# Journal of Range Management

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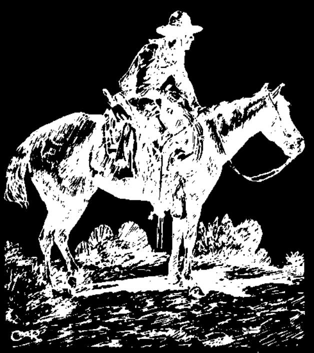
The Trail Boss

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TECHNICAL NOTES

The Trail Boss ®

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The objectives for which the corporation is established are:

*—to properly take care of the basic rangeland resources of soil, plants and water;*

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

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

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

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

*—to promote professional development of its members.*

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

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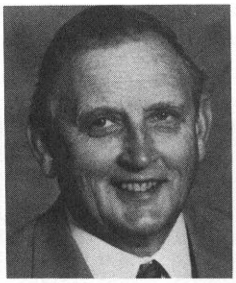
## President's Address

# Is it time for a change?

**WILLIAM A. LAYCOCK**



I want to try to do two things in this address—talk about some of the progress and plans of the new task groups formed in the last year and then talk about some new ideas and some potential new directions that SRM should at least consider.

### Some Thank You's

First, I would like to express my thanks to some of the people that helped me make it through the year as president of SRM. First, I would like to thank my wife, Charlotte, for her support, help, and encouragement during the year and for putting up with the long periods of my absence from home. Within SRM I would like to give special thanks to Pete Jackson. He is the one person that really holds this organization together and is truly "Mr. Range Management." Presidents are around for only one year, so Pete is the one that is known by people and organizations outside the Society as the one to contact about Range Management. Another individual who is doing a tremendous job for SRM in Washington, D.C., is Ray Housley. I made 4 trips to DC during the year and, every time, was impressed with the variety of people that Ray knows and that know Ray as the SRM representative. Any expression of thanks is not complete without thanking the staff in our Denver office. They really are a dedicated group of people and, by dealing with the day-to-day routine matters of the Society, make it run. The other group of people who attend to the professional work of the Society are the committee chairmen, the members of the various committees and task groups, and the Section officers and committees. Except for our Denver staff, SRM is run by volunteers, most of whom have another job. We never can say thank you enough to these people as well as all of the members of SRM who make this such an exciting organization.

### Special Task Groups

The standing committees of SRM do the routine and continuing work of the Society and we cannot function without them. The progress made by each of these committees will be published in *Rangelands* and I urge you to read their reports. What I want to do in this report is talk about the progress being made by the special Task Groups formed during the last year and a half that are dealing with different or potentially important issues.

*The Conservation Reserve Program Task Group* was formed late in 1987 to address the implications of this major program and to consider the charges given to SRM by Wilson Scaling at the CRP symposium in Denver in September, 1987. The committee, chaired by Harold Goetz, has contacted all Section presidents and requested that they each establish CRP committees within each Section. SRM's program on CRP was presented at a meeting of the Grazing Lands Forum in October 1988 and also as part of a program presented to the USDA Joint Council in January, 1989. One of the main concerns of SRM, as well as many other organizations, is how to keep erodible lands now in CRP in that protective cover when the CRP contracts end in the mid 1990's.

*The Watershed/Riparian Task group* was formed at Corpus Christi, with Fred Gifford as chairman, to provide a focus for the concerns about watershed and riparian issues not only within SRM but nationwide. This task group has arranged for a symposium at the 1990 annual meeting in Reno to address how healthy, self-perpetuating riparian zones and intact watershed are important components of a quality environment. The National Wildlife Federation, Trout Unlimited, Sierra Club, The Wilderness Society, National Audubon Society, The Izaak Walton League, and the Defenders of Wildlife have all been invited to participate. The task group also reviewed the 1988 GAO report on riparian areas.

*The Wildlife/Wildlife Habitat Task Group* was also formed at Corpus Christi with Kieth Severson as chairman. The Task Group is planning a text book, to be published by SRM if it is approved, dealing with Wildlife and Wildlife Habitat on Rangelands. The Task Group also plans to sponsor a symposium "Can Livestock Be Used To Enhance Wildlife Habitat?" at the 1990 SRM meeting in Reno. An important contact has been made through the Task Group with the president of The Wildlife Society, which should lead to closer and better relations and cooperation between our two societies in the future.

*The Task Group on Small Tract Range and Pasture Management with Emphasis on Horses* was also formed at Corpus Christi with John Buckhouse as chairman. The committee was very small to start with but has now expanded. The task group feels that the concern for management of small tracts is real and should be represented in SRM. They are exploring the possibility of preparing a book dealing with the subject.

*The Remote Sensing Task Group* met informally at Corpus Christi was formalized as a task group a couple of months late with Paul Tueller as chairman. This working group is committed to the future importance of remote sensing for rangeland resources inventory and monitoring. A reconsideration of this matter is important now in light of the increased emphasis on the inventory and monitoring of the earth's renewable natural resources. Dr. Tueller and some other members of the working group have been involved in planning a session on International Range Inventory and Monitoring to be part of the international conference on "Global Natural Resource Monitoring and Assessment: Preparing for the 21st Century" to be held in Venice, Italy, in September 1989.

*The Coordinated Resources Management Task Group* also has been working together informally for several years and was formalized as a Task Group in March with Brent Lathrop as chairman. This group also has planned a CRMP symposium for the 1990 meeting in Reno. A workshop for State Advocacy team members and a Task Group breakfast were held at the Billings meeting.

The newest group is the *Task Group for Unity in Terms and Concepts* formed in January and met for the first time in Billings. The charges given this new Task Group were to continue professional dialogue on terminology and ecological concepts relating to range classification, inventory, and monitoring and seek agency commonality and unity in technology and methodology relating to rangeland condition and trend.

### Publications

Several other accomplishments by committees and others during 1988 need some comment. At Corpus Christi, the Publications

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This address was presented 22 February 1989 at the 42nd annual meeting of the Society for Range Management in Billings, Montana. Dr. Laycock was 1988 president of the Society.

Committee presented the Board of Directors with an updated version of the *Glossary of Terms*. The subcommittee that prepared it had done a tremendous amount of work bringing the terms up to date. Even so, there were still a number of terms in the glossary that lacked universal acceptance, and some terms (such as a few from the RISC Report) were missing. First Vice-President Tom Bedell took the draft *Glossary* and has spent a great deal of time adding the missing terms and trying to make it as accurate as possible. The *Glossary* should be published early in 1989.

Two other publications were prepared in 1988 and will be published by SRM in 1989. One is a Range Research Initiative that has been in preparation for several years by several members—Gary Evans, Phil Sims, Fee Busby, and others. It outlines range research needs along with the additional budget required. A similar document by the Research Affairs Committee, prepared at the request of the Experiment Station Committee on Policy, was completed about the same time. The two documents are completely parallel in subject matter and budget requests. The range research initiative paper is now available from the SRM office in Denver. This publication was presented to the USDA Joint Council and discussed at their meeting in Washington, D.C., in January.

The other publication, entitled "Assessment of Rangeland Condition and Trend of the United States, 1989," was prepared in 1988 by a subcommittee of the Public Affairs Committee. It is the culmination of several years of work by the subcommittee chaired by Dr. George Ruyle and with members from FS, BLM, and SCS and several universities. It shows the most current data on range condition and trend within each agency. One of the problems brought out in the report is that some of the data is not as recent as it should be because of lack of money, manpower, and emphasis within each agency to monitor rangelands at the proper intensity and frequency. The results of this study were also presented to the USDA Joint Council in January. This publication also should be available from the Denver office by the time this article is in print or shortly thereafter.

## Are Changes Needed?

There are a number of encouraging things about SRM and range management in general. Membership in SRM increased slightly in 1988 and we went over the 5,000 member mark for the first time in several years. After a continuous decline for 5–6 years, the number of students in colleges and university range science departments has leveled off and some schools have had small increases in student enrollment the last two years. There have been more jobs available for range management graduates the last couple of years, and summer jobs for students are plentiful.

In spite of all of these positive signs, there are other indications that the profession may be in trouble. As I commented in a column in 1988, the image of the profession and of SRM to many other groups is not what we want it to be. We are perceived by many of the environmental organizations as strictly a livestock organization. This perception prevents SRM from forming coalitions with some wildlife, fisheries, and other types of organizations that would be beneficial to SRM and to rangelands.

Funding for range management programs and range management research has declined dramatically in the last decade and a half. Some of this has been budget cuts from Congress but much has been the result of shifts of funding from range to other activities as a result of priority shifts within the Forest Service and BLM. The Rangelands Research Grants Program under CSRS has not been allocated any funds again in the FY90 President's budget. Range management research in the Forest Service has been cut to the level that it hardly exists. All of these things indicate a low priority for range management in the federal government.

The 2 GAO reports issued in June, 1988, dealing with riparian areas and overstocked allotments were very critical of the range management programs of our two largest land management agencies and of livestock grazing on public lands. Livestock grazing on public lands seems to be under attack from a number of fronts. One example is Earth First's slogan of "Cattle Free by 93", which describes one of their goals for public lands.

One thing that some people believe reinforces our image as a grazing organization is the Trail Boss logo. This is an emotional subject but we (SRM) need to seriously consider our logo and what it portrays. To many, it simply portrays a single use orientation for SRM. In a letter from a former SRM president he stated: "True, I would miss the Trail Boss—for a while. But, in real life his job changed too, with time. In today's world, resisting change is courting disaster. We cannot afford to let that happen."

Along with, or before we consider changing our logo, I believe we have to consider changing our name. As I indicated in the October President's Notes in *Rangelands*, we need to add something to our name to make us identifiable in a world where country and regional Rangeland Societies are becoming common. I was fortunate enough to be able to travel to Kenya, Mexico, and India in 1988. In every situation, I found that SRM was referred to as the "United States Rangeland Society", the "American Society for Range Management" or something similar. I took part in the closing ceremony of the 3rd International Rangeland Congress in India and was introduced as the president of the "American Rangeland Society" in spite of numerous letters to the organizers on official SRM stationery. As I pointed out earlier, we are no longer "*THE* Society for Range Management and we are not the "*INTERNATIONAL*" Society. We are just one of a number of rangeland societies in the world and our name should reflect it. I received some mail supporting a change to the "North American Rangeland Society" or "North American Society for Range Management". Some mail simply said, "Leave our name alone."

I also received mail indicating that simply adding a country or regional part to our name was not enough. These letters advocated a name change to something completely different such as the "Society for Natural Resource Management" as well as a change in our logo. One writer said, "It's time (actually 15–20 years past time) the society made a serious effort to convey the message of multiple use management to the rest of the United States (world?)." Another writer said, "As the Society for Natural Resource Management, we would broaden our membership base immeasurably. We have long prided ourselves on membership diversity; this change would truly give us opportunities for diversity of backgrounds and expertise in our society".

In August, I received two thoughtful and thought provoking letters from two ranchers, both quite active in SRM affairs. I am going to quote a few things from these letters and hope that they serve to make all of us think about the role of SRM, its name, and its members.

> To have a first class, respected, professional-scientific society that is creative and gaining stature in the scientific arena is a *must* for SRM. The Soil Science Society, Society of Agronomy and Animal Science Society have few to no farmer or rancher members. These are old societies and I am sure they represent the right way to be an effective society....(We) have convinced ourselves that the opportunity for growth on a permanent, constructive basis lies within the employees of the (agencies and universities) that have the responsibility for developing new technology plus getting all of it applied where needed....If all of the professional people who work in range management from the classroom to the ranch were SRM members and were properly trained, our ranchers would soon become interested in the application of sound practices and be a strong support group for SRM and its programs. Ranchers could become members, and we will have a few, but let's not waste our real responsibility of being a strong, sound source of scientific information and professional guidance in range management....Let's work to stock SRM with the right kind (of individuals) and then assist

> and encourage them to carry the ball in the game where ranchers are involved. I personally would feel honored to belong to the organization that was recognized as representing the very best scientific and professional people in the field of Range Management...So let's forget trying to be all things for all people and concentrate on being the best in our field."

Is this the direction SRM should take? Many members will say "no" but, considering the source of the comments, I think we have to take the ideas seriously and at least consider them.

In the other letter, similar ideas were presented—"We are looking for new members. Especially new members who can influence the application of sound range use practices. What better group could we solicit than the large number of technical people who work with landowners every day as agency representatives?...If every person from the university to the ranch who works with rangeland management was an active member of SRM, we would see miracles occurring on the land. We could double our membership and quadruple our on-the-land accomplishments if we just had as members, the university and agency people who, by their assignments, should belong to SRM." I don't believe anyone would disagree with the latter quote.

## In Summary

To survive, any organization has to be dynamic and not become a dinosaur. Most of the ideas I have presented above came from members, members who are deeply concerned about the future of the range management profession and of SRM. The least we can do is seriously consider all of those potential areas of change as well as other areas that might need change that I have not even thought of. I encourage all of the officers, directors, and committees of SRM; all of the Advisory Council officers and members; and all other members of SRM to think seriously about the future of SRM and to not resist change just because the way we operate now or what we call ourselves is "the way it always has been."

It has been an honor and a pleasure to serve as president of SRM. One thing that became very obvious to me is that one year is too short for one person to have very much influence on the course of a dynamic organization such as SRM. I encourage all members of SRM to work together and work with the officers and committees of both the parent Society and the Sections to continue to help SRM both improve and grow.

# Crested wheatgrass growth and replacement following fertilization, thinning, and neighbor plant removal

BRET E. OLSON AND JAMES H. RICHARDS

## Abstract

**The growth and annual replacement of crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) tillers are affected by resource availability. Fertilization and grazing affect the resources available to crested wheatgrass plants directly, by increasing nutrient supply or by reducing photosynthetic area and root elongation, and indirectly, by changing the competitive status of neighboring plants. To determine the time and manner of crested wheatgrass response to alterations in resource availability, we assessed the growth, flowering, and replacement of tillers on plants treated as follows: tiller thinning, neighbor plant removal, combined thinning and neighbor plant removal, and nitrogen fertilization. These treatments were repeated on different sets of plants in early spring 1984 and 1985. Plant response was inferred from tiller heights, number of flowering culms, and new spring tiller production within the season of manipulation, and the number and heights of replacement tillers the following spring. Neighbor removal, and in 1 year fertilization, increased the size of tillers and stimulated the emergence of new spring tillers. Fertilization effects did not persist into the following year whereas neighbor removal increased annual tiller replacement at least two-fold on target plants. Tiller-tiller competition was not important in plants of crested wheatgrass because tiller growth and replacement on thinned plants did not differ from that of intact plants. This result occurred when thinned and intact plants were compared when both were growing with or without neighbors. Thinned plants replaced only the remaining tillers by the following spring. They did not regain their pretreatment status, presumably because of the encroachment of neighbors. These results indicate that thinned plants probably would lose their position in a plant community unless their neighbors are affected similarly.**

**Key Words: *Agropyron desertorum*, bunchgrass, tiller dynamics, competition**

The productivity of grasslands fluctuates in time and space as water and nutrient availability varies. Populations of long-lived clonal grasses in these grasslands may respond to fluctuations in water and nutrient availability by altering the number of plants, the number of tillers per plant, or the size of individual tillers. In many undisturbed grasslands, increases in plant numbers by seedling recruitment or reductions by the mortality of established bunchgrasses are uncommon (West et al. 1979, Gurevitch 1986, Salihi and Norton 1987). When plant population dynamics are unimportant in grasslands, the response to water and nutrient availability occurs in the plasticity of tiller numbers per plant, and tiller size.

Harper (1977) cites several studies in which tiller (or shoot) and plant population processes maintain a dynamic equilibrium with resource availability, but most of these studies were conducted with rhizomatous grasses in glasshouses or growth chambers. Several field studies have shown that the removal of neighboring bunchgrasses increases tiller number, tiller size, or basal area of the remaining grasses (Mueggler 1972, Robberecht et al. 1983, Fowler 1986, Gurevitch 1986, Nobel and Franco 1986). Competition among grasses is usually used to explain these responses. Within grasses, tiller-tiller interactions may also be competitive (Kirby and Faris 1972, Colvill and Marshall 1984) or mutually beneficial (Gifford and Marshall 1973, Welker et al. 1985). A positive response of grasses to neighbor removal could be explained by a relaxation of tiller-tiller competition. Competition among tillers has seldom been determined with grasses in the field.

In grasslands, resource variability may result from localized disturbances or areas of defecation by large herbivores, or changes in the competitive status of grasses following grazing. Because of the hierarchical organization of bunchgrasses, grass response to resource variability will first be expressed in population processes of tillers.

For this study, we used the tussock-forming Nordan crested wheatgrass (*Agropyron desertorum* Fisch. ex Link) Schult.). Crested wheatgrass has been established on more than 5 million hectares in western North America because it tolerates drought and herbivory better than most of the native grasses (Rogler and Lorenz 1983). Tiller growth, flowering, and replacement were assessed in the field following: (i) fertilizing small areas, (ii) thinning individual plants, and (iii) removing neighbor plants. These treatments simulated areas of resource enhancement, a reduction in the competitive status of plants, and a reduction in plant densities, respectively.

Plant response to such treatments may be expressed immediately or in following years. Therefore, growth, tillering, and flowering within the spring growing season and tiller replacement by the following spring growing season were monitored. Although the focus of this study was on tiller population processes, plant response can be inferred directly, and population and community dynamics indirectly, from such observations.

## Materials and Methods

The study area, Tintic Valley in west-central Utah (39° 51'N, 112° 08'W, 1,750 meters above sea level), typifies Great Basin foothill rangelands. Soils are Typic Haploxerolls; textures range from coarse to fine sandy loams. Utah juniper (*Juniperus osteosperma* (Torr) Little) and basin big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.) were mechanically removed at the site in 1951. That autumn, crested wheatgrass was seeded to increase livestock forage and remains the dominant species. Long-term (25-year) average annual precipitation 9 km from the site is 370 mm. During this study, weather information was obtained from an automated station located 1 km from the site. Total annual precipitation was slightly above the long-term average in 1984 (122%) and 1985 (108%).

Tillers of crested wheatgrass live a maximum of 14 months at our site. Without perturbation, almost all tillers are produced in

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autumn, overwinter, resume growth in spring, flower in late June, and senesce shortly thereafter. With the onset of autumn rains, replacement tillers are produced from axillary buds on the senescent tillers (Mueller and Richards 1986).

The study was repeated during 2 years on different sets of plants. Treatments were imposed on 20–21 April 1984 and 23–24 April 1985, 2 to 3 weeks after snowmelt. The treatments were: plant thinning, neighbor plant removal, combined plant thinning and neighbor plant removal (1985–1986 cycle only), nitrogen fertilization, and controls. Plants were thinned by selectively removing 50% of the tillers on a plant with a razor blade. Care was taken not to damage adjacent tillers. Neighboring plants within a 1.5 m radius in 1984, 1 m radius in 1985, of target individuals were removed with a glyphosate herbicide. We used a nonpersistent herbicide rather than mechanical removal to minimize soil disturbance. Nitrogen fertilizer was applied as ammonium nitrate in solution at 56.1 kg ha$^{-1}$ of nitrogen. At the same time all other treatments received an equivalent watering treatment.

We used a randomized complete block design with 3 replicates. Within each block, a 5-m by 5-m plot was randomly assigned to each of 4 treatments in 1984, and to 5 treatments in 1985. A 1-meter buffer separated each plot. In each plot, 5 randomly selected plants were monitored. In the thinning and neighbor removal treatments, only monitored plants were treated whereas all plants within fertilized plots received treatment. We analyzed the mean response of the 5 monitored plants.

To determine plant response, 20 and 10 tillers per plant were marked with wire rings on 9 May 1984 and 11 May 1985, respectively. Half of the marked tillers were equally spaced on the perimeter and the remaining tillers were similarly spaced within the core of the plant. Overall, each treatment consisted of 300 tillers in 1984, 150 in 1985, evenly distributed on 15 plants (5 plants per treatment per block, 3 blocks).

In both years, tillers were measured immediately after all had been marked and subsequent observations were at 7-day intervals until summer senescence. Observations included tiller heights (most extended leaf), emergence of new spring tillers, and the phenological status of all marked and new spring tillers. All tillers are produced intravaginally in this species; therefore, new spring tillers and autumn tillers emerged within the wire rings of their living and senescent progenitors, respectively. Most autumn tillers survived winter. Those that survived were replacements for the marked tillers that had been subjected to treatment a year earlier. Annual tiller replacement was the average number of replacement tillers per progenitor. Observations on the replacement tillers included heights.

All data were analyzed as a randomized complete block analysis of variance and means were separated with Tukey's standardized range test. Each year was analyzed separately. Control plants were not included in the analysis of spring tiller production because they did not produce new spring tillers. Within a treatment, analysis of variance of new spring tiller heights included only plants which produced at least 1 new tiller.

## Results

In cold-desert regions such as the Great Basin, winter precipitation (snow) is the main source of soil water for the spring-early summer growing period. At our site, September through March precipitation was 30% greater in 1984 (293 mm) than in 1985 (227 mm). In April, as the fall-produced tillers were resuming growth and floral primordia were forming, precipitation was almost 60% greater in 1984 (42.4 mm) than in 1985 (26.7 mm). In 1984, April was relatively wet and May was dry whereas the converse occurred in 1985 (Fig. 1).

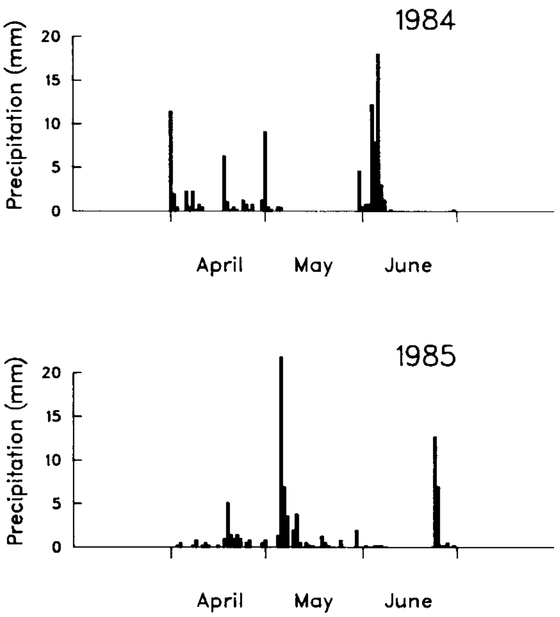

**Fig. 1.** *Spring precipitation during 1984 and 1985 at the Tintic study area.*

### Tiller Growth, Flowering and Production

Fertilization increased the percentage of flowering culms (61%) over all treatments (average 34%) in 1984 (Fig. 2a; $P<0.05$). In contrast, there were no significant differences among the low percentage (average 10%) of tillers flowering in 1985. Tillers on fertil-

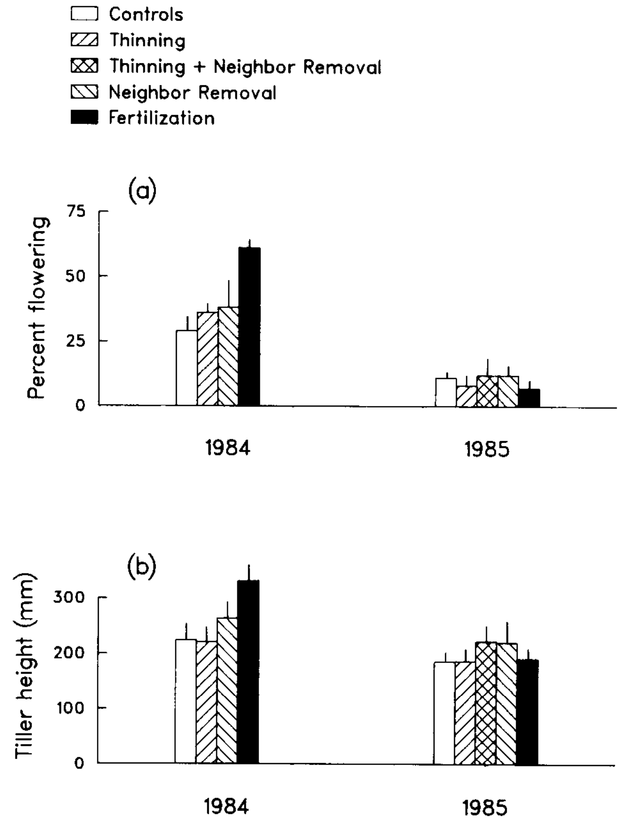

**Fig. 2.** *(a) Percentage of marked tillers of* A. desertorum *flowering during each growing season. (b) Heights of marked tillers at cessation of growth. Vertical bars represent standard error of the mean (n = 3).*

ized plants were 25 to 50% taller than all other tillers by late June in 1984 (Fig. 2b; $P<0.05$). In 1985, the tillers on plants without neighbors were about 16% taller than those on plants with neighbors, including the fertilized plants ($P<0.01$). Average tiller heights in 1985 were lower than in 1984.

All treatments both years stimulated at least some spring tiller production, whereas control plants only produced new tillers in the autumn. There was no significant difference in spring tillering between the fertilized and thinned-neighbor removal plants, and the other treatments in 1985 because of high plant-to-plant variability for tillering (Fig. 3a). Within a treatment, tillering did not occur on all plants (range 4–10 of 15 plants in 1984, 1–12 of 15 in 1985). Unlike flowering, which was greater in 1984 than in 1985, spring tillering was higher in 1985 than in 1984. New spring tillers on fertilized plants were taller than those on thinned plants in 1984 (Fig. 3b; $P<0.05$); high variability among plants resulted in no significant differences in 1985.

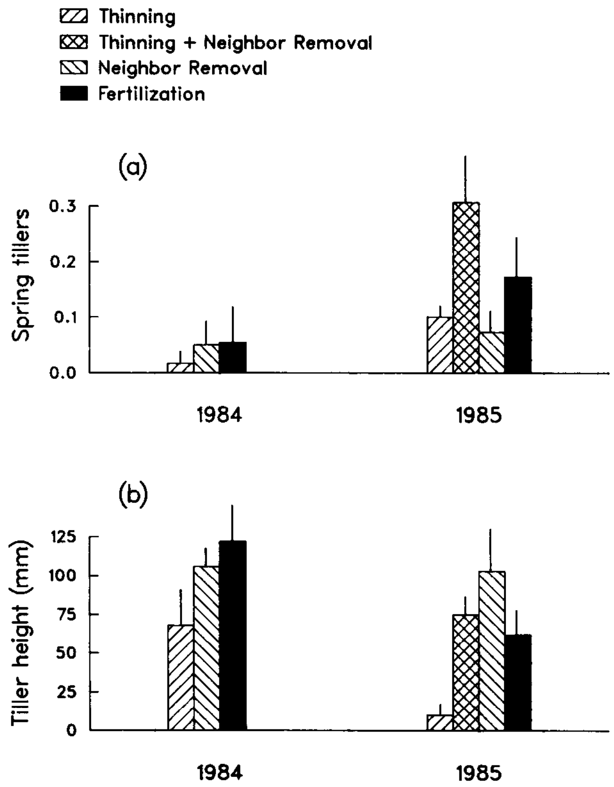

**Fig. 3.** *(a) Average spring tiller production per marked tiller of* A. desertorum. *(b) Heights of spring-produced tillers at cessation of growth. Vertical bars represent standard error of the mean* (n = *3).*

## Tiller Replacement by the Following Spring

Although fertilization and neighbor removal increased tiller growth, flowering, and tillering shortly after the treatments were imposed, effects of fertilization were not evident the following spring (Fig. 4a). However, tiller replacement in both years was much higher on plants whose neighbors had been removed than on those with neighbors, including the fertilized plants (Fig. 4a; $P<0.05$). Similarly, replacement tiller height on plants without neighbors was greater than on plants with neighbors both years (Fig. 4b; $P<0.01$).

## Discussion

Since establishment and mortality of crested wheatgrass plants were infrequent at the study site (Salihi and Norton 1987, M.K. Owens unpublished data), plant response to resource variability was expressed mainly in changes in tiller growth, flowering and replacement. The effects of these processes differed between years and treatments, presumably because each manipulation affected the magnitude of resource availability and the biology of the plants in a different manner.

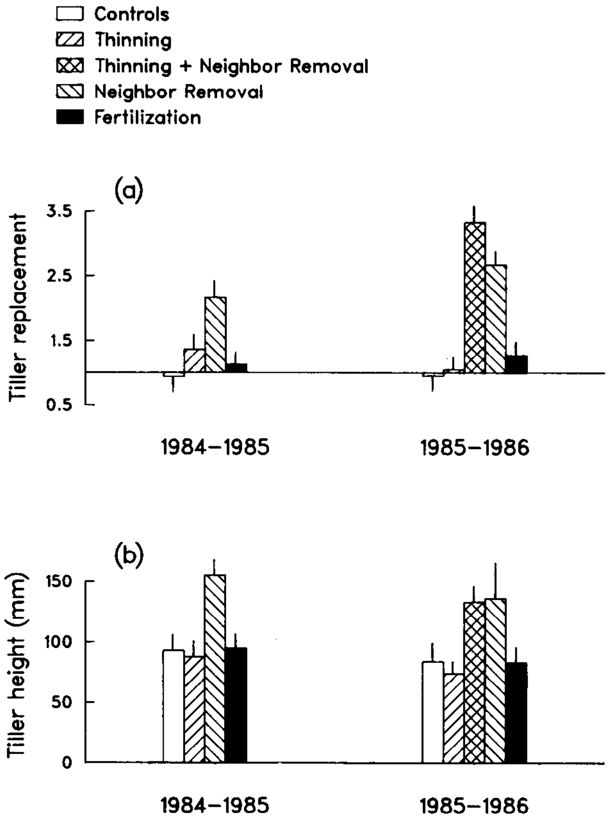

**Fig. 4.** *(a) Annual tiller replacement on plants of* A. desertorum *1 year following treatments. (b) Mean height of replacement tillers. The first year indicates the spring when treatments were applied; the second year indicates when replacement was observed. Vertical bars represent standard error of the mean* (n = *3).*

Roots of crested wheatgrass grow rapidly in the moist upper layers of the soil profile in April and May (Caldwell et al. 1981, Eissenstat 1986). These fine roots effectively increase nitrogen and phosphorus uptake (Caldwell et al. 1981, 1985, 1987), which may enhance floral development and increase tiller growth. Following the wet April of 1984, fertilization did increase flowering and tiller heights (Fig. 2a, b); e.g., tillers on these plants were up to 80% taller than those on control plants. Others have also found increased tiller size with fertilization of wildland plants (McGraw 1985, Shaver et al. 1986). In contrast, fertilization had no effect on tiller size or flowering following the drier April of 1985, but did increase the production of new spring tillers. Tillering often increases with fertilization (Noble et al. 1979, Fetcher and Shaver 1983, McGraw 1985), usually with a concomitant increase in the mortality of mature tillers. In this study, however, the increase in tillering with fertilization did not increase tiller mortality (unpublished data).

The year to year differences in developmental response to fertilization probably were not influenced by total annual precipitation as both years were slightly above normal, but were affected by the different amounts and timing of spring precipitation (Fig. 1). Small differences in soil moisture during early tiller growth and floral development affect crested wheatgrass response to fertilization (McGinnies 1968). With ample soil moisture in April, increased tiller growth and flowering may have been the quickest way for crested wheatgrass to respond to a pulse of nutrients. Such rapid growth did not occur during the dry April of 1985, however. Although nitrogen would have still been available in May, the induction period for floral primordia had passed, thus the nitrogen was apparently allocated to the production of new spring tillers.

Although fertilization increased flowering and tiller size in 1984 and the number of spring tillers in 1985, the effects of fertilization were not evident in 1985 and 1986, respectively. The lack of any carryover effects may reflect the rapid use of the nitrogen, the relatively low rate of application, the continued presence of neighbor plants, immobilization by soil microorganisms (Ingham et al. 1986), or other losses of nitrogen.

McGinnies (1968) found that annual applications of nitrogen fertilizer to crested wheatgrass produced higher yields than biennial applications indicating rapid use, or immobilization, in the year of application. He also detected no carryover effect on yield response to nitrogen applications of less than 67 kg $ha^{-1}$, which is higher than the rate that was used in this study. Furthermore, neighbor plants were also fertilized; thus they provided a constant background of competitors for the same resources in time and space.

If our added nitrogen had been immobilized by microorganisms, we would have expected increased production 2 to 3 years after fertilization when the nitrogen is mineralized as some have found in the Great Plains (Mason and Miltimore 1972, White 1985). Increased production was not evident in 1987, 2 to 3 years after the 1984 and 1985 nitrogen applications, however.

Unlike fertilization, neighbor removal eliminated any competitors around monitored plants. Because root systems of neighboring plants overlap substantially in cold desert regions, reduced competition increases resource availability rapidly for the remaining individuals (Caldwell et al. 1985, 1987). Similar rapid increases in resource availability may occur anytime abiotic or biotic factors, e.g., grazing (Olson and Richards 1988a), reduce plant size or cause the selective mortality of mature plants on rangelands.

Despite increased resource availability with neighbor removal, flowering and tiller heights increased relatively little following removal (Fig. 2a, b). But neighbor removal, especially when combined with thinning, increased the production of new spring tillers (Fig. 3a). Because flower development and growth of existing tillers were presumably determined soon after neighbors were removed in late April, the production of new spring tillers was probably the only remaining developmental response to enhanced resource availability.

Unlike fertilization, neighbor removal significantly increased tiller replacement by the following spring (Fig. 4a). Annual tiller replacement on plants without neighbors was high enough that the plots could approach pretreatment tiller densities within 2 years (about 500 tillers $m^{-2}$). For example, the neighbor removal treatment in 1985 (radius = 1 m) created a 3.14-$m^2$ bare zone (aboveground) around target individuals. If target individuals and plants on the perimeter of these bare zones can colonize them equally, then an average-sized plant (100 tillers per plant, unpublished data) in the center could potentially colonize 0.78 $m^2$ of the area. The remaining area would be colonized by plants on the perimeter of the bare zone. A central plant with 390 tillers (500 tillers $m^{-2} \times 0.78$ $m^2$) would represent full occupation of this area. The 2.6 annual tiller replacement in 1985 would increase tiller numbers from 100 to 260 per plant only 1 year after the removal of neighbors. If this increase in the number of replacement tillers is combined with the 60% increase in their size relative to controls (Fig. 4b), the forage yield of plants in the center of the 1-m radius (1985) bare zones would exceed that of equal areas nearby. Although the thinned-neighbor removal plants had an even higher replacement than neighbor removal only plants, they began with 50% fewer tillers thus it would take them longer to reach pretreatment tiller densities.

Tiller processes may reflect either sharing of or competition for resources among tillers within plants (Kirby and Faris 1972, Gifford and Marshall 1973). Plant thinning, by reducing competition or the demands for resource sharing among tillers, should have stimulated growth rates or tillering of the remaining tillers if tiller-tiller competition was important but it did not. Thinning only reduced the competitive status of plants. Thinned plants maintained themselves with tiller replacement close to or slightly above 1 both years (Fig. 4a), but replacement should have been 2 for these plants to regain pretreatment tiller numbers. Reducing tiller numbers by thinning probably had a concomitant effect on belowground function. Reducing tiller size of crested wheatgrass by severe clipping has been shown to curtail root growth up to 50% and phosphate acquisition by 60% within 2 weeks (Richards 1984, Caldwell et al. 1987). In this study, intact neighbors may have quickly occupied soil volume lost by the thinned plants; roots of crested wheatgrass rapidly invade zones of enriched or disturbed soil (Eissenstat 1986, Eissenstat and Caldwell 1988). Such rapid encroachment or resource depletion by neighbors probably prevented thinned plants from regaining their pretreatment status.

To further define the relative importance of tiller-tiller versus plant-plant competition, thinned plants were compared with intact plants in the absence of neighbors. Tiller heights and flowering were similar between thinned and intact plants when both were without neighbors. Thinned plants, however, had somewhat higher spring tillering (Fig. 3a) and tiller replacement (Fig. 4a) than intact plants. These differences likely reflect thinning-induced microclimatic differences within plants that can influence tiller production (Deregibus et al. 1985). Apparently, thinned plants with neighbors could not regain their prethinning size because of plant-plant competition, and not because of constraints on tillering within plants.

The remarkably consistent replacement of tillers on control plants indicated that each of these bunches was maintaining a constant tiller density, and thus competitive position in the stand. Changes in resource availability or competitive status alter this equilibrium, but it can be quickly restored by the high tiller replacement capabilities of crested wheatgrass. Tiller replacement may be constrained, however, by neighboring plants, e.g., thinned bunches with intact neighbors were unable to regain their pretreatment status and their position in the stand. The thinning of bunchgrasses has been observed on many rangelands (Pechanec et al. 1937, Sharp 1970, Olson and Richards 1988b). Our study indicates that the recovery of thinned grasses will depend on the grazed status of their neighbors along with climatic trends. In this cold-desert region where plant population dynamics are relatively unimportant, stands of crested wheatgrass apparently persist by rapidly adjusting tiller population processes to changes in resources and neighbors.

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# Pinyon-juniper chaining and seeding for big game in central Utah

J.G. SKOUSEN, J.N. DAVIS, AND J.D. BROTHERSON

## Abstract

**Vegetation and soils were evaluated on 5 different-aged, mechanically treated and seeded pinyon-juniper sites and compared to adjacent untreated areas. Plant cover was significantly changed after treatment: trees were reduced from 26 to 6% total ground cover; shrubs were increased from 2 to 8% ground cover; and herbaceous plants increased from 2 to 13% ground cover. Annuals and perennial forbs were 75% of the total plant cover on the 2-year-old site, perennial grasses and shrubs dominated the plant cover (52 to 83%) on three, 14- to 20-year-old sites, while shrubs and trees combined for 84% of the plant cover on the 24-year-old site. Two *Agropyron* grass species showed good establishment and persistence after seeding. Seeded forbs contributed about 5% of the total plant cover on the 2-year-old treated site and they declined on older treated sites. Seeding of shrubs was only successful on sites where the shrub species was already present in the understory naturally. Seeding of nonnative shrub seed did not produce stands. Even though tree cover was reduced after treatment, total tree density was not. Shrub density increased from an average of 800 plants/ha on untreated areas to 2,750 plants/ha on treated areas. Juniper mortality during mechanical treatment varied from 60 to 91% and was related to the percentage of trees estimated to be 60+ years old ($r = 0.97$) and with the number of trees greater than 5 cm in stem diameter ($r = 0.71$) on the adjacent untreated sites. Big game pellet group counts were not different between untreated and treated sites, suggesting that big game make use of these treated areas because of increased forage and browse and in spite of reduced security cover.**

**Key Words: revegetation, tree mortality, woodland structure, pioneer species, competition**

The pinyon-juniper (*Pinus* spp.—*Juniperus* spp.) woodland type covers from 17 to 32.5 million ha in the southwestern United States (Kuchler 1964, West et al. 1975). More than 25% of Utah's land area is dominated by pinyon-juniper, which often suppresses growth of understory shrubs, grasses, and forbs. Big game populations in Utah use the pinyon-juniper type extensively for winter range (Plummer et al. 1968). During the severe winter of 1948–1949, poor winter range contributed to losses of up to 42% in some deer herds, while other deer herds with good winter range had losses comparable to those occurring during a moderate winter. Because of such losses the Utah Division of Wildlife Resources in cooperation with the USDA Forest Service's Intermountain Research Station initiated a program to improve depleted big game winter range. Such improvements involved mechanical tree removal and artificially seeding adapted grass, forb, and shrub species to increase forage production (Plummer 1958, Plummer et al. 1960, 1968, 1970).

