^2 plots, respectively, on each soil in each brush control treatment, and in adjacent untreated areas.

In March 1981, gypsum moisture blocks were buried 15 and 40-cm below the soil surface in 5 coppice and interspace locations of each soil and read at 2-week intervals throughout the growing season. The moisture blocks were placed in areas of complete sagebrush control. The moisture blocks were used to measure relative differences in the drying rates of each soil after winter-spring precipitation ceased in late spring.

In July 1981, biological sampling was done in the burned treatment. The same parameters were sampled by the same procedures used for the plowed and sprayed treatments the previous year.

The data were analyzed statistically using analysis of variance and simple and multiple linear regression. Statistical differences between means resulting from effects of sprayed and plowed treatments and the 4 major soils on sagebrush mortality and seedling establishment of crested wheatgrass were determined using analysis of variance and Duncan's multiple range test. Relationships between specific edaphic factors and big sagebrush mortality and seedling establishment of crested wheatgrass were determined using simple and multiple linear regression. Means of 5 samples per soil were used in the regression. By using data from coppices, interspaces, the 4 major soils, and other soil inclusions, 8 and 9 means were used in regressions in which seedling establishment was correlated with edaphic factors in sprayed and plowed treatments, respectively. By using data from the 4 major soils and other soil inclusions, 6 means were used in regressions in which sagebrush mortality was correlated with edaphic factors in both sprayed and plowed treatments. Data of brush mortality and seedling establishment from the prescribed burning treatment were analyzed separately because this treatment was conducted in a different year than were spraying and plowing.

Results and Discussion

Soils

Four distinct landforms were defined: (a) alluvial fans occupying 33% of the study area; (b) inset fans, 28%; (c) offshore bars, 24%; and (d) lagoons, 15% (Peterson 1981). Alluvial fans were formed at the openings of each major canyon along the Simpson Park escarpment. During the Pleistocene, pluvial Lake Gilbert filled Grass Valley to 1,870 m above sea level creating a beach across the base of the alluvial fans (Mifflin and Wheat 1979). Wave action formed a series of offshore bars and lagoons shoreward of the bars as the lake receded during the interglacial period (Born 1972). Lake Gilbert dried during the early Holocene leaving a large fine-textured playa (Motts 1970) on the valley floor. Many alluvial fans were cut off from further stream flow because of channeling of the limited water sources into valleys between the fans or into streambeds.

Because of this physiographic development, the 4 landforms developed distinct soils. As Lake Gilbert receded to successively lower stages, lagoons were separated from the main body of the lake by their associated offshore bars. Lagoons, being topographical depressions, accumulated silt and clay which washed off the alluvial fans. Offshore bars, still being washed by waves of the lake, became highly gravelly. After Lake Gilbert completely dried, aeolian material from the playa was deposited on the alluvial fans adding very fine sand, silt, and clay to the upper horizons. Areas such as inset fans which were still subject to stream washing were purged of fine-textured particles during periods of runoff and maintained high gravel contents and course textures.

This geomorphic history is reflected in the kinds of soil dominating each landform today. Alluvial fans, inset fans, offshore bars, and lagoons are occupied by Abgese loam, Zineb very gravelly sandy loam, McConnel gravelly sandy loam, and Bubus silty loam, respectively (Table 1). Abgese is a soil series belonging to the Xerollic Haplargid subgroup. These soils have a well-developed soil profile, a Bt horizon which is permeable to moisture, and relatively more organic matter and moisture than the Typic subgroup. Zineb is a series belonging to the Durixerollic Camborthid subgroup. These soils have a subhorizon with weak cementation by silica which is still permeable to moisture, and have relatively more organic matter and moisture than the typic subgroup. They are probably soils of recent formation. McConnel is a series belonging to the Xerollic Camborthid subgroup. These soils also have relatively more organic matter and moisture than the Typic subgroup and are also probably soils of recent formation. Bubus is a series belonging to the Durorthidic Torriorthent subgroup. Soils of this subgroup are typified by little or no evidence of development of diagnostic horizons. They are primarily formed by recent depositional processes. They are dry or salty, and have weak cementation with silica in one or more horizons. All soils except Zineb have some degree of vesicular crusting (Table 1).

Discriminate analysis of the interspace soil surface samples showed that the original physiographic delineation of the soils based on the aerial photographs was valid, in that samples from within each landform were not statistically different, but samples compared among landforms were statistically different (p=0.05) based on the properties which were measured. Discriminate functions correctly classified the surface soil samples into the landforms and soils from which they were obtained 95% of the time. Percent gravel and silt were the most important features separating the soils. The soil series Abgese and McConnel were the most difficult to separate from each other, whereas Zineb and Bubus were the easiest to separate. These results indicate that geomorphological development of the soils within each landform produced surface soils with very similar physical and chemical properties (Table 2).

Surface soil textures ascribed to each soil series (phase criteria) from profile descriptions were not always the same as those ascribed to each landform from samples used in the discriminate

Table 1. Pertinent data from pedon descriptions for soil series in the experimental area at Grass Valley, Nevada.

Series, slope (landform)	Horizon	Depth (cm)	Texture[1]	Dry consistence[2]	Pores[3]
Abgese, 5-10% (alluvial fan)	A1	0-13	l	so	2vfv
	A2	13-33	l	sh	1vfv
	2Bt1	33-48	cl	h	0
	3Bt2	48-88	vgrcl	h	0
	3Bq	88-123	exgrl	h	0
Zineb, 5-15% (inset fan)	A1	0-5	vgrsl	so	0
	A2	5-18	vgrl	so	3vf
	BW1	18-33	vgrsl	so	0
	BW2	33-40	vgrsl	so	0
	C1	40-85	vgrl	sh	0
	2C2	85-110	grl	sh	0
	3C3	110-180	exgrsl	so	0
McConnel, 4-8% (offshore bar)	A1	0-5	grsl	so	3vfv
	A2	5-18	l	so	3vfv
	BW	18-38	grl	sh	3vf
	2C1	38-63	vgrsl	sh	0
	3C2	63-90	exgrsl	lo	0
	3C3	90-163	exgrs	lo	0
Bubus, 0-2% (lagoon)	A1	0-8	sil	sh	3vfv
	A2	8-18	l	sh	3vfv
	Bgk1	18-30	l	sh	3vfv
	Bgk2	30-48	fsl	sh	0
	Bgk3	48-75	vfsl	sh	0
	2Ck4	75-115	vfsl	so	0
	3Ck5	115-163	sicl	sh	0

[1]Texture abbreviations: l = loam; cl = clay loam; sl = silt loam; sicl = silty clay loam; v = very; gr = gravelly; ex = extremely; f = fine; vf = very fine.
[2]Dry consistence abbreviations; so = soft; sh = slightly hard; h = hard; lo = loose.
[3]Pores abbreviations: 1 = few; student = common; 3 = many; vf = very fine; vfv = very fine vesicular.

analysis. Alluvial fan, offshore bar, and lagoon surface textures were identified as a loam, gravelly sandy loam, and silty loam, respectively, from profile descriptions, and as a sandy loam, gravelly loam, and clay loam, from the average of the discriminate analysis samples (Table 1 and 3). This disparity occurred because soil properties obtained from profile descriptions were not averages, but constituted single samples. Because the surface layer is the most active and variable layer of the soil profile, land managers should recognize this variability when using survey data for making seeding-suitability recommendations.

Wyoming Big Sagebrush Control

Spraying and plowing resulted in significantly (p=0.05) different mortalities of 75 and 62%, respectively, averaged over the 4 major soils. Numerically higher brush control was achieved by spraying rather than by plowing on 3 of the soils, but neither method worked well on the Bubus soils (Table 3). Significantly higher brush mortality was achieved by spraying (87%) compared with plowing (64%) on Abgese soils. Sagebrush was easiest to control on Zineb soils with 98% mortality by spraying and 84% by plowing. Sagebrush control was more difficult on Bubus soils with 46% mortality by spraying and 48% by plowing. Burning killed 100% of the sagebrush on all soils. On Bubus soils, small infestations of greasewood *(Sarcobatus vermiculatus)* and salt rabbitbrush *(Chrysothamnus nauseosus* ssp. *consimilis)* resprouted.