Average tree kill with cabling or chaining ranges from 40 to 80% (Arnold et al. 1964, Aro 1971, 1975, Parker 1971). In the Great Basin, Phillips (1977) noted that chaining reduces tree overstory by nearly 100% and that the majority of trees observed on chained areas are those that survived the chaining. There is little evidence on most sites of rapid invasion by young trees establishing from seed (Stevens 1987). Reduction of tree cover by mechanical methods reduces competition for light, soil nutrients, and moisture (O'Rourke and Ogden 1969) and stimulates understory browse and grass growth (Arnold et al. 1964, Phillips 1977, Plummer et al. 1968). An early study in Utah (Plummer et al. 1970) estimated that total understory production before treatment of several pinyon-juniper sites was 22 kg/ha. Ten years after 2-way chaining and seeding with 4 grasses and 3 legumes, total production increased to 1,912 kg/ha on grazed areas and 1,717 kg/ha on ungrazed areas.

Despite increases in forage production, some problems associated with pinyon-juniper treatment for big game include: (1) a 5-to 10-year rejuvenation period before some of the slower growing browse species become available; and (2) loss of security cover for big game animals if large open tracts of land (greater than 250 m wide) are treated. In an attempt to alleviate such problems researchers recommend clearing small, localized areas, or long, narrow, contoured strips from 30 to 200 m in width and seeding desirable species in the openings (Minnich 1969, Phillips 1977, Short et al. 1977, Short and McCulloch 1977).

The objectives of this study were to evaluate: (1) plant species composition and cover changes between treated and adjacent untreated sites; (2) seeded species establishment and growth on treated areas; (3) mechanical treatment effects on woody plant densities; and (4) the consequences of these changes in relation to big game use. Because differences existed between sites, the study examined similarities and general trends of vegetation change in response to mechanical treatment and seeding, and the influence that management may have had on treated sites.

## Study Sites

The areas selected for study are along the western benches of the Pahvant Mountains in Millard County and on the Wasatch Plateau in Sanpete County in central Utah. The Utah Division of Wildlife Resources owns 4 of the study sites. These were treated specifically to increase forage and browse production for big game. A 5th site (Nine Mile) is privately owned and was treated to improve forage production primarily for sheep.

Elevation, aspect, slope, and precipitation were similar on these sites (Table 1). Soils had a thin, light-colored surface horizon, underlain by a subsurface horizon of weathered parent material derived from limestone, sandstone, and shale. The soils were moderately calcareous with pH ranging from 6.5 to 7.5. Soil textures were sandy loams, loams, and clay loams.

Vegetation cover before treatment consisted of pinyon pine (*Pinus edulis* Engelm.), Utah juniper (*Juniperus osteosperma* (Torr.) Little), Gambel oak (*Quercus gambelii* Nutt.), and infrequent and scattered grasses, forbs, and shrubs in the understory

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(Plummer et al. 1970). Native shrubs that occurred in woodland openings were big sagebrush (*Artemisia tridentata* Nutt.), black sagebrush (*Artemisia nova* A. Nels), true mountain mahogany (*Cercocarpus montanus* Raf.), bitterbrush (*Purshia tridentata* (Pursh) DC.), cliffrose (*Cowania mexicana* D. Don), and broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby). Browse species had been overgrazed by livestock and big game and were in a state of low vigor at the time of treatment (Plummer et al. 1970). Cheatgrass (*Bromus tectorum* L.) was typically the most prominent understory species.

Mayfield, Nine Mile, Corn Creek, and Hilltop were chained 1-way, aerially seeded, then chained in the opposite direction in the late fall of 1960, 1967, 1967, and 1979, respectively, with 41 kg chain links (Table 1). The Pioneer site was first seeded, then cabled 1-way in October 1957. Cabling was used on this site because large numbers of big sagebrush and cliffrose were present in the understory and this method does less damage to these desirable understory species than chaining (Plummer et al. 1968). Seeded species and seedling rates are shown in Table 2 along with their relative cover on each treated site in 1981.

Management policy of the Utah Division of Wildlife Resources is to graze rehabilitated big game winter ranges with cattle during the spring to reduce grass and forb cover, thereby enhancing browse production for wintering big game. Grazing animal and stocking rate varied among the sites studied (Table 1).

## Sampling Methods

Study sites were sampled during July and August of 1981 along 4 randomly located transects of 300 m each that were placed perpendicular to the edge of treated areas. One half, or 150 m, extended into the native, untreated woodland and 150 m into the treated area. Quadrats (1 $m^2$) were placed at 5-m intervals (240 quadrats per site) along the transect to estimate total ground cover by plants and individual plant species cover. A modified Daubenmire (1959) technique with 7 cover classes was used to estimate vegetation cover. Relative cover of different plant life forms and seeded species was calculated as a percent of total ground cover by plants for each untreated and treated area on each site.

Density of trees and shrubs was evaluated by using 50-$m^2$ circular plots. The enlarged plot was centered on every 3rd quadrat along the transect (80 plots per site). Every shrub and tree within the plot was identified and its stem diameter measured at 10 cm above ground. The largest stem of each shrub was measured if it had multiple stems.

Stem diameters were related to tree age by regression analysis after cutting and counting the growth rings of 20 different-sized juniper trees on each untreated and treated site. These trees were cut near the transects on each site. One growth ring was taken to equal 1 year's growth. Juniper mortality was calculated by estimating the age of the trees (by their measured stem diameter). We assumed the juniper density and age structure was the same between untreated areas and treated areas (before the treatment was applied). Those trees on the treated area that were estimated to be older than the length of time since treatment were considered to have survived the mechanical treatment. Those trees that were estimated to be younger than the length of time since treatment were those that were assumed to reinvade the site by seed. Juniper mortality was determined by calculating the density of trees in the untreated area that were present when the mechanical treatment was done and comparing it to the density of trees older than the length of time since treatment on the treated area.

Relative big game use of these areas was estimated by counting pellet groups within the enlarged plot. A pellet group was counted when a minimum of 15 pellets were found together and when the group was determined to be from the current year (Ferguson 1955). Some investigations have reported problems with pellet group counts as an index to mule deer habitat preferences (Collins and Urness 1981, Neff 1968). Nevertheless, due to time and survey money constraints of this study, pellet group data were used to estimate and compare relative big game use on untreated vs treated areas.

Soil samples were taken after vegetation sampling was completed to a depth of 25 cm at every 10th quadrat (16 samples per site) to determine if vegetational differences were related to soil factors. Soil samples were analyzed for 10 nutrients. Phosphorus, K, Ca, Mg, and Na were extracted by ammonium acetate, while Zn, Fe, Mn, and Cu were determined with DTPA-TEA (Black 1965). Percent N (Kjeldahl method), soil texture (hydrometer method), and pH (pH electrode on 1:1 soil:water paste) were also determined.

Vegetation and soil data were analyzed by analysis of variance to determine significant differences for these parameters on untreated and treated areas across all sites. Duncan's multiple mean comparison test was used to determine significant differences across sites on the untreated and treated sites (Steel and Torrie 1980).

## Results and Discussion

### Species Composition and Relative Cover

With few exceptions, plant life form composition (annual grasses and forbs, perennial grasses, perennial forbs, shrubs, and trees) on untreated areas was relatively similar for all sites (Table 3). Trees contributed most of the cover while annuals, grasses, forbs, and shrubs were present in small amounts. Total ground cover by plants on untreated areas averaged 31% with about 90% of that ground cover accounted for by tree canopies.

Relative cover of the different plant life forms changed significantly on treated sites when compared to adjacent untreated areas (Table 3). Added together, relative cover of annuals and perennial forbs was 75% on the 2-year-old treated site but decreased to less than 15% on older treated sites. This concurs with Tausch and Tueller (1977) and others (Barney and Frischknecht 1974, Tausch 1973) who reported annuals and perennial forbs dominate treated sites for 1 to 2 years following treatment with gradual replacement by grasses, shrubs, and trees. The annual and perennial forbs (e.g., *Descuriana sophia* (L.) Webb, *Bromus tectorum, Verbascum thapsus* L., *Verbena hastata* L., *Viguiera ciliata* (Robins. and Greenm.) Blake) observed on our 2-year-old treated site were weedy species that invade quickly after soil disturbance.

Perennial grasses and shrubs dominated the 14- to 20-year-old treated sites (Nine Mile, Corn Creek, and Mayfield). Shrub cover was significantly greater on treated compared to untreated areas and tended to increase as the length of time since treatment increased. The Pioneer site (24-year-old, cable-treated site) supported the greatest shrub and tree cover and lowest perennial grass cover compared to any other site. The cable did not disturb the shrub and tree components as much as double-chaining. Therefore, shrub expansion and tree development may have hindered grass establishment on this site. Our records show limited livestock grazing on Pioneer during the 20 years after treatment, but it is possible that grazing pressure reduced grass cover from 1978 through 1981. Cattle were present on the site when vegetation sampling was conducted. The relative amount of cover contributed by trees on these sites was reduced from 87 to 22% after treatment. Actual ground cover by trees on treated sites ranged from 0.5% on the 2-year-old chained site to 18% on the 24-year-old cabled area.

### Establishment of Seeded Species

Relative cover of seeded species varied across the sites from 15% on the 2-year-old site to 72% on the 21-year-old site (Table 2). Crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) was found

**Table 1. Summary of characteristics of 5 study sites in central Utah.**

| Characteristic | Pioneer | Mayfield | Corn Creek | Nine Mile | Hilltop |
|---|---|---|---|---|---|
| Elevation (m) | 1770 | 2010 | 1680 | 1950 | 1920 |
| Aspect | SW | SW | W | SW | SW |
| Ave slope (%) | 6 | 12 | 9 | 8 | 10 |
| Ave precip (cm) | 37 | 32 | 35 | 32 | 33 |
| Range site class | Upland stoney loam | Upland stoney loam | Upland stoney loam | Upland shallow loam | Upland shallow loam |
| Year treated | 1957 | 1960 | 1967 | 1967 | 1979 |
| Treatment method | Cabled and seeded | Double-chain and seeded | Double-chain and seeded | Double-chain and seeded | Double-chain and seeded |
| Size of treated area (ha) | 810 | 345 | 292 | 492 | 30 |
| Grazing animal | Cattle | Cattle | Cattle | Sheep | None |
| Stocking rate (ha/animal unit) | 1978–81=1.5 | 1965–79=5.6<br>1980–81=0 | 1972–78=5.0<br>1979–81=0 | 1967–81=2.5 | 1979–81=0 |
| Length of grazing (days) | 30 | 55 | 45 | 60 | None |

**Table 2. Seeding rate (kg/ha) of the major species seeded at the time of treatment and the relative amount of cover (% of total ground cover by plants) for these seeded species in 1981 on treated pinyon-juniper ranges in central Utah.**

| | Study site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pioneer | | Mayfield | | Corn Creek | | Nine Mile | | Hilltop | |
| Seeded species | Rate (kg/ha) | Rel Cov (%) | Rate (kg/ha) | Rel Cov (%) | Rate (kg/ha) | Rel Cov (%) | Rate (kg/ha) | Rel Cov (%) | Rate (kg/ha) | Rel Cov (%) |
| *Agropyron cristatum* | 1.6 | 3.1a[1] | 2.4 | 21.8ab | 4.7 | 28.3b | 6.2 | 17.8ab | 1.8 | 4.4a |
| *Agropyron intermediu* | .5 | .2[2] | .6 | 1.0 | 1.9 | 5.1 | 3.1 | 5.9 | .9 | 6.0 |
| *Bromus inermis* | | | 2.3 | 10.6b | 1.2 | | 2.1 | .3a | | |
| *Elymus junceus* | | | 1.2 | 5.1 | 1.1 | | 2.0 | 3.1 | .9 | |
| *Medicago sativa* | .1 | | 1.8 | | .8 | .1 | 1.0 | .2 | 2.7 | .9 |
| *Melilotus officinale* | | | 1.2 | | .4 | | .6 | .1 | .9 | 1.4 |
| *Sanguisorba minor* | | | .6 | | .4 | | .5 | | .9 | 2.5 |
| *Artemisia tridentata* | .1 | 31.8a | .6 | 1.2b | .4 | 17.1ab | .5 | 1.5b | .9 | |
| *Artemisia nova* | | | | 16.1b | .1 | | .1 | 4.1a | | |
| *Atriplex canescens* | .2 | | .1 | .1 | 1.1 | | .7 | .2 | .9 | |
| *Chrysothamnus nauseosus* | .1 | | | | .4 | | .6 | .2 | .5 | |
| *Cowania stansburiana* | .1 | 15.7 | .1 | | .1 | 15.0 | .1 | | .2 | |
| *Purshia tridentata* | .3 | | .1 | | .1 | .1 | .1 | .1 | .2 | |
| Totals[3] | | | | | | | | | | |
| Seeded grasses | 2.6 | 3.9b | 7.0 | 50.2a | 9.7 | 33.9ab | 14.3 | 27.1ab | 3.6 | 10.5ab |
| Seeded forbs | .1 | | 3.6 | | 2.0 | .1 | 1.5 | .3 | 5.0 | 4.8 |
| Seeded shrubs | .8 | 47.6a | .8 | 22.1ab | 2.3 | 32.2ab | 1.9 | 6.0b | 2.9 | |
| Total of seeded species[3] | 3.5 | 51.5a | 11.4 | 72.3a | 14.0 | 66.2a | 17.7 | 33.4ab | 11.4 | 15.3b |

[1] Cover values for each species across sites with the same letter are not significantly different at $p<0.05$.

[2] Where no letter appears, the cover values for that species are not significantly different.

[3] Totals include other seeded species which were seeded (<0.1 kg/ha).

**Table 3. Total plant cover (% ground cover by all plants) and relative cover (% of total plant cover) by different plant life forms on untreated (Unt) and treated (Trt) big game ranges in central Utah.**

| | Study site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pioneer | | Mayfield | | Corn Creek | | Nine Mile | | Hilltop | |
| Characteristic | Unt | Trt | Unt | Trt | Unt | Trt | Unt | Trt | Unt | Trt |
| Total plant cover | 46a[1] | 44a | 36a | 29a | 21ab | 30a | 24a | 17ab | 28a | 15b |
| Annuals | 2c | 6b | 0c | 1b | 5c | 10b | 2c | 8b | 2c | 34a |
| Perennial grasses | 1c | 8b | 4c | 54a | 5c | 36ab | 4c | 33ab | 1c | 19ab |
| Perennial forbs | 0c | 2b | 2c | 4b | 2c | 3b | 0c | 2b | 1c | 35a |
| Shrubs | 9b | 43a | 11b | 29a | 14b | 38a | 1b | 19a | 1b | 9a |
| Trees | 88a | 41b | 81a | 12b | 74a | 13b | 93a | 38b | 95a | 3b |

[1] Values for each characteristic across sites with the same letter are not significantly different at $p<0.05$.

**Table 4. Soil characteristics on untreated (Unt) and treated (Trt) pinyon-juniper ranges in central Utah. All nutrient concentrations except N are reported in mg/kg.**

| | Study site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pioneer | | Mayfield | | Corn Creek | | Nine Mile | | Hilltop | |
| Characteristic | Unt | Trt | Unt | Trt | Unte | Trt | Unt | Trt | Unt | Trt |
| % Sand | 39a[1] | 37b | 37a | 33b | 46a | 45b | 46a | 41b | 46a | 44b |
| % Clay | 26[2] | 26 | 31 | 33 | 23 | 26 | 24 | 27 | 28 | 29 |
| pH | 6.5b | 6.2b | 7.2a | 7.2a | 7.2a | 7.2a | 7.3a | 7.2a | 7.2a | 7.2a |
| P | 36a | 37a | 11b | 10b | 10b | 10b | 8b | 18b | 17b | 8b |
| K | 301 | 272 | 194 | 309 | 224 | 240 | 263 | 218 | 208 | 251 |
| Ca | 6756b | 4230b | 10408a | 10866a | 10356a | 10025a | 10908a | 11275a | 12083a | 13333a |
| Mg | 381 | 368 | 367 | 433 | 281 | 281 | 525 | 575 | 308 | 366 |
| Na | 44b | 46b | 60a | 60a | 59a | 57a | 65a | 64a | 65a | 67a |
| Zn | 1.6 | 1.6 | 1.2 | 1.1 | 1.3 | 1.5 | 1.0 | .8 | .9 | 1.1 |
| Fe | 76 | 80 | 41 | 92 | 61 | 82 | 70 | 88 | 13 | 15 |
| Mn | 62 | 81 | 32 | 84 | 60 | 77 | 65 | 61 | 14 | 11 |
| Cu | 1.1b | 1.2b | 1.4a | 1.0b | 1.0b | 1.0b | .7c | .9bc | .6c | .6c |
| % N | .2 | .1 | .2 | .5 | .3 | .2 | .2 | .2 | .2 | 2 |

[1] Mean values across sites with the same letter are not significantly different at $p<0.05$.
[2] Where no letters appear, the values for that nutrient across sites are not significantly different.

on all treated sites and was most prevalent on intermediate-aged sites. Intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) also established and persisted on these sites. Smooth brome (*Bromus inermis* Leyss.) and Russian wildrye (*Elymus junceus* Fisch.) established and persisted on the Mayfield and Nine Mile sites. Alfalfa (*Medicago sativa* L.), yellow sweetclover (*Melilotus officinale* (l.) Lamb.), and small burnet (*Sanguisorba minor* Scop.), all biennial or perennial forbs, were present in the greatest amounts on the 2-year-old treated site. These species have been known to persist and maintain themselves after seeding (Plummer et al. 1968), but they were found only in scarce amounts on the 14-year-old sites (Table 2).

Soil analysis revealed several significant differences between soils of untreated and treated areas, and between sites (Table 4). Sand content was significantly lower on treated compared to untreated areas. Soils at Pioneer were lower in pH and Ca, and higher in P than the other sites. A soil pH of 6.5 on this site may have released greater amounts of P and K for plant uptake. These 2 nutrients have been shown to be limiting to juniper growth (Bunderson et al. 1985). Differences in texture and other nutrients showed no specific trends and were not consistent with any particular vegetation characteristic (Leonard et al. 1987).

### Woody Plant Density

Juniper density after treatment was significantly lower on only 2 of the 5 sites (Table 5) (Rippel et al. 1983). Pinyon density was reduced by treatment on 2 out of 3 sites where it was found. Gambel oak, a prolific root sprouter, can spread after mechanical treatment. Gambel oak response to mechanical treatment varied across our sites.

Shrub density was significantly higher on 4 out of 5 sites with density increases from 2 to 10 times on treated sites when compared to untreated areas (Table 5). In this study, artificial seeding of shrubs was only successful on sites where the shrub species was already present in the understory naturally. Some shrub species are better adapted to the soils and climate of particular sites (Plummer et al. 1968). Seeding of nonnative shrub seed did not produce stands. Broom snakeweed density probably increased on the treated areas because it is a weedy invader shrub adapted to disturbed sites (Arnold et al. 1964).

### Pinyon-Juniper Stand Relations

Mature tree canopies attenuate from 50 to 90% of the light that reaches the outside of the crown, which in turn reduces the light available to the understory (Larcher 1980). Large trees also monopolize basic resources (such as soil moisture and nutrients)

**Table 5. Density (plants/ha) of woody plant species on untreated (Unt) and treated (Trt) pinyon-juniper ranges in central Utah.**

| | Study site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pioneer | | Mayfield | | Corn Creek | | Nine Mile | | Hilltop | |
| Characteristic | Unt | Trt | Unt | Trt | Unte | Trt | Unt | Trt | Unt | Trt |
| Trees | | | | | | | | | | |
| *Juniperus osteosperma* | 771a[1] | 405bc | 442bc | 276c | 852a | 973a | 678ab | 569ab | 586ab | 129c |
| *Pinus edulis* | | | 503a | 121b | | | 606a | 352a | 149b | 10c |
| *Quercus gambelii* | 2660a | 1079ab | 389b | 1039ab | 369b | 49b | 768ab | 280b | 139b | 9b |
| Total | 3431a | 1484b | 1358b | 1436b | 1221b | 1022b | 2052ab | 1201b | 874b | 148b |
| Shrubs | | | | | | | | | | |
| *Artemisia tridentata* | 1351ab | 2039a | 0c | 132c | 305bc | 1605ab | 253bc | 244bc | 10c | 99c |
| *Artemisia nova* | | | 99a | 1027b | | | 135b | 768a | | |
| *Cercocarpus montanus* | | | 575 | 332 | | | | | | |
| *Chrysothamnus nauseosus* | 0[2] | 14 | | | | | 9 | 54 | | |
| *Cowania stansburiana* | 108b | 533a | | | 149b | 334a | | | | |
| *Purshia tridentata* | | | 0 | 22 | 78 | 28 | 0 | 9 | | |
| *Gutierrezia sarothrae* | 389c | 1371b | 0c | 221c | 85c | 931b | 99c | 3380a | 268c | 477b |
| Total | 1848b | 3957a | 796c | 1911b | 617c | 2898a | 496c | 4455a | 298c | 586c |

[1] Values within species across sites with the same letter are not significantly different at $p<0.05$.
[2] Where no letters appear, the density values for that species across sites are not significantly different.

and allow only a small amount of these resources to be available to smaller plants in the understory. Mechanical treatment removes most of the large pinyon and juniper trees (Parker 1971) that tie up the basic limited resources at the site. As these larger trees are removed, the resources become available to understory grasses, forbs, and shrubs; but removal of large trees also makes resources available to small trees present in the understory that might not have been uprooted or killed by mechanical treatment. Many of these small trees, which have persisted for long periods in a stunted or depressed condition under the canopy, are released after chaining (Grime 1979). In addition, seeds buried in the soil may germinate in response to the increased quantity and quality of light and soil moisture following canopy removal.

The size and age-structure of pinyon-juniper stands at the time of treatment are important in terms of the success and longevity of mechanical treatments. For example, the Mayfield juniper stand before treatment was an old, even-aged stand with 77% of the trees being 60+ years old (Table 6). The juniper trees on this site were also large with 75% of the trees having stem diameters of greater than 5 cm. Based on this age analysis of the trees in the untreated area, Mayfield was an excellent site for mechanical treatment. According to our analysis, 91% of the trees on the site at the time of treatment were successfully eliminated by double-chaining. Furthermore, age analysis of the trees on the treated area indicates that only 12% of the juniper were older than the length of time since treatment (i.e., older than 20 years old), and juniper establishment from seed was also low (Fig. 1). Good establishment of seeded grasses and shrubs on the Mayfield site has slowed tree establishment and development (Stevens et al. 1975).

**Table 6. Percent of juniper eliminated by mechanical treatment on treated areas related to the percent of juniper 40+ and 60+ years old, and greater than 5 cm in stem diameter on adjacent untreated areas.**

| | Study site | | | | |
|---|---|---|---|---|---|
| Juniper trees | Pioneer | Mayfield | Corn Creek | Nine Mile | Hilltop |
| % eliminated | 64 | 91 | 68 | 60 | 78 |
| % 40+ years old | 63 | 90 | 53 | 71 | 65 |
| % 60+ years old | 44 | 77 | 40 | 38 | 55 |
| % >5 cm | 61 | 75 | 46 | 59 | 74 |

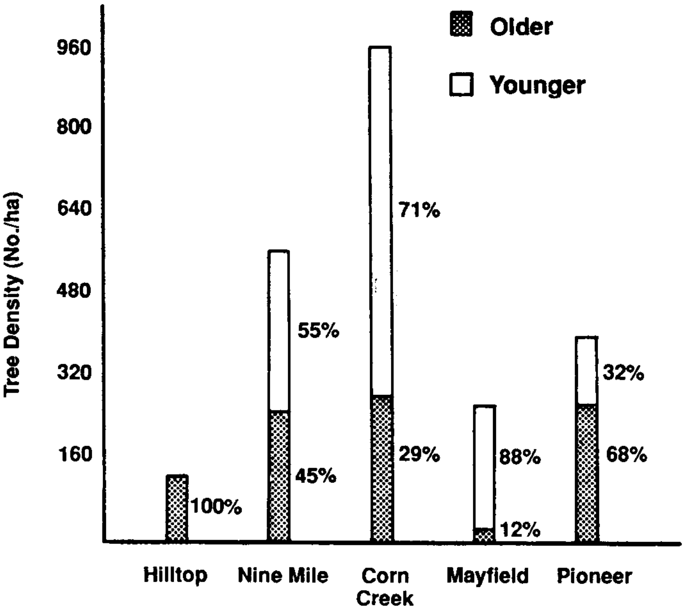

**Fig. 1.** *Density (No./ha) and percentage of juniper trees that are older (survived the treatment) or younger (emerged since treatment) than the length of time since treatment on pinyon-juniper big game ranges.*

In contrast, the untreated juniper stand at Pioneer revealed a more diverse age structure with approximately 37% of the trees between 0 and 40 years old and 44% greater than 60 years old (Table 6). The trees also were smaller with 39% having stem diameters of 5 cm or less. This site was cabled because numerous plants of cliffrose and big sagebrush were present in the understory, and cabling does less damage to understory plants. Cabling is generally less effective than chaining for eliminating juniper because young, flexible trees bend under the cable (Plummer et al. 1968). Because younger and smaller trees were present at the time of treatment, and because a cable was used, juniper mortality following treatment at the Pioneer site was only 64%. The low juniper mortality on this site is demonstrated by the fact that 68% of the trees in the treated area are older than the treatment date (i.e., older than 24 years) (Fig. 1). However, cabling spared and rejuvenated many of the existing desirable understory shrubs. Juniper mortality during treatment on these sites was related to the percentage of trees 41 years or older ($r = 0.68$) and 61 years or older ($r = 0.97$), and with the number of trees greater than 5 cm in stem diameter ($r = 0.71$) on adjacent untreated areas (Table 6).

A stand analysis should be done for all pinyon-juniper sites that are to be mechanically treated. Evaluating the size and age distribution of the stand would provide an estimate of the percentage of trees expected to be eliminated by the use of a particular weight and type of chain. Therefore, the resource manager may predict pinyon and juniper mortality resulting from a specific mechanical treatment and predict the number of trees that will probably survive the treatment. If the estimate of surviving trees is high, the site may not be suited for mechanical treatment, or some kind of follow-up treatment, such as prescribed burning (Bunting 1987) or herbicides (Johnson 1987), could be done within several years after mechanical treatment.

Regardless of woodland structure and age, treatment technique, or successful establishment of seeded species, some juniper reestablishment will occur. Even so, removing tree competition to allow establishment of seeded species is important to improve forage and browse on pinyon-juniper big game ranges. As tree mortality increases, the potential for establishment of forage and browse species increases, which in turn prolongs the effectiveness of a mechanical treatment. Treatment should always include seeding species that are specifically adapted to the site, meet management objectives, and provide competition to help suppress tree reestablishment (Plummer et al. 1968).

The Utah Division of Wildlife Resources habitat management program provides for livestock grazing on Division-owned lands if it serves as a strategy to benefit wildlife habitat. In most cases, this involves spring grazing by livestock to maintain a proper balance between grasses, forbs, and shrubs on mule-deer winter ranges. Heavy spring grazing by cattle on grasses and forbs on big game winter ranges can accelerate changes toward shrub-dominated communities (Arnold et al. 1964, Plummer et al. 1968). Grazing pressure by livestock or big game may explain why some treated pinyon-juniper areas are quickly dominated by shrubs and trees after mechanical treatment. Heavy grazing by sheep at Nine Mile has increased the density of snakeweed and has helped to accelerate this site toward a tree-dominated community.

### Use of Treated Pinyon-Juniper Ranges by Big Game

No significant differences were found for pellet group densities when treated and untreated big game ranges were compared. Our data show that as the unit of time following treatment increased, treated sites showed a trend of increasing numbers of pellet groups per hectare relative to their adjacent untreated areas (Fig. 2). Pellet group data on our sites showed no decline in pellet group density as

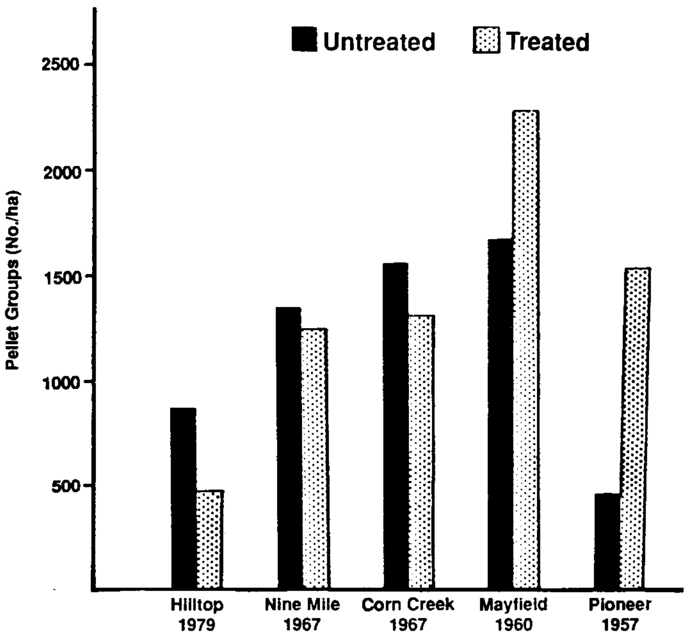

**Fig. 2.** *Pellet groups (No./ha) on untreated and treated pinyon-juniper big game ranges in central Utah.*

the distance into the treated area increased up to 150 m. Some researchers report that big game use of treated pinyon-juniper sites increased due to greater amounts of forage and browse on the treated area, and their pellet group data support this finding (Minnich 1969, McCulloch 1969, Plummer et al. 1966). Others indicate that treatment has reduced security cover to the extent that big game use declined (Lyon and Jensen 1980, Short et al. 1977, Terrel and Spillett 1975). Phillips (1977) states that young pinyon-juniper chaining projects contribute little to big game until shrubs and trees become established within the treated area (see also Short and McCulloch 1977). Other reports, such as this study, show both higher and lower pellet group densities on treated sites when compared to adjacent untreated areas (Howard et al. 1987, Payne 1981, Phillips 1977). Our experience and research on Utah big game range has shown that big game utilize treated areas as much or more than untreated areas; and, perhaps more importantly, big game use of these treated areas during critical times of the year (i.e., late fall, winter, and early spring) is extended. Because greater amounts of herbs, grasses, and browse are available on treated sites, big game use is enhanced and increases with time as browse and tree species develop in the site.

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# Atrazine and fertilizer effects on Sandhills subirrigated meadow

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## Abstract

**Many Nebraska Sandhills subirrigated meadows have shifted to predominantly cool-season grasses. Meadows are often cut in July when forage quality of cool-season is lower than that of warm-season species. The objective of this research was to evaluate a one-time application of atrazine [6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] in restoring dominance of warm-season grasses and to determine if nitrogen (N) with and without phosphorus (P) would enhance or prolong the atrazine effect on species composition, yield, crude protein, and in vitro dry matter digestibility (IVDMD). Atrazine was applied once at 0, 2.2, and 3.3 kg/ha in spring or fall 1983 and 1984 to a Gannett fine sandy loam (coarse loamy mixed mesic Typic Haplaquoll). The year after atrazine application one-half of each spring-treated plot was fertilized with N (50 kg/ha). One-half of the fertilized area received P (18 kg/ha). Both spring and fall applied atrazine decreased cool-season grass species composition and yield. Spring-applied atrazine reduced first-year yields, but yields recovered by the end of the second year. Conversion of plots to warm-season grasses increased crude protein in mid-July for 2 growing seasons. Percentage IVDMD was increased the year of atrazine application on both sets of plots and also the year following application on the 1983-treated plots. A single fertilizer application did not enhance or prolong the effect of atrazine on forage quality. Cool-season grasses regenerated in atrazine-treated plots after 2 years so changes in yield and quality were only temporary, making atrazine use in subirrigated meadows uneconomical.**

**Key Words: Yield, IVDMD, crude protein, nitrogen, phosphorus, warm-season grasses, cool-season grasses, species composition**

Historically, most Nebraska Sandhills subirrigated meadows were dominated by tall, warm-season grasses (Rydberg 1895, Tolstead 1942) and ranchers introduced cool-season grasses early in the 20th century (Brouse 1930). Hay is harvested in mid-summer because most meadows are too wet for earlier harvest, so cool-season forage is nearly mature. Warm-season grasses have the potential to produce higher hay yield and quality than cool-season grasses with a summer harvest (Keim et al. 1932), but only remnants of warm-season grasses remain (Ehlers et al. 1952).

Atrazine [6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-,2,4-diamine] restored warm-season grass dominance in eastern Nebraska upland pasture that had shifted to cool-season grasses where remnant warm-season grasses were present (Samson and Moser 1982, Waller and Schmidt 1983, Dill et al. 1986). Nitrogen (N) and phosphorus (P) have been used in combination with atrazine to renovate warm-season grass pastures (Baker and Power 1978, Rehm 1984). McConnell and Waller (1986) reported that repeated annual atrazine (2.2 kg/ha) applications in combination with N and P shifted the period of optimum forage quality from spring and fall to mid-summer on native subirrigated meadows of eastern Nebraska.

Results from fertilizer experiments on subirrigated meadows were often variable depending on species composition, soil factors, growing conditions, and rate and time of application (Brouse et al. 1955, Brouse and Burzlaff 1968).

The purpose of this research was to determine if single applications of atrazine could be used to restore warm-season grass dominance in Sandhills subirrigated meadows and to determine if common fertilization programs (50 kg N/ha and 50 kg N + 18 kg P/ha) would enhance or prolong the effect of atrazine on yield, species composition, crude protein, and in vitro dry matter digestibility (IVDMD).

## Materials and Methods

Experiments were conducted from 1983 through 1985 at University of Nebraska's Gudmundsen Sandhills Laboratory (GSL), located in Grant County, 12 km northeast of Whitman, Nebr. The GSL lies in a precipitation zone of 500–560 mm per year, of which 75–80% falls during the growing season from April through September. Precipitation recorded for 1983–1985 at GSL for April through August is given (Table 1). Soil at the study site was a Gannett fine sandy loam (coarse loamy mixed mesic Typic Haplaquoll). Soil properties for the top 30 cm are: texture of 70% sand, 18% silt, and 12% clay; 6% OM; Bray and Kurtz #1 P level of 1 mg/kg; 1 M $NH_4C_2H_3O_2$ extracted K level of 135 mg/kg and a pH (1:1 soil-water ratio) of 8.3 Kentucky bluegrass (*Poa pratensis* L.) timothy (*Phleum pratense* L.), quackgrass (*Agropyron repens* L.), redtop bent (*Agrostis stolonifera* L.) and red clover (*Trifolium pratense* L.) were the major components of the plant community

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**Table 1. Growing season precipitation (mm) at the Gudmundsen Sandhills Laboratory April through August for 1983–1985, and 30 year average from Arthur, Nebraska.[1]**

| Month | Year 1983 | Year 1984 | Year 1985 | 30-year Average |
|---|---|---|---|---|
| April | 53 | 64 | 32 | 46 |
| May | 78 | 19 | 47 | 86 |
| June | 159 | 177 | 17 | 88 |
| July | 117 | 86 | 36 | 84 |
| August | 98 | 16 | 51 | 54 |
| Total | 505 | 362 | 183 | 358 |

[1] Data obtained from the Climatological Data for Nebraska, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, NC.

prior to treatment.

In 1983 and 1984, a single atrazine application was made in late May (spring) or late August (fall) in a water solution (200 L/ha), at 0, 2.2, and 3.3 kg/ha in a randomized complete block design with 3 replications (6 × 12 m plots). Season of atrazine application was analyzed as a split plot within the year of atrazine application (no fertilizer treatments). There was no significant effect due to season of herbicide application. One-half of each spring-treated plot (6 × 6 m) was fertilized the second growing season with 50 kg/ha of N as $NH_4NO_3$ (34-0-0). One-half of the fertilized area (3 × 6 m) received 18 kg/ha of P as triple superphosphate (0-45-0). Fertilizer was hand broadcast during the second week of May for the untreated plots dominated by cool-season grasses, and the second week of June for the warm-season dominated atrazine-treated plots. The purpose of the fertilizer treatments was to stimulate the dominant vegetation so that yields of a cool-season system could be compared to yields of the warm-season system. The warm-season plots (atrazine-treated) and the cool-season plots (untreated) were each fertilized at the optimum time (Rehm et al. 1976). The field plot design was a split plot. Whole plot treatments were the spring applied atrazine levels arranged in a randomized complete block. Split plot treatments were fertilizer treatments (O, N, NP). This experiment was initiated twice, once in 1983 and once in 1984. Repeated measurements were taken on each subplot in 1983, 1984, and 1985 for the experiment initiated in 1983 and in 1984 and 1985 for the experiment initiated in 1984. Yield and species composition were determined during August of each year.

Relative species composition was determined using the method outlined by Dill et al. (1986). In plots not receiving fertilizer, 2 transects were randomly located in the middle of each unfertilized plot 2 m apart. Ten rods (1 m) were randomly placed at ground level perpendicular to each transect. Since fertilized subplots were not as wide, only 1 transect was located near the middle of the subplot and 10 rods were randomly located as in the unfertilized plots. Each plant base touching the rod was counted. Species counts were combined into categories of (1) major warm-season grasses comprised of big bluestem (*Andropogon gerardii* Vitman) and indiangrass [*Sorghastrum nutans* (L) Nash.)], (2) other warm-season grasses, (3) cool-season grasses, (4) forbs, and (5) rushes. Percent species composition for each category was determined by dividing counts in each category by total number of plants touching the rod.

Yield was determined by randomly locating 2 (0.6 m²) quadrats within each plot and hand clipping herbage at ground level. A 15-cm by 60-cm subsample of the clipped material in each quadrat was separated into categories of warm-season grasses, cool-season

**Table 2. Species composition (%) of subirrigated meadow plots treated with atrazine and fertilized the year following with O (control), 50 kg/ha N or 50 kg/ha N and 18 kg/ha P.**
**A: Treated with atrazine in May 1983, fertilized in 1984, and sampled in August 1983–1985.**
**B: Treated with atrazine in May 1984, fertilized in 1985, sampled in August 1984–1985.**

| Year | Atrazine (kg/ha) | Warm-season grasses O | N | N+P | Cool-season grasses O | N | N+P | Rushes O | N | N+P | Forbs O | N | N+P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | 1983 Atrazine-treated plots | | | | | | | |
| 1983 | 0 | 39 | — | — | 38 | — | — | 8 | — | — | 15 | — | — |
| 1984 | 0 | 13 | 12 | 13 | 57 | 67 | 63 | 8 | 7 | 9 | 22 | 14 | 15 |
| 1985 | 0 | 11 | 6 | 8 | 69 | 73 | 75 | 9 | 12 | 8 | 11 | 9 | 9 |
| 1983 | 2.2 | 65 | — | — | 27 | — | — | 7 | — | — | 1 | — | — |
| 1984 | 2.2 | 51 | 47 | 41 | 31 | 36 | 40 | 12 | 12 | 11 | 6 | 5 | 8 |
| 1985 | 2.2 | 20 | 23 | 14 | 56 | 54 | 67 | 15 | 11 | 8 | 9 | 12 | 11 |
| 1983 | 3.3 | 71 | — | — | 28 | — | — | 11 | — | — | <1 | — | — |
| 1984 | 3.3 | 49 | 47 | 48 | 21 | 30 | 31 | 10 | 16 | 14 | 9 | 7 | 7 |
| 1985 | 3.3 | 30 | 24 | 22 | 47 | 50 | 60 | 13 | 13 | 13 | 10 | 13 | 5 |
| | Standard Errors | | | | | | | | | | | | |
| | 1983 | | 2.6 | | | 2.7 | | | 2.1 | | | 4.3 | |
| | 1984[1] | | 3.9 | | | 4.7 | | | 2.0 | | | 3.4 | |
| | 1985[1] | | 3.8 | | | 5.5 | | | 2.3 | | | 0.8 | |
| B | | | | | | 1984 Atrazine-treated plots | | | | | | | |
| 1984 | 0 | 22 | — | — | 59 | — | — | 4 | — | — | 15 | — | — |
| 1985 | 0 | 24 | 21 | 19 | 65 | 70 | 72 | 6 | 6 | 6 | 5 | 3 | 3 |
| 1984 | 2.2 | 81 | — | — | 7 | — | — | 11 | — | — | 1 | — | — |
| 1985 | 2.2 | 62 | 66 | 69 | 18 | 13 | 13 | 11 | 12 | 10 | 9 | 8 | 8 |
| 1984 | 3.3 | 80 | — | — | 0 | — | — | 11 | — | — | 1 | — | — |
| 1985 | 3.3 | 66 | 64 | 70 | 11 | 12 | 12 | 7 | 10 | 6 | 16 | 14 | 12 |
| | Standard Errors | | | | | | | | | | | | |
| | 1984 | | 8.7 | | | 2.0 | | | 2.7 | | | 4.3 | |
| | 1985[1] | | 7.4 | | | 2.9 | | | 2.6 | | | 2.0 | |

[1] Standard errors are for fertilizer treatments within atrazine levels.

grasses, forbs, and rushes. Samples were oven dried in a forced-air oven at 65° C for 48 hours and weighed. After quadrats were harvested, the rest of the plot was clipped with a sicklebar mower and the forage removed. Restricted randomization was used in subsequent years to avoid hand clipped areas.

Forage samples were hand clipped (2.5 cm) in mid-July from the middle two-thirds of each plot to determine quality at the time hay is generally harvested. Samples were dried for 48 hours at 65° C in a forced-air oven, and ground in a Wiley mill to pass a 1-mm screen. Kjeldahl N was determined colorimetrically (Bremner and Mulvaney 1982), and percentage protein estimated (N × 6.25). Analysis for IVDMD was determined by the two-stage direct acidification method (Marten and Barnes 1980).

Species composition data were analyzed using multivariate analysis of variance to detect overall differences among treatments and among years (Stroup and Stubbendieck 1983). In the multivariate analysis, only the groups of major warm-season grasses, other warm-season grasses, cool-season grasses, and rushes were used. The forbs category was not included in the analysis because unequal variances were created when atrazine eliminated red clover, the major component of the forbs category from treated plots. The effect of atrazine on species composition was evaluated on unfertilized areas as a split plot in time. The effect of fertilizer on species composition was evaluated as a split-split plot in atrazine level and time. Treatment differences were evaluated using Wilks' criterion test statistic. Yield data were analyzed using univariate analysis of variance for the warm-season grasses, cool-season grasses, forbs, rushes, and hay yield categories. Preplanned orthogonal contrasts were used to compare treatments for species composition, yield, crude protein, and IVDMD. Statistical significance was declared at $P = 0.05$.

## Results and Discussion

### Species Composition

*Atrazine*

There was no statistical difference in response to atrazine between treatment years. Atrazine shifted species composition [Wilkes criterion: $P = 0.05$ (1983), $P = 0.01$ (1984) Table 2]. The shift in composition was due to a decrease of cool-season grasses and an increase in warm-season grasses in the year of treatment (Table 2, unfertilized). Most of the increase in warm-season grasses was due to big bluestem and indiangrass since they were the major rem-

**Table 3. Yield (kg/ha) of warm-season grasses, cool-season grasses and total yield for subirrigated meadow plots treated with atrazine and fertilized the year following treatment with O (control), 50 kg/ha N or 50 kg/ha N and 18 kg/ha P.**
**A: Treated with atrazine in May 1983, fertilized in 1984, and sampled in August 1983–1985.**
**B: Treated with atrazine in May 1984, fertilized in 1985, and sampled in 1984 and 1985.**

| Year sampled | Interaction/contrasts | Atrazine rate (kg/ha) | Warm-season grasses | | | | Cool-season grasses | | | | Yield | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Control | N | NP | P>F | Control | N | NP | P>F | Control | N | NP | P>F |
| A. | 1983 Atrazine-treated plots | | | | | | | | | | | | | |
| 1983 | | 0 | 740 | —— | —— | | 2890 | —— | —— | | 4690 | —— | —— | |
| | | 2.2 | 1270 | —— | —— | | 780 | —— | —— | | 2150 | —— | —— | |
| | | 3.3 | 1610 | —— | —— | | 390 | —— | —— | | 2070 | —— | —— | |
| | Control vs. atrazine[1] | | | | | .04 | | | | <.01 | | | | <.01 |
| | 2.2 vs 3.3 | | | | | NS | | | | NS | | | | NS |
| 1984 | | 0 | 370 | 500 | 660 | | 3780 | 4090 | 4370 | | 5400 | 6080 | 6110 | |
| | | 2.2 | 2600 | 3950 | 3340 | | 2160 | 2520 | 2700 | | 5260 | 6840 | 6480 | |
| | | 3.3 | 3640 | 3940 | 5110 | | 1470 | 2060 | 1320 | | 5670 | 6486 | 7010 | |
| | Atr × fert interaction | | | | | NS | | | | NS | | | | NS |
| | Control vs. atrazine | | | | | .01 | | | | NS | | | | NS |
| | 2.2 vs 3.3 | | | | | NS | | | | NS | | | | NS |
| | Control vs. fertilizer[2] | | | | | .01 | | | | NS | | | | .02 |
| | N vs NP | | | | | NS | | | | NS | | | | NS |
| 1985 | | 0 | 690 | 580 | 530 | | 3130 | 3540 | 3650 | | 4310 | 4460 | 4600 | |
| | | 2.2 | 1340 | 1650 | 1260 | | 2540 | 2400 | 2820 | | 4330 | 4540 | 4480 | |
| | | 3.3 | 1590 | 1760 | 900 | | 2030 | 3100 | 2600 | | 4030 | 5340 | 3860 | |
| | Atr × fert interaction | | | | | NS | | | | NS | | | | NS |
| | Control vs. atrazine | | | | | <.01 | | | | NS | | | | NS |
| | 2.2 vs 3.3 | | | | | NS | | | | NS | | | | NS |
| | Control vs. fertilizer | | | | | NS | | | | NS | | | | NS |
| | N vs NP | | | | | NS | | | | NS | | | | NS |
| B. | 1984 Atrazine-treated plots | | | | | | | | | | | | | |
| 1984 | | 0 | 470 | —— | —— | | 3110 | —— | —— | | 4490 | —— | —— | |
| | | 2.2 | 3060 | —— | —— | | 10 | | | | 3230 | —— | —— | |
| | | 3.3 | 2964 | —— | —— | | 5 | —— | —— | | 3020 | —— | —— | |
| | Control vs. atrazine | | | | | <.01 | | | | <.01 | | | | .05 |
| | 2.2 vs 3.3 | | | | | NS | | | | NS | | | | NS |
| 1985 | | 0 | 900 | 900 | 990 | | 2550 | 3500 | 3910 | | 3770 | 4650 | 5150 | |
| | | 2.2 | 3070 | 4060 | 4130 | | 390 | 100 | 150 | | 3960 | 4520 | 4820 | |
| | | 3.3 | 3360 | 3570 | 3580 | | 120 | 100 | 360 | | 3960 | 4490 | 4310 | |
| | Atr × fert interaction | | | | | NS | | | | .01 | | | | NS |
| | Control vs. atrazine | | | | | <.01 | | | | <.01 | | | | NS |
| | 2.2 vs 3.3 | | | | | NS | | | | NS | | | | NS |
| | Control vs. fertilizer | | | | | NS | | | | .03 | | | | .03 |
| | N vs NP | | | | | NS | | | | NS | | | | NS |

[1] Control versus the average effect of 2.2 and 3.3 kg/ha atrazine application.
[2] Control versus the average effect of N and NP fertilizer application.

nants. A significant negative correlation ($r = -0.95$ and $r = -0.87$ for 1983 and 1984 respectively) occurred between the decrease in percentage composition of cool-season grasses and the increase in percentage composition of major warm-season grasses. Other warm-season grasses (not shown) and rushes were variable and did not exhibit a significant response to atrazine. Forbs, primarily red clover, were nearly eliminated with atrazine during both treatment years. No significant difference in species composition occurred between 2.2 and 3.3 kg/ha atrazine rates when analyzed over all species groups.

Differences in species composition still existed the second growing season after treatment between untreated and atrazine-treated plots. However, changes in species composition were temporary. A year × treatment interaction occurred with both 1983 and 1984 treated plots. Between 1983 and 1984, cool-season grasses increased and warm-season grasses decreased on untreated plots. Above-average rainfall during April and June of 1984 (Table 1) apparently favored cool-season grasses. Cool-season grass increase between 1983 and 1984 was not as dramatic on atrazine-treated plots. However, cool-season grasses increased sharply and warm-season grasses decreased from 1984 to 1985 on both 1983 and 1984 treated plots while untreated plots remained unchanged.

By the third growing season after application, species composition of warm- and cool-season grasses was rapidly approaching the untreated condition (Table 2). Cool-season grasses did not invade from the edges but uniformly throughout the plot, indicating that some rhizomes evidently survived. Reproduction by new seedlings would be minimal with the heavy thatch over subirrigated meadows. Red clover did not reestablish on atrazine-treated plots after 3 growing seasons. Black medic (*Medicago lupulina* L.) accounted for much of the forb population in 1984 and was particularly abundant in 1985. Scattered alfalfa (*Medicago sativa* L.) plants survived the atrazine treatments.

### *Fertilizer*

Fertilizer had no effect on species composition of the meadow during the year of fertilizer application, and no atrazine × fertilizer interaction occurred for any species group on either the 1984 or 1985 fertilized plots (Table 2). The combination of P with N stimulated cool-season grasses, primarily Kentucky bluegrass, beyond that of N only the year following fertilizer application on atrazine-treated plots (Table 2). Similarly, Brouse et al. (1955) and Mader (1956) reported that P with N stimulated Kentucky bluegrass.

## Forage Yield and Quality

### *Atrazine*

Warm-season grass yields were higher in plots treated with atrazine than the untreated area the treatment year (Table 1). Cool-season grass yields, forbs (not shown), and total August yield were lower in treated areas. There was no difference in yield response between atrazine rates. Warm-season grass yields remained higher in atrazine-treated plots than untreated plots the year fol-

**Table 4. Protein concentration and IVDMD values for mid-July samples from subirrigated meadow plots treated with atrazine and fertilized the year following with O (control), 50 kg/ha N or 50 kg/ha N and 18 kg/ha P.**
**A: Treated with atrazine in May 1983, fertilized in 1984, and sampled in mid-July 1984 and 1985.**
**B: Treated with atrazine in May 1984, fertilized in 1985, and sampled in mid-July 1985.**

| Year sampled | Atrazine rate (kg/ha) | Protein (%) Control | Protein (%) N | Protein (%) NP | Protein (%) P>F | IVDMD (%) Control | IVDMD (%) N | IVDMD (%) NP | IVDMD (%) P>F |
|---|---|---|---|---|---|---|---|---|---|
| A. | | | | 1983 Atrazine-treated plots | | | | | |
| 1984 | 0 | 6.4 | 7.5 | 8.2 | | 56.0 | 56.7 | 56.5 | |
| | 2.2 | 7.4 | 7.8 | 8.9 | | 59.4 | 57.6 | 58.1 | |
| | 3.3 | 7.4 | 9.0 | 9.4 | | 60.4 | 58.9 | 60.1 | |
| Atr × Fert interaction | | | | | NS | | | | NS |
| Control vs. atrazine[1] | | | | | .03 | | | | .01 |
| 2.2 vs 3.3 | | | | | NS | | | | .05 |
| Control vs. fertilizer[2] | | | | | .01 | | | | NS |
| N vs NP | | | | | NS | | | | NS |
| 1985 | 0 | 6.5 | 6.8 | 6.2 | | 50.9 | 50.8 | 53.5 | |
| | 2.2 | 6.5 | 6.3 | 6.8 | | 52.8 | 52.5 | 51.5 | |
| | 3.3 | 6.8 | 6.4 | 5.8 | | 51.7 | 54.2 | 52.7 | |
| Atr × Fert interaction | | | | | .03 | | | | NS |
| Control vs. atrazine | | | | | NS | | | | NS |
| 2.2 vs 3.3 | | | | | NS | | | | NS |
| Control vs. fertilizer | | | | | NS | | | | NS |
| N vs NP | | | | | NS | | | | NS |
| B. | | | | 1984 Atrazine-treated plots | | | | | |
| 1984 | 0 | 7.3 | — | — | | 55.4 | — | — | |
| | 2.2 | 10.6 | — | — | | 58.2 | — | — | |
| | 3.3 | 11.3 | — | — | | 56.9 | — | — | |
| Control vs. atrazine | | | | | <.01 | | | | .04 |
| 2.2 vs 3.3 | | | | | NS | | | | NS |
| 1985 | 0 | 7.2 | 8.5 | 8.1 | | 51.0 | 55.0 | 54.9 | |
| | 2.2 | 8.1 | 9.5 | 9.4 | | 53.2 | 55.1 | 57.4 | |
| | 3.3 | 7.7 | 9.1 | 9.1 | | 53.7 | 54.6 | 57.1 | |
| Art × Fert interaction | | | | | NS | | | | NS |
| Control vs. atrazine | | | | | .01 | | | | NS |
| 2.2 vs 3.3 | | | | | NS | | | | NS |
| Control vs. fertilizer | | | | | .01 | | | | .01 |
| N vs NP | | | | | NS | | | | NS |

[1] Control versus the average effect of 2.2 and 3.3 kg/ha atrazine application.
[2] Control versus the average effect of N and NP fertilizer application.

lowing treatment. However, this effect was only temporary. Warm-season grass yields for 1985 were lower than 1984 yields in the 1983 treated plots. During this period cool-season grass yields increased. Apparently, warm-season grasses were unable to maintain a competitive advantage without repeated atrazine application.

The change of the atrazine-treated plots from cool- to warm-season grasses increased crude protein the treatment year (1984) (Table 4). This response was still evident the year after treatment for both treatment years. Atrazine-treated plots had higher IVDMD the treatment year (1984). However, this response was only maintained the year following treatment in 1983-treated plots.

### Atrazine and Fertilizer

Fertilizer increased yield and crude protein the year of application (Table 4). However, residual fertilizer effects were not detected with a mid-July harvest. Brouse and Burzlaff (1968) reported no significant residual effects of N fertilizer applied alone below 88 kg/ha. In this study, response to fertilizer was temporary and inconsistent, reflecting a combination of environmental factors and management rather than treatment. Fertilizer did not extend or enhance the atrazine effect. It altered warm-season grass yield and crude protein without affecting vegetation composition and/or warm-season grass persistence.

## Conclusion

Atrazine at 2.2 or 3.3 kg/ha was effective in shifting species composition of the subirrigated meadow from cool- to warm-season grasses. May or August applications were equally effective. However, control of cool-season grasses by a single atrazine application was temporary. Cool-season grasses regained dominance after 2 years. Total yield was reduced the year of treatment. However, in the second growing season, increased warm-season grass compensated for the loss of cool-season grass yield. Warm-season grass dominance increased crude protein at a mid-July harvest. This benefit was lost when the meadow reverted back to cool-season dominance. Nitrogen fertilizer boosted yields and increased crude protein the year of fertilization. Percentage IVDMD appeared to be more sensitive to the stage of grass maturity than treatment effect, and varied by year. Conversion of subirrigated meadows from cool- to warm-season grasses shifted the period of optimum forage quality from spring and fall to mid-summer. However, since this shift was only temporary, use of atrazine would not be recommended for subirrigated meadows in the Sandhills.

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# Genetic variability of Mg, Ca, and K in crested wheatgrass

H.F. MAYLAND AND K.H. ASAY

## Abstract

**Increasing available Mg in crested wheatgrass (*Agropyron* spp.) could reduce the incidence of grass tetany (hypomagnesemia) in ruminants grazing this forage. Raising the Mg levels might be done through genetic processes if enough variation in ion concentration existed in the *Agropyrons*. The purpose of this study was to determine the genetic variation in Mg, Ca, and K concentrations in 2 crested wheatgrass populations. Parent plants were vegetatively propagated to provide 6 replicates each of 12 clones of crested wheatgrass (*A. desertorum*) and 16 $F_3$ clones of colchicine-induced tetraploid *A. cristatum* × natural tetraploid *A. desertorum*. Each plant was selected on a basis of seedling and mature plant vigor, forage, and seed yield, leafiness, resistance to pests, and response to environmental stress. The 2 populations were grown in separate, space-planted nurseries at Logan, Utah. Herbage was harvested at the pre-boot and early flowering stage in each of 2 years. Magnesium and Ca were determined by atomic absorption and K by flame emission. A reduced tetany potential (RTP) index for each clone was calculated as the sum of normalized Mg and (Ca+Mg)/K values. Significant ($P<0.01$) differences for all traits were detected among clones in each population. All traits, except K and RTP, were closely correlated. Broad-sense heritability values for most traits ranged from 0.61 to 0.84. Enough genotypic variation existed in both populations to warrant breeding lines with higher concentrations of Mg and larger RTP values. Such changes could reduce the incidence of grass tetany in livestock grazing crested wheatgrass.**

**Key Words: *Agropyron desertorum*, grass tetany, hypomagnesemia, broad sense heritability, forage quality**

Cool-season ($C_3$) grasses are responsible for most cases of grass tetany (hypomagnesemia) in ruminants. The risk of tetany can be reduced by supplying more available Mg to the animals. The quantity of available Mg may increase with increases in Mg concentration in forage (Moseley and Griffiths 1984). However, increasing the concentration of K relative to Mg and Ca reduces the amount of available Mg and increases the risk of tetany (Mayland 1988). This risk is presumed to increase exponentially when the forage K/(Ca + Mg) value, expressed on an equivalent basis, exceeds 2.2 (Kemp and 't Hart 1957). Other factors may also reduce available Mg, but these are likely to be less important (Mayland 1988).

There is increasing evidence that ion uptake by plants is under genetic control (Clark 1983, Saric 1983, and Vose 1963). Such control has already been shown for Ca, Mg, and K in perennial ryegrass (*Lolium perenne*, Cooper 1973), Italian ryegrass (*Lolium multiflorum*, Hides and Thomas 1981), *Lolium-Festuca* hybrids (Buckner et al. 1981), reed canarygrass (*Phalaris arundinacea*, Hovin et al. 1978), orchardgrass (*Dactylis glomerata*, Mika et al. 1988 and Stratton and Sleper 1979), and tall fescue (*Festuca arundinacea*, Nguyen and Sleper 1981). Sleper et al. (1977) noted that K/(Ca + Mg) was highly heritable in *Dactylis* and *Festuca* spp.

Plant breeding programs to increase available Mg have been started on Italian ryegrass (Hides and Thomas 1981) and tall fescue (Sleper et al. In Press). Crested wheatgrass (*Agropyrons* spp.) may have enough genetic variation in Mg, Ca, and K values to justify a breeding program to increase available Mg. This is particularly important because crested wheatgrass may account for 30% of the grass tetany cases in the United States (Mayland 1986). To test this potential, we determined the magnitude of genetic variability and broad-sense heritability in Mg, Ca, and K uptake by crested wheatgrass.

## Materials and Procedures

Forage samples were obtained from 2 *Agropyron* populations grown in separate nurseries near Logan, Utah. Parent plants were vegetatively propagated to provide 6 replicates of each clone. The first nursery contained 12 clones of standard crested wheatgrass *(Agropyron desertorum)*. Each plant was selected on a basis of seedling and mature plant vigor, forage and seed yield, leafiness, resistance to pests, and response to environmental stress. The second nursery included 16 of the original 18 parents of a synthetic strain, later released as the cultivar 'Hycrest' (Asay et al. 1986). These parents were the $F_3$ plants of colchicine-induced tetraploids of *A. cristatum* × natural tetraploid of *A. desertorum*. The 18 parents had been selected from among 8,000 plants, and selection criteria were the same as for the other population. The 2 populations will be referred to as Agdes and Hycrest, respectively.

Nursery plants were spaced 1 m apart in a randomized, complete block design having 6 replications. The areas were fertilized with nitrogen and phosphorus and sprinkler irrigated as needed. The soil at the Hycrest site was a Nibley silty clay loam series, a fine mixed mesic aquic Argiustoll. The Agdes study was conducted on a Timpanogos silt loam series, a fine loamy mixed mesic calcic Argixeroll.

One-half of each plant was clipped to a standard 5-cm stubble height at the early boot stage (8 May 1985 and 15 May 1986), and the remaining half was clipped at flowering (13 June 1985 and 15 June 1986) in each of 2 years. This harvested leaf and stem material was initially dried in the greenhouse and, later, in forced draft ovens at 60° C for 24 hours. Samples were ground to pass a 40-mesh Wiley screen. Subsamples were digested in 3:1 nitric:-perchloric acid and diluted with 1 g La/liter as $LaCl_2$. Magnesium and Ca were analyzed by atomic absorption and K by flame emission.

Analytical precision was typified by an in-house alfalfa sample which was analyzed with the wheatgrass series. This sample was analyzed to contain $3.4 \pm 0.3$ mg Mg/g, $14.5 \pm 0.8$ mg Ca/g and $23.5 \pm 1.0$ mg K/g. All elemental data were expressed on a dry matter basis. The ratio of K/(Ca + Mg) was calculated on an equivalent basis.

An index for reduced tetany potential (RTP) was calculated as follows:

$$\mathrm{RTP_u} = \frac{\mathrm{Mg}_i - \mathrm{Mg}_p}{s\,\mathrm{Mg}_p} + \frac{\left[\frac{\mathrm{Ca + Mg}}{\mathrm{K}}\right]_i - \left[\frac{\mathrm{Ca + Mg}}{\mathrm{K}}\right]_p}{s\left[\frac{\mathrm{Ca + Mg}}{\mathrm{K}}\right]_p}$$

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where the subscript *'i'* is the value for the individual plant. The subscript *'p'* is the mean value for the population, and the *'s'* is the square root of the error mean square in the F test for the appropriate trait at a given harvest date. The $RTP_u$ (as shown above) is a normalized function having a mean value of zero for a given population. Values of RTP in this paper are shown as $RTP_u + 10$ so all values are positive.

Analysis of variance was calculated with replications, clones, and years considered as random variables and harvests as a fixed variable. Broad-sense heritabilities ($H_b$) were computed on a mean basis from variance components (Burton and DeVane 1953). The $H_b$ was the ratio $\sigma^2C/\sigma^2_{ph}$, where $\sigma^2C$ was the variance component due to differences among clones, and $\sigma^2_{ph}$ was the variance of the mean for each clone.

## Results and Discussion

Significant differences ($P<0.01$) were found among clones for all traits measured in the Agdes and Hycrest populations (Table 1). Differences between harvests and years were also significant, corroborating the year and seasonal variation in the occurrence of grass tetany. Harvest and year mean squares for RTP were zero because values were normalized within each harvest.

The mean square error terms for clones were highly significant for all traits measured in each of the Agdes harvests (combined data shown in Table 1). Similarly, all main effects were significant ($P<0.05$) for Hycrest, except Ca in harvest 2 in 1985, K/(Ca + Mg) ratio in harvest 2 and the 1986 combined analysis, and the RTP index in harvest 2 of 1986. It is concluded from these results that elemental uptake is under genetic control in both populations and that genetic variability is available for selection purposes.

Clone × harvest and clone × year interactions were often significant because relative differences among clones were not consistent across harvests and years. Some clones had consistently high or low values for the measured characteristics.

The RTP index should be a good measure of "available Mg". It includes information on the interactions of Mg, Ca, and K (Kemp and 't Hart 1957, Mayland and Grunes 1979) while also giving additional weight or consideration to the Mg concentration in the forage. Using the RTP index would allow an evaluation of progress in selection programs.

There were wide ranges among the clones for all traits studied in Agdes (Table 2) and Hycrest (Table 3). Dividing the range (max − min) by the mean provided a normalized measure of dispersion. Relative ranges among means of Agdes clones, when computed over years and harvests, made up 31, 36, 26, 27, and 38% of the mean Ca, Mg, K, (K/(Ca + Mg), and RTP index, respectively. Corresponding values for Hycrest were 40, 37, 24, 17, and 27%. These ranges provide additional evidence of the opportunities for increasing Mg concentrations in crested wheatgrass through breeding and selection and reducing the incidence of grass tetany in livestock.

Calcium, Mg, and K concentrations were lower in the second harvest than in the first in both populations (Tables 2 and 3). A reduction was expected as the plants accumulated more photosynthate thereby diluting the elemental concentrations. Values for Ca and Mg decreased more than K when evaluating the changes associated with increased maturation. This resulted in K/(Ca + Mg) ratios which were 50% higher in the second harvest of Agdes and 12% higher in second harvest of Hycrest. The ratio means exceeded the 2.2 critical level at the second harvest for both populations. Means of elemental traits for Hycrest and Agdes could not be statistically compared because the 2 populations were grown on different soils.

The Agdes plants contained higher concentrations of Ca, Mg, and K in 1986 than in 1985. Hycrest clones also had higher Ca concentrations in 1986 but lower levels of Mg and especially K than did these same plants in 1985. This may reflect small differences in phenology at the time of sampling each year or perhaps differences in soil moisture, temperature, and nutrition over sites and years. The 1985 K/(Ca + Mg) values were slightly higher than in 1986 for the Agdes population (Table 2) but much higher for the Hycrest populations (Table 3).

**Table 1. Analysis of variance of elemental traits combined over harvests and years for *Agropyron desertorum* and Hycrest clones.**

| Source | | d.f. | Mean squares | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | K/(Ca + Mg) | RTP index |
| *Agropyron desertorum* | | | | | | | |
| BLOCKS | (B) | 5 | 0.6 | 0.2 | 8.9 | 24.5 | 1392** |
| CLONES | (C) | 11 | 2.3** | 0.4** | 47.0** | 91.2** | 2238** |
| ERROR | a | 55 | 0.3 | 0.0 | 3.4 | 7.6 | 304 |
| HARVEST | (H) | 1 | 286. ** | 40.0** | 1283. ** | 5150. ** | 0 |
| C X H | | 11 | 0.3 | 0.1 | 22.2** | 48.2** | 1472** |
| YEARS | (Y) | 1 | 20.2** | 2.0** | 18.6** | 380. ** | 0 |
| C X Y | | 11 | 0.8** | 0.3** | 6.9** | 19.8** | 1409** |
| H X Y | | 1 | 2.1** | 1.2** | 38.4** | 70.1** | 0 |
| C X H X Y | | 11 | 0.3 | 0.1 | 2.2 | 9.1 | 300* |
| Residual | | 180 | 0.3 | 0.1 | 2.2 | 7.7 | 372 |
| *Hycrest* | | | | | | | |
| BLOCKS | (B) | 5 | 0.8 | 0.2 | 35.9 | 12.8 | 1090** |
| CLONES | (C) | 15 | 2.2** | 0.3** | 32.5** | 37.8** | 1640** |
| ERROR | a | 75 | 0.2 | 0.0 | 5.4 | 8.2 | 320 |
| HARVEST | (H) | 1 | 146. ** | 31.4** | 5010. ** | 599. ** | 0 |
| C X H | | 15 | 0.6** | 0.1* | 8. | 13.5 | 496** |
| YEARS | (Y) | 1 | 47.6** | 0.6** | 4710. ** | 8940. ** | 0 |
| C X Y | | 15 | 0.6** | 0.1* | 5.2 | 16.5 | 681* |
| H X Y | | 1 | 2.5** | 1.1** | 2160. ** | 152. ** | 0 |
| C X H X Y | | 15 | 0.2 | 0.1* | 3.1 | 7.4 | 360** |
| RESIDUAL | | 240 | 0.2 | 0.0 | 5.1 | 9.8 | 384 |

*,**Significant at $P<0.05$ and $P<0.01$, respectively.

**Table 2. Ranges, means, standard errors of the difference (SEd), and broad-sense heritabilities (H) of elemental traits in 12 *Agropyron desertorum* clones grown at Logan, Utah, in 1985 and 1986.**

| | Years Combined | | Harvests Combined | | Yrs-Harv Comb. |
|---|---|---|---|---|---|
| Traits | Cut 1 | Cut 2 | 1985 | 1986 | |
| Calcium[1] | | | | | |
| Range | 3.53–4.69 | 1.58–2.43 | 2.18–3.33 | 2.80–3.97 | 2.56–3.50 |
| Mean | 4.04** | 2.05** | 2.78** | 3.31** | 3.04** |
| SEd | 0.12 | 0.12 | 0.19 | 0.22 | 0.15 |
| H | 0.52 | 0.81 | 0.88 | 0.77 | 0.64 |
| Magnesium[1] | | | | | |
| Range | 1.23–1.89 | 0.73–.93 | 0.94–1.37 | 0.98–1.58 | 0.98–1.41 |
| Mean | 1.57** | 0.82** | 1.11** | 1.28** | 1.19** |
| SEd | 0.13 | 0.04 | 0.09 | 0.11 | 0.07 |
| H | 0.23 | 0.38 | 0.80 | 0.81 | 0.27 |
| Potassium[1] | | | | | |
| Range | 15.5–22.6 | 14.0–18.2 | 15.9–19.8 | 14.8–21.0 | 15.4–20.0 |
| Mean | 20.4** | 16.2** | 18.0** | 18.5** | 18.3** |
| SEd | 0.80 | 0.52 | 0.25 | 0.74 | 0.53 |
| H | 0.88 | 0.78 | 0.85 | 0.91 | 0.83 |
| K/(Ca + Mg) | | | | | |
| Range | 1.27–1.94 | 1.99–2.83 | 1.82–2.50 | 1.62–2.45 | 1.82–2.37 |
| Mean | 1.64** | 2.48** | 2.18** | 1.95** | 2.06** |
| SEd | 0.096 | 0.104 | 0.127 | 0.100 | 0.080 |
| H | 0.72 | 0.91 | 0.87 | 0.82 | 0.78 |
| RTP index | | | | | |
| Range | 8.54–11.5 | 7.78–12.5 | 8.14–12.1 | 8.01–12.6 | 8.16–12.0 |
| Mean | 10.0** | 10.0** | 10.0** | 10.0** | 10.0** |
| SEd | 0.72 | 0.61 | 0.76 | 0.76 | 0.50 |
| H | 0.43 | 0.75 | 0.82 | 0.80 | 0.40 |

[1] Traits expressed in mg/g, except H.

*,**Mean squares for genotypes are significantly different at $P<0.05$ or 0.01 respectively.

**Table 3. Ranges, means, standard errors of the difference (SEd), and broad-sense heritabilities (H) of elemental traits in 16 Hycrest clones grown at Logan, Utah, in 1985 and 1986.**

| | Years Combined | | Harvests Combined | | Yrs-Harv Comb. |
|---|---|---|---|---|---|
| Traits | Cut 1 | Cut 2 | 1985 | 1986 | |
| Calcium[1] | | | | | |
| Range | 2.73–4.56 | 1.88–2.78 | 2.23–3.14 | 2.39–3.85 | 2.31–3.49 |
| Mean | 3.59** | 2.36** | 2.62** | 3.33** | 2.97** |
| SEd | 0.18 | 0.16 | 0.14 | 0.20 | 0.12 |
| H | 0.80 | 0.50 | 0.83 | 0.89 | 0.71 |
| Magnesium[1] | | | | | |
| Range | 1.13–1.80 | 0.73–1.02 | 1.02–1.36 | 0.84–1.49 | 0.93–1.35 |
| Mean | 1.48** | 0.91** | 1.24** | 1.16** | 1.20** |
| SEd | 0.10 | 0.05 | 0.07 | 0.10 | 0.06 |
| H | 0.63 | 0.78 | 0.72 | 0.76 | 0.61 |
| Potassium[1] | | | | | |
| Range | 19.4–25.6 | 14.7–18.7 | 21.3–25.8 | 12.8–18.3 | 17.0–22.1 |
| Mean | 24.3** | 17.1** | 24.2** | 17.2** | 20.7** |
| SEd | 0.9 | 0.7 | 0.7 | 0.8 | 0.7 |
| H | 0.93 | 0.69 | 0.78 | 0.82 | 0.83 |
| K/(Ca+Mg) | | | | | |
| Range | 1.78–2.34 | 2.07–2.58 | 2.39–2.94 | 1.54–1.94 | 2.04–2.43 |
| Mean | 2.11** | 2.36** | 2.72** | 1.75* | 2.23** |
| SEd | 0.09 | 0.12 | 0.12 | 0.12 | 0.08 |
| H | 0.81 | 0.56 | 0.78 | 0.50 | 0.61 |
| RTP index | | | | | |
| Range | 8.38–11.4 | 8.36–11.6 | 8.26–11.9 | 8.48–11.9 | 8.37–11.1 |
| Mean | 10.0** | 10.0** | 10.0** | 10.0** | 10.0** |
| SEd | 0.72 | 0.70 | 0.84 | 0.73 | 0.52 |
| H | 0.51 | 0.76 | 0.72 | 0.60 | 0.63 |

[1] Traits expressed in mg/g, except H.

*,**Mean squares for genotypes are significantly different at $P<0.05$ or 0.01 respectively.

Table 4. Correlations among Ca, Mg, K, K/(Ca + Mg) and index values for *Agropyron desertorum* (upper right) and Hycrest (lower left) populations combined over years.[1]

| | Harvest | Ca | Mg | K | K / (Ca+MG) | RTP index |
|---|---|---|---|---|---|---|
| Ca | 1 | | 0.77** | 0.14 | –0.77** | 0.75** |
| | 2 | | 0.43** | 0.24** | –0.69** | 0.60** |
| | Combined | | 0.89** | 0.63** | –0.88** | 0.38** |
| Mg | 1 | 0.41** | | 0.32** | –0.64** | 0.83** |
| | 2 | 0.51** | | 0.37** | –0.38** | 0.73** |
| | Combined | 0.72** | | 0.66** | –0.78** | 0.46** |
| K | 1 | –0.23** | 0.43** | | 0.41** | –0.06 |
| | 2 | –0.15* | 0.29** | | 0.43** | –0.15 |
| | Combined | 0.29** | 0.66** | | –0.29** | –0.07 |
| K / (Ca+Mg) | 1 | –0.63** | 0.05 | 0.87** | | –0.77** |
| | 2 | –0.85** | –0.43** | 0.56** | | –0.82** |
| | Combined | –0.66** | –0.22** | 0.47** | | –0.54** |
| RTP index | 1 | 0.64** | 0.79** | –0.04 | –0.43** | |
| | 2 | 0.50** | 0.90** | 0.08 | –0.53** | |
| | Combined | 0.42** | 0.52** | 0.01 | –0.46** | |

[1] n = 144 for individual and 288 for combined harvest of *A. desertorum*, n = 192 for individual and 384 for combined harvest of Hycrest.

*,**Significant at $P<0.05$ and $P<0.01$, respectively.

In general, more than 50% of the phenotypic variance among clones in the 2 populations was due to genetic effects, even when considered over years and harvests. Broad-sense heritabilities (H) ranged from 0.27 to 0.83 in Agdes and 0.61 to 0.83 in Hycrest for the analyses combined over years and harvests (Table 2, 3). Heritabilities of Mg were much lower for Agdes in the analyses combined over years within each harvest than comparable values obtained from the analyses for each year combined over harvests (Table 2). This can be explained, at least partially, because years were considered as random variables while harvests were treated as fixed in the computation of the genetic variance among clones. Heritabilities are big enough that selection for RTP would be effective in both populations, especially Hycrest.

Correlations among the 5 traits were computed from data combined over the 2 years (Table 4). Magnesium was significantly ($P<0.01$) and positively correlated with Ca in both the Agdes ($r$ = 0.89) and Hycrest ($r$ = 0.72) populations. Magnesium was more closely associated with K ($r$ = 0.66 and 0.66) than was Ca ($r$ = 0.63 and 0.23) in the 2 respective populations. The K/(Ca + Mg) ratio was negatively related to Mg and Ca and positively to the K values. The correlations of K with the ratio in each of the Agdes harvests were positive ($r$ = 0.41 and 0.43). However, K levels were only slightly less in the second than the first harvest whereas Ca and Mg levels were much less. This resulted in a small negative correlation ($r$ = –0.29) between the ratio and K levels. Similar shifts in regression slopes occurred between Ca and K in Hycrest.

The RTP index was significantly correlated with Mg, Ca, and the K/(Ca + Mg) ratio but not with K (Table 4). Simple and stepwise multiple regression of the RTP index against the other elements illustrated that Mg accounted for 21 and 27% of the variation in the RTP of Agdes and Hycrest, respectively. Potassium was the second most important parameter which, including Mg, accounted for 33 and 49% of the variation in RTP in the 2 populations, respectively. Regressing the RTP index against Mg, Ca, K, and the K/(Ca + Mg) data accounted for 42 and 51% of the variability in the RTP index in the Agdes and Hycrest populations, respectively. Variation in the Mg:K, Ca:K, and Mg:Ca values plus the biological and analytical errors were responsible for the remaining variability in the RTP values. Thus, the RTP index seems most sensitive to variability in Mg and, to a lesser extent, to that in K concentrations in these 2 populations. Examining the correlations among elemental parameters in other populations would be useful in determining the value of the RTP index.