Sagebrush mortality in sprayed areas was positively correlated with gravel and sand content of soils, and negatively correlated with silt and clay (Table 4). The finer the soil texture, the lower the sagebrush control by spraying. Possibly, sagebrush control by spraying was affected by available soil moisture resulting from the interaction between precipitation and soil texture. Multiple regression analysis correlated (p=0.05) sand, silt, clay, and infiltration rate with soil moisture potential (R=0.93). These results agree with those of Cook (1963) and indicated that available soil moisture is needed at time of spraying of 2,4-D for sagebrush control. Results

Table 2. Physical and chemical properties of interspace surface samples of soil series from the study area in Grass Valley, Nevada[1].

Series (landform)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Nitrate (ppm)	Penetration (kg)	EC (mmhos/cm)	Infiltration rate (cm/hr)	May 1981 soil moisture potential (-bars) 15 cm	40 cm	Coppice (%)
Zineb (inset fan)	60a	26b	10c	4b	5.7a	24b	1b	.2a	48a	1.2a	0.5a	—
Abgese (alluvial fan)	32c	39a	21b	7b	1.7b	24b	3b	.2a	3b	2.8a	0.5a	54a
McConnel (offshore bar)	47b	26b	19bc	7b	1.6b	39a	3b	.1a	2b	0.7a	1.6a	51a
Bubus (lagoon)	12d	27b	36a	25a	1.3b	20b	7a	.3a	.5c	3.4a	1.7a	42b

[1]Means within columns followed by the same letter are not significantly different at the 0.05 probability level as determined by Duncan's multiple range test.

Table 3. Wyoming big sagebrush control and seedling establishment of crested wheatgrass as related to soil, landforms, and surface soil texture at Grass Valley, Nevada.[1]

Series (landform)	Surface texture	Brush mortality Spray	(%) Plow	Seedling establishment Spray	seedlings/m of row Plow
Zineb (inset fan)	very gravelly sandy loam	98a	84a	8bc	11b
Abgese (alluvial fan)	sandy loam	87a	64bc	6c	17a
McConnel (offshore bar)	gravelly loam	67b	52bd	10b	6c
Bubus (lagoon)	clay loam	46d	48cd	1d	1d

[1]Means within a variable (brush mortality or seedling establishment) followed by the same letter are not significantly different at the 0.05 probability level as determined by Duncan's multiple range test.

of this study also indicate that available soil moisture is a function of soil texture as it affects infiltration and soil matric potential as well as a function of precipitation.

Sagebrush mortality in plowed areas was positively correlated with gravel and infiltration rate, and negatively correlated with silt, clay, nitrate, and force of penetration (Table 4). Mortality was also positively correlated with soil moisture at 15 cm depth; however, this was probably the result of the relationship among brush mortality, soil moisture, and soil texture properties. These results suggest that the coarser the soil texture, the softer the soil, and the more effective the removal of crowns of sagebrush by plowing. This agrees with observations by Pechanec et al. (1954) that heavy compact soils should be plowed twice for good brush control. However, plowing twice in this study did not result in good sagebrush control in any soil except the Zineb soils (Table 3). The SCS soil survey parameter which best reflects these results is that of dry consistence (Table 1). Only the Zineb soils had a dry consistence rating of soft below 18 cm, while the other soils were rated as slightly hard in one or more layers below 18 cm.

Multiple regression analysis showed that sagebrush mortality in sprayed and plowed areas could be predicted from edaphic factors. Percent sand and silt were used to predict brush mortality by spraying with the following equation:

$$\text{Mortality (\%)} = .24 \times \text{sand (\%)} - .79 \times \text{silt (\%)} + 88.9$$

The R for the regression was 0.97 (p=0.05). Force of penetration, percent sand, and percent silt, in decreasing order of importance, were used to predict brush mortality by plowing with the following equation:

$$\text{Mortality (\%)} = -4.3 \times \text{force of penetration (kg)} + .66 \times \text{sand (\%)} - .13 \times \text{silt (\%)} + 71.8$$

The R for the regression was 0.99 (p=0.05). Good correlations were found if edaphic factors from coppice or interspace were used as independent variables, although data for the above regressions are from interspace samples only. These results reflect the previously mentioned effects of soil texture on soil moisture availability and force of penetration.

Soil survey data collected by SCS does not include force of penetration. Dry consistence is a qualitative property which is related to force of penetration, however, and could be quantified for use in mathematical models predicting brush mortality by plowing.

Seedling Establishment

Seedling establishment of crested wheatgrass averaged 6 plants per meter of row on the 4 major soils with sagebrush control by spraying of 2,4-D and 9 plants per meter of row with plowing (p=0.05). Burning and seeding averaged 4.5 seedlings per meter of row with 2 seedlings per meter establishing on Zineb soil and 7 seedlings per meter on Abgese soil, but the seedling year for this treatment was drier than with the sprayed and plowed treatments. Wood et al. (1982) found that plowing reduced emergence but increased the frequency of established crested wheatgrass plants in areas with vesicular crusting soils. They attributed the beneficial effects of plowing to improved soil tilth, aeration, porosity, and microtopography which could increase the quantity of water percolating into the soil. However, in this study, increased emergence of crested wheatgrass seedlings resulted from plowing compared to spraying. Possibly, plowing was advantageous for increased emergence because coppice soils were mixed with those in the interspaces to make overall improvement for seedling growth.

However, seedling establishment was not higher with plowing on every soil compared to spraying (Table 3). Significantly (p=0.05) higher seedling establishment resulted from spraying on McConnel soils. Plowing and spraying resulted in 17 and 6 seedlings per meter of row for Abgese soils and 6 and 10 seedlings per meter of row for McConnel soils, respectively. Abgese soils and McConnel soils were the most alike with respect to the measured edaphic properties (Table 2). However, the top 40 cm of Abgese

Table 4. Simple correlation coefficients between soil surface properties and Wyoming big sagebrush mortality or seedling establishment of crested wheatgrass as affected by spraying or plowing.[1]

Dependent variable	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	O.M. (%)	I.R. (cm/hr)	EC (S/m)	NO^3 (ppm)	PN (kg)	Ψs -bars)
Brush control										
Spray	+.86*	+.74*	−.95**	−.84**	+.69	+.68	−.69	−.47	−.54	+.60
Plow	+.82*	+.26*	−.79*	−.97**	+.83*	+.88*	−.24	−.96**	−.82*	+.79
Seedling establishment										
Spray	+.02	+.46*	−.52*	−.22	+.16	+.12	−.46*	+.60*	−.07	+.79*
Plow	+.57*	+.57*	−.64*	−.70*	−.01	−.07	−.65*	−.12	−.10	+.12

[1]Means of 5 samples. O.M. = organic matter, I.R. = infiltration rate, EC = electrical conductivity, NO^3 = nitrate, PN = penetration, Ψs = soil moisture potential, May 1981, at 15 and cm for seedling establishment and brush control, respectively. * = significant at 0.05 probability level, ** = significant at 0.01 probability level.

soils were finer textured than those of McConnel soils (Table 1). Fine soil texture seemingly is related to the differential effects of plowing and spraying in terms of infiltration and available soil moisture. Possibly, there is a range of silt content within which plowing improves aeration, porosity, and microtopography for seedling establishment.

Neither spraying or plowing resulted in satisfactory seedling establishment on Bubus soils; either method yielded an average of 1 seedling per meter of row. Five plants per square meter is considered good stand establishment in the Intermountain region (Cook et al. 1967). With the row spacing of the standard rangeland drill this would equal about 2 plants per meter of row, so only on the Bubus soils was seedling establishment unsatisfactory. Wein and West (1971) found poor seedling establishment of crested wheatgrass in bottoms of gully plugs where ponding of runoff water resulted in fine-textured, flood prone areas similar to lagoons (Bubus soils). They attributed high seedling mortality to drowning and soil heaving which broke off seedlings at the soil surface. The Bubus soils showed the greatest degree of vesicular crusting as indicated by the depth of very fine vesicular pores (Table 1). Wood et al. (1978) demonstrated that vesicular crusting formed in soils with high silt and low organic matter content, and that crusting reduced infiltration rate and increased stress on emerging seedlings. They showed that crusting was greatest on interspace soils. In this study, lagoon soils had the least percentage of coppice and, conversely, the greatest percentage of interspace (Table 2). Therefore, poor seedling establishment on Bubus soils can probably be attributed to the greater degree of vesicular crusting as compared with the other soils.