## Conclusions

A wide range in genetic variability and values for heritability were measured for ion uptake in these *Agropyrons*. Developing germplasm with higher Mg concentrations is a realistic goal to reduce the grass tetany potential of this genus. However, mineral elements are not inherited independently of each other. Genetic increases in Mg will likely be accompanied by increases in Ca, a positive response, and by slight increases in K, a negative response. The present studies were not designed to derive estimates of narrow-sense heritabilities or the proportion of the genetic variance that is conditioned by additive effects. Research is underway to determine these values and to test genetic gains in progenies of selected plants. The relationships between the RTP index and traits such as seedling establishment, drought tolerance, winter hardiness, insect and disease tolerance, forage yield, and forage quality must also be assessed.

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# Observations on biomass dynamics of a crested wheatgrass and native shortgrass ecosystem in southern Wyoming

EDWARD F. REDENTE, MARIO E. BIONDINI, AND JOHN C. MOORE

## Abstract

**Above- and belowground net primary production (ANPP and BNPP) were compared between a 30-year-old crested wheatgrass site and an adjacent native shortgrass prairie. ANPP was estimated using successive harvests in May, June, July, and October 1985. BNPP was estimated using soil cores to a depth of 100 cm at the same time that aboveground harvests were made. ANPP was significantly greater in the crested wheatgrass site compared to the native site, but belowground and total net primary production were not different. The native shortgrass system, however, had greater live root biomass early in the growing season. The crested wheatgrass system had a high accumulation of aboveground dead material at the start of the growing season, which was followed by a significant decline in June and an increase in July and October. The native shortgrass system, however, had significantly lower accumulations of aboveground dead material. Approximately 92% of the fixed carbon in the native site was allocated belowground, while crested wheatgrass allocated about 85% of its fixed carbon belowground.**

**Key Words: aboveground production, belowground production, standing dead litter, *Agropyron cristatum,* blue grama, western wheatgrass**

Large areas of abandoned croplands in the western U.S. were seeded with crested wheatgrass [*Agropyron cristatum* (L) Gaertn.] during the 1930's (Rogler and Lorenz 1983). More than a million hectares were seeded with this species in both Montana (Woolfolk 1951) and Canada (Smoliak and Dormaar 1985). Some of these communities have remained virtual monocultures for more than 50 years without apparent successional trends (Vallentine 1971).

Earlier studies by Brown and Trlica (1977a, b), Detling (1979), Kemp and Williams (1980), Caldwell et al. (1981), and Monson et al. (1983) on photosynthesis and carbon allocation have shown major differences in carbon and nutrient allocation for crested wheatgrass and 2 major components of the shortgrass steppe, blue grama [*Bouteloua gracilis* (HBK) Lag.] and western wheatgrass (*Agropyron smithii* Rydb.). Power (1980) and Smoliak and Dormaar (1985) have shown differences in production between native grassland sites and crested wheatgrass communities, while Sims et al. (1978) and Sims and Singh (1978 a,b) have reported differences in plant structure and function between warm- and cool-season species in major grassland types in North America.

The objective of this study was to make a detailed comparison in the: (1) dynamics of above- and belowground live and dead biomass; (2) dynamics of litter deposition; and (3) above- and belowground net primary production between a stable 30-year-old crested wheatgrass monoculture and an adjacent native shortgrass prairie.

## Methods

### Study Site

The High Plains Grassland Research Station (HPGRS) is a USDA-ARS research station located 7 km west of Cheyenne, Wyo. The topography of the area is nearly level to undulating at an elevation of about 1,900 m. The soil of the experimental areas is an Ascalon fine, loamy, mixed mesic Aridic Arguistol (Young and Singleton 1977). The climate is semiarid-temperate with an average growing season of 120 days. The average annual temperature is 9° C with extremes ranging from 42° C to –36° C. Precipitation averages 365 mm with recorded extremes of 159 to 544 mm. Approximately 78% of the precipitation falls between 1 April and 30 September.

Blue grama is the dominant warm-season species in the native site, while western wheatgrass, needle-and-thread (*Stipa comata* Trin. & Rupr.), junegrass [*Koleria cristata* (L.) Pers.], and Sand-

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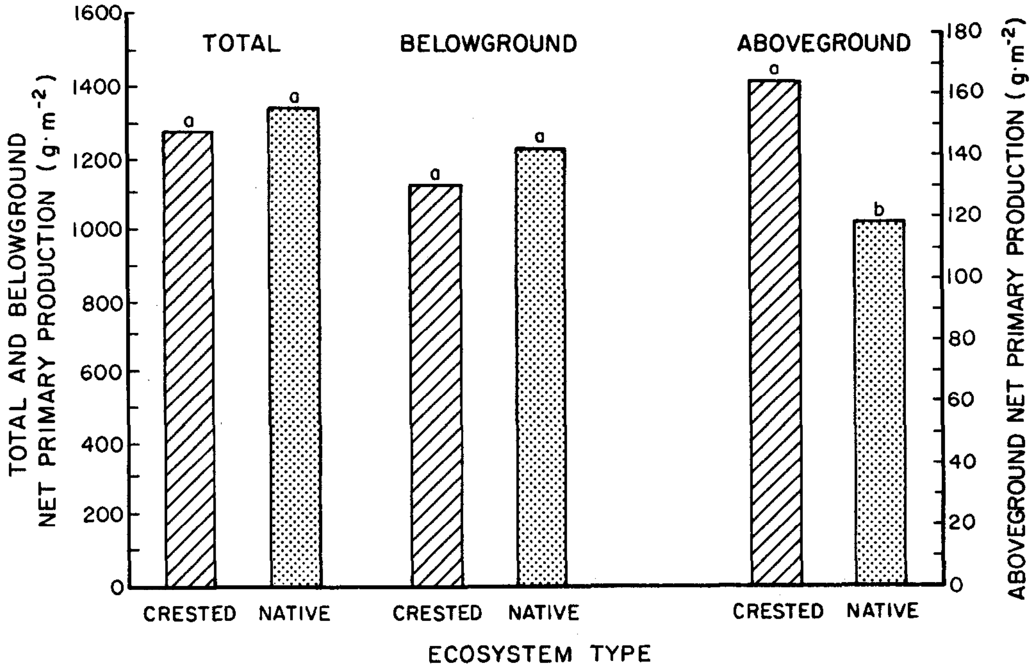

**Fig. 1.** *Aboveground, belowground, and total net primary production for crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at* $P \leq 0.01$. *Data collected in 1985 in southeastern Wyoming.*

berg bluegrass (*Poa secunda* Presl.) are the principal cool-season grasses.

The crested wheatgrass site, located within 0.8 km of the native site, was plowed in the 1930–1940 period and used for research plots for many years. The site was seeded to crested wheatgrass in the early 1950's and has not been tilled since that time. This site is still virtually a monoculture even though it is surrounded by native shortgrass prairie. Both sites were grazed at a moderate level in the past, but were fenced to exclude livestock grazing prior to this study.

### Design

The total size of each research area was about 0.3 ha. Four adjacent blocks were established in both the native shortgrass and the nearby crested wheatgrass systems in October 1984. Rectangular (1.5×32-m) plots within each block served as basic experimental units for vegetation sampling. The study was conducted as a randomized complete block design with 4 replications in each plant community.

### Sampling

Above- and belowground vegetation sampling was conducted throughout the 1985 growing season. Successive harvests were made in May, June, July, and October in both the native shortgrass and crested wheatgrass ecosystems. The July harvest date represented peak production based on phenological stage of development and root growth using the root periscope technique described by Richards (1984). Harvests were made utilizing 10 rectangular sample plots (0.4 × 1.25 m) randomly located in each plot.

Standing crop samples were clipped to ground level, and live material was separated by major species. Standing dead and litter were collected and treated as separate components. All samples were oven dried at 60° C for 48 hr before weighing.

Belowground biomass was estimated using 5-cm diameter cores. One core was taken from each sample plot to a depth of 1 m. Cores were divided into 5 depths in the crested wheatgrass system (0–5, 5–10, 10–20, 20–60, and 60–100 cm) and 4 depths in the native shortgrass system (0–5, 5–10, 10–30, and 30–100 cm). Root cores were divided differently for the 2 ecosystems because of differences in soil horizonation that resulted from plowing the crested wheatgrass site in the 1930's. Root samples were removed from the soil using a modified hydropneumatic elutriation system (Smucker et al. 1982). Root samples were separated into live and dead components using color and friability as the primary basis for separation. In addition, a subsample of roots from 1 core per block at each sampling date was placed in a 10-ml solution of 0.1% 2,3,5-triphenyl tetrazolium chloride (TTC) to better distinguish live and dead roots (Jacques and Schwass 1956). Root samples in TTC solution were incubated in the dark at room temperature for about 16 hr before separation. The basis for this technique is that live root cells reduce TTC (colorless) to formazan (red), while dead roots lack the ability to reduce TTC and therefore remain unstained. All roots were oven dried at 60° C for 48 hr before weighing. Root samples were ashed in a muffle furnace at 1,000° C for 5 hr and then re-weighed to express root biomass on an ash free basis.

Above- and belowground net primary production (ANPP and BNPP) were estimated following Sala et al. (1981a):

$$\text{ANPP} = \sum_{i=1}^{n} P_i + S_c + F_c \text{ where:}$$

$P_i$ = positive differences in 2 successive measurements of aboveground live biomass for species i. If the difference was negative, the value calculated was called specific net senescence ($S_i$).

$S_c$ = correction factor to account for the senescence process. It represents the increment of standing dead material not accounted for by the summation of

individual species specific net senescence ($\sum_{i=1}^{n} S_i$).

It consists of material that was produced but did not generate an increase in live biomass because it occupied the place left by material which was senesced during the same period. $S_c$ is calculated as:

$$S_c = \Delta^+ \text{ standing dead} - \sum_{i=1}^{n} S_{ci}$$

$F_c$ = correction factor to account for the decay process. It represents the increase in litter not accounted for by the decrease in standing dead. $F_c$ is calculated as:

$$F_c = \Delta^+ \text{ litter} + \Delta^- \text{ standing dead}$$

BNPP = RP + $RS_c$ where:

RP is the belowground equivalent of $\sum_{i=1}^{n} P_i$

$RS_c$ is the belowground equivalent of $S_c$

### Analyses

The data were analyzed using a modified split-plot ANOVA model with system in the whole plot and depth and date in the sub-plot. To account for auto-correlation of dates and depths, the degrees of freedom for depth and date were reduced after ANOVA (Geisser and Greenhose 1958, 1959). Tukey's Honest Significance Difference (HSD) or an F-protected LSD were used following a significant F-ratio at the $p \leq 0.05$ and $p \leq 0.10$ respectively.

## Results

Aboveground net primary production (ANPP) was significantly greater in the crested wheatgrass system compared to the native shortgrass system (Fig. 1). Belowground net primary production (BNPP) and total net primary production (TNPP), however, did not differ between the 2 sites (Fig. 1).

Aboveground live biomass increased in the crested wheatgrass system between May and July to a peak of 114 g/m², declining later to a low of 20 g/m² in October (Fig. 2). Aboveground live biomass in the native shortgrass ecosystem followed a similar pattern, but peaked in June at 75 g/m² (Fig. 2). The only significant difference in aboveground biomass between the 2 ecosystems was found in July (Fig. 2).

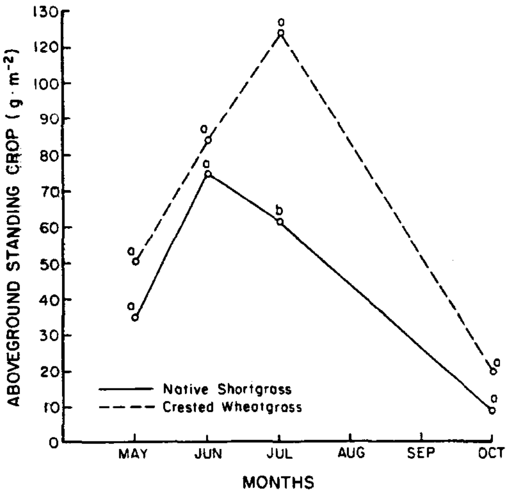

**Fig. 2.** *Aboveground live biomass for crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at $P \leq 0.05$. Data collected in 1985 in southeastern Wyoming.*

The native shortgrass ecosystem allocated approximately 8% of its fixed carbon to aboveground biomass, while the crested wheatgrass system allocated about 15% of its fixed carbon aboveground.

The standing dead component of each ecosystem followed a similar trend throughout the growing season (Fig. 3). The amount of standing dead in the crested wheatgrass system declined significantly during the first half of the growing season and then increased during the last half of the season. Standing dead was similar between the 2 systems in May and significantly lower in the crested wheatgrass ecosystem in June and July. At the end of the season, the crested wheatgrass system had significantly more standing dead than the native system (Fig. 3).

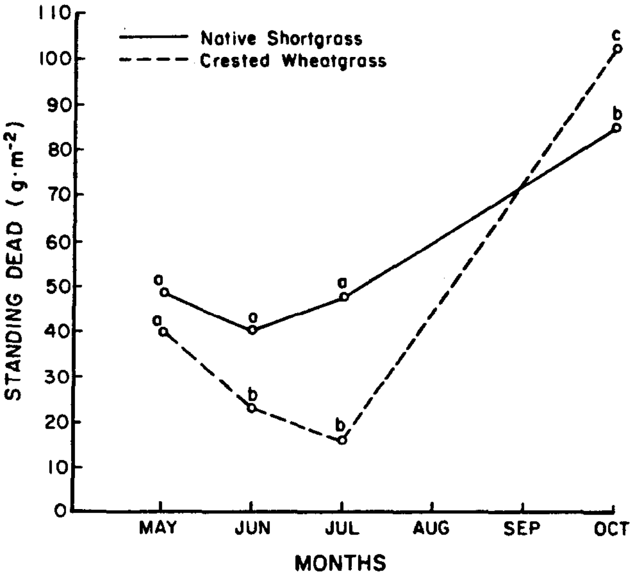

**Fig. 3.** *Standing dead biomass for crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at $P \leq 0.05$. Data collected in 1985 in southeastern Wyoming.*

Litter accumulation was significantly greater in the crested wheatgrass system compared to the native system throughout the growing season (Fig. 4). There was little variation in the amount of litter present in the native shortgrass system between May and October.

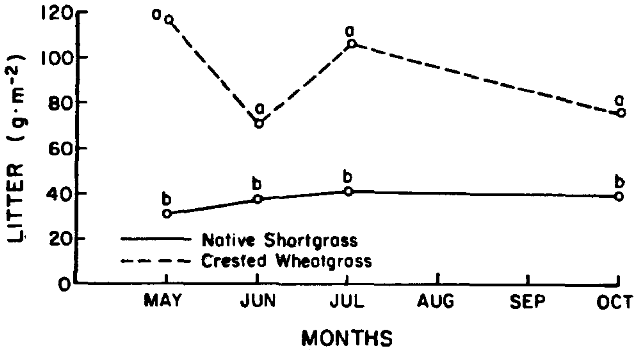

**Fig. 4.** *Litter production in crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at $P \leq 0.10$. Data collected in 1985 in southeastern Wyoming.*

Belowground live biomass was significantly greater in the native shortgrass ecosystem than in the crested wheatgrass system only at the start of the growing season (Fig. 5). Beginning in June, both systems followed similar trends (Fig. 5). Approximately 85% of the fixed carbon in the crested wheatgrass system was allocated below-

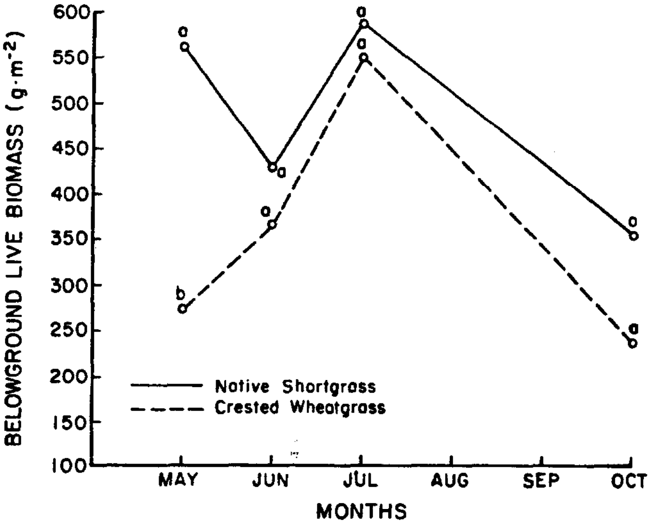

**Fig. 5.** *Belowground live biomass for crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at $P \leq 0.10$. Data collected in 1985 in southeastern Wyoming.*

ground, while the native system allocated belowground about 92% of the carbon it fixed during the growing season.

The dead component of the root mass was significantly greater in the crested wheatgrass system than the native system at each sampling period except in October (Fig. 6). Both systems followed similar trends with an increase in belowground dead material between May and June, followed by a steady decline until the end of the growing season.

Table 1 shows live root dynamics by depth within the 2 ecosystems. The pattern of root growth in the crested wheatgrass system was the same at all depths throughout the growing season (Table 1). Root biomass increased between May and July and then declined to the lowest level in October. The native shortgrass ecosystem displayed a different pattern or root growth in that there was an initial decline in root biomass at all but the deepest depth between May and June (Table 1). This was followed by an increase in root mass at all but the deepest depth between June and July. Root biomass then declined at all depths between July and October.

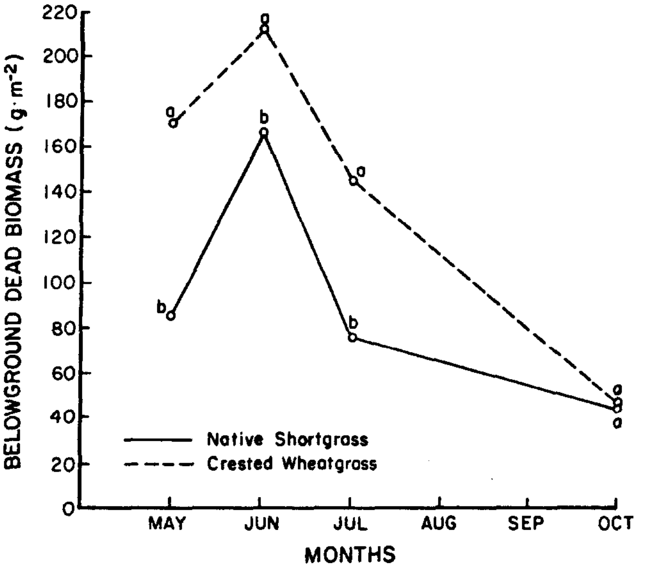

**Fig. 6.** *Belowground dead biomass for crested wheatgrass and native shortgrass ecosystems. Different letters denote significant differences at $P \leq 0.05$. Data collected in 1985 in southeastern Wyoming.*

## Discussion

The purpose of this study was to document differences in the structure and function of primary producers between a 30-year-old crested wheatgrass ecosystem and an adjacent native shortgrass prairie. The data idicate that the 2 systems differ in ANPP with the crested wheatgrass system having greater ANPP than the native system. However, BNPP was expected to be greater in the native system than the crested wheatgrass ecosystem as hypothesized by Power (1980) and Smoliak and Dormarr (1985), but this was not the case. In this study the crested wheatgrass site had BNPP and TNPP that was similar to the native site. Although BNPP was not different between the 2 systems, the native ecosystem had significantly greater live root biomass early in the growing season. This may be an indication that the major plant species in the native ecosystem were able to maintain a larger proportion of live roots during the winter period than did crested wheatgrass, or that the

**Table 1. Belowground live biomass ($g\ m^{-2}$) by depth for the native and crested wheatgrass systems. Data collected in 1985 in southeastern Wyoming.**

| | Native Ecosystem | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth | May | | June | | July | | October | |
| (cm) | $\bar{x}$ | (SE)* | $\bar{x}$ | (SE) | $\bar{x}$ | (SE) | $\bar{x}$ | (SE) |
| 0–5 | 183 | (44) | 75 | (32) | 166 | (47) | 90 | (65) |
| 5–10 | 107 | (55) | 68 | (22) | 136 | (50) | 79 | (34) |
| 10–30 | 152 | (28) | 100 | ( 36) | 156 | (9) | 114 | (41) |
| 30–100 | 118 | (36) | 186 | (133) | 129 | (41) | 74 | (36) |

| | Crested Wheatgrass Ecosystem | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth | May | | June | | July | | October | |
| (cm) | $\bar{x}$ | (SE)* | $\bar{x}$ | (SE) | $\bar{x}$ | (SE) | $\bar{x}$ | (SE) |
| 0–5 | 79 | (21) | 88 | (13) | 160 | (77) | 40 | (10) |
| 5–10 | 61 | (20) | 103 | (94) | 140 | (35) | 67 | (30) |
| 10–20 | 58 | (5) | 71 | (42) | 76 | (42) | 60 | (13) |
| 20–60 | 47 | (20) | 97 | (54) | 125 | (87) | 53 | (23) |
| 60–100 | 30 | (17) | 38 | (38) | 52 | (16) | 17 | (8) |

*SE = Standard error

native system actually began root production earlier in the season than crested wheatgrass.

Peak aboveground standing crop occurred in July for crested wheatgrass and June for the native ecosystem. Since the native ecosystem was dominated by a $C_4$ grass (blue grama) and the crested wheatgrass site was dominated by a $C_3$ species, we hypothesized that the native site would show peak production in July and the crested wheatgrass site in June (Kemp and Williams 1980). If total standing crop (above- and below-ground) is considered, both systems peaked in July, which was a result of the unusually high precipitation received at both sites in July (110 mm).

The crested wheatgrass ecosystem had a higher accumulation of aboveground dead material (standing dead and litter combined) in May, which was followed by a significant decline in June and an increase in July and October. This is compared with lower accumulations of aboveground dead material in the native ecosystem and minimal seasonal variation in litter accumulation. The lignin to nitrogen (N) ratio of the aboveground litter and total N immobilized in dead material were significantly higher in the crested wheatgrass system than in the native ecosystem (Ingham et al. 1988). Lower quality litter has lower decomposition rates and therefore may account for the higher accumulation of dead material in the crested wheatgrass system throughout the growing season. This lower quality litter may need to be weathered over winter before it will be rapidly decomposed by soil microflora. This mechanism may explain the pulse type decomposition even (reduction in standing litter) observed in early June (Fig. 4). The higher quality litter in the native ecosystem (Ingham et al. 1988, Uresk et al. 1975), on the other hand, may produce a more stable and constant decomposition rate, resulting in even distribution of litter throughout the growing season as was observed in the native system (Fig. 4). If this "pulse" vs. "even" decomposition hypothesis is true, then one can predict that the crested wheatgrass ecosystem may be more N limited than the native ecosystem at certain times of the growing season. Preliminary evidence in support of this hypothesis has been provided by Klein et al. (1987) with data that show net microflora N immobilization in the crested wheatgrass system but no immobilization in the native ecosystem in June 1985.

Power (1980) and Smoliak and Dormaar (1985) have shown that a substantial amount of carbon (70 to 80%) is allocated to the roots of native species such as blue grama, while crested wheatgrass allocated more carbon to the aboveground photosynthetic tissue. Our studies confirm even greater proportions in that the native system allocated approximately 92% of its carbon belowground and the crested wheatgrass system allocated about 85%. The crested wheatgrass system allocated nearly twice the amount of carbon to photosynthetic tissue than plants in the native ecosystem.

Approximately 74% of the root mass in the native system was found in the upper 30 cm while 68% of the root mass in the crested wheatgrass site was found in the upper 20 cm. This compares to a 75 to 90% range for both crested wheatgrass and native mixed prairie reported by Power (1980) for similar depths. Peak root growth for crested wheatgrass occurred in July at all depths, which corresponds to the wettest month of the growing season. The native shortgrass site displayed a different pattern of root growth when compared to crested wheatgrass and appeared to be more sensitive to the low amount of precipitation received between the May and June sampling (53 mm). The decline in root production during this period at all depths above 30 cm and an increase in root production at depths below 30 cm indicates that water may have been limiting root production in the native site at shallow depths during the later half of May and first half of June. Trlica and Biondini (1989) have shown that soil water depletion on this native shortgrass site was greater at shallower soil horizons than the crested wheatgrass site throughout the 1985 growing season. This suggests that the decline in root growth in the native ecosystem at depths less than 30 cm was due to lower precipitation during mid May to mid June.

The results from this study indicate that the 2 systems differ in biomass allocation and dynamics in the year studied. These differences and the persistence of both ecosystems might well represent alternative stable states that allow these 2 systems to exist under similar environmental conditions. Plant species from the native system have had little success in displacing crested wheatgrass over the past 30 years and crested wheatgrass has essentially been confined to the area originally seeded.

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# Seeded wheatgrass yield and nutritive quality on New Mexico big sagebrush range

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## Abstract

**Establishment, yield, and nutritional quality of 'Nordan' crested wheatgrass (*Agropyron desertorum* [Fischer ex Link] Schultes), 'Fairway' crested wheatgrass (*Agropyron cristatum* [L.] Gaertner), 'Arriba' western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve), 'Luna' pubescent wheatgrass (*Thinopyrum intermedium* subsp. *barbulatum* [Schur.] Barkw. and D.R. Dewey), and 'Largo' tall wheatgrass (*T. ponticum* [Pod] Barkw. and D.R. Dewey) were evaluated on big sagebrush range *(Artemisia tridentata* Nutt. *tridentata)* in northcentral New Mexico during a 5-year study. All the above wheatgrasses showed high initial densities and long-term persistence. Wheatgrass yields across years and seasons during the last 2 years of study averaged 760 kg/ha compared to forage yields of 355 kg/ha on surrounding ungrazed native rangeland. There were no differences ($P > .05$) among wheatgrasses in standing crop of current year's growth during spring, summer, or fall. Crude protein concentrations did not differ ($P > .05$) among wheatgrasses with seasonal advance. However, all the wheatgrasses showed a consistent decline in nutritional quality from spring to summer to fall. All the wheatgrasses we studied will provide high-quality, spring (mid-April to mid-June) forage for livestock. During summer, use of native range is advantageous because it contains a high component of warm season grasses and forbs. Interseeding shrubs in wheatgrass seedings could reduce protein supplementation costs in winter.**

**Key Words: range improvement, revegetation, seeding, nutrition**

The big sagebrush *(Artemisia tridentata* Nutt. *tridentata)* range type is of considerable importance in the western United States because of its large size (approximately 50 million hectares). Past heavy grazing by livestock has severely depleted this range type, particularly the southern portion in northern Arizona, northern New Mexico, and southern Colorado (Wooten 1908, Carlson 1969). After depletion, rest from grazing has showed little potential as a tool for range recovery of big sagebrush range in northcentral New Mexico (Holechek and Stephenson 1983), northwestern Arizona (Hughes 1980), and southwestern Idaho (Anderson and Holte 1980). These studies and others indicated sagebrush control is an important part of any program to increase forage production in this type.

Several studies have shown seeding of crested wheatgrass (*Agropyron desertorum* [Fischer ex Link] Schultes) can drastically increase forage production after brush control on big sagebrush range (Hull and Holmgren 1964, Springfield and Reid 1967, Frischknecht and Harris 1968). In northern New Mexico, Springfield and Reid (1967) reported crested wheatgrass is long-lived and productive when seeded on big sagebrush range. It provides succulent, nutritious forage earlier than most native grasses in the spring. This period is critical because nutritional needs of range cattle and sheep are highest then because of lactation. Other wheatgrasses may have potential for seeding in northern New Mexico. However, their use in range improvement programs depends largely on how their yield, persistence, and nutritional quality compares with the proven performance of crested wheatgrass. The objectives of our research were to compare the establishment, yield, and nutritional quality of 'Nordan' crested wheatgrass (*Agropyron desertorum* [Fischer ex Link] Schultes), 'Fairway' crested wheatgrass (*Agropyron cristatum* [L.] Gaertner), 'Largo' tall wheatgrass (*Thinopyrum ponticum* [Pod] *Barkw. and D.R. Dewey), Luna pubescent wheatgrass (T. intermedium* subsp. *barbulatum* [Schur.] Bark. and D.R. Dewey), and 'Arriba' western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve) on plowed big sagebrush range in northcentral New Mexico.

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## Study Area and Methods

The study area is 38 km northwest of Taos, New Mexico, in a 25 to 35-cm precipitation zone at 1,900 m elevation. About 50% of the precipitation occurs in winter and spring, and 40% occurs in summer; July and August are months of peak rainfall. Annual precipitation during the study (1982–1986) averaged about 30 cm, and none of these years were extremely wet or dry. Soils on the study site are classified Cumulic Haplaustols in the Manzano series. They are well drained and clay loam in texture.

Vegetation on the study area before plowing was dominated by big sagebrush (*Artemisia tridentata* Nutt. *tridentata)* with a sparse understory of blue grama (*Bouteloua gracilis* [H.B.K.] Griffiths) and western wheatgrass. Other important species found on the study area include fourwing saltbush (*Atriplex canescens* [Purs] Nutt.), galleta (*Hilaria jamesii* [Torr.] Benth.), winterfat (*Eurotia lanata* [Pursh] Moq.), plains prickly pear cactus (*Opuntia polyacantha* Haw.), scarlet globemallow (*Sphaeralcea coccinea* [Pursh.] Rydb.), Russian thistle (*Salsola iberica* Sennen and Pau), fireweed summercypress (*Kochia scoparia Bornm.), buckwheat (Eriogonum* sp.), ring muhly (*Muhlenbergia torreyii* [Kunth] A. Hitchc. Ex Bush.), and crested wheatgrass.

The area selected for study is controlled by the Bureau of Land Management. We believe it is typical of big sagebrush ranges in northern New Mexico in terms of precipitation, soils, vegetation, and grazing management. During the past 15 years the study area has been grazed by cattle at a moderate stocking rate (30 to 40% use of current year's growth) during the winter from early November until late March.

The 1-ha study site was offset-disk plowed twice and fenced with rabbit-proof fencing in August 1980. In May 1981, 2 blocks of ten 100-$m^2$ experimental units were established within the fenced area. Five seeding treatments were randomly assigned to plots in each block and applied to one-half of each block (split block design) on 6 July 1982, and to the other half on 6 July 1983. Before application of seeding treatments, plots were hand weeded to remove competition. Seeding treatments included 'Nordan' crested wheatgrass, 'Fairway' crested wheatgrass, 'Largo' tall wheatgrass, 'Luna' pubescent wheatgrass, and 'Arriba' western wheatgrass. Seed for 'Fairway' crested wheatgrass and 'Nordan' crested wheatgrass was obtained from Sharp Brothers Seed, Greeley, Colo. Seed for 'Luna' pubescent wheatgrass, 'Largo' tall wheatgrass, and 'Arriba' western wheatgrass was donated to us by Wendall Oaks, manager, Soil Conservation Service Plant Materials Center in Los Lunas, New Mexico. All wheatgrasses were broadcast seeded at 508 pure live seeds per square meter, the recommended rate for broadcast seeding (Vallentine 1980). Seed was covered by hand raking immediately after broadcasting.

Plant density data were collected 5 October 1982 and 1983 to evaluate initial wheatgrass establishment. Ten randomly placed 400-$cm^2$ quadrats were evaluated on each experimental unit on each sampling date. A complete randomized block analysis of variance was used to analyze each year of seeding. The least significant difference test protected by a significant F-test was used to compare treatment means. Yield of seeded and non-seeded species was evaluated by harvesting to ground level 10 randomly placed 400-$cm^2$ quadrats per plot on 6 May (Spring), 8 July (Summer), and 4 November (Fall) of 1985 and 1986. Only current year's growth was used for yield estimation. Past year's growth was hand separated from new growth. All yield estimates are expressed on a dry matter basis. Although half of each plot was seeded in 1982 and 1983, yield data for 1982 and 1983 seedings were not separated. A factorial split plot analysis of variance was used to evaluate these data. Years (1985, 1986), seasons (spring, summer, fall), and seeding treatments were used as factors. The least significant difference test protected by a significant ($P<.05$) F-test was used to compare treatments. Samples used for yield were ground to pass through a 1-mm Wiley Mill screen after weighing, evaluated for total nitrogen by the Kjeldahl procedure, and analyzed for phosphorus by the Molybdovanadate method (AOAC 1984). Insoluble unavailable nitrogen (ADIN), neutral detergent fiber, acid detergent fiber, and acid detergent lignin were determined using the methods of Goering and Van Soest (1970). Silica was determined by AOAC (1984) procedures. The statistical analysis applied to these data was the same as that used for yield data.

Part of the north and south ends of the fenced area was left unplowed in 1980 so herbage yield on ungrazed, untreated native range could be evaluated. These 2 plots were 900 $m^2$ each. Forage yield was evaluated on 6 May, 8 July, and 4 November of 1985 and 1986 by harvesting to ground level twenty 400-$cm^2$ quadrats on each plot. Only current year's growth was used to evaluate yield.

## Results and Discussion

Although the 5 wheatgrasses differed in initial seedling densities (Table 1), yield data indicate no differences in long term establishment (Table 2). Our data are consistent with those of Hull and Holmgren (1964) in Idaho and Springfield (1965) in New Mexico who found wheatgrass stands with widely varying numbers of initial seedlings all produced essentially the same yields, size of plants, and numbers of plants per unit area 5 years after planting. These studies did indicate plant numbers differed greatly between treatments during the first 3 years after planting.

**Table 1. Density (#/$m^2$) of wheatgrass at the end of the growing season on plots seeded on 6 July 1982 and 1983.**

| Treatment | 1982[1] seeding | 1983[1] seeding |
|---|---|---|
| 'Fairway' crested wheatgrass | 145 | 45 |
| 'Luna' pubescent wheatgrass | 65 | 8 |
| 'Arriba' western wheatgrass | 152 | 88 |
| 'Nordan' crested wheatgrass | 172 | 79 |
| 'Largo' tall wheatgrass | 188 | 68 |
| SE | 23 | 16 |
| LSD.05 | 58 | 42 |

[1] Data were collected 6 October 1982 and 1983.

**Table 2. Factorial split plot analysis of variance used to evaluate influences of species, season and year on wheatgrass yield.**

| | DF | Wheatgrass | Other grasses | Forbs | Total Yield |
|---|---|---|---|---|---|
| Species | 4 | NS | * | NS | NS |
| Season | 2 | ** | NS | NS | ** |
| Species × season | 8 | NS | NS | NS | NS |
| Year | 1 | NS | ** | NS | ** |
| Species × year | 4 | NS | * | NS | NS |
| Year × season | 2 | ** | NS | NS | * |
| Species × season × year | 8 | NS | NS | NS | NS |

*,**Significant at the 0.05 and 0.01 levels, respectively.
NS = Non-significant ($P>.05$).

Wheatgrass yield or total forage yield did not differ among wheatgrass species plots ($P>.05$) (Table 2). When data were pooled across years and seasons, yields were 579, 838, 718, 866, and 796 kg $ha^{-1}$ for 'Fairway' crested, 'Nordan' crested, 'Largo' tall, 'Arriba' western, and 'Luna' pubescent wheatgrass, respectively. Wheatgrass yield increased ($P<.05$) as season advanced from spring to summer in 1985. However in 1986 yield increased ($P<.05$) between summer and fall. Both 1985 and 1986 were years of slightly above-

**Table 3. Yield (kg/ha) of wheatgrasses and total forage, averaged over wheatgrass species, as affected by the interaction of season and year.**

| | 1985 | | | 1986 | | | | |
|---|---|---|---|---|---|---|---|---|
| Forage component | Spring | Summer | Fall | Spring | Summer | Fall | SE | LSD.05 |
| | kg/ha | | | | | | | |
| Wheatgrasses | 153 | 1026 | 1160 | 546 | 710 | 964 | 82 | 177 |
| Total Forage | 155 | 1100 | 1162 | 899 | 924 | 1296 | 146 | 315 |

average total precipitation. In 1985 much of the spring–summer rainfall occurred in May and June while in 1986 it was more evenly distributed throughout the period between early April and late August. Our observations and data indicate all the wheatgrasses we studied grow during both spring and summer in northern New Mexico.

Crude protein concentrations showed no differences ($P>.05$) among wheatgrass species (Table 4). Acid detergent insoluble nitrogen as a percentage of total nitrogen provides a measure of nitrogen that is unavailable to the animal. It did not differ ($P<.05$) among wheatgrass species (Table 4). Nutritional quality of all wheatgrasses declined with seasonal advance (Table 5).

All 5 wheatgrass species met the crude protein requirements (NRC 1984) for growing heifers and steers (minimum wt 255 kg) gaining 0.5 kg per day (8.5 – 9%, dry matter basis) and lactating cows (8 – 8.5%, dry matter basis) between mid-April and mid-June. Crude protein requirements of a dry, pregnant, mature cow (5.9%, dry matter basis) would probably not be met during fall and winter, even by selective grazing. Protein supplementation during this period is advised when wheatgrasses are used as winter feed.

An alternative to protein supplementation during winter would be to interseed shrubs such as fourwing saltbush and winterfat in wheatgrass stands. Current year's growth of these shrubs have crude protein levels well above 8% (dry matter basis) during winter (Otsyina et al. 1982, Jeffers 1985). Otsyina et al. (1982) reported, during a 20-day grazing trial, sheep on winter range in Utah lost about 5% of their body weight on a pure crested wheatgrass pasture, but only 1% on wheatgrass pastures containing the above shrubs. Gade and Provenza (1986), working in Utah, reported sheep grazing pure crested wheatgrass had winter diets averaging 5.7% crude protein, compared to 8.0% when grazing crested wheatgrass interspersed with shrubs. In southern Idaho, Monsen (1980) found interseeded fourwing saltbush did not reduce wheatgrass density or herbage yields, and was readily accepted as a winter forage species by cattle. Both fourwing saltbush and winterfat are common on big sagebrush ranges in northern New Mexico and appear well suited for interseeding with wheatgrasses. Unpublished studies we have conducted in northern New Mexico on similar sites have shown poor establishment of fourwing saltbush and winterfat when seeded in mixtures with wheatgrasses. In the big sagebrush type it appears shrubs are best established in grass stands by interseeding rather than direct seeding (Plummer et al. 1968, Giunta et al. 1973, Van Epps and McKell 1977).

Native big sagebrush range in northern New Mexico typically

**Table 4. Factorial split plot analysis of variance used to evaluate influences of species, season and year on wheatgrass chemical composition.**

| | DF | Crude Protein | Acid detergent insoluble Nitrogen | Neutral detergent Fiber | Acid detergent Fiber | Acid detergent Lignin | Phosphorus | Silica |
|---|---|---|---|---|---|---|---|---|
| Species | 4 | NS | NS | NS | NS | NS | ** | NS |
| Season | 4 | ** | ** | * | * | ** | ** | * |
| Species × season | 8 | NS | NS | NS | NS | NS | NS | * |
| Year | 1 | NS | NS | NS | * | NS | NS | NS |
| Species × year | 4 | NS | NS | NS | NS | NS | NS | NS |
| Year × season | 2 | ** | ** | ** | ** | ** | ** | ** |
| Species × season × year | 8 | NS | NS | ** | ** | NS | NS | NS |

*,** Significant at the 0.05 and 0.01 levels, respectively.
NS = Non-significant ($P>.05$).