Seedling establishment of crested wheatgrass in sprayed areas was positively correlated with soil moisture potential, nitrate, and sand, and negatively correlated with silt and electrical conductivity. Seedling establishment in plowed areas was positively correlated with gravel and sand, and negatively correlated with silt, clay, and electrical conductivity (Table 4). Why seedling establishment in plowed areas was not significantly correlated with soil moisture potential is not known. Perhaps mixing of coppice and interspace in plowed areas mitigated the effects of soil factors, like infiltration rate, on moisture potential. Silt and electrical conductivity were negatively correlated and sand was positively correlated with seedling establishment in both sprayed and plowed soils (Table 4). This indicates that crested wheatgrass seedlings survived better in well-drained, nonsaline soils. It must be noted that the correlations were for variables within the limits measured for each soil and cannot be extrapolated to greater or lesser amounts. For example, seeding establishment of crested wheatgrass was correlated (r=0.79) with average May soil moisture potential in sprayed areas. Moisture potentials ranged from −3.4 to −0.4 bars and seedling establishment ranged from 0 to 19.5 seedlings per meter of row. Greater crested wheatgrass seedling establishment could not be expected in soils averaging higher moisture potentials than −0.4 bars. the same is true for other variables such as percent sand and silt.

Multiple regression analysis relating seedling establishment in sprayed and plowed areas to edaphic factors showed that seedling establishment could be predicted. With the following equation, nitrate, electrical conductivity, percent silt and percent clay in decreasing order of importance, were used to predict seedling establishment on soils following brush control by spraying:

$$\text{Establishment (seedlings/m of row)} = 6.6 \times \text{nitrate (ppm)} - 4.9 \times \text{EC (mmhos/cm)} - 0.25 \times \text{silt (\%)} + 0.73 \times \text{clay (\%)} + 9.6$$

The R for the regression was 0.96 (p=0.05). Percent clay, infiltration rate, and percent silt, in decreasing order of importance, were used to predict seedling establishment on plowed soils with the following equation:

$$\text{Establishment (seedlings/m of row)} = 0.56 \times \text{clay (\%)} - 2 \times \text{infiltration rate (cm/hr)} - 0.38 \times \text{silt (\%)} + 22.5$$

The R for the regression was 0.81 (P=0.05). Lower predictability for seedling establishment on plowed soils probability reflected the variable effects within each soil series of mixing coppice, interspace, and subsurface horizons.

Significantly more seedlings (p=0.05) were established on coppice than interspace soils. Seedling establishment averaged 14 and 5 seedlings per meter of row on coppice and interspace soils, respectively. Coppice and interspace were not well developed on Zineb soils and were not differentiated on those soils. On the other soils, where coppice and interspace were evident, coppice always produced significantly more seedlings than interspace. Abgese, McConnel, and Bubus soils averaged 17, 20, and 6 seedlings per meter of row in coppice and 6, 9, and 0 seedlings per meter of row in interspace soils. These results agree with those of Wood et al. (1982), showing that emergence of crested wheatgrass seedlings is higher on coppice soils compared with interspace soils in areas of vesicular crusting. Bubus soils had significantly less coppice than Abgese and McConnel soils. Abgese, McConnel, and Bubus soils averaged 54, 51, and 42% coppice, respectively (Table 2). This indicates that there is an inverse relationship between amount of coppice and seedling establishment on these soils. Soil survey data collected by the SCS does not include percentage of coppice and interspace. Soils data are for interspace soils, which, in areas with vesicular crusting, are very poor for seedling establishment compared with the accompanying coppice soils.

The type of drill used significantly (p=0.05) affected the number of crested wheatgrass seedlings per meter of row, but not the density of seedlings. Averaged over the 4 major soils, deep-furrow drilling resulted in 10 seedlings per meter of row whereas standard drilling resulted in 7 seedlings per meter of row. However, because of wider row spacing on the deep-furrow drill, a nonsignificant difference in seedling density of 22 and 25 seedlings per square meter resulted for the deep-furrow and standard drills. There was no significant interaction between type of drill and soil. Deep-furrow drilling resulted in the same relative seedling density as standard drilling in each soil.

Downy Brome

Downy brome is considered a major competitor with crested wheatgrass for early spring and summer moisture on western rangelands (Evans 1961, Harris and Wilson 1970). In this study, the yield of downy brome was affected by method of brush control and soils. Averaging over the 4 soils, plowing and seeding resulted in significantly (p=0.05) more downy brome than spraying and seeding, while both treatments significantly increased yield of downy brome over the control areas. Burning and seeding also significantly increased yield of downy brome over the control areas. In 1979, yield of downy brome averaged 930, 360, and 30 kg/ha in plowed and seeded, sprayed and seeded, and control areas, respectively. In 1980, yield of downy brome was 150 kg/ha with burning and seeding and 5 kg/ha in the control areas. Averaging over all treatments, the yield of downy brome was 65, 61, 44, and 3 kg/ha on McConnel, Zineb, Abgese, and Bubus soils. Downy brome yielded significantly (p=0.05) less on Bubus soils than on the other soils. Generally, the coarser textured soils produced the most downy brome. However, there were no negative correlations between yield, frequency, or percent cover of downy brome and seedling establishment of crested wheatgrass on any soil. This indicates that effects of downy brome competition on crested wheatgrass establishment were overshadowed by differential effects of edaphic factors among the soils.

Conclusions

Although most Wyoming big sagebrush/grassland communities are probably not as heterogeneous in respect to landforms and soils as the one in this study, they are not as homogeneous as early range recommendations implied. Our results indicate that it is possible to differentiate soils within sagebrush/grassland communities by delineation of landforms on aerial photographs and with appropriate ground truth data. Measurements of edaphic properties of individual soils can be used to predict mortality of sagebrush by spraying or plowing and seedling establishment of crested wheatgrass after brush control and seeding. Soil texture, among all edaphic factors, was best correlated with mortality of Wyoming big sagebrush and seedling establishment of crested wheatgrass. It would probably be incorrect to extrapolate these results to areas with soils that are not predominantly Aridosols with vesicular crusting or areas outside the Wyoming big sagebrush community where adequate winter-spring precipitation does not occur for seedling establishment of crested wheatgrass.

Presently, land managers must subjectively use information from soil surveys to determine the relative suitability of a site for seeding. However, development of mathematical models based on quantified soil data, as in this study, would allow the land manager to make more accurate predictions of success or failure of a particular range improvement technique based on relationships with specific soil properties. More quantitative data of soils are needed before land managers can use such mathematical models. Quantitative measurements of soil hardness such as force of penetration, could prove useful in predictive models. The amount and characteristics of coppice and interspace should be included in soil surveys. Also, because surface horizons are the most variable and important to establishment of crested wheatgrass, surveys developed for making seeding recommendations should concentrate on the features and variability of these horizons. Determination of site suitability for brush control and seeding based only on soil series criteria is not adequate. Phase criteria, especially those of textures of surface soils, should be used. Characteristics of subsurface horizons should not be ignored because they may later affect yield of mature crested wheatgrass. These recommendations would also allow range scientists access to pertinent data that could be used in developing better predictive models.

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Host Plant Utilization by Grasshoppers (*Orthoptera: acrididae*) from a Sandhills Prairie

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Abstract

Host plant use by 31 species of grasshoppers from a sandhills prairie was determined; gut analysis was used to determine diet. In the composite diet for all species, forbs constituted 37.2% of the total, grasses and sedges contributed 58%, and insects made up 4.8% of the diet. Compared to the plants available at this site, 43% of the plant species and 36% of the plant families were included in the composite diet. Although some grasshopper species did not include many host plants in their diet, most included representatives of more than one plant family. Grasshopper species were typically polyphagous with no true specialist feeders. Relatively few plant taxa constituted a large fraction of the composite diet for all grasshopper species and the relative abundance of food plants in the environment appeared to affect the overall use of food plants. Subfamily affinities are obvious. Gomphocerines have the lowest average diet breadth and are primarily grass-feeders while melanoplines feed primarily on forbs and have large average diet breadths; oedipodines are intermediate for these categories. Vegetation-dwelling species have significantly lower diet breadths than do ground-dwelling species. Results do not generally support recent theories concerning the evolution of insect herbivore feeding patterns.

General patterns of feeding behavior in grasshoppers, such as the number of taxa in the diet, specific food plants, and types of food plants are varied. Determination of feeding patterns and the underlying reasons for observed patterns will undoubtably prove useful for understanding the importance of grasshoppers in range systems. Feeding by entire assemblages of grasshoppers has been examined in creosote-bush deserts (Otte and Joern 1977), arid grasslands (Joern 1979, Ueckert and Hansen 1971), shrub-steppe habitats (Sheldon and Rogers 1978), tall grass pastures (Mulkern et al. 1969), and short-grass prairies and pastures (Mulkern et al. 1969, Pfadt and Levigne 1982). Many other studies have been performed as well to determine the factors influencing host plant selection by grasshoppers (Barton-Browne 1975; Bernays and Chapman 1974, 1978; Gangwere 1961, 1972; Mulkern 1967; Otte and Joern 1977).

The present study provides information on host plant selection by grasshopper species from an arid, sandhills grassland in Nebraska which is composed of both short and tall grasses. Trends seen in the patterns of food plant use will be presented and compared with previous work to examine: (1) degree of specialization of grasshoppers from this site, (2) importance of phylogenetic relationships among grasshoppers and plants associated with host plant selection, (3) types of food plants taken by generalist versus specialist feeders, (4) differences between grass-feeders and forb-feeders, and (5) similarities and differences in feeding behavior by the entire assemblage from this site compared with those from different types of grassland and desert systems. These trends will also be discussed in relation to current thoughts concerning the evolution of diet specialization of insect herbivores.

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Study Site

Feeding by grasshoppers was studied at Arapaho Prairie, a grassland research site in the sandhills of Nebraska (Arthur County) in 1978 and 1980. Sandhills prairie is a unique mixed grassland created by dry continental climate in association with extensive sand dunes (Barnes 1980, Keeler et al. 1980). Annual rainfall is approximately 40 cm of which 80% falls between April and September. Temperature and rainfall patterns in these 2 years were within the normal range for this site (Jones, unpublished). No striking differences in plant phenologies were observed during the study.

Approximately 200 species of plants from 45 families have been recorded from this site (Keeler et al. 1980). Perennial tall grasses (both C_3 and C_4 species) are dominant while grasses typically associated with short-grass prairies are also abundant. Numerous forbs are also present. Dominant species include *Bouteloua gracilis,* (H.B.K.) Griffiths (blue grama) and *B. hirsuta* Lag. (hairy grama) which are typically found in short-grass prairies as well as grasses found primarily in tall-grass prairies such as *Andropogon hallii* Hack. (sand bluestem), *Calamovilfa longifolia* (Hook.) Scribn. (prairie sandreed), *Stipa comata* Trin. and Rupr. (needle-and-thread grass), and *Andropogon scoparius* Michx. (little bluestem). Important subdominant species include *Agropyron smithii* Rydb. (western wheatgrass), *Koeleria pyramidata* (Lam.) Beauv. June grass), and *Carex heliophila* Mack. (sedge). Major forbs include: *Psoralea tenuiflora* Pursh., *Ratibida columnifera* (Nutt.) Woot. and Standl., *Sphaeralcea coccinea* (Pursh.) Rydb., *Croton texensis* (Klotzsch) Muell., *Tradescantia occidentalis* (Britt.) Smyth., *Helianthus rigidis* (Cass.) Desf., *Ambrosia psilostachya* D.C., and *Artemisia ludoviciana* Nutt. (Keeler et al. 1980). Relative abundances of plants at Arapaho Prairie during the period of this study are reported by Barnes (1980).

Thirty-nine species of grasshoppers have been collected at this site in varying degrees of abundance (Joern 1982). Phenologically, grasshopper species are dispersed throughout the period from late March or April to November with the adult diversity peaking in August and early September. Dominant grasshopper species include *Ageneotettix deorum* (Scudder), *Phoetaliotes nebrascensis* (Thomas), *Mermiria bivattata* (Serv.), *Opeia obscura* (Thomas), *Amphitornus coloradus* (Thomas), *Melanoplus angustipennis* (Dodge), and *Melanoplus foedus* (Scudder).

Methods

Diets of grasshoppers were determined through the technique of gut analysis (Mulkern and Anderson 1959, Otte and Joern 1977, Joern 1979). Adult grasshoppers were killed immediately after collection and the foreguts removed and placed in 70% ethanol within an hour after death. Plant fragments from the gut were mounted on slides and compared with permanently mounted fragments taken from plants collected at Arapaho Prairie. Entire slides were scanned. Trichomes, cell wall structures, and stomata patterns were used to identify the plant in the gut. Although most plant fragments could be classified to species, some fragments had no recognizable characters suitable for identification and are lumped as either *unknown* forbs or grasses. Other fragments had unique characters but could not be matched with plant samples from the study site. These plants were coded as members of the unique but *unidentified* categories. All insect fragments are lumped since they could not typically be identified as species.

Relative abundances of the plant materials in the diet were estimated. The most abundant material in the gut was scored as such and all other plant species present in the gut recorded as present. These data were then weighted to give the resource utilization of specific food plants by each grasshopper species. In the following analyses, abundant food plants are weighted 3 times as much as the other plants in the gut. This weighting scheme is chosen because the most abundant plant in the gut was immediately apparent and easily dominated the plant species composition of a particular gut sample. Other sampling methods, such as scanning 10 fields per slide, were not employed because individual fragments could not always be identified.

The degree of diet specialization is measured using either the actual number of plant taxa in the composite diet of a grasshopper species or with an index which weights the relative amount of each food plant taken. The index of diet diet breadth (B) used here is:

$$B = \exp(H')$$

where

$$H' = -\sum_i p_i \ln p_i.$$

Here, p_i represents the proportion of each plant species in the diet of a particular species. The standard error of the H′ estimate is calculated according to Poole (1974).

Results

Species-specific diets for most of the grasshopper species at Arapaho Prairie indicated a wide range in selection of plants. Yet, individual species tended to be relatively restrictive in terms of the particular food plants included in the diet. Overall, 77 food categories (excluding unknown forbs and grasses or flower parts) were found in the guts from these 31 species. This represents 43% (76/179) of the dry prairie plant species recorded at Arapaho Prairie and 36% (13/36) of the plant families. In terms of a composite diet for all species (not weighted by abundance or microhabitat use of particular grasshoppers), forbs constituted 37.2% of the diet, grasses, and sedges contributed 58% of the diet and insects made up

Table 1. Grasshopper diets. Patterns of diet selectivity for each grasshopper species are presented to indicate overall patterns of food use. Species are arranged by subfamily. Unknown forbs and grasses are excluded while categories of unique but unidentified plants and insects are included.

Grasshopper species	Sample	Number of diets categories eaten	Diet B	Number of plant families	species for of plant families	Number species for 30% diet	Number species for 50% diet	Forbs: % of diet
Gomphocerinae								
Acrolophitus hirtipes	50	7	3.5	1.3	5	1	1	99
Ageneotettix deorum	74	9	5.8	1.2	3	1	2	1
Amphitornus coloradus	49	6	1.8	1.4	3	1	1	Trace
Cordillacris occipitalis	51	9	6.2	1.3	1	1	2	0
Eritettix simplex	20	5	4.6	1.3	2	1	2	0
Mermiria bivittata	60	10	7.4	1.2	3	1	3	3
Opeia obscura	50	7	2.7	1.4	1	1	1	0
Parapomala wyomingensis	50	10	6.1	1.3	3	1	2	4
Phlibostroma quadrimaculatum	50	7	3.6	1.4	2	1	1	2
Psoloessa delicatula	84	10	5.5	1.3	6	1	2	5
Oedipodinae								
Arphia conspersa	28	6	3.4	1.6	3	1	1	8
Arphia pseudonietana	49	14	10.2	1.3	6	3	4	17
Dissosteira carolina	18	15	12.7	1.4	8	2	4	18
Hippiscus ocelote	16	10	5.7	1.6	2	1	2	0
Spharagemon collare	50	16	10.1	1.3	7	1	3	11
Trachyrhacys kiowa	50	6	2.0	1.4	1	1	1	0
Trimerotropis citrina	15	12	8.4	1.6	10	2	2	60
Melanoplinae								
Aeoloplides turnbulli	51	12	4.7	1.5	8	1	1	98
Hesperotettix speciosus	44	14	7.3	1.4	6	2	2	98
Hesperotettix viridis	50	14	4.4	1.4	5	1	1	98
Hypochlora alba	49	5	1.5	1.4	6	1	1	99
Melanoplus angustipennis	50	23	16.5	1.2	7	2	5	39
Melanoplus bivittatus	51	27	19.3	1.2	13	3	6	75
Melanoplus confusus	43	22	15.3	1.3	15	2	4	90
Melanoplus differentialis	50	20	9.2	1.4	7	2	3	46
Melanoplus femurrubrum	19	13	7.3	1.6	4	2	3	81
Melanoplus flavidus	50	22	9.4	1.4	13	1	2	92
Melanoplus foedus	46	28	22.4	1.1	14	4	7	79
Melanoplus gladstoni	40	22	13.9	1.4	11	3	4	73
Melanoplus sanguinipes	50	29	16.8	1.3	8	2	5	50
Phoetaliotes nebrascensis	52	15	11.0	1.3	8	2	4	11
Average		13.7	8.4		6.2	1.6	2.7	40.6
(2 S.E.)		(2.6)	(1.9)		(1.4)	(0.3)	(0.6)	(14.6)

4.8% of the diet. Forbs constituted 22% of the available vegetation at this site (Barnes 1980) while grasses and sedges constituted 78%.