**Table 5. Chemical composition (dry matter basis) averaged over wheatgrass species, as affected by the interaction of season and year.**

| | 1985 | | | 1986 | | | | |
|---|---|---|---|---|---|---|---|---|
| Forage component | Spring | Summer | Fall | Spring | Summer | Fall | SE | LSD.05 |
| | % | | | | | | | |
| Crude protein | 14.5 | 7.2 | 5.5 | 12.3 | 9.3 | 5.6 | 0.35 | 0.75 |
| Acid detergent insoluble nitrogen[1] | 4.8 | 8.0 | 12.6 | 5.4 | 8.0 | 17.0 | 0.79 | 1.69 |
| Neutral detergent fiber | 60.3 | 67.5 | 71.6 | 62.1 | 64.7 | 67.0 | 0.58 | 1.24 |
| Acid detergent fiber | 29.8 | 35.1 | 38.6 | 37.5 | 38.5 | 45.7 | 0.82 | 1.76 |
| Acid detergent lignin | 3.7 | 6.4 | 6.9 | 3.9 | 5.1 | 5.3 | 0.21 | 0.45 |
| Phosphorus | 0.25 | 0.15 | 0.09 | 0.21 | 0.16 | 0.10 | 0.005 | 0.01 |
| Silica | 7.0 | 5.9 | 6.9 | 8.1 | 7.2 | 11.9 | 0.40 | 0.86 |

[1] % of total nitrogen.

has a high component of blue grama and galleta. These grasses have crude protein concentrations above 9% (dry matter basis) during July and August (Pieper et al. 1978, Jeffers 1985). Native range also contains several palatable forbs (e.g., scarlet globemallow) with crude protein levels above 12% (dry matter basis) during summer (Jeffers 1985). Thus, when native big sagebrush range and wheatgrass seedings are available, the native range is best used during the months of July, August, and September.

'Luna' pubescent wheatgrass was superior to other wheatgrass species in phosphorus concentration (Tables 4, 5). Phosphorus values for data pooled across seasons and years for 'Fairway' crested, 'Luna' pubescent, 'Arriba' western, 'Nordan' crested, and 'Largo' tall wheatgrass were 0.17, 0.18, 0.14, 0.15, and 0.16%, respectively. The least significant difference value ($P<.05$) was 0.01%.

Lactating beef cows, growing heifers, and growing steers require about 0.20 to 0.25% phosphorus (dry matter basis) (NRC 1984). This requirement was met by all the wheatgrasses in spring. However, during summer (June through September), phosphorus was below NRC recommendations. During fall and winter, phosphorus concentrations were below those required for maintenance (.15%) (NRC 1984). The use of a phosphorus supplement appears advisable if these wheatgrasses are grazed in fall and winter. Cook (1946) found that cattle and sheep showed no response to phosphorus supplements in late spring when grazed on crested, tall, and pubescent wheatgrass pastures, although analyses of forage samples showed phosphorus was deficient. Apparently, livestock in his study used the phosphorus they stored during early spring to carry them over the deficient period in late spring.

Both neutral and acid detergent fiber concentrations showed wheatgrass species year by season interactions ($P<.05$) (Table 4). The erratic and inconsistent nature of fiber differences among wheatgrass species with seasonal advance and between years prevents drawing any meaningful conclusions about the superiority of particular wheatgrass species. Fiber data do reflect the decline in forage quality with seasonal advance (Table 5). Neutral detergent fiber concentration shows a high negative association with forage intake (Van Soest 1982). Forage digestiblity is negatively associated with acid detergent fiber concentration (Van Soest 1982).

Total forage yield on the native range plots across seasons and years averaged 355 kg/ha. Yield of western wheatgrass, blue grama, other grasses, and forbs were 275, 43, 15, and 22 kg/ha, respectively. In contrast, average total yield for seeded wheatgrass plots were 923 kg/ha. Wheatgrasses, other grasses, and forbs averaged 760, 133, and 30 kg/ha, respectively. These data show wheatgrass seeding nearly tripled forage yields, compared to those of native range.

Studies from nearby locations by McDaniel and Balliette (1986) show chemical control of big sagebrush using tebuthiuron pellets resulted in forage yields after 3 years similar to those on plots seeded to wheatgrasses in our study. They also found blue grama production was similar on treated and untreated plots. Forb production was low (less than 50 kg/ha) and little influenced by herbicide application.

In central Utah, Cook (1966) evaluated the long-term effectiveness of converting big sagebrush ranges to wheatgrasses. He found both crested and pubescent had good initial establishment and long-term persistence. During spring, cattle and sheep had superior gains on rangelands seeded to these grasses, compared to native range. During summer after mid-July, gains dropped off sharply on wheatgrass seedings, presumably caused by lower nutritive quality as the wheatgrass matured.

Tall wheatgrass was also evaluated in the Cook (1966) study. During spring, cattle had higher gains on crested and pubescent wheatgrasses than on tall wheatgrass. However, after mid-July, cattle performed better on tall wheatgrass. Crested wheatgrass yields were highest, tall wheatgrass yields were intermediate, and pubescent wheatgrass yields were lowest. Results from Cook (1966) cannot be completely applied to our study because central Utah has more spring precipitation and less summer precipitation than northcentral New Mexico. However, average total annual precipitation in both studies was nearly the same.

## Conclusions

Our 5-year study of 'Nordan' crested wheatgrass, 'Fairway' crested wheatgrass, 'Arriba' western wheatgrass, 'Largo' tall wheatgrass, and 'Luna' pubescent wheatgrass shows all these wheatgrasses have good establishment, yield, and nutritive quality in northcentral New Mexico. None of the wheatgrasses showed any definite superiority in productivity or nutritional quality during any season. All these wheatgrasses are well suited to spring grazing. A limitation of our study is that only 1 location was evaluated. However, empirical observations show all 5 wheatgrasses grow well in northcentral New Mexico and are palatable to livestock in spring. During summer, native range will better meet the nutritional needs of livestock than wheatgrass seedings because of a high component of blue grama and galleta. In winter, including interseeded shrubs in wheatgrass stands could reduce supplemental feed costs.

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# Silicon in C-3 grasses: Effects on forage quality and sheep preference

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## Abstract

**Silicon in forage reduces dry matter digestibility and may reduce grazing preference. Two studies were conducted with the following objectives: (1) to evaluate a method of determining grazing preference, and (2) to characterize the distribution and solubility of silicon in 31 accessions of C-3 grasses and relate these traits to grazing preference and estimated forage digestibility. Forage samples were clipped at the beginning of each 7 to 10-day grazing period corresponding to 6 phenological stages of the *Agropyron* sp. Samples were washed and analyzed for acid detergent fiber (ADF), neutral detergent fiber (NDF), and silicon in ADF and NDF residues. Leaf silicon concentrations increased from the vegetative to seed-ripe stage. Genera were aligned into 3 groups based on the increase in leaf silicon concentration with advancing phenological age. Silicon concentrations in leaves of *Agropyron, Pseudoroegneria,* and *Thinopyrum* increased at nearly twice the rate of those in *Critesion, Hordeum, Leymus* and *Psathyrostachys. Elymus* leaves contained higher concentrations of silicon at the vegetative stage than the other groups, but the accumulation rate was intermediate. About 32% of total leaf silicon remained in NDF and 76% in ADF residues at the vegetative stage. These insoluble portions of silicon increased with aging. Preference was positively related to estimated dry matter digestibility at boot and anthesis, but was not related to fiber or silicon measurements. Leaf harshness was negatively related to preference at seed-ripe stage. Further progress in characterizing the role of silicon in C-3 forage grasses should be possible by studying a representative species from each group.**

**Key Words: soluble silicon, insoluble silicon, harshness score, digestiblity, *Agropyron,* ADF, NDF, crested wheatgrass, wildrye**

Silicon (Si) is absorbed as monosilicic acid [$Si(OH)_4$] by plant roots, transported throughout the plant, and deposited primarily in the epidermal cells, stoma, and trichomes of leaves (Jarvis 1987). Some of this silicon remains in soluble forms. Most silicon, however, is incorporated into or onto the cell wall structure or precipitated with other elements to form amorphous crystalline deposits called phytolyths (Blackman and Bailey 1971, Moore 1984). Silicon uptake is largely passive, i.e., taken up with the transpiration stream. However, recent evidence has demonstrated that some energy mediated uptake of silicon occurs in grasses (Jarvis 1987).

The incorporation of silicon into scabrous tissue is perceived as a defense mechanism against some insects (Moore 1984) and possibly against grazing by large herbivores (McNaughton et al. 1985). Silicon taken up by forage plants may also reduce rumen microbial accessibility to cell wall structure (Smith and Nelson 1975, Harbers et al. 1981), thereby reducing apparent digestibility of herbage (Van Soest and Jones 1968, Smith et al. 1971). Mika (1986) reported that a water-soluble form of silicon inhibited activity of cellulases and other digestive enzymes, whereas the insoluble form was chemically inert. Thus, exogenous silicon from ingested soil or dust adhering to herbage probably has little direct effect on digestibility.

Silicon, in addition to affecting forage quality, has been implicated in animal health (Jones and Handreck 1967). In some early research, urolithiasis in steers was related ($r = 0.56$) to silicon concentrations in Montana forage grasses (Parker 1957). However, Bailey (1976) later reported that frequency of urinary calculi encountered in Alberta cattle was inversely related to urine volume and water intake. This cause and effect relationship has not been resolved.

Smith et al. (1972) have reported weight gains in wether but not in ewe lambs provided 800 mg $SiO_2L$ in their drinking water. Similar sex by silica interactions were also reported for rats (Smith et al. 1973), suggesting a physiological or hormonal response to the added silicon. These findings have not, however, been confirmed by other research groups.

The distribution of silicon in C-3, semiarid forage grasses and the effect of silicon on forage quality and animal preference have not been determined. These studies were initiated to develop methods and test the following hypotheses: (1) Silicon concentration in leaves of temperate grasses increases with advancing physiological maturity; (2) Rates of silicon accumulation differ among grass genera; (3) Leaf-silicon concentrations relate positively to leaf harshness and negatively to animal preference; (4) Silicon is more soluble in NDF than in ADF extractions; and (5) Silicon reduces forage dry matter digestibility.

Information on concentration and distribution of silicon in grasses will be useful for breeding and managing grasses for higher

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digestibility, or conversely, for greater insect/herbivore resistance.

## Materials and Methods

### Study I

This phase of the experiment evaluated a nondestructive method of determining animal preference for forage species. A nursery was established with 9 species (Table 1) planted in a randomized, complete block having 4 replications. The plots were 2 × 18 m and grasses were seeded in the fall on 20-cm row spacings. The nursery was established on a Portneuf silt loam (coarse, silty, Durixerollic calciorthid) soil near Kimberly, Idaho.

Supplementary irrigation water and 45 kg N/ha were applied the next summer to promote good growth. Border areas were clean cultivated. Test plants were mowed the following September. Five nonlactating ewes grazed the regrowth in late October and early November of 1980. Five different nonlactating ewes grazed the nursery at the seed-ripe stage (15 August to 15 September 1981). Eight lambs (each approximately 60 kg) grazed the nursery from 7 through 20 May 1982, 26 May through 8 June 1982, and 15 September through 9 October 1982, at the boot, anthesis, and seed-ripe stages of *Agropyron*, respectively. Preference scores were subjectively rated by the degree of utilization. Utilization of each grass was estimated daily by 3 observers. Daily ratings ranged from 0, not grazed, to 10, heavily grazed. The values were summed over the grazing period, calculated as the percent of the most preferred accession for each phenological stage (corresponding to the *Agropyrons*), and subjected to analysis of variance (SAS 1985).

### Study II.

A second nursery of 31 accessions, representing 26 species (Table 2), was established on the same area described for Study I. Six of the species were also evaluated in Study I. The individual plants were started in Conetainers[1] in a greenhouse and transplanted to the field in early April. The experimental design was a randomized complete block with 1 replication. Plants were placed on 1-m spacings with each accession occupying a 6 × 6-m plot (36 plants per plot). The area was fertilized with 45 kg N/ha and irrigated to establish good growth. Border areas were tilled to eliminate other plants. Plants were clipped to 5-cm stubble height in March of the following year to eliminate any remaining dry stalks.

Leaf harshness was ranked at the seed-ripe stage. This subjective scoring was based on 0, very soft, to 10, very coarse and sharp. The scoring was performed by 3 observers passing the leaves through their hands. Scores were added to make up the harshness value for each grass.

Six, 4- to 5-year-old ewes, having good teeth, were placed in the nursery for 7 to 10-day periods at times corresponding to each phenological stage of the *Agropyron* species. Drinking water, but not shade, was available within the enclosure. Preference was determined as described in Study I.

Subsamples of aerial herbage were harvested at a 5-cm stubble height prior to each grazing period. Harvested samples were agitated for 1 to 2 minutes in distilled water containing Prell[1] detergent in a concentration of 1 ml/L. Samples were then rinsed in distilled water for another 1 to 2 minutes, dried at 60° C for 24 hours, and ground through a Wiley[1] mill to pass a 40-mesh screen.

Silicon in grass tissue was determined by the molybdenum blue colorimetric method (Fox et al. 1969). Silicon was also determined in residues of acid detergent fiber (ADF) and neutral detergent fiber extractions [NDF, (Goering and Van Soest 1970)]. A barley-straw reference sample was analyzed with each batch of unknowns to determine precision. All data were reported on a dry matter basis.

Insoluble silicon in the ADF and NDF residues was calculated by the equation: Insoluble Si = (mg Si/mg residue)*(mg residue/g leaf). Estimated dry matter digestibility (EDMD) of leaves was calculated by the formula: EDMD in mg/g = 1000 – [mg NDF/g + mg NDF-soluble Si/g].

Data were subjected to analysis of variance and regression using SAS Institute's general linear models procedure, including the Duncan's multiple range mean comparison procedure (SAS 1985). The phenological stages from vegetative through seed-ripe were assigned values of 0 through 4, respectively. A *t*-test was used to evaluate differences between the slope coefficients (b) of silicon concentration regressed against phenological stage, for each genotype (Steele and Torrie 1960). Grass nomenclature follows the genomic system of classification (Dewey 1984). Accessions were further designated by variety (e.g., 'Nordan') or chromosome number (e.g., 2n=28).

## Results and Discussion

### Study I.

#### *Preference Methodology*

Preference scores for each stage and species were significantly different ($P<.001$) as shown in Table 3. The species by stage

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[1] Reference to commercial products and services is made with the understanding that no discrimination is intended and no endorsement by the U.S. Department of Agriculture is implied.

**Table 1. Accessions and sheep preference as a percent of the most preferred accession (Study I).**

| | | Relative sheep preference by year and phenological stage | | | | |
|---|---|---|---|---|---|---|
| | | 1982 | 1982 | 1981 | 1982 | 1980 |
| | Genus & specie | Boot | Anthesis | Seed-ripe | Seed-ripe | Regrowth |
| | | Relative Preference[1] (%) | | | | |
| Indian ricegrass[2] | *Oryzopsis hymenoides* Roem. & Schult. 'Nezpar' | 99 a | 100 a | 24 d | 47 cd | 100 a |
| Orchardgrass | *Dactylis glomerata* L. 'Pomar' | 100 a | 84 b | 54 bc | 77 b | 98 a |
| Intermediate wheatgrass | *Thinopyrum intermedium* Host 'Tegmar' | 81 b | 64 d | 42 cd | 22 e | 67 b |
| Crested wheatgrass | *Agropyron desertorum* Fisch. 'Nordan' | 69 b | 59 de | 26 d | 45 cd | 70 b |
| Creeping foxtail | *Alopecurus arundinaceus* Poir. 'Garrison' | 70 b | 73 c | 100 a | 100 a | 15 d |
| RS hybrid | *Elytrigia repens* L. × *Pseudoroegneria spicata* Pursh | 45 c | 50 f | 27 d | 34 cd | 24 d |
| Russian wildrye | *Psathyrostachys juncea* Fisch. | 45 c | 54 ef | 74 b | 66 c | 6 d |
| Tall fescue | *Festuca arundinacea* Schreb 'Alta' | 24 d | 1 g | 25 d | 14 e | 60 bc |
| Regar brome | *Bromus biebersteinii* Roem. & Schult. 'Regar' | 21 d | 0 g | 42 cd | 18 e | 44 c |

[1] Means in same column followed by the same letter are not significantly different ($P<.01$) as determined by Duncan's multiple range test.
[2] Indian ricegrass was so highly preferred that it was entirely consumed in some periods.

**Table 2. Nomenclature of accessions and sheep preference as percent of the most preferred accession at 4 phenological stages (Study II).**

| Nomenclature | | | Relative ranking by preference score | | | | |
|---|---|---|---|---|---|---|---|
| | | | Phenological stage[4] | | | | |
| Common | Traditional | Proposed[1] | 1 | 2 | 3 | 4 | Mean[2] |
| Orchard grass | *Dactylis glomerata* L. 'Latar' | | 94 | 100 | 100 | 87 | 95 a |
| Orchard grass | *Dactylis glomerata* L. 'Pomar' | | 100 | 95 | 76 | 88 | 90 ab |
| Mountain rye[3] | *Secale montanum* Guss. | | 83 | 88 | 87 | 100 | 90 ab |
| Bearded wheatgrass[3] | *Agropyron caninum* L. | *Elymus caninus* | 80 | 98 | 94 | 88 | 88 abc |
| Wheatgrass[3] | *Agropyron tsukushiense* Honda | *Elymus tsukushiensis* | 81 | 57 | 78 | 91 | 88 abc |
| Smooth brome | *Bromus inermis* Leyss. 'Manchar' | | 80 | 88 | 87 | 90 | 86 abcd |
| Bulbous barley[3] | *Hordeum bulbosum* L. | | 83 | 82 | 67 | 100 | 83 abcd |
| Pubescent wheatgrass | *Agropyron trichoporum* Host 'Topar' | *Thinopyrum intermedium* | 59 | 81 | 73 | 83 | 74 abcde |
| Squirreltail[3] | *Sitanion hystrix* Rafin. (Utah) | *Elymus elymoides* | 69 | 75 | 44 | 86 | 69 bcdef |
| Tall fescue | *Festuca arundinacea* Schreb 'Alta' | | 52 | 81 | 58 | 80 | 68 bcdef |
| Standard crested wheatgrass[3] | *Agropyron desertorum* Fisch. 'Nordan' | | 61 | 68 | 49 | 78 | 64 cdef |
| Wheatgrass | *Agropyron libanoticum* Hackel | *Pseudoroegneria libanotica* | 63 | 60 | 51 | 81 | 64 cdef |
| Indian ricegrass | *Oryzopsis hymenoides* Roem. & Schult. 'Nezpar' | | 57 | 67 | 56 | 72 | 63 defg |
| Fairway crested wheatgrass[3] | *Agropyron cristatum* L. (2n=28) | | 57 | 70 | 40 | 78 | 62 defg |
| Squirreltail[3] | *Sitanion hystrix* Rafin. (Oregon) | *Elymus elymoides* | 30 | 72 | 40 | 84 | 62 defg |
| Fairway crested wheatgrass[3] | *Agropyron cristatum* L. 'Fairway' | | 46 | 72 | 44 | 72 | 59 efgh |
| Regar brome | *Bromus biebersteinii* Roem. & Schult. 'Regar' | | 56 | 70 | 42 | 64 | 58 efgh |
| Wheatgrass | *Agropyron podperae* Nabelek | *Thinopyrum podperae* | 46 | 49 | 53 | 84 | 58 efgh |
| Russian wildrye[3] | *Elymus junceus* Fisch. (2n=28) | *Psathyrostachys juncea* | 41 | 77 | 44 | 64 | 57 efgh |
| Wild barley[3] | *Hordeum stenostachys* Godron | *Critesion stenostachys* | 54 | 74 | 31 | 62 | 55 efghi |
| Tall wheatgrass[3] | *Agropyron elongatum* Podp. (2n=70) | *Thinopyrum ponticum* | 37 | 63 | 49 | 71 | 55 efghi |
| Great Basin wildrye[3] | *Elymus cinereus* Trin. | *Leymus cinereus* | 11 | 77 | 53 | 74 | 54 efghi |
| Russian wildrye[3] | *Elymus junceus* Fisch. (2n=14) | *Psathyrostachys juncea* | 22 | 84 | 40 | 67 | 53 efghi |
| Beardless-bluebunch[3] | *Agropyron inerme* Scrib. & Smith 'Whitmar' | *Pseudoroegneria spicata* | 33 | 61 | 31 | 52 | 44 fghij |
| Bluebunch wheatgrass[3] | *Agropyron spicatum* Pursh (2n=14) | *Pseudoroegneria spicata* | 39 | 23 | 24 | 67 | 38 ghij |
| Wild barley[3] | *Hordeum violaceum* Schenk (2n=28) | *Critesion violaceum* | 48 | 37 | 0 | 57 | 36 hij |
| Bluebunch wheatgrass | *Agropryon spicatum* Pursh (2n=28) | *Pseudoroegneria spicata* | 24 | 25 | 24 | 54 | 32 ijk |
| Wildrye[3] | *Elymus fragilis* Boiss. | *Psathyrostachys fragilis* | 48 | 37 | 0 | 28 | 28 jk |
| Durar hard fescue | *Festuca ovina* var. *longifolia* L. 'Durar' | | 15 | 32 | 11 | 45 | 26 jkl |
| Wildrye[3] | *Elymus karataviensis* | *Leymus karataviensis* | 7 | 25 | 2 | 10 | 11 kl |
| Salina wildrye[3] | *Elymus salina* M.E. Jones (2n=56) | *Leymus salinus* | 4 | 7 | 2 | 7 | 51 |

[1] Nomenclature follows that proposed by Dewey (1984). Accessions are listed in sequence of overall preference ranking.
[2] Means with the same letter are not significantly different ($P<.01$) as determined by Duncan's multiple range test.
[3] Accessions selected for ADF and NDF determinations.
[4] Phenological stages are: 1, 2, 3, and 4 representing vegetative, boot, anthesis, and seed-ripe, respectively.

interaction was also significant ($P<.001$), suggesting that relative differences among species were not consistent at the different stages of growth. Indian ricegrass (Table 1) was highly preferred and the stand was greatly weakened. Orchard grass was also highly preferred except at the seed-ripe stage. Creeping foxtail and Russian wildrye were the more preferred species at the seed-ripe stage. This is probably because both species grew more actively and remained greener throughout the season. Preference changed with season of use.

**Table 3. Analysis of variance of relative[1] preference for 9 species at boot, anthesis, seed-ripe (2 years) and regrowth phenological stages (Study I).**

| Source | df | Mean squares |
|---|---|---|
| Blocks (B) | 3 | 563** |
| Species (Sp) | 8 | 8316** |
| Sp × B | 24 | 100 |
| Stage (St) | 4 | 1600** |
| St × Sp | 32 | 2984** |

[1] Relative preference is calculated as the percent of the maximum preference score (mean for an accession) for that grazing period.

There was a significant block effect ($P<.01$) which was attributed to animal behavior (Table 3). Drinking water and the gate through which the sheep entered at the beginning of the grazing trials were located near the corner of the nursery. Preference scores were highest for the block nearest this corner and lowest for the block farthest away, even though the distance was less than 50 m. Nevertheless, the preference scoring consistently ranked the species in the same order, as shown by the nonsignificant species × block interaction. This established the repeatability of the scoring system which was then used in the subsequent evaluation of the 31 accessions in Study II.

### Study II.

#### *Silicon in Leaves*

In each accession silicon concentrations in leaves increased linearly as the grasses matured. Silicon accumulation rates were not different between species within a given genera ($P<.05$). The accumulation rates (b) for individual accessions and for accessions grouped by genera were different from zero ($P<.05$) in all cases (data not shown). Data were then composited by genera and submitted to regression analysis. Coefficients were then compared with each other in a pair-wise testing for similarities. Based on these tests the 8 genera were aligned into 3 distinct groups (Table

**Table 4. Regression of silicon accumulation (mg/g) in grass leaves on phenological stage, where x (0–4) represents the phenological stages vegetative, boot, anthesis, dough, and seed-ripe, respectively.**

| Genera | Degrees of freedom | a (intercept) | b (slope) | r | Standard error of Intercept | Standard error of Slope |
|---|---|---|---|---|---|---|
| Group I[1] | 37 | 17 | 7.9** | .79** | 2.4 | 1.0 |
| Group II[2] | 43 | 16 | 3.3** | .58** | 1.7 | 0.7 |
| *Elymus* | 18 | 21 | 6.1** | .71** | 3.5 | 1.5 |

**Values significantly different from zero at $P<.01$.
[1]Group I genera include *Thinopyrum, Agropyron,* and *Pseudoroegneria.*
[2]Group II genera include *Critesion, Hordeum, Psathyrostachys* and *Leymus.*

4). Slopes for genera *within* a group were not different ($P<.06$); however, slopes between groups were different ($P<.05$).

Group 1, contained the *Pseudoroegneria, Thinopyrum,* and *Agropyron* genera (traditional wheatgrasses). This group accumulated silicon at a faster rate in leaves ($P<.05$) than group 2, which contained the *Critesion, Hordeum, Psathyrostachys* and *Leymus* genera (wild barley and wildrye) (Table 4). The *Elymus* group was intermediate in silicon accumulation rate and did not differ ($P<.05$) from *Thinopyrum* and *Agropyron* genera in group 1 or *Critesion* in group 2. Leaves of groups 1 and 2 had similar concentrations of silicon at the vegetative stage of maturity with values of 17 and 16 mg Si/g, respectively. However, at the seed-ripe stage these concentrations had increased to 49 and 29 mg Si/g, respectively. At the vegetative state ($x$=0) the *Elymus* genus contained 21 mg Si/g and this increased to 45 mg Si by the seed-ripe stage.

The wheatgrasses (group 1) generally reach physiological maturity quicker than wildryes (with the exception of Russian wildrye) and wild barleys (group 2). Group 1 plants tend to have fewer leaves, which on the average may be chronologically older than leaves on group 2 plants. These older leaves of group 1 plants may have higher concentrations of silicon because passively-transported silicon (taken up as a soluble component in the transpiration stream) had a longer time to accumulate in the leaves. In contrast, group 1 may differ from group 2 because of differences in active transport (requiring energy) of silicon from roots to the leaves. This latter hypothesis may be very real, but was outside the scope of the present study.

## Silicon in Plant Parts

Comparison of silicon concentrations in plant parts could only be done at the soft dough stage. Concentrations were highest in leaves, intermediate in inflorescences, and lowest in stems (Fig. 1). This may be the same order as water loss by transpiration.

Silicon could be distributed differently in other gramineae. Handreck and Jones (1968) reported silicon concentrations and contents of various plant parts in oats. Leaves had higher concentrations of silicon than stems. The various parts of the mature inflorescence contained up to 5 mg Si/g tissue and about 70% of the total silicon in the aboveground portions of the oat plant. The large amount of silicon in the oat panicle may occur because it has an open structure and large surface area to mass ratio. Indian ricegrass (not shown) has an anatomical structure similar to oats and contained 25, 15, and 9 mg Si/g in the leaves, inflorescence and stem, respectively, at the anthesis stage. These silicon values were higher than those reported by Handreck and Jones (1968) for oats, but lower than those shown for equivalent plant parts of many other grasses (Fig. 1). These relatively lower silicon levels may explain the often higher grazing preference for Indian ricegrass when compared with many other grasses.

Silicon concentrations in leaves of *Pseudoroegneria* (bluebunch wheatgrass and related species) were greater ($P<.05$) than in leaves of Hordeum and Leymus genera (Fig. 1). Silicon concentrations and differences in silicon in heads and stems of the several genera tested are also shown in Figure 1.

### *Silicon in Leaf Fiber Residues*

The proportion of total leaf silicon recovered in leaf fiber residues increased with increasing plant maturity (Table 5). The amount of silicon retained in the ADF residue (Table 5) was

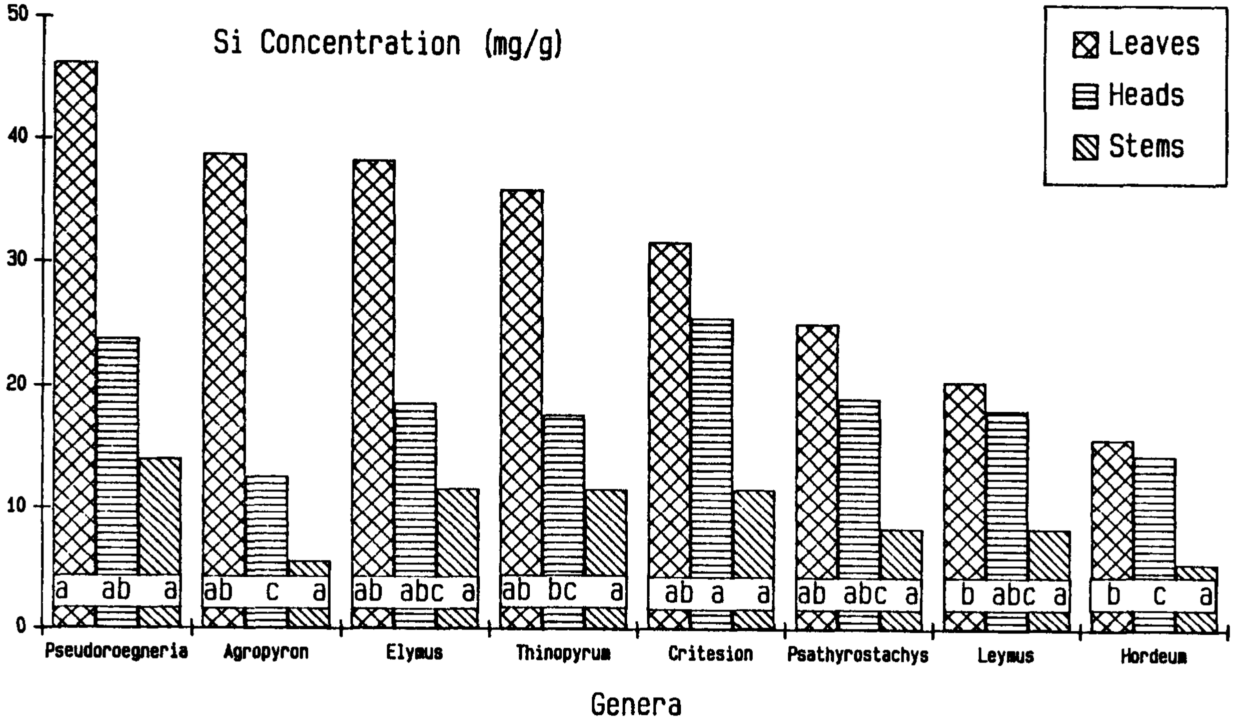

**Fig. 1.** *Silicon concentrations (mg/g plant part) of leaves, heads, and stems of 8 grass genera at the soft dough stage. Silicon concentrations, within a given plant part, that do not have a common small letter are different* ($P<.05$).

Table 5. Forage quality traits and silicon distrubtion[1] in leaves of 20 grass accessions[2] harvested at each of 6 phenological stages.

| Phenological stage | Acid detergent fiber (ADF) | Neutral detergent fiber (NDF) | Estimated dry matter digestibility | Silicon | | |
|---|---|---|---|---|---|---|
| | | | | Total | ADF insoluble | NDF insoluble |
| | (mg/g dry leaf tissue) | | | | | |
| Vegetative | 210 ± 34 | 440 ± 47 | 544 ± 41 | 17 ± 4.7 | 13 ± 3.7 | 5.6 ± 1.9 |
| Boot | 280 ± 35 | 470 ± 59 | 495 ± 46 | 22 ± 6.1 | 16 ± 4.2 | 6.5 ± 2.3 |
| Anthesis | 320 ± 29 | 500 ± 37 | 455 ± 39 | 29 ± 7.0 | 21 ± 5.1 | 9.8 ± 3.7 |
| Soft dough | 350 ± 31 | 540 ± 38 | 427 ± 40 | 30 ± 11.2 | 24 ± 9.3 | 10.8 ± 5.6 |
| Seed-ripe | 390 ± 32 | 580 ± 52 | 378 ± 50 | 40 ± 13.1 | 30 ± 10.8 | 15.0 ± 6.1 |
| Regrowth | 270 ± 33 | 470 ± 72 | 502 ± 77 | 22 ± 7.4 | 21 ± 6.1 | 7.9 ± 2.8 |

[1] Means ± standard error of mean.

[2] Accessions are those designated by the "3" footnote on Table 2.

generally twice that in the NDF residue. This reflects the polymerization of more plant silicon upon exposure to strong acid (pH about 1) in the ADF extractant. Silicon was the main component in ashed-ADF residue [360 ± 47 (SE) mg/g] and NDF residue [276 ± 79 (SE) mg/g], across all species and phenological stages. Total leaf silicon and that insoluble in the ADF or NDF extractions were significantly correlated ($P<.01$) at all except the regrowth stage, where correlations were only significant at $P<.15$ level.

### Silicon Ingestion by Ruminants

These results and others by Bailey (1976) and Parker (1957) illustrate that herbivores can consume large amounts of silicon that has been taken up by plants. Endogenous silicon (taken up by the plant) may be more active in reducing forage quality (Mika 1986) than exogenous silicon occurring as dust on plants or that associated with ingested soil. Cattle can potentially ingest large amounts of soil (Mayland et al. 1977) which can provide up to 300 g $\text{Si} \bullet \text{cow}^{-1} \bullet \text{day}^{-1}$. This silicon is probably insoluble at the physiological pH of the rumen. Jones and Handreck (1967) noted that only a minor portion of ingested exogenous silicon is dissolved in passing along the alimentary tract. They did not provide any detailed information about the solubilization of soil-silicon in the rumen.

### Analytical Reference

The barley-straw reference sample analyzed with each batch of unknowns contained a mean of 19.7 ± 1.2 (SE) mg Si/g. This value is compared with 20.0 ± 0.8 (SE) determined by another laboratory using the same procedure. Therefore the analysis of silicon was considered to be within acceptable precision tolerances.

### Estimated Digestibility

Concentrations of anti-quality factors (ADF, NDF, and silicon) in grass leaves increased with advancing plant maturity (Table 5). Leaf EDMD decreased as physiological age of the plant increased.

Silicon may act as a structural component or "varnish" on cell walls. This would prevent or delay accessibility of rumen microorganisms to cell contents (Harbers et al. 1981). Van Soest and Jones (1968) suggested that both total silicon and, more importantly, soluble silicon decreased in vivo organic matter digestibility. Smith and Urquhart (1975) reported in vitro digestibility of semiarid grasses was decreased by silica. Water-soluble silicon inhibits the activity of cellulases and other digestive enzymes, whereas insoluble forms are chemically inert (Mika 1986, Shimojo and Goto 1985). Authors are generally in agreement that silicon decreases forage quality, but few of the studies have considered the contributions of silicon simply as an inert component. To accomplish this, digestibility should be reported on an ash-free basis.

It is our opinion that soluble silicon might complex with an element, like zinc, limiting its supply to rumen microorganisms. This elemental deficiency would limit microbial growth and production of cellulytic enzymes, and ultimately reduce organic matter digestibility (R.J. Moir, Univ. of Western Australia, Nedlands, personal communication).

### Sheep Preference

Relative preference scores of the 31 accessions (Study II) and 5 growth stages were subjected to analysis of variance. Preference scores differed between species and within growth stages ($P<.01$), which supports the premise that preference changes with season of use (Table 2). 'Latar' orchardgrass was the most preferred accession when compared across all stages. 'Nezpar' Indian ricegrass was only moderately preferred, although in Study I it was highly preferred. The difference in seasons, age and class of animals, and the experimental design (row seeding versus spaced plants) might explain some differences in preference. The grazing periods were chosen to correspond to the phenological growth stages of the *Agropyrons*. Not all plants were at the same phenological stage during grazing periods. By describing the periods in this manner, there was undoubtedly some bias added to the ranking of the other grasses. It is interesting that bluebunch wheatgrasses were generally less preferred than the crested wheatgrasses. Preference scores of some of the wildryes were less than expected. It is evident that interactions between preference and sites, soils, seasons, and different classes of livestock occur.

In general, genotypes expected to have low preference by cattle (authors' experience) were also ranked low by sheep in this study. Conversely, those highly preferred by cattle were also highly preferred by sheep. There are several exceptions to the ranking noted either in comparison with data in Tables 1 and 2 or from experience. For example, the rankings of Indian ricegrass and the 2 squirreltails seem to be different than expected. The Russian wildryes, *Psathyrostachys juncea,* were moderately preferred at the boot stage. Relative preference doubled from the vegetative to the boot stage for both Russian wildryes, and then dropped in preference at anthesis to about the same level as at boot stage, contrary to Study I. The wildryes now classified as *Leymus* had consistently low preferences across all growth stages. We are unable to explain these findings.

### Silicon and Preference Score

Preference scores in Study II were not related to soluble or insoluble silicon in the ADF and NDF residue, nor to total silicon at any of the phenological stages. Preference scores were similarly not related to total silicon in Study I. Thus, sheep preference for these grasses was a function of factors other than silicon components. In Study II, EDMD values were positively related ($P<.05$) to preference scores across all accessions at the boot and anthesis stages. Variation in EDMD values accounted for 48 ($P<.001$) and 32% ($P<.01$) of the variability in preference at the 2 growth stages, respectively.

**Harshness and Preference**

Leaf:stem ratios at anthesis and soft dough averaged .51 ± .34 (SE) and .55 ± .27 (SE), respectively. These ratios were not significantly different from those at the seed-ripe stage. The leaf:stem ratios were positively related with preference scores accounting for 13 ($P<.10$) and 27% ($P<.05$) of the variation in scores at the anethesis and soft dough stages, respectively. Murray (1984) also evaluated sheep utilization of many of these same accessions and found that preference was positively related to the proportion of leaves present. Utilization decreased as the proportion of reproductive tillers increased.

Harshness scores for 22 accessions were negatively related to preference scores at seed-ripe stage ($r= -.69$, $P<.05$). Harshness was determined at a single growth stage in this study, but has been used in other studies to evaluate palatability. Hanna et al. (1974) showed that cattle preferred the trichomeless pearl millet over accessions with trichomes. Marten (1970), in his review of forage palatability, noted that several orchard grass breeders had selected against harshness or, more specifically, the silicified dentations on the leaf edges. The harhness score method combined with other aspects of palatability could have potential for preference estimation and plant selection of C-3 grasses.

## Conclusions

Silicon concentrations in leaves increased with advancing phenological maturity. Silicon concentrations were greatest in leaves, intermediate in inflorescences, and least in stems.

Leaf silicon concentrations of some genera increased at distinctly different rates as plants matured. Whether this was a result of a greater rate of uptake in the first group, or whether the second group continued to develop new leaves with a net lower concentration of silicon, was not determined.