Diet breadths for each grasshopper species are presented in Table 1. The average number of categories in the diet is 13.7 and the average value of B is 8.3. Confidence intervals (95%) allow the comparison of diet breadths among species. The fewest number of plants species in a diet was found in *Eritettis simplex* (Scudder) and *Hypochlora alba (Dodge) (5 plant species) and Amphitornus coloradus* (Thomas), *Arphia pseudonietana* (Thomas), and *Trachyrhachys kiowa* (Thomas) (6 plant species). All except *H. alba* are grass feeders. Grasshopper species feeding on the greatest number of plant species include *Melanoplus sanguinipes* (Fabr.) (29 plant species), *Melanoplus foedus* (Scudder) (28 plant species), and *Melanoplus bivittatus* (Serv.) (27 plant species). Similar results are obtained when diet breadths based on the weighting of particular items (B) are compared. The forb-feeding *H. alba* has the lowest value of B (1.5) followed by *E. simplex* (1.8) and *T. kiowa* (2.0). All species with the highest values of B *(M. foedus, M. bivitattus, M. sanguinipes,* and *M. angustipennis)* are forb feeders.

No significant relationship exists between B and the percentage of forbs in the diet ($r = 0.28$, $P>0.05$). Forb feeders are often generalist feeders. A significant positive relationship exists between B and the number of plant families included in the diet ($r = 0.77$, $P<0.01$).

Relatively few plant species constitute a large fraction of the diets for all grasshopper species. On the average, 1.6 plant species make up 30% of the diet and 2.7 species make up 50% of the diet. Even in grasshopper species with the broadest diets, half of the diet is made up of 7 or fewer diet categories. Overall, 7 categories (including insects) make up 50% of the collective diet for all species. This represents 9% (7/77) of the total categories eaten by this assemblage of grasshoppers.

The relative abundance of food plants in the environment appears to affect the overall utilization of food plants. Relative food plant use within the collective grasshopper diet is positively and significantly correlated with the relative abundance of plants in the habitat ($r = 0.8$, $P<0.01$), although individual species are selective feeders.

Comparisons of feeding patterns among subfamilies are presented in Table 2. One-way ANOVAs detected significant feeding differences among all subfamilies ($P\leq.05$). Average values for each subfamily in each category are given along with 95% confidence intervals for comparisons. The following trends are observed: (1) gomphocerines tended to have the lowest diet breadth (both in terms of number of plant species in the diet and B) while the melanoplines had the greatest diet breadth. (2) The fewest plant families were found in the diets of gomphocerines and the most in melanoplines. (3) Although the diets are typically made up of a relatively small number of plants, a smaller number of plants made up 30% and 50% of the diets of gomphocerines than was seen in melanoplines which have the greatest number. (4) Melanoplines were typically forb feeders (mean = 73.5% forbs in diet) while gomphocerines and oedipodines were primarily grass feeders. Exceptions to these generalizations are indicated in Table 1.

Table 2. Comparisons of diet selectivity among subfamilies of grasshoppers. Means and 95% confidence intervals are presented for each subfamily. For category of feeding behavior, a one-way analysis of variance was performed to determine if overall differences among subfamilies existed. The asterisk indicates statistical significance. Species-specific valus are given in Table 2.

Feeding Behavior	Gomphocerinae (n = 10)	Oedipodinae (n= 7)	Melanoplinae (n = 14)
Diet Breadth**	4.7 (1.2)	7.5 (3.7)	11.4 (3.6)
Number species eaten*	8.0 (1.3)	11.3 (3.8)	17.1 (6.0)
Minimum number of plant families in diet*	2.8 (1.2)	5.3 (3.1)	8.9 (2.1)
Number of species for 30% of diet*	1.0 (0)	1.6 (0.6)	2.0 (0.5)
Number of species for 50% of diet*	1.7 (0.5)	2.4 (1.3)	3.4 (1.1)
% forbs in diet*	11.5 (22.0)	16.3 (19.0)	73.5 (15.7)

*$P\leq.05$ **$P<.01$

Vegetation-dwelling grasshoppers have significantly lower diet breadths than do ground-dwelling grasshopper species (Mann Whitney U, $P<.025$, one-tailed). The diet breadth for species found on vegetation is 5.5 and for ground-dwelling species, B = 10.4. Grasshopper species from disturbed areas tend to have larger diet breadths (mean B = 7.9) although this was not statistically significant (Mann Whitney, U, P = 0.12). This comparison was conservative in that 3 species with the high diet breadth *(Melanoplus confusus* (Scudder), *M. foedus,* and *M. sanguinipes),* which are very common in disturbed areas, were not included in this group as they are found frequently in other portions of Arapaho Prairie.

Discussion

Coexisting species of grasshoppers show a wide range of feeding behavior. Although some grasshopper species eat only a few species of plants and others feed on many, grasshoppers are not indiscriminant feeders. This is in keeping with established views (Joern 1979, Mulkern 1967, Otte and Joern 1977).

Cates (1980) proposed the following criteria to delineate the degree of diet specialization: (1) monophagy - 1 or more species within a genus; (2) oligophagy - 2 or more closely related genera, and (3) polyphagy - 2 or more plant families. None of the species

Table 3. Overall patterns of diet selectivity in assemblages of grasshoppers from various habitats. The mean diet breadth (B) and 95% confidence intervals (C.I.) for the entire assemblage at each site is given.

Study	Habitat	Number grasshopper species studies	Mean B	95% C.I.	Reference
Arizona (USA)	Desert	16	2.6	0.85	Otte & Joern 1977
Argentina	Desert	12	2.8	0.66	Otte & Joern 1977
Washington (USA)	Shrub-Steppe (Desert)	8	3.7	1.42	Sheldon & Rogers 1978
Pawnee Site, Colorado (USA)	Shortgrass Prairie	24	4.2	1.34	Pfadt & Lavigne 1982
Marathon, Texas (USA)	Arid Grassland	24	4.7	1.66	Joern 1979
Kansas (USA)	Tallgrass Pasture	19	5.2	1.16	Mulkern et al. 1969
Altuda, Texas (USA)	Arid Grassland	22	5.7	1.66	Joern 1979
North Platte, Nebraska (USA)	Mixed Prairie/Pasture	36	5.9	1.42	Mulkern et al. 1969
Colorado (USA)	Sandhills Grassland	14	8.2	5.08	Ueckert & Hansen 1971
Arapaho Prairie, Nebraska (USA)	Sandhills Grassland	32	8.4	1.94	Joern (This Study)
North Dakota (USA)	Sandhills Grassland	32	8.6	1.53	Mulkern et al. 1969

considered in this study can be considered monophagous. In all cases, a range of food plants was used, even though some were used infrequently. Some species are oligophagous, but the majority of species must be considered polyphagous using the above criteria.

Compared with other studies (Table 3), diet breadths at Arapaho Prairie are high. A similar methodology for diet determinations was employed in these studies. Grasshoppers from desert sites have the lowest diet breadths (Arizona, B = 2.6; Argentina, B = 2.7) (Otte and Joern 1977). Diet breadths of grasshoppers from grasslands (western Texas, Kansas, North Dakota, western Nebraska, and Colorado) show higher diet breadths than desert sites. The present study has the second highest average diet breadth (B = 8.4). Other sandhills studies also have high average diet breadths (Table 3).