Ratings of sheep grazing preference for the grasses varied according to phenological stage. These findings support the conclusion that preference can change with season of use. Preference scores, at specific phenological stages, were positively related to the EDMD and leaf:stem ratio of the accessions and negatively related to estimates of leaf harshness. Preference was not related to measures of silicon or ADF and NDF and their respective silicon contents.

Silicon was nearly twice as soluble in the NDF extractant as in the ADF extractant. This is attributed to polymerization of silicon at the very low pH of ADF extraction. The NDF extractant is buffered at near neutral and thus is more like the rumen conditions. Nevertheless, it would be interesting to determine the solubility of forage silicon fractions in vivo.

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# American jointvetch improves summer range for white-tailed deer

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## Abstract

**Livestock production is limited on upland forested sites in the Southeast by the low quality of native range. Supplemental feeding in the form of improved pastures has dramatic effects on herd production and individual animal performance. Similar relationships probably exist for wild herbivores; and food plots with highly palatable, high quality forages might improve animal performance for wild as well as domestic herbivores. Sixteen American jointvetch *(Aeschynomene americana)* plots ($\bar{x} \pm$ SE = 0.21 ± 0.02 ha) were established in pastures adjacent to mixed pine (*Pinus* spp.)—hardwood habitat on a 980-ha tract in southeast Louisiana to estimate the influence of summer-fall food plots on diets of free-ranging white-tailed deer *(Odocoileus virginianus)*. American jointvetch accounted for 32.4% of the dry matter in deer diets and occurred in 90.7% of fecal pellet groups. Individual deer consumed about 0.45 kg (ovendry weight) of American jointvetch per day over 2 growing seasons. For all sampling periods, crude protein, phosphorus, in vitro digestible dry matter, and calcium levels were higher ($P \leq 0.006$) in supplemented diets compared to native diets. Calcium:phosphorus ratios in supplemented diets were lower ($P \leq 0.0001$) (improved) compared to ratios in native diets. Dietary crude protein, phosphorus, in vitro digestible dry matter, and calcium were positively associated ($P \leq 0.0001$) with proportions of American jointvetch in deer diets. Warm-season food plots should be considered as viable options for intensive deer management programs in parts of the southeastern United States.**

**Key Words:** ***Aeschynomen americana*, American jointvetch, Louisiana, microhistological analysis, nutrition, *Odocoileus virginianus*, supplemental feeding, white-tailed deer.**

The white-tailed deer is the most popular and economically valuable game species in the United States. Changing land-use practices leading to decreased habitat availability (Newsom 1984:376) and increasing demand for hunting (Dudderar 1981) indicate that intensive management may be needed to maintain healthy, productive deer populations. Artificially increasing carrying capacities may be justified to satisfy future demands for sport hunting.

Nutrient levels in native forages on southern upland range are often insufficient for maximum deer growth and reproduction during summer and fall (Lay 1957, Short 1969, Blair et al. 1977, Sowell et al. 1985, Thill et al. 1987). Crude protein (CP) and phosphorus (P) deficiencies limit individual deer growth and population size in parts of the southeastern United States (Lay 1969, Short 1969, Thill and Morris 1983, Thill et al. 1987).

Although food supplies are least abundant during winter, late summer may be a critical period in the South due to heat, low forage quality, and reduced forage intake (Goodrum and Reid 1962, Hafez 1967, Ockenfels and Bissonette 1982, Blair et al. 1984). The need for high quality forage during summer is compounded by high metabolic costs of growth and reproduction. Gestation (which can extend into October) (Roberson and Dennet 1967), lactation, and subsequent recovery for breeding create a need for high-quality forage (Verme 1963, 1967; Short 1969). Bucks need high-quality forage for antler development (Gore 1984, Jacobson 1984). Fawn survival and growth are affected by the ability of does to produce milk and the quality of forage as fawns are weaned (Verme 1963, Murphy and Coates 1966, Meyer et al. 1984).

Reasons for supplemental feeding include diet supplementation on poor-quality range, increased diet variety, improved survival of stocked game, protection of agricultural crops, improved harvest rates, and improved relations between landowners, game managers, and sportsmen (Halls and Stransky 1968). Ozoga and Verme (1982) found that captive deer supplemented year-round with a pelleted ration increased growth rates, antler development, and productivity.

American jointvetch is a warm-season tropical legume (Moore and Hilman 1969) that is highly palatable to deer and produces large quantities of high-quality forage (Moore 1978, Keegan and Johnson 1987). Weight gains and antler development of captive yearling bucks grazing American jointvetch improved compared with bucks fed simulated native diets (S.R. Schultz, La. State Univ., unpub. data). However, effects of warm-season food plantings on free-ranging deer are not known.

We selected American jointvetch as a model forage to determine impacts of warm-season food plots on free-ranging deer in upland, mixed pine-hardwood habitat and to estimate nutritional improvements that may occur in diets containing supplemental forage.

## Study Area

The study was conducted on Blairstown Plantation, about 5 km south of Clinton, East Feliciana Parish, Louisiana. The study area consisted of about 190 ha of open, native-grass pasture dispersed among 790 ha of forest. Cattle were continuously grazed on most pastures throughout summer at about 1 animal unit per ha. Pasture management for cattle consisted of summer mowing for weed control and occasional prescribed burning in late winter. Based on annual line transect surveys (Hayne 1949), fall deer populations were about 1 deer/6.6 ha and 1 deer/5.5 ha in 1985 and 1986, respectively.

Soils are in the Providence and Lexington series of the Loessial Hills association. These soils are moderately well to well-drained, acid, silt loams occurring on gentle to moderately sloping uplands (SCS Soil Survey of Idlewild Experiment Station, Clinton, Louisiana 1970). Natural fertility of these soils is low with respect to crop and pasture production. Soil tests performed at the Louisiana Agr. Exp. Sta. Soil Testing Laboratory, Baton Rouge, indicated low levels of exchangeable phosphorus (P) (7.4 ppm), extractable potassium (K) (34.7 ppm), and calcium (Ca) (609 ppm), and soil pH (4.5–5.9). Forested areas were typical of mixed pine-hardwood upland forests in southeast Louisiana. Keegan (1988) reported common vegetative cover that occurred on the study area.

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## Methods

### Food Plot Establishment

Johnson et al. (1987) established 14 plots on the study area for cool-season forage research in 1983 and we established another plot in May 1985. Plots occurred in pastures at forest edges; American jointvetch was presumably available to most, if not all, deer on the study area. Plot size ranged from 0.08 to 0.34 ha ($\bar{x}$ = 0.21, $S\bar{x}$ = 0.02). Plots were fenced with 3-strand barbed wire to exclude cattle but not deer, or located in areas where cattle did not range.

We planted 15 plots (3.0 ha) to American jointvetch (11.2 kg/ha) in early June 1985. A well-disked seedbed was broadcast with inoculated seed and harrowed lightly to insure seed-soil contact. Annual fertilization rates were about 225 kg/ha of 8-24-24, and dolomitic limestone was applied at a rate of 2,240 kg/ha in spring 1986 (Peevy 1972). Cattle destroyed 1 plot in 1985 so it was deleted from analyses, leaving about 2.8 ha.

Optimum grazing potential for American jointvetch occurs when plants are grazed to about 36 cm (Hodges et al. 1982) and removal equals about 50% of the standing crop (Moore and Hilman 1969). According to these criteria, several plots were underutilized in 1985. Therefore, 8 plots were removed from the American jointvetch management system in 1986. We estimated that production from 8 plots would be sufficient for herd supplementation. In May 1986, we disked 7 of the original 15 plots to improve germination from natural reseeding and reduce grass competition. A new plot was established to maintain distribution over the study area.

Broadleafs and grasses were reduced with applications of 2,4-D (2.3 L/ha) and flauzifop butyl (1.1 kg/ha), respectively, where particular weed problems were judged to be critical with regard to American jointvetch survival.

### Food Plot Production and Deer Use

We randomly placed a deer exclosure (about 1.2 $m^2$) in the center of each plot in late June. A standard clipping frame (0.94 $m^2$) was used to define sampling areas inside and outside each exclosure. We sampled during the last week of each month from July through November 1985 and from June through October 1986. Exclosures were randomly relocated after each sampling period. We did not sample in November 1986 due to American jointvetch senescence.

Plants were clipped with hand shears about 1 cm above the soil, oven-dried at 100° C for 25 hours, and weighed to the nearest 0.1 g. Differences between paired samples were used to estimate average forage removal by deer during the previous month. We calculated season-long production by adding the amount of standing forage clipped to ground level inside an exclosure during the last month to amounts of forage removed by deer during all previous months.

### Fecal Collection and Analyses

We collected 30 fresh fecal pellet groups ($\geq$5 individual pellets) each month during each period that food plots were sampled. Pellet groups were collected at random throughout forested areas to estimate proportions of the deer population using food plots. Pellets were assumed to be fresh if they had not completely dried following defecation.

We used microhistological analysis (Johnson et al. 1983) to determine botanical composition of fecal pellet groups. Pellets in an individual group were oven-dried, ground in a Wiley mill (1.0-mm mesh screen), soaked in a 50:50 household bleach-water solution for 15 minutes to remove plant pigments, rinsed over a 120-mesh sieve, and placed in a blender for 45 seconds at high speed to disperse clumped plant fragments. We mounted about 0.1 g of each sample on each of 5 slides for examination at 125-power magnification and examined 20 fields per slide for a total of 100 fields per pellet group.

Relative particle densities were calculated for each taxa and used as estimators of relative dry weight of each forage ingested (Sparks and Malechek 1968, Johnson 1982). We averaged relative particle densities among all samples within a month (*n* = 30) for monthly estimates and among all samples within a year (*n* = 150) for season estimates. We realize that microhistological analyses do not provide perfect estimators of herbivore diets. However, it is the only nondestructive method available and is useful because material representing large numbers of different meals from many animals can be collected. Mushrooms and mast can be adequately identified and quantified (Johnson et al. 1983). We choose to ignore mushrooms because mycelia and spores were rarely observed in the samples and the extra effort needed to quantify mushrooms was not justified based on our microscopic observations. Furthermore, our primary objective was to estimate whether deer use of American jointvetch was large or small rather than to precisely estimate its exact contribution to the diets.

### Forage Quality

Samples of probable native-forage taxa used by deer (Matthews and Glasgow 1981, Thill 1983) and American jointvetch were collected randomly from the study area at the end of each month. We collected the most recent plant growth to simulate deer feeding behavior (Short 1967, Thill and Morris 1983). Forage taxa were collected separately and oven-dried at 100° C for 24 hours. Four 15-g samples of each taxa were ground in a Wiley mill (1.0-mm mesh screen) and analyzed for CP, in vitro digestible dry matter (IVDDM), P, and Ca at the Forage Analysis Laboratory of the Southeast Research Station following methods of the Association of Official Analytical Chemists (1970). Determinations of IVDDM used bovine rumen fluid (Nelson et al. 1972) to provide reliable approximations of IVDDM by deer rumen fluid (Robbins et al. 1975, Palmer et al. 1976).

We estimated nutrient concentrations for plant taxa that occurred in fecal pellets but were not collected for analyses from Causey (1964), Short et al. (1975), Ensminger and Olentine (1978), Everitt and Gonzalez (1981), Pearson et al. (1982), DeLany (1985), and Hoveland et al. (1986). We applied average nutritive values of forage groups (forb or browse) from similar habitat (Pearson et al. 1982) when values for any taxon were not reported in the literature. Although these estimates may have varied from nutrient levels actually available on our study area, differences would not significantly affect our data because estimates from the literature were used for less than 5% of the diet composition.

Dietary CP, IVDDM, P, and Ca in deer diets were estimated monthly by multiplying percentage dry weight of each forage in a fecal sample by the corresponding nutrient concentration and summing values among forage taxa in each fecal sample. We averaged among all fecal samples for each month (*n* = 30) and season (*n* = 150) to estimate mean nutrient levels obtained by deer. We estimated nutrient concentrations in diets composed solely of native forages (native diets) similarly, under the assumption that availability of American jointvetch did not affect relative amounts of individual native forages consumed by deer.

### Statistical Analyses

We used paired *t*-tests (Steel and Torrie 1980:102) to determine whether nutrient concentrations varied significantly between diet types (native versus supplemented) within sampling periods. We used the general linear models procedure (GLM) of SAS (1985:433-506) to determine if dietary nutrient concentrations varied significantly with proportions of American jointvetch in deer diets within years. Data are reported as means and standard errors. We accepted significance at the 0.10 level of probability of Type I error.

## Results and Discussion

### Food Plot Production and Deer Use

The proportion of fecal pellet groups containing American jointvetch averaged 90.7% over both years (Table 1). Results are similar to those for deer use of cool-season food plots on the same study area (Johnson et al. 1987).

**Table 1. Percentage of deer fecal pellet groups ($n = 30$/month) containing American jointvetch, and proportion of botanical fragments in fecal pellets made up by American jointvetch (% dry weight), Blairstown Plantation, East Feliciana Parish, Louisiana, June through November, 1985 and 1986.**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Frequency (%) | Proportion of fragments in fecal pellets (%) | Frequency (%) | Proportion of fragments in fecal pellets (%) |
| Jun | | | 86.7 | 18.0 ± 3.2 |
| Jul | 83.3 | 29.4 ± 3.4 | 90.0 | 29.8 ± 3.4 |
| Aug | 96.7 | 42.9 ± 4.1 | 90.0 | 28.3 ± 3.3 |
| Sep | 83.3 | 34.2 ± 5.0 | 100.0 | 49.3 ± 4.3 |
| Oct | 86.7 | 39.2 ± 5.7 | 100.0 | 37.3 ± 3.7 |
| Nov | 90.0 | 15.7 ± 3.2 | | |
| Season | 88.0 | 32.3 ± 2.1 | 93.3 | 32.5 ± 1.8 |

Average monthly yields of American jointvetch (ovendry weight) were similar between 1985 (2,239 ± 553 kg/ha) and 1986 (2,273 ± 252 kg/ha) (Table 2). However, average monthly deer use almost doubled from 1985 (578 ³ 199 kg/ha) to 1986 (1,129 ³ 221 kg/ha). Increased use per plot in 1986 may have been caused by decreased available hectarage. Deer apparently concentrated their foraging efforts on fewer plots.

**Table 2. Ovendry production and deer use (kg/ha) of American jointvetch on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 ($n = 14$ plots) and 1986 ($n = 8$ plots).**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Production | Use | Production | Use |
| Jul | 412 ± 111 | 248 ± 78 | 1698 ± 440 | 1107 ± 320 |
| Aug | 2386 ± 278 | 1347 ± 195 | 2845 ± 271 | 1742 ± 187 |
| Sep | 1598 ± 353 | 526 ± 226 | 2503 ± 401 | 964 ± 197 |
| Oct | 3657 ± 416 | 463 ± 141 | 2047 ± 307 | 704 ± 193 |
| Nov | 3143 ± 387 | 305 ± 122 | | |
| Season[a] | 5727 ± 350 | 2889 ± 429 | 5860 ± 709 | 4517 ± 625 |

[a] Total production equals production of last month plus the amount of forage consumed by deer in previous months.

American jointvetch accounted for about 32% of summer-fall deer diets each year. Peak dietary occurrence of American jointvetch coincided with peak use of standing forage in 1985, but not in 1986. The discrepancy between apparent use and dietary occurrence may have been caused by changes in deer feeding behavior. During hot weather, deer may reduce total forage intake (Hafez 1967, Ockenfels and Bissonette 1982) while concentrating foraging efforts on food plots (Byford 1970). Diets would contain relatively high proportions of American jointvetch even though apparent forage use was relatively low. Changes in availability and palatability of native foods probably altered deer feeding behavior as well.

Total biomass of American jointvetch consumed by the deer population was about 8,200 kg dry forage in 1985 and 7,800 kg in 1986 (ovendry weight), respectively. The deer population was about 120 and 144 animals in 1985 and 1986, respectively. Based on these estimates, daily consumption of American jointvetch averaged about 0.45 kg/animal (ovendry weight) in 1985 and (July through November) and about 0.44 kg/animal in 1986 (June through October). These data support the previous decision to reduce the number of food plots from 14 in 1985 to 8 in 1986.

Our estimate of American jointvetch use derived from clip-plot analyses (0.45 kg/deer/day) is about 32% of the estimated 1.4 kg daily dry forage intake of deer (Fowler et al. 1968). This value is similar to our estimates from microhistological analyses, supporting our contention that estimates of supplemental forage use are reasonable.

### Diet Composition and Forage Quality

We identified 51 plant taxa during microhistological analyses of fecal pellets. Fourteen taxa that occurred in <5% of all pellet groups were classified as miscellaneous forb or miscellaneous browse. Final estimates of diet composition included 37 taxa and 3 miscellaneous categories (Table 3). Diets contained more American jointvetch than any other taxon and introduced species made up more than 50% of season-long deer diets. Other introduced species in diets were Japanese honeysuckle *(Lonicera japonica)*, privet *(Ligustrum sinense)*, corn *(Zea mays)*, soybean *(Glycine max)*, and subterranean clover *(Trifolium subterraneum)*.

**Table 3. Botanical composition (% dry weight) of summer-fall deer diets, Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986, estimated by microhistological analysis of fecal pellets.**

| Forage taxa[a] | 1985 | 1986 |
|---|---|---|
| American jointvetch | 32.3 ± 2.07 | 32.5 ± 1.81 |
| Japanese honeysuckle | 10.4 ± 0.82 | 14.5 ± 0.87 |
| Rattan-vine *(Berchemia scandens)* | 6.7 ± 0.48 | 2.7 ± 0.35 |
| Yellow jessamine *(Gelsemium sempervirens)* | 5.3 ± 0.31 | 4.8 ± 0.30 |
| Unknown | 5.1 ± 0.25 | 5.4 ± 0.23 |
| Oak leaves (*Quercus* spp.) | 3.9 ± 0.50 | 4.2 ± 0.40 |
| Privet | 3.6 ± 0.23 | 3.3 ± 0.26 |
| Miscellaneous browse | 3.5 ± 0.45 | 2.5 ± 0.32 |
| Corn (kernels) | 3.5 ± 0.56 | 1.2 ± 0.39 |
| Partridgeberry *(Mitchella repens)* | 3.4 ± 0.27 | 2.9 ± 0.28 |
| Oak mast | 3.3 ± 0.46 | 2.8 ± 0.59 |
| Soybean | 3.0 ± 0.76 | 0.4 ± 0.08 |
| Grape (*Vitis* spp.) | 2.2 ± 0.26 | 2.9 ± 0.28 |
| Blackberry (*Rubus* spp.) | 1.6 ± 0.20 | 2.1 ± 0.25 |
| Subterranean clover | 1.4 ± 0.28 | 0.5 ± 0.19 |
| Grass (Poaceae) | 1.3 ± 0.23 | 2.9 ± 0.34 |
| Greenbrier (*Smilax* spp.) | 1.2 ± 0.19 | 0.4 ± 0.09 |
| Flowering spurge *(Euphorbia corollata)* | 1.1 ± 0.13 | 1.0 ± 0.12 |
| Wood sorrel *(Oxalis stricta)* | 0.1 ± 0.03 | 2.3 ± 0.35 |
| Sida *(Sida rhombifolia)* | 0.4 ± 0.14 | 1.9 ± 0.29 |
| Black medic *(Medicago lupulina)* | 0.2 ± 0.05 | 1.1 ± 0.21 |

[a] Other taxa identified in trace amounts (<1.0%) were beggar lice (*Desmodium* spp.), bracken *(Pteridium aquilinum)*, chocolate-weed *(Melochia corchorifolia)*, cross vine *(Anisostichus capreolata)*, dogwood (*Cornus* spp.), elderberry *(Sambucus canaden-* [illegible]

CP and P levels in forages were generally lower in 1985 than in 1986. American jointvetch contained more CP than any other plant taxa collected from the study area and contained more P, except in July 1985. American jointvetch was the most digestible plant collected in June and July 1985 and throughout 1986. Complete nutritional data are reported in Keegan (1988).

### Deer Diet Quality

Monthly CP levels in summer-fall native diets in Blairstown ranged from 9.3% to 13.5% (Table 4) and generally fell within the range (9–11.5%) estimated by Thill et al. (1987) for similar habitat in central Louisiana. For all sampling periods, supplemented diets contained significantly higher concentrations of CP compared to estimated native diets ($P \leq 0.0001$). Assuming that use of American

**Table 4. Estimated levels of dietary crude protein (% ovendry weight) in native and supplemented deer diets on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986.**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Native | Supplemented | Native | Supplemented |
| Jun | | | 13.5 ± 0.18 | 16.0 ± 0.45 |
| Jul | 10.9 ± 0.24 | 15.6 ± 0.49 | 11.7 ± 0.11 | 16.7 ± 0.55 |
| Aug | 9.8 ± 0.18 | 15.2 ± 0.48 | 12.3 ± 0.10 | 17.2 ± 0.56 |
| Sep | 9.9 ± 0.28 | 17.4 ± 1.00 | 13.2 ± 0.19 | 21.1 ± 0.69 |
| Oct | 9.7 ± 0.14 | 17.9 ± 1.15 | 9.8 ± 0.18 | 16.5 ± 0.63 |
| Nov | 9.3 ± 0.20 | 12.5 ± 0.60 | | |
| Season | 9.9 ± 0.07 | 15.7 ± 0.38 | 12.1 ± 0.13 | 17.5 ± 0.30 |

jointvetch did not alter proportional use of native plants was the only way to index relative diet quality between supplemented and unsupplemented diets because native diets would not be identical among years or different areas. No control was possible for the experiment. We believe that the method was reasonable under the circumstances because we found no native plants used as diet staples that were as nutritious as American jointvetch. Our analysis suggests that use of any amount of American jointvetch would improve diet quality. The practical problem is determining if the improvement is biologically significant rather than only statistically significant. A compilation of research findings suggests that dietary CP should fall between 7% and 13% for maintenance, and dietary CP should exceed 13% to maximize deer growth and reproduction (Thill et al. 1987). Native diets provided maintenance levels of CP during all sampling periods, but exceeded 13% in only 2 months, June and September 1986; whereas dietary CP in supplemented diets fell below 13% in only 1 month, November 1985. Not only is this result statistically significant but it is probably biologically significant. In the previous study on Blairstown, Johnson et al. (1987) detected significant improvements in live weights of yearling bucks associated with an increase in dietary crude protein of about 20%. In the present study, our estimated dietary crude protein improved by 58.6% for summer-fall 1985 and by 44.6% for summer-fall 1986. We were not able to associate use of American jointvetch with live weights of deer on Blairstown because winter forage crops were also being used but live weights have continued to increase since the previous study. However, American jointvetch was added to Avondale (a portion of Blairstown with similar habitat used as a control area for the study reported by Johnson et al. 1987) in summer 1987 and winter plots have not been used. From 1982 through 1986, yearling bucks taken ($N = 65$) averaged 43.4 ± 1.3 kg and there were no differences among years. A sample ($N = 12$) in fall 1987 after using American jointvetch food plots averaged 47.7 ± 1.4 kg and these yearling bucks were significantly larger ($P \leq 0.05$). Although circumstantial, these data provide some evidence that performance of deer can improve due to use of improved forages during summer.

Monthly P concentrations in native diets from Blairstown ranged from 0.14% to 0.18% (Table 5), exceeding values presented by Thill et al. (1987) (0.10–0.13%) by a small margin both years. Phosphorus concentrations were higher in supplemented diets than in native diets every month both years ($P \leq 0.0001$). Previous estimates indicate that dietary P should fall between 0.20% and 0.40% (Ullrey et al. 1975, Verme and Ullrey 1972). Native diets never provided more than 0.18% P, suggesting that P levels were suboptimum throughout the summer-fall period. However, mean dietary P in supplemented diets fell below 0.20% in only 1 month, November 1985.

**Table 5. Estimated levels of dietary phosphorous (% ovendry weight) in native and supplemented deer diets on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986.**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Native | Supplemented | Native | Supplemented |
| Jun | | | 0.18 ± 0.005 | 0.21 ± 0.006 |
| Jul | 0.17 ± 0.006 | 0.20 ± 0.005 | 0.17 ± 0.003 | 0.23 ± 0.007 |
| Aug | 0.14 ± 0.005 | 0.20 ± 0.005 | 0.17 ± 0.004 | 0.22 ± 0.006 |
| Sep | 0.16 ± 0.005 | 0.22 ± 0.008 | 0.18 ± 0.004 | 0.27 ± 0.008 |
| Oct | 0.15 ± 0.006 | 0.21 ± 0.007 | 0.14 ± 0.005 | 0.23 ± 0.008 |
| Nov | 0.14 ± 0.004 | 0.17 ± 0.006 | | |
| Season | 0.15 ± 0.002 | 0.20 ± 0.003 | 0.17 ± 0.002 | 0.23 ± 0.004 |

Monthly Ca levels in native diets from Blairstown ranged from 0.74% to 0.95% (Table 6) and were generally lower than values reported by Thill et al. (1987). Monthly Ca:P ratios in native diets from Blairstown ranged from 4.6:1 to 6.9:1 (Table 7), almost one-half the values estimated from central Louisiana (Thill et al. 1987). Ca concentrations were greater and Ca:P ratios were improved (lower) in supplemented diets, compared to native diets, for every month both years ($P \leq 0.001$). Native and supplemented diets contained more than the 0.30–0.50% Ca generally recommended for deer (Ullrey et al. 1973). Most plants in the Coastal Plain region contained high levels of Ca, probably exceeding the amounts required by deer. Excess Ca can disrupt P metabolism in deer through chemical complexing. Optimum Ca:P ratios for deer are not well defined, but ratios of 1:1 to 2:1 are recommended for domestic ruminants. Ca:P ratios in native diets on Blairstown fell within the "satisfactory" limit (7:1) reported by Ensminger and Olentine (1978:102), but ratios approached levels where animal performance might have been adversely affected. Ca:P ratios in supplemented diets were 16–18% lower than ratios in native diets.

**Table 6. Estimated levels of dietary calcium (% ovendry weight) in native and supplemented deer diets on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986.**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Native | Supplemented | Native | Supplemented |
| Jun | | | 0.91 ± 0.02 | 0.93 ± 0.02 |
| Jul | 0.95 ± 0.02 | 1.00 ± 0.02 | 0.86 ± 0.01 | 0.95 ± 0.01 |
| Aug | 0.91 ± 0.02 | 1.04 ± 0.02 | 0.82 ± 0.01 | 0.95 ± 0.02 |
| Sep | 0.90 ± 0.02 | 1.00 ± 0.02 | 0.83 ± 0.02 | 1.00 ± 0.01 |
| Oct | 0.85 ± 0.02 | 1.01 ± 0.03 | 0.74 ± 0.03 | 0.94 ± 0.03 |
| Nov | 0.93 ± 0.02 | 0.99 ± 0.02 | | |
| Season | 0.91 ± 0.01 | 1.01 ± 0.01 | 0.83 ± 0.01 | 0.95 ± 0.01 |

**Table 7. Estimated calcium:phosphorous ratios in native and supplemented deer diets on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986.**

| | 1985 | | 1986 | |
|---|---|---|---|---|
| Month | Native | Supplemented | Native | Supplemented |
| Jun | | | 5.09 ± 0.17 | 4.47 ± 0.15 |
| Jul | 5.75 ± 0.18 | 5.11 ± 0.11 | 5.23 ± 0.08 | 4.30 ± 0.09 |
| Aug | 6.64 ± 0.24 | 5.17 ± 0.09 | 4.99 ± 0.13 | 4.24 ± 0.08 |
| Sep | 5.83 ± 0.17 | 4.81 ± 0.15 | 4.57 ± 0.15 | 3.76 ± 0.10 |
| Oct | 5.75 ± 0.25 | 4.85 ± 0.15 | 5.49 ± 0.23 | 4.16 ± 0.12 |
| Nov | 6.85 ± 0.21 | 6.11 ± 0.21 | | |
| Season | 6.17 ± 0.10 | 5.21 ± 0.08 | 5.08 ± 0.07 | 4.18 ± 0.05 |

Digestibility of native diets from Blairstown ranged from 46.6% to 49.9% (Table 8) and was lower than warm-season values reported by Thill et al. (1987). Supplemented diets were more digestible than native diets every month both years ($P \leq 0.006$). These values were low relative to digestibility levels (65–70%) recommended for maximum lactation and growth in domestic livestock (Natl. Res. Counc. 1975, 1977, 1984). Although Ameri-

**Table 8. Estimated levels of dietary in vitro digestible dry matter (% ovendry weight) in native and supplemented deer diets on Blairstown Plantation, East Feliciana Parish, Louisiana, 1985 and 1986.**

| Month | 1985 |  | 1986 |  |
|---|---|---|---|---|
|  | Native | Supplemented | Native | Supplemented |
| Jun |  |  | 47.9 ± 0.74 | 51.1 ± 0.77 |
| Jul | 49.8 ± 0.70 | 56.2 ± 0.75 | 47.7 ± 0.49 | 52.0 ± 0.59 |
| Aug | 49.9 ± 0.61 | 56.0 ± 0.61 | 47.8 ± 0.48 | 52.7 ± 0.58 |
| Sep | 49.3 ± 0.58 | 51.3 ± 0.45 | 48.8 ± 0.69 | 56.9 ± 0.82 |
| Oct | 49.5 ± 0.78 | 52.1 ± 0.52 | 48.9 ± 0.66 | 55.7 ± 0.60 |
| Nov | 46.6 ± 0.76 | 47.5 ± 0.62 |  |  |
| Season | 49.0 ± 0.32 | 52.6 ± 0.38 | 48.2 ± 0.28 | 53.7 ± 0.35 |

can jointvetch improved dietary digestibility, further improvements might be needed to promote maximum performance of free-ranging deer.

In general, native diets on Blairstown were probably suboptimal with respect to maximum deer growth and reproduction. This hypothesis is supported by Johnson et al. (1987), who reported significant improvements in weights of yearling bucks on the study area following winter range improvements. During the previous winter (1984–1985), native diets for the same study area (Johnson et al. 1987) contained about 25% higher levels of CP and were 25% more digestible than native diets in summer 1985. These comparisons support the contention that summer and fall may be limiting seasons for deer because physiological costs are higher during summer and fall, compared to winter, in the Southeast.

For 1985 and 1986, dietary CP, IVDDM, P, and Ca were positively associated with proportions of American jointvetch in deer diets ($P \leq 0.001$) and $n = 150$ for all correlations each year). Associations were strongest for CP ($r^2 = 0.97$ and 0.98, respectively) and P ($r^2 = 0.75$ and 0.85, respectively) because American jointvetch contained higher concentrations of these nutrients than other staple food items. Associations for dietary IVDDM ($r^2 = 0.67$ and 0.69, respectively) and Ca ($r^2 = 0.46$ and 0.53, respectively) were weaker because other forages contained similar and sometimes higher levels of these nutrients. Diets supplemented with American jointvetch provided deer with levels of CP, P, and IVDDM that should improve animal performance.

Values for nutritional parameters that are reported as percentages are not absolutes by which one can determine diet quality. Such figures are generally used by convention, but actual assimilation of a particular nutrient is determined by forage intake rate and digestibility. This convention may account for some disparities in existing literature concerning nutrient requirements of white-tailed deer. Because microhistological techniques do not allow for estimation of dry matter intake, we did not estimate actual assimilation of dietary nutrients. Following the earlier study (Johnson et al. 1987), we continued to analyze crude protein content of fecal pellets of Avondale and Blairstown. Deer use of winter food plots increased fecal crude protein by about 13% (Johnson et al. 1987). During late-summer months deer fecal pellets on Avondale, an area without food plots prior to 1987, contained 15.6 ± 2.2% crude protein ($N = 79$) while those from Blairstown contained 21.9 ± 3%, which is a 40% increase. There were no differences in levels of fecal protein between Avondale and Blairstown during months when food plots were not present. Dietary and fecal protein are significantly associated in ruminants (Mould and Robbins 1981). However, the levels we observed are beyond levels where the direct linear association is usually high and much higher than values we found in fecal samples from winter months. These data suggest that use of American jointvetch significantly improved dry matter intake rates. We suspect that deer using American jointvetch were consuming more protein than could be assimilated. We suspect that our estimates of dietary quality are lower than what the supplemented deer actually obtained.

### Costs

Ozoga and Verme (1982) calculated that supplementally feeding a captive deer herd with high-quality pelleted feed year-round cost about $83/deer/year from the feed alone. Based on pelleted feed costs and deer population estimates, costs of feeding deer on the study area from June through November would have been about $4,621 and $5,545 in 1985 and 1986, respectively.

Establishment cost for American jointvetch food plots on clear land, exclusive of fencing, was about $227/ha (seed, fertilizer, herbicide, and labor). Annual cost for regeneration of food plots was about $62/ha. Because total consumption of American jointvetch was similar between years, food plot acreage probably exceeded herd requirements in 1985. Assuming 8 plots (1.7 ha) were sufficient for herd supplementation, establishment and annual costs would have totaled $386 and $105, respectively. Therefore, food plots would have cost about $3.22/deer in 1985 (establishment year, 120 deer) and $0.73/deer/year thereafter (144 deer). Supplemental feeding costs will be better defined when optimum food plot acreage for a deer herd is known. Although costs may vary with location, food plots are an economical alternative to bagged feed for supplementing diets of free-ranging deer.

## Management Implications and Conclusions

American jointvetch was used intensively by deer and supplemental forage provided by food plots was the most important component of summer-fall deer diets. Diet quality was significantly improved when deer supplemented their diets with American jointvetch and supplemented diets appeared to provide nutrient levels that would improve animal performance. Future research concerning summer-fall diet supplementation should focus on forage species that might further enhance deer diets at lower costs. Although American jointvetch is adapted only to the southeastern United States, its use provides a model for potential deer range improvements in many areas of North America where quality of native range is low.

Food planting programs have successfully focused hunter interest on habitat improvements in North Carolina (Betsill and Sharpe 1985). Our research with American jointvetch has drawn wide public interest in summer food plantings throughout the Southeast. We believe that hunter interest in American jointvetch has stimulated an increased awareness of many aspects of deer management and that sportsmen are spending more recreational time managing deer during closed seasons. We anticipate that the end result will be improvements in deer management by sportsmen who control private land.

For some lease holders, food plots are the only range improvement practice available because some landowners do not permit timely timber thinning or prescribed burning, or because prescribed burning is not possible or practical in some habitats. Under the assumption that forage quality is more limiting to deer than quantity in the South (Lay 1957), supplemental feeding may be the only practice that can be employed to effectively improve diet quality. Food plots are the most efficient method for attaining this goal.

Supplemental feeding in the form of food plots is not a panacea for current deer management problems, nor should it be considered a replacement for other range management practices. However, like stocker cattle grazing, improved pastures may be the most economical way to maximize growth rates of animals when range quality is poor. Summer-fall food plots improve range quality for free-ranging deer and should, therefore, be considered as viable options for intensive deer management programs in some parts of the southern United States.

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# Comparing the economic value of forage on public lands for wildlife and livestock

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## Abstract

**Deciding how to allocate forage among animals is a fundamentally important process in range management. The wisdom of these decisions can be enhanced by estimating the marginal value of forage needed by competing species. We present a method for obtaining such estimates and apply this method to generate net economic values of forage for elk and deer in Challis, Idaho. Specifically, a demand curve derived using a regional travel cost model is used to statistically estimate the marginal value of wildlife and forage. Comparisons of the value of forage to livestock and wildlife indicate equivalent values in the Challis, Idaho, area for these 2 uses.**

**Key Words: benefit-cost analysis, economic efficiency, marginal value, big game wildlife, elk, deer**

On many tracts of public lands there is some degree of competition between domestic livestock and wildlife. Economically efficient use of these public rangelands requires adjusting the mix of livestock and wildlife such that the mixture is roughly proportional to the relative values these different animals provide. Often more wildlife and livestock can be accommodated by boosting range productivity through investments such as water developments and manipulation of the vegetation. However, the U.S. Office of Management and Budget and some economists (Stroup and Baden 1983:48) are skeptical about the returns to these investments.

In response to the scrutiny that its rangeland investments were receiving from economists and environmental groups, the Bureau of Land Management (BLM) developed a model called SAGERAM. This model is used to perform benefit-cost analysis on resource investments including livestock and wildlife (U.S. Bureau of Land Management 1985). As part of its overall Forest Planning effort, the U.S. Forest Service is using a large scale linear programming model called FORPLAN to evaluate its resource tradeoffs, including livestock grazing (Johnson et al. 1982). Although these models are useful, their analytical capabilities are limited by difficulty in estimating marginal values of wildlife and forage used by wildlife in a manner commensurate with livestock forage values (See Godfrey 1982; Bartlett 1982, 1984; Dyer 1984).

Marginal values of elk and deer on public lands are rarely estimated (Cory and Martin 1985, Keith and Lyon 1985). Cory and Martin use the Contingent Value Method for determining the marginal value per elk. Keith and Lyon use a household production function (hedonic) approach within an optimal control framework to estimate a marginal value per deer. Their approach develops a dynamic bio-economic model.

In contrast to previous research, we use the travel cost method (TCM) to estimate marginal values of 2 big game species (elk and deer) and calculate the marginal value product of an animal unit month (AUM) of forage to these species. Comparisons of the marginal value of forage between wildlife and cattle and between different big game species are made. Like Cory-Martin, our model is not dynamic but does capture simple bio-economic production relationships between harvest, big game populations, and habitat.

## Methods

### Marginal Valuation of Wildlife with Travel Cost Method

The economic value of any good or service is defined as consumers' or producers' net willingness to pay (Freeman 1979). Measuring consumers' net willingness to pay (WTP) involves measuring the area under their demand curve. Because the travel cost method estimates the demand curve for recreation, the willingness to pay for recreation under existing conditions can be calculated. Maler (1974) first developed the theoretical conditions which must be met to use the travel cost method for valuing *changes* in environmental quality. Drawing on Maler's (1974) concept of "weak complementarity" between a private good (travel) and a public good (environmental quality), Freeman (1979:196-214) discusses alternative ways in which the travel cost method can be used to estimate

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the benefits of improved conditions at a recreation site. For example, consider an ordinary demand equation for a recreation site of the following form:

$$V = h(P,Q,Y) \tag{1}$$

where: V = visits, P = price, Q = site quality and Y = income.

Weak complementarity allows us to state the benefits (i.e., net WTP) of improving site quality from Qo to Q1 as:

$$\text{Net WTP}(Q1 - Qo) = \int_{Po}^{P2} h(P,Q1,Y)dP - \int_{Po}^{P1} h(P,Qo,Y)dP \tag{2}$$

where P1 and P2 drive visits to zero for demand curves associated with the current and improved level of quality, respectively, and Po is the current price. The marginal (incremental) value of a harvested animal is the ratio of the increase in net WTP (Eq. 2) to the increment of animals harvested associated with moving from Qo to Q1.

Empirical estimation of a demand function with a variable for quality is not possible when estimating a demand curve for just 1 site because there is no variation in site quality across visitors. Freeman (1979:212) suggested a 2-step process for pooling data across sites to estimate a coefficient on site quality. Later Vaughan and Russell (1982:453) demonstrated how to estimate a coefficient on quality using 1 equation of the following form:

$$Vij = B_0 - B_1TCij + B_2Qj + B_3(TCij * Q_j) + \ldots B_{n-1}Zij + B_n(Zij * Qj) \tag{3}$$

Where: Vij = visits by individual i to site j, i = 1,...t and j= 1,...s

TCij = transportation and time costs of individual i to site j

Qj = a measure or index of site j's quality

Zij = other variables including price of substitutes, demographics of recreationists, etc.

Equation 3 presents the full interaction model where site quality is assumed to affect all of the other variables (Vaughan and Russell 1982:453). Whether the quality variable affects all of the other variables is a testable hypothesis. A similar approach was developed earlier by Knetsch, et al. (1976). The varying parameter model allows for pooling of visitation data across many sites. If these sites have sufficient variation in site quality, then the analyst will be able to estimate coefficients that predict how visitation will change with changes in site quality. As such, a new second stage site demand curve is estimated for each site under improved site conditions. As discussed above, the area between these curves is the incremental (marginal) benefits attributable to that improvement.

## Data Sources

The state of Idaho provides a good opportunity to compare wildlife forage values to that of cattle. Idaho is a state with over two thirds of its land in public ownership. A survey of persons hunting in Idaho in 1982 was performed to collect the necessary data for this model. The sampling frame was any resident or nonresident having a valid Idaho hunting license. To insure the assumptions of TCM were met, only hunters stating that hunting was the primary trip purpose and that hunt unit was the primary destination were included in the analysis. The elk hunting survey contacted, via telephone, 2.1% of licensed elk hunters for a total sample of 1,629 elk hunters during January–February 1983 regarding the 1982 hunting season (Sorg and Nelson 1986). The deer hunting survey contacted 0.917% of licensed deer hunters for 1,445 deer hunters during January–February 1983 regarding their 1982 hunting season (Donnelly and Nelson 1986). Data were collected on hunter expenditures, travel distances, success, days afield and other trip characteristics. Unfortunately, interviewers were not allowed to collect data on individual hunter income and other demographic characteristics of hunters.

## Demand Model

A zonal or aggregate travel cost model is estimated for several reasons. In terms of structure, using trips per capita reflects both the quantity of trips consumed by current hunters and also the probability of participation in hunting at site j. This form of the dependent variable adjusts for several problems that arise when estimating an individual observation TCM demand model with ordinary least squares regression: (1) censoring and truncation of the data due to omission of observations of hunters who did not hunt at the particular area j; (2) entry of new hunters visiting site j under improved hunt quality at site j. While separate estimation of these 2 components of total trips is sometimes desirable, data limitations preclude such a solution here. In addition the survey did not include individual specific data on explanatory variables such as income. As noted by Brown et al. 1983, the zonal TCM model also minimizes the effect of recall of trip distances on estimated coefficients.

It was desirable to estimate both elk and deer demand equations using the double log demand model. This functional form produces a diminishing marginal value per animal when the coefficient on harvest is less than one. However, we could not estimate this functional form with the full interaction model. As specified in equation 3, this model had very high multicolinearity due to presence of the interaction terms. This resulted in a near singular matrix. The simplified model proposed in this study for elk and deer is thus closer to a pooled multi-site demand equation. The resulting model is:

$$\ln(Vij/POPi) = BO - Bl(\ln DISTij) +- B2(\ln INCi) + B3(\ln THVSTj) \tag{4}$$

Where: VIJ = hunter trips from origin i to site j

POPi = county i's population, i = 1,...95 for elk, i=1,...64 for deer

DISTij = round trip distance from origin i to site j.

INCi = county i's per capita income

THVSTj = total hunt unit harvest of respective species at site j, where j=1,...63 for elk and j = 1,...78 for deer.

Because the quality variable is total site harvest, the possibility exists that this variable is endogenous in a time dependent bioeconomic system. Even though the dependent variable is trips *per capita* from each origin to site j rather than total trips to site j, simultaneity may be present. In particular, the demand equation in equation (4) may be part of a 2 equation bio-economic system. Equations 4–5 show one such system:

$$\ln(Vij/POPi)=BO - B1(\ln DISTij) + B2(\ln INCi) + B3(\ln THVSTj) \tag{4}$$

$$\ln(THVSTj)=AO + A1(\ln APOPjt-1) + A2(\ln Vij/POPi) + A3(\ln HAj) + A4(\ln THABj) \tag{5}$$

where: APOPjt-1 = Elk or deer populations at site j in time t-1

HAJ = Huntability of site j in terms of terrain, denseness of vegetation, etc.

THABj = Total habitat in site j measured in square miles.

All over variables are as defined earlier.

However, data is not available for all of the variables in this system and therefore equation 4 is estimated using two-stage least squares. Because data is available on the exogenous variable THABj and APOPjt-1 as well as DISTij and INCi, the order condition for equation 4 is met for both deer and elk. In essence, our application of two-stage least squares involves regressing

THVST on all the exogenous variables in equations 4 and 5 (except HA for which no data is available) and then using the predicted values of THVST when estimating equation 4.

The demand curve in equation 4 uses distance as the price variable. The area under this demand curve but above the current travel distance (equation 2) is net willingness to pay in added miles. Therefore, we must convert the resulting willingness to pay in miles to dollars. This translation requires estimates of transportation costs plus the value of travel time. Travel distances are converted to dollars using the average transportation cost of $0.31 per vehicle mile reported by elk hunters and $0.183 per vehicle mile of deer hunters. These figures are divided by the average number of hunters per vehicle to arrive at transportation cost per mile per hunter. Travel time is valued at one-third of the wage rate, the mid point in Cesario's (1976) survey of transportation planning literature. While Smith et al. (1983) questions the use of a fraction of the wage rate rather than the entire wage rate other analyses of recreation travel behavior support use of a fraction of the wage rate (McConnell and Strand 1981). Recent empirical results for deer hunting in Wisconsin by McCollum, Bishop and Welsh (personal communication) provide strong support for a value of travel time between 20% and 33% of the wage rate.

### Calculating Marginal Productivity of Forage

To calculate the marginal value product of the forage in producing elk requires site specific knowledge of the production relationships. Hunt areas 36 and 36B in the Challis, Idaho, area were selected to calculate site specific production relationships and marginal values of elk and deer for this study. The Challis area was designated by the Natural Resources Defense Council vs Morton court decision as the area for Bureau of Land Management's first Grazing Environmental Impact Statement (EIS). The Challis area has been the scene of substantial controversy over grazing versus wildlife prior to, during and after the preparation of the EIS (Nelson 1980). BLM's Final EIS (U.S. Bureau of Land Management 1977: Chap 3:21) states that during May and June there is spatial and dietary competition for grasses between cattle and antelope, deer and elk in the area. Elk and cattle have strong dietary similarities (particularly in the spring) in terms of their preferences for consuming grasses. Therefore the potential dietary competition from increasing elk or cattle populations may be the greatest. There also exists substantial evidence of social avoidance of cattle by elk, with presence of cattle (and associated humans tending the livestock) causing elk to leave an area of otherwise desirable habitat (Lyon 1985:17; Nelson 1984).

Because there is still some debate about the exact form and extent of competition between cattle and elk in general and specifically in the Challis area, no attempt is made to establish an explicit production possibilities curve in this paper (see Nelson 1984, Cory and Martin 1985 for attempts in other areas). Rather we will analyze the incremental values of wildlife and forage for likely increases in wildlife numbers. This increase in wildlife involves costs in terms of either reduced cattle numbers or capital investment to increase range productivity.

BLM's Final EIS states that at least a 30% increase in deer is sustainable with additional forage. This figure is consistent with Idaho State Department of Fish and Game's objectives for deer herds in those units (U.S. Bureau of Land Management 1977, Chap 3:27). The potential for increased carrying capacity of elk habitat due to new grazing systems is about 20% (U.S. Bureau of Land Management 1977, Chap 3:29). Although there are many important components of habitat for elk and deer in the Challis area, forage on winter and spring ranges appears to be limiting populations in the Challis area. The purpose of these estimates is to provide a benchmark of what the potential improved condition might be. The remaining analysis calculates marginal values of wildlife and forage using current harvest and a 25% increase in elk and deer populations that results from range improvements and better grazing practices such a sequential rest-graze systems.

A 25% increase in elk harvest in unit 36 requires 28 more bull elk. According to information provided by the Idaho Fish and Game (Parker, personal communication) production of 28 more bull elk for harvest (surplus production) annually would require the elk herd in unit 36 increase by a total of 378 elk. The composition of the increase is 19% bulls, 54% cows and 27% calves. The available literature (Bureau of Land Management 1977: 1-2; Thomas 1984) suggests that each adult elk consumes between 0.4 and 0.67 AUM's of forage each month. Our analysis uses the average of these 2 estimates or 0.54 AUM's per adult elk and half this amount per calf. This latter information is combined with the herd structure to generate a simple production relationship relating the number of elk available for harvest to quantity of forage. Using unit 36 to illustrate the calculations, the relationship is:

$$EH = 1/[(9.85AE * .54AUM * 12\text{months}) + (3.65CE * .27AUM * 12\text{months})] \qquad (6)$$

where: EH = bull elk available for harvest
AE = adult elk (bulls and cows),
CE = calf elk
AUM = Animal Unit Month of forage

Carrying out the calculations in equation (6) yields the simple elk-forage relationship for Unit 36 of:

$$EH = 0.0132AUM \qquad (7)$$

If instead of using .54 as the AUM's required by an elk, one uses the .4 of Thomas or the .67 value of BLM, the resulting production relationship would be .0178AUM and .010AUM, respectively. The implications of these differences are discussed in the results section.

For unit 36B the elk-forage relationship is:

$$EH = 1/[10.22AE * .54AUM * 12\text{months}) + (3.78CE * .27AUM * 12\text{months})] = .0127AUM,$$

with a range of .01AUM to .017AUM if .4 and .67 AUM's per elk are used. (8)

The simple deer forage relationship for unit 36 is:

$$DH = 1/[(6.935AD * .25AUM * 12\text{months}) + (2.565F * .12AUM * 12\text{months})] = 0.0408AUM \qquad (9)$$

Where: DH = deer harvested
AD = adult deer
F = fawn
AUM = Animal Unit Month of forage

If instead of .25AUM's per deer from U.S. Bureau of Land Management (1977) one uses .2AUM's per deer (Thomas 1984) in equation 9, the deer-forage relationship becomes DH=.05AUM instead.

For unit 36B the simple deer-forage relationship is:

$DH = 1/[(5.548AD * .25AUM * 12\text{months}) + (2.052F * .12AUM * 12\text{months})] = .051AUM$. Using .2AUM instead of .25AUM makes the forage relationship $DH = .063AUM$.

## Results

### Estimated Demand Equations

The elk TCM demand equation estimated using the two stage least squares procedure described above is shown in equation 11:

$$\ln(Vij/POPi) = 24.173 - 1.629(\ln DISTij) - 3.126(\ln INCi) + 0.431(\ln THVSTj)$$

T values (20.85) (−30.28) (−24.09) (5.51) (11)

The $R^2$ was 0.74 and the F value was 526. All of the individual coefficients and the F value are significant at the 1% level. The size of the F values and t statistics shows the double log functional form offers a good explanation of the relationships between the variables.

The negative sign on income may at first appear somewhat counterintuitive. It may be a result of using county per capita income instead of individual hunters income (which was not available). Mendelsohn (1984:98) found a statistically significant negative relationship between number of trips and income even when using primary data on deer hunter income. When dealing with time intensive activities such as hunting, it may be that higher income measures the greater cost of time foregone when hunting. Thus, the negative sign on income reflects a price coefficient for onsite time costs rather than ability to pay in the traditional use of money income. Alternatively, higher income hunters may substitute fewer longer trips for more frequent shorter trips.

The deer demand equations estimated using the two-stage least squares procedures described above is:

$$\begin{array}{lllll} \ln(Vij/POPi)=47.19 & -0.649(\ln DISTij) & -6.381(\ln INCi) & +0.327(\ln THVSTj) & \\ \text{T values } (11.33) & (-11.88) & (-13.14) & (2.21) & \textbf{(12)} \end{array}$$

The $R^2$ was 0.47 and the F value was 160. The distance and income coefficients and the F value are significant at the 1% level. The harvest variable is significant at the 5% level. It was not possible to include a statistically significant variable to reflect the price or quality of substitutes in either the elk or deer equations.

### Calculation of Marginal Values

In unit 36, a 25% increase in bull elk harvest (28 more), generates a rightward shift in the elk hunting demand curve. The area between the new and old curves for Unit 36 is an increase in net economic benefits of $14,075, annually. The marginal value of a harvested bull elk is $502. The marginal value per elk and deer in Unit 36B is $647 and $310, respectively. Table 1 displays marginal values per animal under current and improved conditions.

**Table 1. Marginal values (MV) of wildlife in Challis, Idaho.**

| | Current herd sizes | | | Twenty-five percent increase in herd size | | |
|---|---|---|---|---|---|---|
| | MV per animal Harvested | MVP per AUM | | MV per animal harvested | MVP per AUM | |
| Unit 36 | | | | | | |
| Elk | $535 | $5.70 | $9.55 | $502 | $5.35 | $8.96 |
| Deer | $167 | $6.82 | $8.47 | $155 | $6.32 | $7.85 |
| Unit 36B | | | | | | |
| Elk | $685 | $7.04 | $11.78 | $647 | $6.65 | $11.13 |
| Deer | $333 | $17.00 | $21.11 | $310 | $15.81 | $19.64 |

The values for deer in Table 1 are midway between what Keith and Lyon (1985) estimated for the marginal value of deer in Utah using a hedonic approach within an optimal control framework. Specifically, they estimated a value of $39.52 per deer in the herd. Using their percentage of the herd harvested figure of 16% yields a value of $247 per buck harvested. In terms of our elk results, the values in Table 1 are about one-half to one-third those estimated by Cory and Martin (1985) in Arizona using the Contingent Valuation Method. Their value of $106 per elk in the population translates to $1,162 to $1,484 per elk harvested. However, given the large excess demand for elk hunting permits in Arizona compared to the study area in Idaho, the higher value in Arizona is not suprising. Specifically, the 2 different elk hunts in Arizona saw 3,840 applicants for 400 permits and 3,277 applicants for 1,500 permits. In Idaho there is no excess demand for resident elk permits.

Combining the marginal product of forage calculated from equation 10 (.051) with the marginal value of a deer in unit 36B ($310) yields a value marginal product of $15.81 per AUM. The $15.81 represents the maximum amount hunters would bid per AUM for the increased forage to produce 25% more deer in hunt unit 36B. Calculation of the marginal value product for elk follows this same procedure used for deer. Table 1 presents marginal values per animal and per AUM for big game units 36 and 36B. Table 1 displays 2 estimates of marginal value product (MVP) of forage. The first is computed using BLM's deer/elk per AUM and the other reflecting Thomas' (1984) deer/elk per AUM figure.

Although marginal values per animal are higher for elk than deer, comparison of equations 8 and 10 reveal that a standardized AUM produces about 4 times as many harvestable deer as it does elk. This is reflected in the MVP figures. The large difference in forage value for deer in the 2 units relates to differences in marginal value per deer and the higher marginal productivity of Unit 36B in producing deer. Specifically, it takes only an increase of 7.6 deer to produce 1 more available for harvest in unit 36B compared to 9.5 deer to produce 1 more for harvest in unit 36 (Parker, personal communication). The higher marginal value per deer in Unit 36B appears to reflect the higher harvest rate in Unit 36B.

### Economic Value of Livestock Forage

A variety of techniques can be used to estimate the value of public land forage to cattle ranchers. Acceptable methods include comparison with market priced forages, capitalization of permit values and production function techniques such as linear programming (Bartlett 1984). The joint U.S. Forest Service and Bureau of Land Management Appraisal Report (Tittman and Brownell 1984) states that fair market value of public land grazing in the region where Challis is located would be $7.60 per AUM. While the representativeness of the values in this report have been questioned (Obermiller, personal communication), it provides one estimate of forage value. Wilson, et al. (1985) use a linear programming approach with ranch budget data to estimate forage per AUM for the BLM land in the Challis area. The weighted average value of the forage across the 4 different size classes of ranches is $6.40 (where the weights are number of BLM AUM's used by each size class). However, the livestock value per AUM ranges from a low of $1.14 to a high of $10.10 in the 2 relevant areas studied by Wilson, et al. Unfortunately, a perfect overlay of the 2 hunting units and allotments is not possible in our current study.

## Discussion and Conclusions

Comparison of the wildlife values in Table 1 with these forage values shows that deer and elk are economically competitive with cattle in the Challis, Idaho area. In particular, the marginal value of forage for wildlife in Unit 36B is quite a bit larger than livestock forage values. A more economically efficient mix of uses would involve providing additional forage to wildlife until the marginal value to wildlife decreased to the marginal value of forage to livestock. Because the functional form of the demand equations we estimate have the property of diminishing marginal value for each additional animal, in theory, one can calculate the increase in wildlife herd size necessary to drive forage values down into equilibrium with livestock. Such "fine tuning" requires more precision in estimates of economic values and production relationships than is present in this study. For the time being, the existing divergence in values of forage between wildlife and livestock in unit 36B shows the direction that resource management should be moving from an economic efficiency standpoint.

Another implication of these results relates to the variation in values of livestock forage relative to wildlife. A few combinations of ranch sizes and allotments have very low values for livestock forage in the range of $1.14 to $3.09. In these areas, elk and deer values would tend to dominate livestock. From an economic efficiency standpoint wildlife habitat issues should have a major role in determining seasons of use, timing of livestock entry and exit from the range and optimal stocking levels. For other combinations of ranch sizes and allotments, livestock grazing values are quite competitive ($8.37 to $10.10 per AUM) with elk and deer forage values of $5.70 to $9.55 per AUM in unit 36. In these areas, both rancher/livestock needs and wildlife habitat concerns should influence seasons of use, timing of livestock entry and optimal stocking levels.

If greater geographical and statistical precision in estimating the value of forage to wildlife and livestock were possible, site specific recommendations could be made for modifying the allocation of forage between cattle and wildlife. For the time being these relative values per AUM at least provide information on which direction livestock and wildlife populations should be moving from an economic efficiency view point.

This paper also demonstrates that marginal values of wildlife and marginal value product of forage to wildlife can be developed with the travel cost method. The resulting values are commensurate with the values of forage to livestock and hence allow use of economic efficiency analysis in dealing with livestock-wildlife trade-offs. In addition, the wildlife values are useful for determining the economic feasibility of investments to increase forage production for wildlife. Incorporation of these more conceptually correct marginal values of wildlife and forage into BLM's SAGERAM and the U.S. Forest Service's FORPLAN models would improve the accuracy of these analytical aids in suggesting economically efficient use of public rangelands.

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# Infiltration parameters for rangeland soils

**W.J. RAWLS, D.L. BRAKENSIEK, AND M.R. SAVABI**

## Abstract

**Important to the management of rangelands is knowledge of the water intake properties of their soils and the effect of soil surface and canopy cover. Using a data base of rangeland infiltration runs covering a wide range of soil and cover conditions, a procedure incorporating the effects of soil properties, soil surface cover, and vegetative canopy on the Green-Ampt hydraulic conductivity parameter was developed. Test results indicate that the estimated Green-Ampt parameters provided good predictions of the mean final infiltration rates and volumes for a variety of soil-cover situations.**

**Key Words: Green-Ampt, infiltration rates, soil properties**

The importance of ground and canopy cover on rangeland infiltration characteristics has long been recognized (Gifford 1984). Generally, it has been shown that as ground cover or canopy cover increase, infiltration amounts increase while increases in bare ground decreases infiltration amounts (Gifford 1984). Most recently Hutten and Gifford (1988) showed that Green-Ampt parameters estimated from soil texture data alone do not adequately model rangeland infiltration. Mehan (1986) showed that infiltration increases with increases in surface rock for a range of soil textures. Also, Lane et al. (1987) conducted infiltration studies on 5 soils in Arizona and Nevada where rainfall simulation experiments were run on plots with natural cover canopy removed and bare plots where the canopy and most of the surface rock and litter were removed. They found that infiltration was greatest for the natural condition, declining when canopy was removed and further declining when surface rock and litter were removed.

At present there are methods for predicting parameters for the Green-Ampt infiltration model based on soil properties (Rawls and Brakensiek, 1983, 1985); however, there is no method for incorporating the effects of rangeland ground cover and canopy cover on infiltration parameters. Therefore, it is the purpose of this paper to develop procedures for incorporating the effects of ground cover and canopy cover into the Green-Ampt infiltration parameters, which may alleviate some of the problems identified by Hutten and Gifford (1988).

The Green-Ampt infiltration rate equation is

$$f = K \left( 1 + \frac{(\phi_c - \text{ASW})\ \Psi_f}{F} \right) \qquad [1]$$

and its integrated form is

$$K(T) = F - (\phi_c - \text{ASW})\ \Psi_f \ln \left( 1 + \frac{F}{(\phi_c - \text{ASW})\ \Psi_f} \right) \qquad [2]$$

where
$f$ = infiltration rate (cm/hr)
$F$ = infiltration amount (cm)
$T$ = time (hrs)
$K$ = hydraulic conductivity (cm/hr)
$\Psi$ = wetting front capillary potential (cm)
$\phi_c$ = corrected porosity (total porosity corrected for rocks and air) (vol)
ASW = antecedent soil water (vol)

In order to predict infiltration with equations [1] or [2], the antecedent soil water (ASW) needs to be inputted and hydraulic conductivity (K), wetting front capillary potential ($\Psi_f$) and the porosity corrected for rocks and entrapped air ($\phi_c$) need to be estimated. The following are equations used for predicting the parameters based only on soil properties:

Effective Porosity ($\phi_c$)

$$\phi_c = \phi = (\text{CFC})\ (\text{EAC}) \qquad [3]$$

where
$\phi$ = total porosity (vol) = (2.65) – BD)/2.65
CFC = Correction for coarse fragments (Brakensiek et al. 1986)
= ((100 – VCF)/100)
EAC = correction for entrapped air (Rawls and Baumer 1989)
= $1.0 - (3.8 + 0.00019\ (\text{CL}^2) - 0.337\ (\text{SA}) + 0.126\ (\text{CEC})\ (\text{CL}) + \text{OM}\ (\text{SA}/200)^2)/100$
BD = 33 KPa bulk density of the fine earth soil (<2 mm) g/cm$^3$
OM = % organic matter
CL = % clay
SA = % sand
CEC = cation exchange capacity/%clay (ranges 0–1)
VCF = % volume coarse fragments (>2 mm) computed from Brakensiek et al. 1986
VCF = ((WCF/2.65) * 100)/((100–WCF/BD + WCF/2.65))
WCF = %weight of coarse fragements (>2 mm)

Wetting Front Capillary Potential ($\Psi_f$)

$$\Psi_f = e^x \qquad [4]$$

where $x = 5.34 + 0.185\ (\text{CL}^2) - 2.484\ (\phi) - 0.0021\ (\text{CL}^2) - 0.0436\ (\text{SA})\ (\phi) - 0.6175\ (\text{CL})\ (\phi) + 0.00144\ (\text{SA}^2)\ (\phi^2) - 0.00855\ (\text{CL}^2)\ (\phi^2) - 0.000013\ (\text{CL})\ (\text{SA}^2) + 0.009\ (\phi)\ (\text{CL}^2) - 0.00073\ (\phi)\ (\text{SA}^2) + 0.000005\ (\text{SA})\ (\text{CL}^2) + 0.5003\ (\text{CL})\ (\phi^2)$ (Rawls and Brakensiek, 1985)

Hydraulic Conductivity (K)

$$K = K_s\ (\text{FGC})\ (\text{CFC}) \qquad [5]$$

where $K_s$ = saturated hydraulic conductivity (Rawls and Baumer 1989)

$$= \left( \frac{(\phi_c - \Theta_r)^3}{(1 - \phi_c)^2} \right) \left( \frac{\text{BD}}{\Theta_r} \right)^2 \left( .0002\ (C^2) \right)$$

FGC = frozen ground correction (Lee 1983)
= 2 – .019 * PFC
$\Theta_r$ = residual soil water (vol) (Rawls and Baumer 1989)
= $0.2 + 0.1\ (\text{OM}) + 0.25\ (\text{CL})\ (\text{CEC}^{0.45})\ (\text{BD}/100)\ (\text{BD}/100)\ (\text{EAC})\ (\text{CFC})$
C = $-0.17 + 0.181\ (\text{CL}) - 0.00000069\ (\text{SA}^2)\ (\text{CL}^2) - 0.00000041\ (\text{SA}^2)\ (\text{SI}^2) + 0.000118\ (\text{SA}^2)\ (\text{BD}^2) + 0.00069\ (\text{CL}^2)\ (\text{BD}^2) + 0.000049\ (\text{SA}^2)\ (\text{CL}) - 0.000085\ (\text{SI})\ (\text{CL}^2)$
SI = percent silt.
PFC = soil water at freezing (% vol)/soil water held at 33 KPa (% vol).
If PFC $\geq$ 1, then FGC = .1 (Lee 1983).

Brakensiek and Rawls (1983) developed a factor for reducing the saturated hydraulic conductivity for an established soil crust. The crust factor is

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Without the cooperation of those investigators who provided data given in Table 1, this study would not have been possible.
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$$CRC = \frac{L}{\frac{L - TC}{SC} + \frac{TC}{B}} \qquad [6]$$

where CRC = soil crust correction (Brakensiek and Rawls, 1983)
L = wetting front depth (cm) (assume 6 cm)
TC = crust thickness (cm) (assume 0.5 cm)
B = $0.0099 + 0.0721\,(TC) + 0.0000068\,(SA^2) + 0.000021\,(SA^2)\,(TC) - 0.000315\,(SA)\,(TC^2)$
SC = correction factor for partial saturation of the subcrust soil (Brakensiek and Rawls 1983)

Management changes are reflected in the above parameters only by changes in the bulk density of the soil.

## Methods

An extensive data search was performed to compile infiltration data sets which included detailed soils, ground cover, and canopy cover information. The physical characteristics of the data sets located are summarized in Table 1.

**Table 1. Summary description of data sets.**

| Study reference | State | General description |
|---|---|---|
| Devaurs (1984) | ID | 3 soil series, grazed and non-grazed sites and 2 soil water levels; 38–59% sand; 9–18% clay; bulk density 1.1–1.5 g/cm³; 30–52% canopy; and 7–32% bare ground. |
| Hutten (1984) | UT | 5 soil sites with 2 management practices (plowed and unplowed); 25–68% sand; 15–33% clay; bulk density 0.9–1.3 g/cm³; 0.65% canopy; and 0–50% bare ground. |
| Lane et al. (1987) | AZ<br>NV | Natural, clipped and bare range cover at 3 sites in AZ and 2 sites in NV; 66–84% sand; 1–9% clay; 0–75% canopy; and 0–41% bare ground. |
| Thurow (1985) | TX | 27–88% sand; 7–42% clay; bulk density 0.85–0.95 g/cm³; 27–57% canopy; and 21–43% bare ground. |
| Ward and Wood (1982) | NM | Grazing levels, pinyon-juniper mgt, sagebrush mgt and others at 3 sites; 32–90% sand; 14–33% clay; 1–90% canopy; and 3–89% bare ground. |
| Williams (1969) | UT | 4 chained pinyon-juniper sites; 16–65% sand, 16–33% clay; bulk density .9–1.6 g/cm³; 0.20% canopy; and 38–97% bare ground. |
| Wood[1] | NM | Dry and wet soil water levels on one range site; 29% sand; 44% clay; and 35% canopy. |

[1] Personal communication

For each infiltration test we calculated the effective conductivity using an approximation to the Green-Ampt equation derived by Li et al. (1976),

$$KE = 2(FR) - (F/T) \qquad [7]$$

where KE = effective conductivity (cm/hr)
FR = final infiltration rate (cm/hr)
F = total infiltration at the final infiltration rate (CM)
T = accumulated time corresponding to the final rate and infiltration amount (hr)

Since the studies contained various replications at each site, we used the mean site value for soil—ground cover, canopy cover, and the geometric mean effective conductivity which represents an area integrated value—for the analyses.

## Parameter Development

Past research (Moore 1981) has shown that the wetting front capillary potential parameter is relatively insensitive in comparison with the hydraulic conductivity parameter. It was thus assumed that ground cover and canopy cover affect only the hydraulic conductivity parameters. Since rangeland conditions reflect long-term climate, cover, and land use patterns, we assumed that all bare soil is crusted and that the bare or covered soil under a canopy has a higher conductivity than the bare or covered soil in the interspace area. In addition, the covered soil has a higher effective conductivity than the uncovered soil surface whether under a canopy or in the interspace area. These assumptions reflect that canopy, ground cover, litter, or surface rocks reduce crust formation. Further, they enhance macroporosity caused by biotic activity and other processes especially in the soil under or around the litter rock soil interface.

We incorporated the canopy and ground cover effect into a simple weighting by the proportions of the unit area composed of canopy and open space and by the proportion of the canopy space and open space in which the soil surface was covered or bare. For the portion of unit area under canopy cover we estimate the effective conductivity parameter, $(KE)_c$, as

$$KE_c = (CF)\,[(BC/CAN)(CRC) + A(1-(BC/CAN))]\,(K) \qquad [8]$$

and for the portion of the unit area outside of canopy cover we estimated the effective conductivity ($KE_O$) as

$$KE_O = [(BO/OP)(CRC)+A(1-(BO/OP))]\,(K) \qquad [9]$$

where

$KE_c$ = effective conductivity under canopy (cm/hr)
$KE_O$ = effective conductivity outside of canopy (cm/hr)
CF = canopy factor
BC = bare area under canopy (%)
CAN = canopy area (%)
OP = open area outside canopy (%)
BO = bare area in open space (%)
CRC = crust factor (equation [6])
A = macro-porosity factor
K = hydraulic conductivity of soil (cm/hr) (equation [5])

Combining equations [8] and [9] for the total unit area consisting of canopy covered area (CAN) and open area (OP), we have

$$KE = (CAN)KE_c + (OP)KE_O \qquad [10]$$

or

$$KE = (CF)\,[(A)(CAN\text{-}BC) + CRC(BC)](K) + [(A)(OP-BO) + CRC(BO)](K) \qquad [11]$$

The canopy factor (CF) and macroporosity factor (A) are the only unknown parameters in equation [11]. In the following sections estimators for these parameters will be developed.

### Canopy Factor

The canopy factor (CF) is defined as the ratio of effective conductivity under canopy ($KE_c$) to effective conductivity without canopy ($KE_{nc}$).

The Hutten (1984) data set was chosen to develop the canopy factor because it covered a wide range of soil texture, ground cover, and canopy cover conditions (Table 1) and included infiltration runs with and without canopy. A geometric mean KE without canopy was determined for the 4 soils and used to determine CF for each of the 12 treatments. Using the data the following equation was developed relating canopy to CF

$$CF = \frac{KE_c}{KE_{nc}} = \left(1 + 0.96\frac{CAN}{100}\right) \quad r^2 = 0.88 \quad n = 13; \qquad [12]$$

where CAN = canopy (%)

### Macroporosity Factor

The macroporosity factor (A) in equation [11] is assumed to represent an enhancement of the infiltration potential of soil that is covered by rocks or litter (Mehan 1986). The Hutten (1984), Devaurs (1984) and Thurou (1985) data sets were chosen for evaluating the macroporosity factor because they covered a range of soil conditions including bulk density and ground cover conditions. Using the previously developed CF predictor equation [12] we solved equation [11] for a mean A for each treatment and then using regression techniques related to A to soil properties resulting in the following prediction equation:

$$A = e^{(2.82 - 0.099\,SA + 1.94\,BD)} \quad r^2 = .88 \quad n = 41 \qquad [13]$$

where

SA = % sand

BD = 33 KPa bulk density of fine earth soil (<2 mm) $g/cm^3$

In fitting equation [13], A was constrained to be greater than one because macroporosity was assumed to only increase hydraulic conductivity. Also, since the data did not include soils with less than 20 % sand, and the form of equation [13] will produce extremely high A values for soils with less than 20% sand, we would limit the equation to a maximum A value of 18 which was the largest value in the data set.

## Testing

We used the Lane et al. (1987), Ward and Wood (1982), Williams (1969) and Wood data sets (Table 1) to test equations [11, 12 and 13] because these data sets were not used in parameter development. Since each data set had different run durations, we predicted the final infiltration rate, total infiltration amount, and the average measured antecedent soil moisture using the Green-Ampt infiltration model equation [1] from equations [3,4,5,6,11,12, and 13]. The predicted infiltration values were compared with the mean and standard deviations of the observed values for each site. The results of the testing are summarized in Table 2.

Lane et al. (1987) reported infiltration results from studies on large rangeland plots in Arizona and Nevada under simulated rainfall. At each of the 5 sites they had 2 plots evaluated spring and fall for several consecutive years with the following designated treatments:

natural – natural site conditions
clipped – all vegetation cut and removed
bare – canopy and nonembedded (>5 mm) surface matrial removed

They reported mean final infiltration rates and amounts for the 30 minute very wet run at each site. As they did not measure bulk density it was calculated with the equation reported by Rawls (1983). Rock, litter, bare soil, under and outside canopy were measured for each AZ plot. The proportion of bare ground beneath the canopy and outside of the canopy was estimated for

**Table 2. Summary of test results.**

| | | | | Infiltration final rate and volume | | | |
|---|---|---|---|---|---|---|---|
| | | | | Measured | | Predicted | |
| Study reference | Site | Treatment | Sample size | Final rate* cm/hr | Volume* cm | Final rate cm/hr | Volume cm |
| Lane et al. (1987) | Bernardino | Natural | 8 | 3.53 ± 0.77 | 1.96 ± 0.82 | 3.87 | 2.19 |
| | | Clipped | 8 | 2.10 ± 0.75 | 1.24 ± 0.65 | 2.69 | 1.67 |
| | | Bare | 8 | 1.37 ± 0.62 | .73 ± 0.60 | 1.79 | 1.21 |
| | Cave | Natural | 8 | 2.63 ± 0.70 | 1.49 ± 0.77 | 1.96 | 1.32 |
| | | Clipped | 8 | 1.50 ± 0.62 | .88 ± 0.80 | 1.81 | 1.23 |
| | | Bare | 8 | 1.16 ± 0.60 | .65 ± 0.65 | 1.08 | 0.81 |
| | Hathaway | Natural | 8 | 3.16 ± 0.99 | 1.72 ± 0.85 | 2.65 | 1.62 |
| | | Clipped | 8 | 1.93 ± 0.85 | 1.04 ± 0.80 | 2.16 | 1.38 |
| | | Bare | 8 | 1.24 ± 0.52 | .74 ± 0.58 | 1.32 | 0.92 |
| | Mercury | Natural | 4 | 2.05 ± 0.48 | 1.08 ± 0.98 | 1.97 | 1.32 |
| | | Clipped | 4 | .73 ± 0.55 | .50 ± 0.70 | 1.93 | 1.29 |
| | | Bare | 4 | .48 ± 0.30 | .25 ± 0.46 | 1.04 | .77 |
| | Area 11 | Natural | 4 | 3.37 ± 1.30 | 1.85 ± 0.75 | 2.55 | 1.60 |
| | | Clipped | 4 | 2.94 ± 0.75 | 1.75 ± 1.00 | 2.18 | 1.42 |
| | | Bare | 4 | 1.63 ± 0.48 | .98 ± 0.48 | 1.31 | 0.94 |
| Williams (1969) | Intermediate sandy soils (30–45%) | | 8 | 4.4 ± 0.98 | 1.88 ± 0.59 | 2.25 | 1.71 |
| | High sand soils (50–65%) | | 8 | 4.98 ± 2.61 | 1.61 ± 0.82 | 5.32 | 3.19 |
| Wood | | Dry | 24 | 6.94 ± 0.32 | 6.28 ± 0.12 | 7.08 | 6.21 |
| | | Wet | 21 | 4.60 ± 0.45 | 5.34 ± 0.20 | 5.66 | 5.28 |
| Ward and Wood (1982) | Grazing | Dry | 6 | 8.56 ± 1.13 | 5.91 ± 0.73 | 7.62 | 5.90 |
| | | Wet | | 7.63 ± 1.85 | 4.25 ± 0.80 | 7.50 | 4.34 |
| | Sagebrush | Dry | 5 | 6.35 ± 2.21 | 4.15 ± 1.10 | 7.88 | 4.81 |
| | | Wet | | 5.81 ± 1.79 | 2.96 ± 0.73 | 4.83 | 2.79 |
| | Pinyon/Juniper | Dry | 5 | 7.50 ± 2.29 | 4.6 ± 1.53 | 11.3 | 6.20 |
| | | Wet | | 7.30 ± 1.65 | 3.86 ± 0.72 | 9.5 | 5.00 |

* ± value is the standard deviation for each measured mean.

the NV sites. Soil rock was estimated from their soil report.

Table 2 compares the predicted Green-Ampt final infiltration rates and total infiltration amount with the measured mean final infiltration rate and amount at each site and treatment. As shown in Table 2, predictions for all sites except Mercury bare and clipped were within ± 1 standard deviation of the measured mean. Since Lane's sites had very high sand (>65) the macroporosity factor derived from equation [11] becomes 1; thus this study gives an independent test of the crust and canopy factors in equation [11]. The natural plots test our procedures for predicting the canopy and crust factors. The clipped plots test our procedure for predicting surface cover factors, while the bare soil plots tested our procedures for predicting crusted soil hydraulic conductivity. The bare plots independently tested the crust factor since the soil surface was primarily bare.

Williams (1969) conducted a number of infiltration tests in Utah on pinyon juniper sites in 1967 and 1968. We stratified the Williams data into 2 groups, intermediate sand and high sand, and the results are shown in Table 2. The predicted rates and amounts are within the 95% confidence intervals; however, the confidence intervals are very wide and absolute error is up to 100% for the high sand total infiltration. The high sand tests the effect of the canopy and crust factors while the intermediate sand soils incorporates the crust, canopy and macroporosity factors.

Wood conducted infiltration tests on a clay loam soil in New Mexico. We ran predictions on the dry and wet treatments; all predictions except the dry final rate, which could be a result of antecedent soil water conditions, were within the 95% confidence intervals.

Ward and Wood (1982) conducted 4 replicate infiltration tests at 17 sites. We subdivided the sites according to cover (grazing sagebrush and pinyon juniper) and dry or wet treatments. The predicted final infiltration rates and amounts were within 95% confidence intervals; however, the standard deviation of the means are very large (Table 2). The numerical error in the pinyon/juniper estimates are 30–50% high.