These results also point to the general scavenging role that grasshoppers play by feeding on dead insects. On a composite basis, insect parts contributed 4.8% of the total diet and ranked fourth in relative importance of all diet categories. Species which included especially high proportions of insect material in the diet were *H. ocelote* (13%), *T. citrina* (20.8%), *M. confusus* (16.9%), *M. foedus* (13.7%) and *M. gladstoni* (11.7%). All of these species except *H. ocelote* are primarily forb feeders and all species would rank as being of relatively large size among species present at this site. However, neither of these factors explains the preponderance of insect material in the diet since many other strictly forb feeders or other large species did not eat insects to any significant degree. Phylogenetic trends in feeding seen here are the same as those seen in previous studies. Gomphocerines are typically grass feeders and have low diet breadth. Oedipodines also feed on grass, or are mixed feeders with an intermediate diet breadth, while melanoplines are primarily forb feeders with high diet breadths.

Many factors are involved in the determination of food selection by grasshoppers. Such factors include: plant chemistry, predictability of the food plant in time and space, phylogenetic constraints, nutrient quality and distribution within the plant, sensory capacities of insects, the types and numbers of all other herbivores feeding on particular plant species, and predation (Bernays and Chapman 1978, Cates 1980, Feeny 1976, Fox 1981, Joern 1979, Otte and Joern 1977, Rhoades 1979, Rhoades and Cates 1976, Rosenthal and Janzen 1979). Secondary plant compounds have been shown to have a great influence over host plant selection through either deterrence or stimulation (Bernays and Chapman 1978).

Feeny (1976) and Rhoades and Cates (1976) have proposed a theory of insect feeding where attributes of the defensive chemistry employed by plants are combined with the likelihood that an insect herbivore will encounter a particular plant. The likelihood that an insect herbivore will encounter a particular plant is referred to as the predictability of the plant. A predictable plant is likely to be found by the insect herbivore. According to this theory, predictable plants are expected to sequester "quantitative" defenses which are typically dosage-dependent and act to deter herbivores by reducing the digestibility of the host plant (such as by complexing proteins and making them unavailable for use). Tannins would be an example of a quantitative defense. Levels of hydrolyzable and condensed tannins in red oak leaves increase after defoliation by gypsy moth larvae (Schultz and Baldwin 1982). Such tannins will affect growth in larval lepidoptera. It is also expected that insects feeding on predictable plants may exhibit high diet breadths compared to those feeding on unpredictable plants.

Unpredictable plants should defend themselves with acutely toxic chemicals which are likely to be "evolutionarily susceptible" to detoxification by herbivores (Feeny 1976, Rhoades and Cates 1976); these toxic chemicals are referred to as qualitative defenses. Alkaloids, mustard oils, and turpenes are examples of qualitative defenses. Herbivores which feed on these plants should be specialist feeders. They are able to detoxify the specific chemicals in a specific plant taxon, but do not have the physiological capacity to detoxify a wide range of chemicals which would be found in a variety of unapparent plants (sensu Feeny 1976, Rhoades and Cates 1976).

Despite the general success of this theory for explaining patterns of food plant use by herbivores, anomalies persist (Bernays and Chapman 1978, Fox 1981, Gilbert 1978, Joern 1979, Otte 1975, Otte and Joern 1977). For example, many grasshopper species are able to adequately deal with tannic acid (considered a quantitative defense) added to food material, contrary to expectations (Bernays 1978, Bernays et al. 1980, Bernays and Chamberlain 1980). Results from the present study do not support these predictions either. Grasshoppers feeding on forbs are encountering a diverse array of defensive chemicals. Yet, they tend to be much more polyphagous than grass-feeding species which are not encountering such chemicals to any great degree.

Food selection revolves around the need for nutrition balanced against the negative effects of antibiotic chemicals (Bernays and Chapman 1978). Grasses and forbs typically represent alternative types of food plants for grasshoppers in this regard. Tradeoffs must exist to explain the evolution of such clear patterns. Costs to grasshoppers feeding on forbs may be expressed as deterred growth, survivorship, or reproduction because of the sequestration of compounds by the plants and subsequent detoxification. Although the presence of particular compounds has been shown to stimulate or inhibit feeding on particular taxa, few studies unequivocably demonstrate negative effects on grasshopper fitness due to the chemical constituents (Bernays and Chapman 1978); some such studies do exist (Harley and Thorsteinson 1967, Navon and Bernays 1978, Schlesinger et al. 1976). However, the great volume of work on other insect groups which does support this view makes it difficult to reject the likelihood of a negative relationship between plant chemicals and fitness in grasshoppers.

Feeding on grasses is one avenue by which grasshoppers may avoid toxic chemicals (Bernays and Chapman 1978). In this process, little or no energy (or other resources) would need to be spent on the detoxification process. For species existing in habitats such as the sandhills grassland at Arapaho Prairie, the food resource is extremely abundant and predictable. However, costs are probably also associated with a grass feeding habit. These might include lowered nutritional quality for such important nutrients as nitrogen and the need to chew the tough, silicaceous leaves of grasses resulting in mandibular wear (McNeil and Southwood 1978, Mattson 1980). Mandibular structures of grass-feeding species of grasshoppers are quite different than those of forb-feeding grasshoppers, and appear suitable for grinding (Isley 1944, Patterson, in press). Wear of mandibular surfaces as a result of feeding on grasses is often noticeable (Chapman 1964).

Some species from subfamilies which are typically grass-feeding also feed on forbs (in some cases exclusively). This suggests that certain reversals in the general feeding habit have taken place (if phylogenies have been correctly inferred) and these are extremely important events in the explanation of the evolution of feeding patterns of grasshoppers. Unfortunately, the data presently available are not sufficient to evaluate these reversals or to explain the phylogenetic relationships associated with the grass-feeding habit. Some insight is provided by Bernays and Chapman (1978).

Predictability of the host plants may greatly influence the diet breadth of grasshoppers. In this regard, grasshoppers feeding on very predictable grasses have low diet breadths. In contrast, forb-feeding grasshoppers using food plants which are unpredictable in time and space have large diet breadths. Species which feed on predictable forbs (such as *H. alba* feeding on *Artemisia ludoviciana*) have narrow diet breadths as predicted from such reasoning. These results have been demonstrated previously in grasshoppers from other sites as well (Joern 1979, Mulkern et al. 1969, Ueckert and Hansen 1971) and for other herbivorous species (Lawton and Strong 1981). Although the predictability of host plants may explain the number of plants in the diet, it does not explain why some grasshoppers feed primarily on grasses while others feed primarily on forbs.

Problems remain in explaining the evolution of feeding habits of grasshoppers. Although patterns of feeding in the grass-feeding forms are at least understandable, it is not obvious how forb-feeding species can have such broad diets. Different defensive chemicals in the plants must be dealt with in non-identical ways. This would require a large arsenal of detoxification mechanisms which is not consistent with present expectations (Feeny 1976, Rhoades 1979). Either these views are not correct or other mechanisms must be explored as well. Unfortunately, relevant studies in this area have not been performed.

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TECHNICAL NOTES

Total Urine Collection from Free-grazing Heifers

M.A. STILLWELL, R. SENFT, AND L.R. RITTENHOUSE

Abstract

A urine collection device for female bovines is described. This device allows simultaneous collections of urine and feces, is reusable, and is designed for use on free grazing animals. Tests of the device were successful and showed no major problems under field conditions.

Studies of nitrogen and energy dynamics of free-grazing animals are essential to the understanding of the function of grazed ecosystems. In most cases, however, intake and fecal excretion are the only parameters examined, even though urine represents an important pathway of excretion of metabolic N and energy (Church 1976). Established procedures exist for determining intake and fecal excretion for free-roaming animals (Van Dyne 1980), but measurement of urinary output remains a difficult task.

Gorski et al. (1957) suggested a system of total collection of both urine and feces for female bovines, but difficulties in harness adjustment and the need for frequent removal of the excreta made it impractical for range conditions. Lesperance and Bohman (1961) used an inflatable catheter and truck inner tube mounted on the back of the animal to collect urine. The disadvantage of this system was difficulty in draining the bag. Further, maintenance of sterile conditions to prevent urea hydrolysis and reuse of bags was impractical. Our objective was to design a urine collection device for simultaneous collection of urine and feces, that was reusable and easily sterilized, and could be used on free-grazing heifers.

Materials and Methods

Fecal Collection Bag

The fecal collection bag and harness was similar to that designed by Garrigus and Rusk (1939). The design was modified only by the addition of two buckles to the girth strap, two D-rings to the breast collar (Kartchner and Rittenhouse 1979), and a vertical 3-cm slit in the fecal bag opposite the heifer's vulva.

Urine Collection Bag

The urine collection device was composed of 2 parts: (1) a carrier, and (2) a series of 6 closed urine drainage bags connected to a urinary catheter. The carrier was made from heavy nylon-reinforced vinyl sown to form 6 pockets (Fig. 1). A small slit was made in the corner of each pocket to allow access to a drainage tube. A strap was added under the front pockets to fasten the carrier to the girth strap of the fecal harness. Grommets in the front and rear corners allowed attachment of D-rings on the breast collar and sides of the fecal bags.

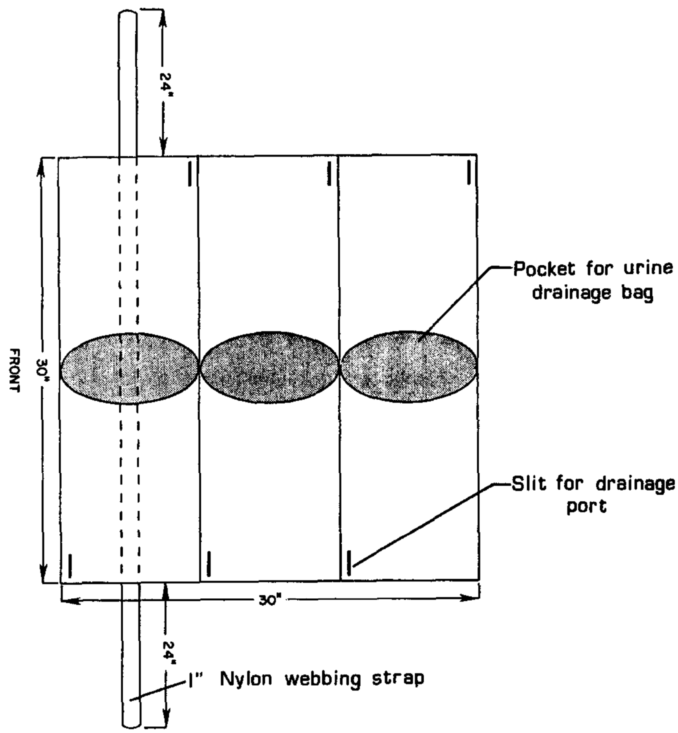

Fig. 1. *The carrier for the urine collection apparatus was made from a single 30 × 60" piece of nylon-reinforced vinyl tarpulin material folded and sewn to form 6 pockets. A urine drainage bag was stuffed into each pocket. The slit in the lower left corner of each pocket allowed easy access to the drainge port of the urine drainage bags. The nylon webbing straps were attached to the girth strap of a modified fecal collection bag harness.*

Urine flowed through a #24 Foley catheter into a series of six 2-liter Pharmaseal closed urine drainage bags with one-way valves (Fig. 2). A 1/4-in. Nalgene Y split the urine stream from the catheter into 2 flows entering the first pair of bags (Fig. 2). A pair of Y's just above each of the front bags shunted backflow from the front bags to the middle pair. Backflow from the middle pair of bags was directed to the rear bags via a second set of Y's. A

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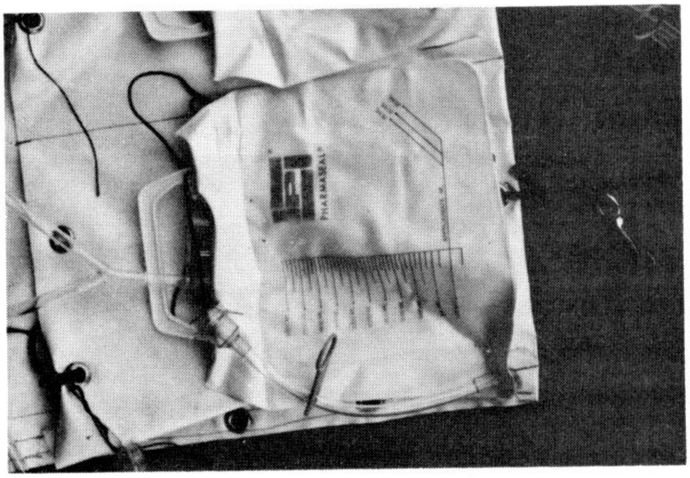

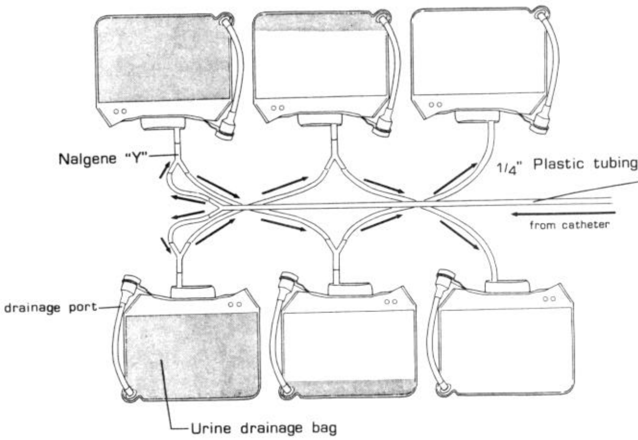

Fig. 2. *Interior plumbing of the apparatus consisted of six 2-liter urine drainage bags connected to a urinary catheter via 1/4" plastic tubing. Diection of urine flow is indicated by the arrows. The tubing was arranged so that the anterior bags filled first at approximately equal rates. Overflow from the forward bags was directed to the middle bags; and overflow from the middle bags went to the rear bags. Drainage ports and tubing are protected from brush and barbed wire by a 30 × 30"* vinyl cover which snaps on the carrier.

drainage bag was stuffed into each pocket of the carrier and drainage tube allowed to extend through the slit. A metal clamp was used to close the drainage tube, which was secured to the top of the pocket. A removable vinyl cover was attached to the carrier to prevent damage to the catheter line or the drainage tubes.

The urine was collected from the bags by lowering the drainage tubes and removing the clamp. Urine was stabilized by adding 10 ml of 10 ppm phenylmercuricacetate solution to each bag after

Fig. 3. *Free-grazing heifer fitted with both urine and fecal collection bags.*

drainage. The bags were reused after cleaning with deionized water and sterilization with ethylene oxide at 55° C (Veterinary Medicine Teaching Hopsital, CSU).

The urine collection apparatus was tested during the summer of 1981 on 4 yearling heifers grazing a 125-ha shortgrass prairie pasture northeast of Fort Collins, Colo. (Fig. 3). The heifers carried the bags for one 7-day period each month from May to October. No major problems occurred with the functioning of the apparatus or with the heifers themselves. The fit of carrier was easily adjusted, and collection of total urine and feces from the 4 animals was accomplished in as little as 20 minutes.

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A Simple Sack-holding Frame

J.A. HANSMIRE, C.M. BRITTON, AND S.S. WALLER

Abstract

A lightweight frame was designed to hold sacks when sampling vegetation by species. Sacks are attached with clips to a pegboard in an organized arrangement with labels that are easily read. The frame is especially useful on windy days.

Harvesting rangeland vegetation by species is a common practice in range research. Weight be species is a valuable meaurement in many plant communities. Once clipped, individual species or groups of species are placed in paper sacks, then dried and weighed. As the number of sacks per quadrat increase, their management in the field becomes more difficult. A lightweight sack frame was designed to hold sacks in an organized arrangement such that identifying labels could be easily read (Fig. 1). This minimizes time spent searching for the proper sack. The frame is especially useful on windy days and is easily transported.

The frame was constructed to handle different numbers of sacks within easy reach of the clipper. The illustrated frame can hold 21, No. 12 sacks. Sacks are attached by clips and arranged on 3 rows of pegboard. The pegboard allowed clips to be adjusted for different sack sizes. The frame can be adapted to meet criteria of individual projects.

Authors are graduate fellow in Department of Range and Wildlife Management, Texas Tech University, Lubbock and Welder Wildlife Foundation, Sinton, Texas; associate professor, Department of Range and Wildlife Management, Texas Tech University, Lubbock; and associate professor, Department of Agronomy (Range Management), University of Nebraska, Lincoln. This is a contribution of the College of Agricultural Sciences, Texas Tech University, No. T-9-311, and Rob and Bessie Welder Wildlife Foundation Contribution No. 273.

The authors wish to express their appreciation to Wayne W. Seipp for his help in constructing the sack frame.

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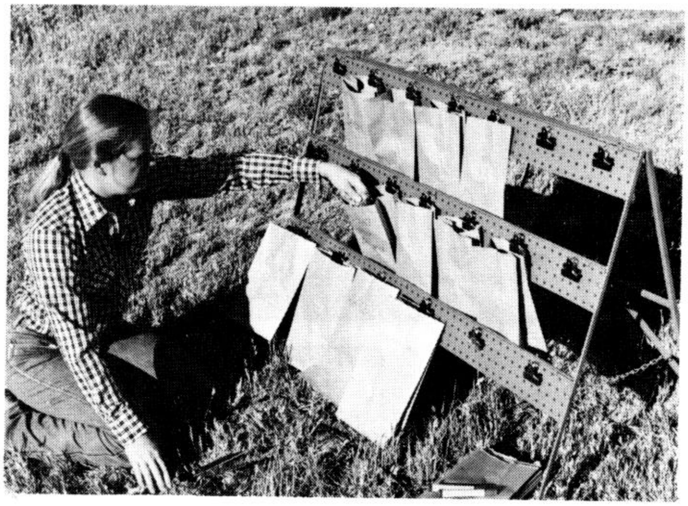

Fig. 1. *Sack-holding frame, made with angle iron and pegboard, holds and organizes sacks.*

To construct the frame, 3 cross-braces (120 cm length) were welded to the front legs (90 cm tall) and 2 cross-braces were welded to the back legs. Angle iron (0.64 cm) was used; however, aluminum material also would be suitable. Pegboard (10 by 118 cm) was bolted on the inside edge of the angle iron. A distance of 16 cm was allowed between the pegboard strips to permit sacks to fall behind the pegboard. Height above the ground to the bottom pegboard was determined by sack length (28 cm in this case). The front and back sides were joined by hinges welded at the top. A lightweight chain was fastened between the front and back legs. The cost was approximately $20.00.

BOOK REVIEWS

Fire Ecology: United States and Southern Canada. By Henry A. Wright and Arthur W. Bailey. 1982. John Wiley and Sons, 1 Wiley Drive, Somerset, NJ 08873. 501 p. $44.95.

Wright and Bailey provide a significant summary of the literature dealing with the effects of wildland fire and the use of fire in managing forest and range lands. The organization of the book makes it very easy to locate information about a specific fire effects topic. Most of the book is structured around chapters on major plant communities, giving a geographic and synecologic framework for sorting the many specific details of fire effects information.

A brief introductory chapter is followed by a discussion of physical fire effects and specific biological effects. The next two chapters treat the effects of fire on soil and water and on selected animal species. The major part of the book is comprised of eleven chapters, each devoted to a major type of plant community. These chapters discuss the historical role of fire, the effects of fire on the plant community and on individual species, and management implications of the use of fire. The final chapter discusses some aspects of conducting prescribed burns.

The same general organization that makes it easy to use *Fire Ecology* as a reference work on specific fire effects information also makes it difficult to read the book as a unifying treatment of fire ecology. This gives the impression that the book is fragmented. The literature is not synthesized into a cogent discussion of ecological principles related to wildland fire. This may reflect the fact that fire ecology is a relatively young science. Nevertheless, the reader who approaches this book seeking a unifying treatment of the ecology of wildland fire may be disappointed.

Another aspect of the book that detracts from its technical subject matter is the strong emphasis on "selling" prescribed burning as a management technique. Although prescribed burning is an increasingly important aspect of wildland management, in this book it is given disproportionate emphasis. The last chapter, "Prescribed Burning," seems particularly out of place in a book devoted to the subject of fire ecology. Parts of this chapter are rather colloquial discussions of various aspects of planning and executing prescribed fires. This information would have been better left to other technical publications.

Despite some of its shortcomings *Fire Ecology* provides a valuable condensation of a large and diverse literature, and is useful as a first source of information about topics related to fire effects or fire use.—*David L. Radloff,* Fort Collins, Colorado.

NEW PUBLICATIONS

Grass Systematics (Second Edition). By Frank W. Gould and Robert B. Shaw. 1983. Texas A & M University Press, Drawer C. College Station, Texas 77843. 397 p. Cloth-$25.00, paper-$15.00.

Prior to Dr. Gould's death in 1981, he asked Dr. Shaw to revise the 1968 edition of this textbook. Included were corrected subfamily names, incorporating Gould's most recent concept of the Paniceae, adding information on the importance of the photosynthetic pathway and C_4 subtype in grass systematics, and updating the literature in the systematics section. No update was attempted for chapters 3 and 6, or to resolve the Triticeae generic relationships controversy.

The second edition of this book consists of six chapters: "Introduction," "The Grass Plant", "Reproduction and the Cytogenetic Basis of Plant Differences," "Grass Classification", "United States Grasses", and "Grassland Associations in North America"; each chapter contains a literature cited section. Following the chapters are two appendices: "The Herbarium and the Preparation and Handling of Grass Specimens"; and "The Naming of Grasses: Rules of Nomenclature". A 15-page glossary and an index complete the text. Six subfamilies of United States grasses are addressed in this second edition: Pooideae (9 tribes), Panicoideae (2 tribes), Chloridoideae (8 tribes), Bambusoideae (2 tribes), Oryzoideae (1 tribe), and Arundinoideae (3 tribes).

The text emphasis remains on the structure and growth of the grass plant, characteristics of the U.S. grass genera, and a discussion of tribes and subfamilies of subtropical and temperate North America. The genera and higher taxa are listed in phylogenetic sequence, and the U.S. genera key is based on infloresence characters.

Grass Systematics has been designed for an undergraduate course in agrostology and as a valuable reference for graduate studies and grass systematics.—*Ed.*

Multivariate Analysis In Community Ecology. By Hugh G. Gauch, Jr. 1982. Cambridge University Press, 32 E. 57th St., New York, New York 10022. 298 p. Cloth-$37.50, paper-$14.95.

Gauch states that "Community ecology concerns assemblages of plants and animals living togther and the environmental and historical factors with which they interact" and "Multivariate analysis is the branch of mathematics that deals with the examination of numerous variables simultaneously. . ." Within this context, the book is relatively brief and emphasizes the preferred techniques of multivariate analysis and stresses both principles and applications.

In the seven chapters of this text, multivariate analysis in community ecology is reviewed and the theory, methods, and applications of classification, ordination, and direct gradient analysis are presented. Also, the inherent limitations, model accuracy, and prospectus of community ecology are offered. Gauch concentrates on plant, animal, and microbial communities; and terrestrial, aquatic, and marine communities. Special emphasis is given to present terrestrial plant communities and brief mention is given to the fields of business, social sciences, and medicine. The book concludes with an appendix of available computer programs, 47 pages of references, and a subject index.

Advanced undergraduate students, graduate students, and professional ecological researchers will benefit from Gauch's up-to-date synthesis of the field and a wide range of illustrative examples.—*Ed.*

Quantitative Plant Ecology (Third Edition). By P. Greig-Smith. 1983. University of California Press, 2120 Berkeley Way, Berkeley, California 94720. 359 p. Cloth-$38.50, paper-$22.00.

This well-known book which was last published in 1964 and difficult to obtain, is now back in print with the third edition. It has become an authoritative, established review of the theory and methods available for quantitative vegetation description and analysis.

Greig-Smith states: "Methods of analysing field data on vegetation have developed so greatly since the last edition was written that some sections, especially the treatment of classification and ordination, have become completely out of date. The book has therefore been extensively revised and rewritten."

The third edition consists of ten chapters: "Quantitative Description of Vegetation", "Sampling and Comparison", "Pattern", "Association Between Species", "Correlation of Species Distribution with Habitat Factors", "Plant Communities-I. Description and Comparison", "Plant Communities-II. Classification", "Plant Communities-III. Ordination", "Vegetation and Environment", and "Practical Considerations," The text is followed by an Appendix of eight statistical tables, a 29-page reference section, an author index, and a subject index.
chapters 1-6; classification and ordination are now seperate chapters (previously chapter 7); chapter 5 has been slightly retitled; "Vegetation and Environment" (chapter 9) is new; the final chapter has been replaced; the previous appendices on meteorological data, and on area and spread of species have been deleted.

This book will continue to be a valuable reference for advanced undergraduate, graduate students, and professional vegetation ecologists. Welcome, third edition!—*Ed.*

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