Regression analysis was performed on the mean measured final infiltration rate versus the predicted final infiltration rate given in Table 2 and the mean measured total infiltration volume versus the predicted infiltration volume given in Table 2. This analysis indicated that the intercepts and slopes were not significantly different from 0 and 1, respectively, at the 0.05 significance level. This indicates that the model predicts accurate and unbiased estimates of the mean final infiltration rate and total infiltration volume.

## Conclusion

A method was developed for incorporating readily available rangeland soil, surface cover, and canopy cover properties into the predictions of the Green-Ampt hydraulic conductivity parameter. The method was evaluated on ten diverse independent rangeland areas and generally predicted the mean final infiltration rate and amount within one standard deviation of the measured mean, indicating that our assumptions and parameter estimators are acceptable. Since the development and testing of data sets did not include high silt soils and grass-dominated vegetative cover, using the proposed procedure may yield questionable results. Also, the proposed procedure yields one of the first quantitative methods for evaluating the relative effects of rangeland treatments on infiltration.

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# Some effects of a rotational grazing treatment on cattle preference for plant communities

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## Abstract

**Rotational grazing is commonly assumed to improve livestock distribution compared to continuous grazing, but little evidence supports this contention. Research was conducted on the effects of rotational grazing (RG) compared to continuous grazing (CG) on the preference of cattle for plant communities. Different livestock densities in the RG treatments were created by varying the size of paddocks in a 465-ha, 16-paddock, cell designed RG treatment stocked at a rate of 3.6 ha/cow/yr. Paddock sizes of 30 and 10-ha were used to simulate RG with 14 (RG-14) and 42-paddocks (RG-42), respectively. The CG treatment consisted of a 248-ha pasture stocked at 5.9 ha/cow/yr. Data consisted of hourly daylight observations of cattle location and activity during 8 seasonal trials lasting 6–15 days. These data were expressed as a percent of the time cattle were observed in each of 4 plant communities and the area surrounding permanent water. Relative electivity (RE), a preference index, and a selectivity index (SI) that measures departures from random distribution were calculated from these data. Relative electivity (i.e., preference) for plant communities was not affected by grazing treatment. However, cattle were less selective for plant communities as livestock density decreased from the RG-42 to the CG treatment. In the RG-14 treatment, the cattle were either unaffected or less selective on the last day than on the first day in a paddock. We hypothesize that grazing systems influence cattle preference for plant communities by affecting the availability of forage biomass per unit land area rather than by their effect on grazing pressure.**

**Key Words: cattle, grazing behavior, community preference, cell grazing, continuous grazing**

The effects of livestock grazing on rangelands are related primarily to the direct effects that defoliation has on the growth and reproduction of individual plants, and the disparity that exists among individual plants in frequency and severity of defoliation as a result of selection. Diet selection involves a hierarchy of decisions by the grazing animal relative to the spatial assemblage of plants across a landscape, that can be classified as: (1) plant community, (2) patch, (3) feeding station, and (4) plant (Senft et al. 1987).

Previous research on spatial distribution patterns of grazing have shown large differences in grazing intensity among plant communities and among patches within communities (Weaver and Tomanek 1951, Wagnon 1968, Low et al. 1981, Roath and Krueger 1982, Tanner et al. 1984, Ring et al. 1985). Investigations designed to determine the capacity of grazing systems to ameliorate community or patch selective grazing have demonstrated variable results. Smith and Owensby (1978) and Ring et al. (1985) reported that intensive early grazing (IES) compared to season long continuous grazing reduced patch grazing on Kansas rangelands. However, Gammon and Roberts (1978) and Kirby et al. (1986) compared continuous grazing (CG) to intensive multi-pasture 1 herd rotational grazing (RG) and found no significant differences in community preference between grazing systems, a result supported by the present study. Still, the presumed reduction in spatial variation in forage utilization is often a major factor justifying the implementation of multi-paddock, 1-herd rotational grazing systems (Kothmann 1980, Savory and Parsons 1980, Malechek and Dwyer 1983).

The objective of this research was to investigate cattle selectivity and preference for plant communities as affected by RG at 2 livestock densities. A yearlong CG treatment was included in the study as a control treatment. Plant communities were chosen as the spatial unit of interest because it is the hierarchical level at which tactical planning decisions are made and because previous work has indicated that this is the spatial unit of relevance to grazing cattle (Senft et al. 1985). We hypothesized that as stock density, grazing pressure, and intensity of rotation increased from the CG to the RG treatment that cattle would show less selectivity for the available plant communities.

## Materials and Methods

### Study Area and Treatments

The study was conducted at the Texas Experiment Ranch located (99° 14′W, 33° 20′N) on the eastern edge of the Rolling Plains resource region. The climate is continental, semiarid, and highly variable. Annual precipitation is bimodally distributed and averages 682 mm. Peak precipitation months are May (96 mm) and September (118 mm). Average maximum daily temperatures range from 11.4° C in January to 35.8° C in July. Average minimum daily temperatures range from –2.4° C in January to 22.0° C in July.

The 465-ha, cell-designed (paddocks radiating from a common center) RG treatment was initiated in March 1981. Initially the treatment consisted of 14 paddocks that averaged 33 ha in size. The treatment was originally stocked with 125 Angus × Hereford crossbed cows at a heavy rate of 3.7 ha • cow$^{-1}$ • year$^{-1}$. Stocking rate was constant until June 1984 when it was reduced to 5.2 ha • cow$^{-1}$ • year$^{-1}$ because of drought. In March 1982 a 30-ha paddock was divided twice creating three 10-ha paddocks for a total of 16 paddocks in the RG treatment. Cattle behavior and distribution data were collected on 5 paddocks including three 10-ha paddocks and two 27-ha paddocks located adjacent to the 10-ha paddocks (Fig. 1). Rate of rotation was flexible and varied according to vegetation growth rates and nutrient requirements of the cows. Days of rest between grazing periods ranged from about 30 to 65. Stocking rate on the different size study paddocks was kept constant by varying the length of graze. Based on desired rest periods, length of graze in the 5 paddocks ranged from 18 hours to 2 days in the 10-ha paddocks and from 2 to 5 days in the 27-ha paddocks. These treatments were designed to simulate either a 14-or 42-paddock RG system. The 10-ha paddocks are referred to as the RG-42 treatment and the 27-ha paddocks as the RG-14

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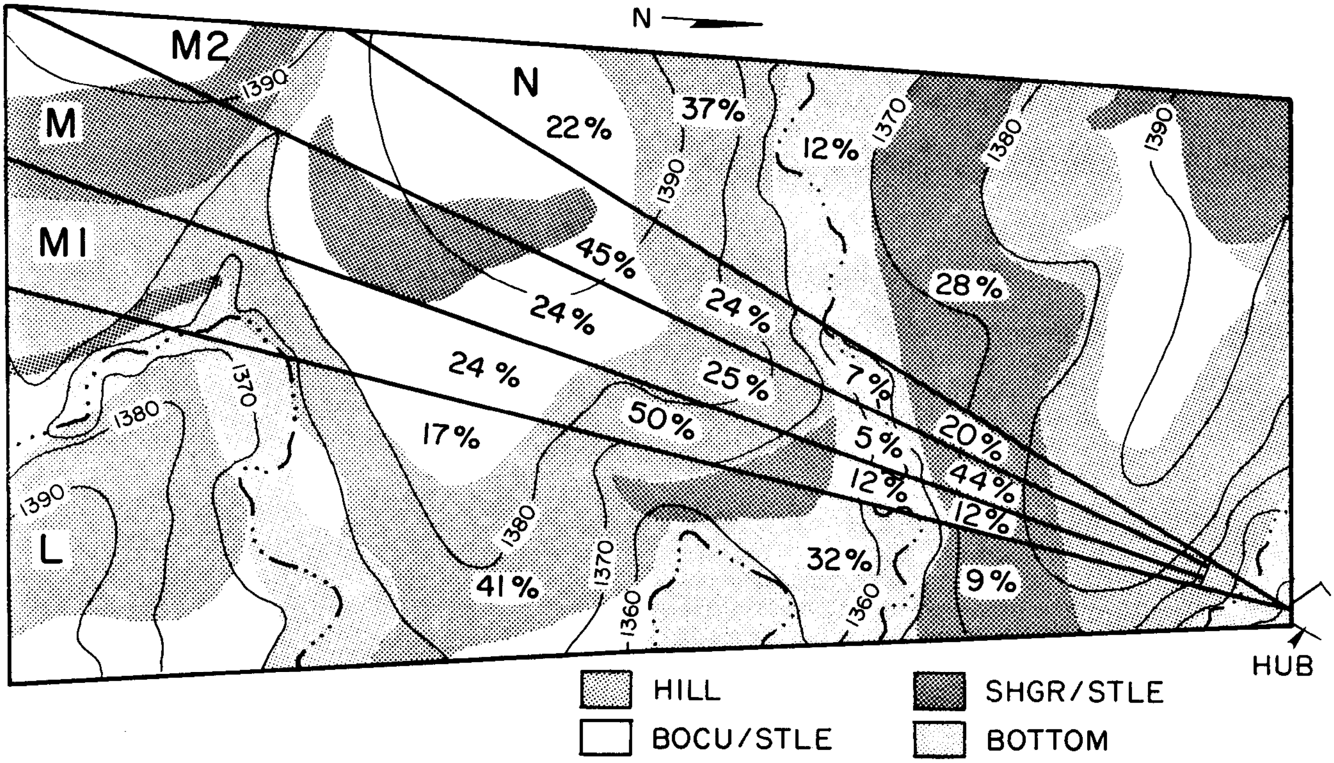

**Fig. 1.** *Map of the rotationally grazed paddocks showing 3-m contour intervals and delineation of plant communities. Paddocks L and N were in the RG-14 treatment and Pastures M1, M, and M2 were in the RG-42 treatment. Numbers within a plant community represent the percent of the paddock that was occupied by each plant community.*

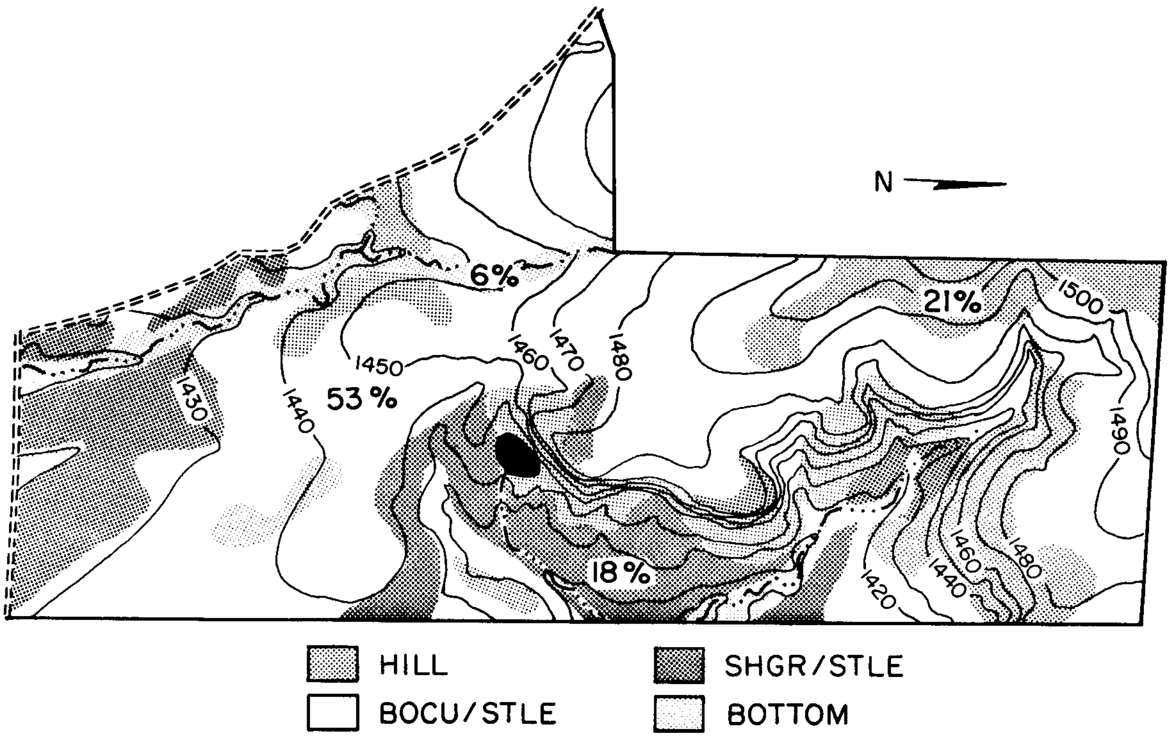

**Fig. 2.** *Map of the continuously grazed pasture showing 3-m contour intervals and delineation of plant communities. Numbers within a plant community represent the percent of the pasture occupied by each plant community.*

treatment. The radial length of all RG paddocks was about 1.3 km.

The CG treatment was a single, 248-ha pasture that had been stocked at a moderate rate since 1960 and was stocked at 5.9 ha • cow$^{-1}$ • year$^{-1}$ throughout this study. The longest dimension of this pasture is 2.7 km and the farthest distance to the centrally located water was 1.4 km (Fig. 2).

For the purposes of this paper 4 plant communities were identified based on differences in floristic composition, soil type, and topographic position. A general description of each is presented in Table 1. Sacrifice areas near permanent water were also delineated in all study areas. Range condition in all treatment pastures was good. For a more detailed description of the study area and study design, see Heitschmidt et al. (1985, 1987).

### Observations of Cattle Behavior

Cattle were observed simultaneously in the CG and RG treatments during 8 seasonal trials conducted between October 1982 and August 1984. Trials were begun when cattle entered the first RG-14 paddock (i.e., pasture L). Trials lasted from 6 to 15 days and observations were made hourly using scan sampling (Altmann 1974) between daylight and dark for a total of 75 observation days in each treatment. The location, area occupied, activity, and number of cows in each herd or subherd was recorded on topographical maps. Activities were classified as grazing, loafing or mixed. Subherds were classified as grazing or loafing when 90% or more of the animals within the subherd were engaged in the specified activity. When less than 90% of the animals within a subherd were engaged in the same activity the subherd was classified as mixed. Night time observations were not attempted because of labor constraints and because night time activity is generally confined to the area where cattle bed for the night (Johnstone-Wallace and Kennedy 1944, Weaver and Tomanek 1951, Dwyer 1961, Senft et al. 1985).

### Data Analysis

Number of animals observed in each plant community at each hourly observation was summed by trial, pasture, and activity, and divided by total number of animals in all communities to determine percent occupancy in each plant community. When the area occupied by a herd was located on more than 1 plant community, the animals in that herd were proportionally allocated to the different communities based on the area of the herd in each community. Data were summarized using selectivity (SI) and relative electivity (RE) indices. The selectivity index is a measure of the proportion of the time that the animals were not selecting communities in proportion to their availability (Van Dyne et al. 1980). This selectivity index has a value of 0 when plant communities are occupied in the same proportion as their availability and a value of 1 at maximum selectivity. Relative electivity estimates preference for individual communities and has a value of zero for random selection and a possible range between 1 (preferred) and -1 (avoided). Lechowicz (1982) stated that RE embodies a measure of the community's value as a function of both its abundance and the abundance of other communities available. He also suggested that RE can be used to make comparisons of preference from diverse environments, and that RE is a non-linear index and not amenable to parametric analysis. However, the data reported in this study were analyzed for departures from analysis of variance assumptions as suggested by Stroup et al. (1986) and within the range of data reported the residual errors were generally normally distributed. Furthermore, rank order transformation (Conover and Iman 1981) of RE had only minor effects on the results of the analysis.

The selectivity index was analyzed separately for each activity (i.e., grazing, loafing, and mixed) using repeated measurements least squares analysis of variance with grazing treatment (i.e., RG-42, RG-14, and CG) as the main plot and trial as a sub-plot. Relative electivity was analyzed in a similar manner except plant communities were sub-plots and trials were sub-sub-plots (Engeman et al. 1986). Data from the RG-14 treatment were further analyzed to determine if distribution (loafing activity was not analyzed because of missing data) differed between the initial and

**Table 1. General descriptive parameters of the 4 plant communities delineated for study.**

| Community | Code | Dominant Grasses[1] | ANPP[2] | Topo-sequence | Slope | Soil texture[3] | Shrub canopy |
|---|---|---|---|---|---|---|---|
| Hill | HILL | Sideoats grama<br>*(Bouteloua curtipendula)*<br>Silver bluestem<br>*(Bothriochola saccharoides)* | 2500 | Ridge | 3-12% | Rocky clays, clay loams, & silty clay loams | <5% |
| Sideoats grama/ Texas wintergrass | BOCU/STLE | Sideoats grama<br>Texas wintergrass<br>*(Stipa leucotrica)*<br>Buffalograss<br>*(Buchloe dactyloides)*<br>Japanese brome<br>*(Bromus japonicus)* | 3000 | Mid-slope | 0-3% | Clay loams | 10-20% |
| Shortgrass/ Texas wintergrass | SHGR/STLE | Buffalograss<br>Texas winter grass<br>Tumblegrass<br>*(Schedonnardus paniculatus)*<br>Japanese brome | 2500 | Variable | 0-3% | Clay | 10-20% |
| Bottom | BOTTOM | Texas wintergrass<br>Buffalograss<br>Japanese brome<br>Sideoats grama | 3300 | Drainage | <1% | Clay | 5-10% |

[1] Dominance based on frequency data from 200 quadrats/community/replication (unpublished). Dominant species had average frequency >40% in 0.25*0.50m frames.
[2] Average above ground net primary production from Heitschmidt et al. (1985).
[3] From Heitschmidt et al. (1985)

final day in a paddock using a within paddock split-plot and split-split-plot analysis for SI and RE, respectively. If the covariance matrix of the repeated measures analysis did not satisfy the Huynh-Feldt condition, the probability level of the associated F-ratio was based on the Box correction for degrees of freedom (Huynh and Feldt 1976). Protected least significant differences were used for mean separation. These analyses used the variation among the 2 paddocks in the RG-14 treatment and the 3 paddocks in the RG-42 treatment to estimate experimental error caused by grazing treatment in this grazing treatment case study.

## Results

The selectivity index for grazing cattle differed among all grazing treatments ($P<0.001$), but was not affected by trial or the grazing treatment by trial interaction (Fig. 3). Mean SI was 0.15, 0.10, and 0.07 for the RG-42, RG-14, and CG treatments, respectively. These results refute our initial hypothesis and the common belief that increasing stock density with rotational grazing will reduce selective grazing of plant communities. There were no significant grazing treatment interactions for the RE of grazing cattle. This indicates that grazing treatments did not affect relative preference or avoidance for communities (Fig. 4). Thus the increase in SI was a result of differences in the degree of selective occupancy of plant communities and not due to major changes in cattle preference for plant communities.

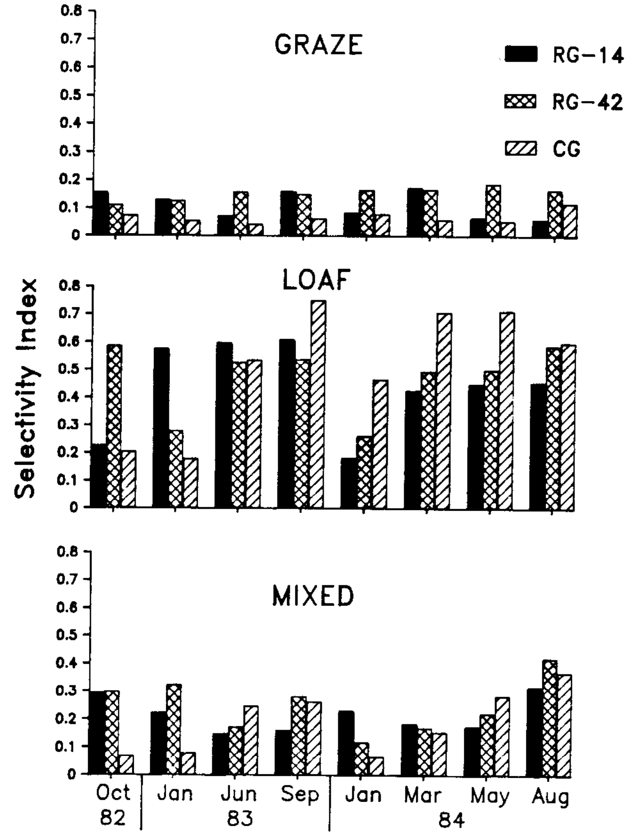

**Fig. 3.** *The effect of grazing treatment on selectivity index in grazing, loafing or mixed activities in 4 plant communities on 8 dates.*

Selectivity of loafing cattle was affected by trial ($P<0.01$) and the trial × treatment interaction ($P<0.07$), but was similar among grazing treatments. Averaged across grazing treatments, cattle were less selective for loafing sites during the October 1982 and January 1983 and 1984 trials compared to the other trials (Fig. 3). The grazing treatment × trial interaction was caused by an inconsistency of this seasonal trend of SI among grazing treatments during different trials. Relative electivity of loafing cattle for plant communities was affected by type of community ($P<0.006$). In general areas around water were preferred loafing sites, and the HILL and BOCU/STLE communities were avoided (Fig. 5). This pattern was modified by grazing treatment and trial. The three-way interaction was caused primarily by a consistent preference for the area around permanent water in the CG treatment compared to a less consistent preference for this site in the rotationally grazed treatments. The cattle in the RG-42 treatment demonstrated greater preference for the BOTTOM communities and greater avoidance of the area near water than the other 2 grazing treatments. However, this pattern was most likely an artifact of pasture configuration and land area classification than a representation of cattle preference. In all RG paddocks the hub area of the grazing cell was the only location classified as water (Fig. 1). Cattle in the RG treatments often loafed in the BOTTOM community adjacent to the hub, and this trend was particularly prevalent in the RG-42 treatment where this area was common to all 3 paddocks in that treatment. Thus, preference for water as a loafing site was somewhat confounded with the BOTTOM community in the RG treatments, and was probably the reason the treatment × community × trial interaction was significant.

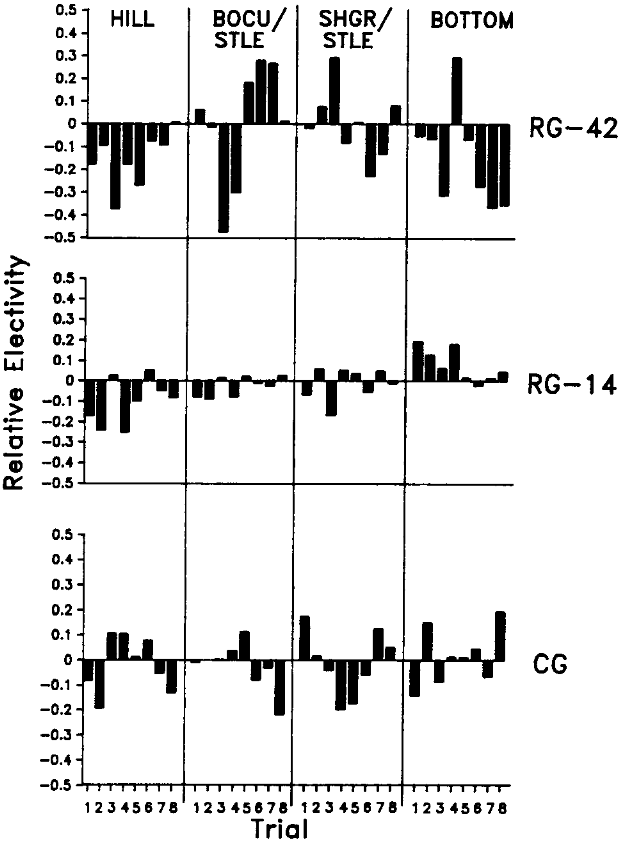

**Fig. 4.** *The effect of grazing treatment on relative electivity based on percentage of grazing cattle observed in 4 plant communities on 8 trials. Trial dates were: 1=Oct 82, 2=Jan 83, 3=Jun 83, 4=Sep 83, 5=Jan 84, 6=Mar 84, 7=May 84, 8=Aug 87.*

Analysis of SI and RE of cattle herds engaged in mixed activities showed that the only significant effect was for type of plant community on RE ($P<0.01$). This effect indicated that cattle engaged in a mixture of activities preferred the BOTTOM communities and avoided the HILL and BOCU/STLE communities (Fig. 6). The similarity in preference for plant communities exhibited by cattle

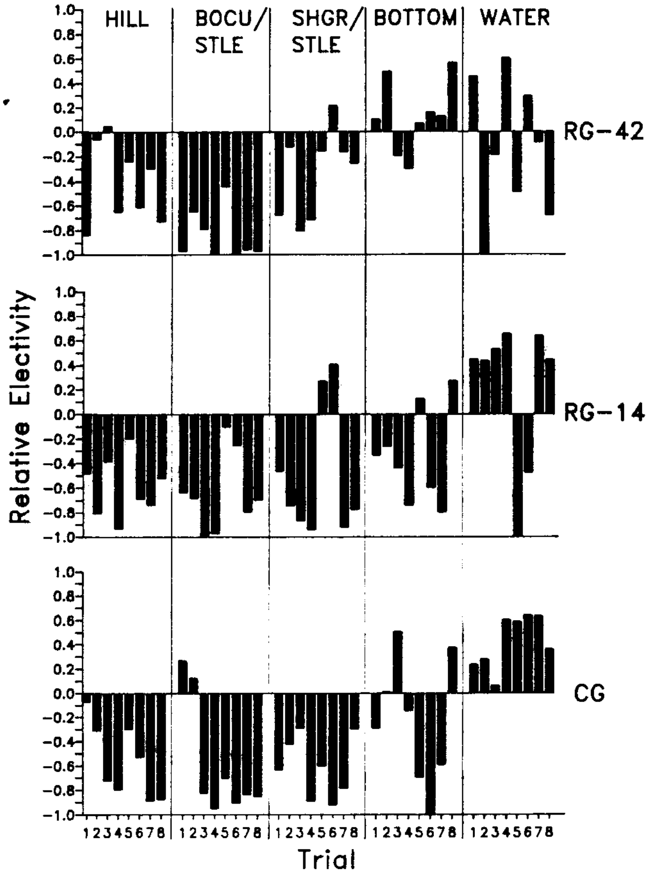

**Fig. 5.** *The effect of grazing treatment on relative electivity based on percentage of loafing cattle observed in 4 plant communities on 8 trials. Trial dates are described in Figure 4.*

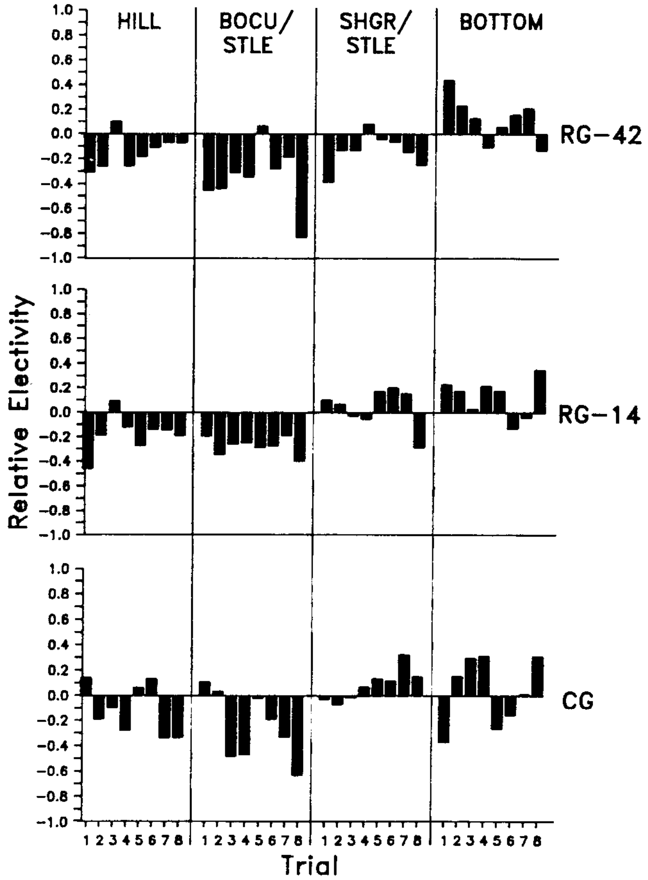

**Fig. 6.** *The effect of grazing treatment on relative electivity based on percentage of cattle observed in 4 plant communities on 8 trials during periods of mixed activity. Trial dates are described in Figure 4.*

engaged in loafing and mixed activities indicated that herds classified as mixed were often in a transition between loafing and grazing.

The degree of selectivity was affected by activity. Grazing cattle were less selective than animals engaged in other activities. The SI averaged 0.10, 0.22, and 0.48 for grazing, mixed, and loafing herds, respectively. This relationship resulted from a decrease in area occupied by herds as their activity changed from grazing to loafing.

There were only minor differences in cattle distribution between the first and last day in the RG-14 paddocks. The SI for plant communities of grazing cattle did not change between the first and last day in a paddock. Although the day × community × trial interaction for RE of grazing cattle was significant ($P<0.05$), subsequent analysis of the ranked data was not significant ($P>0.20$). The SI decreased ($P<0.07$) from 0.29 on the first day to 0.19 on the last day in a paddock for herds engaged in mixed activities. Preference for plant communities by mixed activity herds was affected by the community × trial ($P<0.04$) and day × community × trial ($P<0.01$) interactions. The mixed RE 3-way interaction indicated that generally the HILL community was less preferred, and the BOTTOM community more preferred on the first day in a paddock compared to the last day, but this trend was not consistent across trials.

## Discussion

The results of this study indicate that selection for plant communities by cattle was either not affected or that selectivity (i.e., nonuniform grazing) was slightly increased by rotational grazing systems that created very high stock densities compared to continuous grazing. Stock densities ranged from 0.17 cows • ha$^{-1}$ in the CG pasture to 12.50 cows • ha$^{-1}$ in the RG-42 paddocks; a 74-fold difference. These results indicate that our original hypothesis was false. However, if RE and SI were calculated on a daily basis instead of based on the average use during a trial the results would have been altered. On a daily basis cattle in the CG treatment were more selective for plant communities. This occurred because the communities were not evenly distributed in the CG pasture (Fig. 2) and the animals generally remained either north or south of the centrally located water source during a single day. This behavior was the result of physical limits on the ability of cattle to cover all of this 248-ha pasture in a day. However, by using different ends of the pasture on different days throughout a trial, cattle distribution relative to plant communities was as uniform in the CG as in the RG treatments.

The importance of this study is the relationship of these results to other grazing behavior studies and to the general principles of grazing management. When single-herd multi-pasture rotational grazing has been compared to continuous grazing on a yearlong or seasonlong basis, rotational grazing has not resulted in more uniform utilization of forage at either the individual plant or community level (Gammon and Roberts 1978, Kirby et al. 1986). However, intensive early stocking has resulted in more uniform utilization than continuous grazing (Smith and Owensby 1978, Ring et al. 1985). The major difference between the rotational grazing studies (including ours) and intensive early stocking is that the former require management tactics that insure a forage reserve is accumulated during periods of active growth for consumption during periods of slow growth. This is not a consideration with IES because it is designed to utilize a major portion of the forage available in a paddock during each grazing event. Grazing distribution appears to be more sensitive to the amount of standing herbage than to grazing pressure or stock density. This hypothesis is supported by this study in conjunction with our previous data (Heitschmidt et al. 1987). The previous data collected on the same pastures used in this study indicated more total standing crop but similar amounts of live standing crop in the CG compared to the RG treatments. Thus, in the present study, plant community preference and forage standing crop were rather similar between RG and CG treatments whereas there was about a 74-fold difference among the treatments in livestock density, which would have resulted in similar differences in grazing pressure.

Other grazing behaviors such as grazing time, bite size, and bite rate have been shown to be more sensitive to the amount of forage available on a unit area of land basis than on an animal demand or stock density basis (Chacon and Stobbs 1976, Chacon et al. 1976, Jamieson and Hodgson 1979, Hendricksen and Minson 1980). We hypothesize that most grazing behaviors will be affected more by forage standing crop on an area basis than on an animal demand basis. This hypothesis implies that if pastures are grazed yearlong or seasonlong, grazing systems will have little effect on livestock distribution within the occupied pastures. This is primarily a result of the necessity of leaving sufficient forage at the end of one grazing period to insure that during subsequent grazing periods there will be adequate forage to meet the nutrient demands of the livestock. Reserving current forage production for future demand tends to ensure that forage standing crop dynamics will be rather similar among different grazing systems when they are grazed yearlong or seasonlong. This hypothesis contradicts the hypothesis that short duration grazing will improve grazing distribution of livestock and promote more uniform utilization of forage (Kothmann 1980, Savory and Parsons 1980, Malechek and Dwyer 1983). Our hypotheses are not new and tend to support Voisin's (1959, p. 100) contention that "there is one way to baffle the cow's instinct: starve her". He recommended rotational grazing only on growing pastures, and the use of conserved forages during dormancy.

If the objective of grazing management is to manipulate the environment at the plant-animal interface to increase the efficiency of forage harvest, then controlling the amount of available forage may be the most effective tool. However, this severely limits the alternatives available to producers who maintain livestock on rangelands yearlong. These results also indicate that the grazing management strategy of forcing livestock to graze rangelands uniformly by using high grazing pressure may be ineffective. It was apparent from this study that certain characteristics of the environment such as watering points and shade trees were important determinants of favored loafing sites regardless of grazing system. Because loafing sites influence the distribution of herds engaged in mixed activity (38% of the observations), and to a lesser extent grazing herds, a more complete understanding of environmental cues that attract livestock to loafing sites would be of practical importance. Such knowledge could help managers design pastures that would induce livestock to harvest forage more efficiently.

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# Experimental evaluation of the grazing optimization hypothesis

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## Abstract

**The herbivore grazing optimization hypothesis predicts an increase in aboveground net primary productivity (ANPP) at a moderate grazing intensity. The hypothesis was tested by grazing controlled densities (0 to 145 individuals/m$^2$) of big-headed grasshoppers (*Aulocara elliotti* Thomas) for short time spans (7 to 13 days) on enclosed swards (0.7 m$^2$) of blue grama [*(Bouteloua gracilis)* (Willd. ex H.B.K.) Lag. ex Griffiths]. ANPP of each of 257 experimental enclosures was estimated following regrowth by using a standing crop index (the product of mean total blade length per tiller and percent basal cover) after the grazing period and clipping after the regrowth period. ANPP was not significantly reduced by grazing in any of the 5 short-duration grazing experiments. In 2 of the 5 experiments, ANPP increased significantly with grazing. In 1 of the other 3 experiments there was evidence for the grazing optimization hypothesis.**

**Key Words: grazing effects, *Bouteloua gracilis*, herbivore optimization hypothesis**

The herbivore-plant relationship may be considered as a special case of the predator-prey system in which the logistic growth curve is most appropriate to describe primary productivity (Noy-Meir 1975, Caughley 1976). One prediction of such a model is that as herbivory reduces plant biomass from its maximum standing crop, plant productivity will increase. The herbivore grazing optimization hypothesis (McNaughton 1979, Hilbert et al. 1981) states that as grazing intensity increases, aboveground net primary productivity (ANPP) also increases up to some optimal grazing intensity, then decreases to a level below that of ungrazed plants (Fig. 1). Though commonly accepted for aquatic ecosystems (Carpenter and Kitchell 1984, Carpenter et al. 1985), this hypothesis is currently controversial for terrestrial ecosystems (Belsky 1986, 1987; McNaughton 1986).

Grasses are well adapted to regenerating biomass removed by grazing. Among grasses, shortgrasses are particularly adapted to grazing because their apical meristems are near ground level and less accessible to grazing animals (Dahl and Hyder 1977). Blue grama [*(Bouteloua gracilis)* (Willd. ex H.B.K.) Lag. ex Griffiths] is a warm-season dominant species of the shortgrass prairie (Detling 1979) that increases in relative abundance in heavily grazed areas and is adapted to extremes of environmental conditions. In this study, we evaluated the grazing optimization hypothesis for blue grama by examining its response to short-duration grazing events by big-headed grasshoppers *(Aulocara elliotti* Thomas) at different times during 2 different growing seasons.

## Study Area

The study was conducted on the western edge of the USDA-ARS Central Plains Experimental Range in northcentral Colorado (40°49′N, 104°47′W). Elevation is 1,650 m, the topography is gently rolling plains, and the soil texture is sandy loam (Dickinson and Dodd 1976). Climate of the study area is continental with 82% of the mean annual precipitation occurring from 1 April to 30 September. Mean annual precipitation over a 31-year period was 310 mm, with a range of 110 mm to 580 mm (Detling 1979). The experiments were conducted within a fenced pasture from which large herbivores had been excluded for the previous 10 years. Dominant species on this shortgrass prairie site were blue grama in association with buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.].

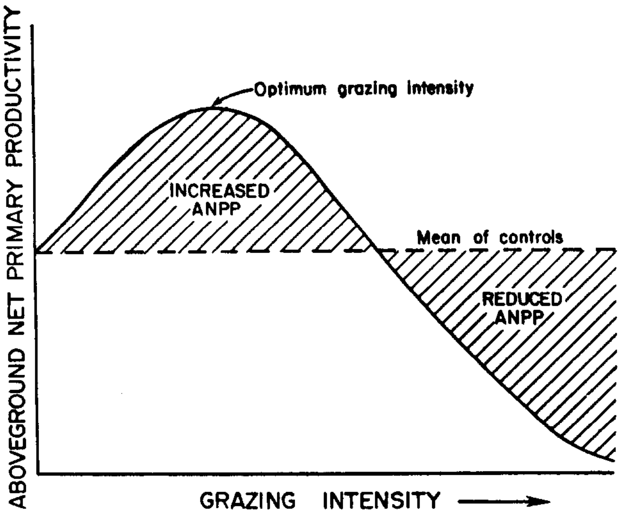

**Fig. 1.** *The herbivore grazing optimization curve. A maximum value of aboveground net primary productivity (ANPP) is predicted at a moderate grazing intensity and a minimum value of ANPP at a high grazing intensity.*

## Methods

Big-headed grasshoppers were chosen as the grazers because they are native to the shortgrass prairie and, with an average dry weight of 0.1 g, are an appropriate size for use in a large number of small experimental units. In addition, they feed well on blue grama, survive well with handling, and are available for mass collections as fourth or fifth instars or adults from early June (from southern locations) through mid-August (Capinera and Sechrist 1981).

Wooden frame cages with inside measurements of 0.83 m by 0.83 m by 0.5 m high were covered with aluminum wire screen and placed on all plots (including the controls) immediately preceding each experiment. Placement sites were chosen randomly, except for avoiding woody shrubs, buffalograss, or disturbances such as ant mounds or rodent burrows. Prior to initial placement of the cages, plant species other than blue grama (always less than 10% of standing crop) were removed from the plot. Mean soil water content (2 readings from 3 access tubes) of the 15- to 60-cm layer was measured biweekly with a neutron probe. Water content of the 0-to

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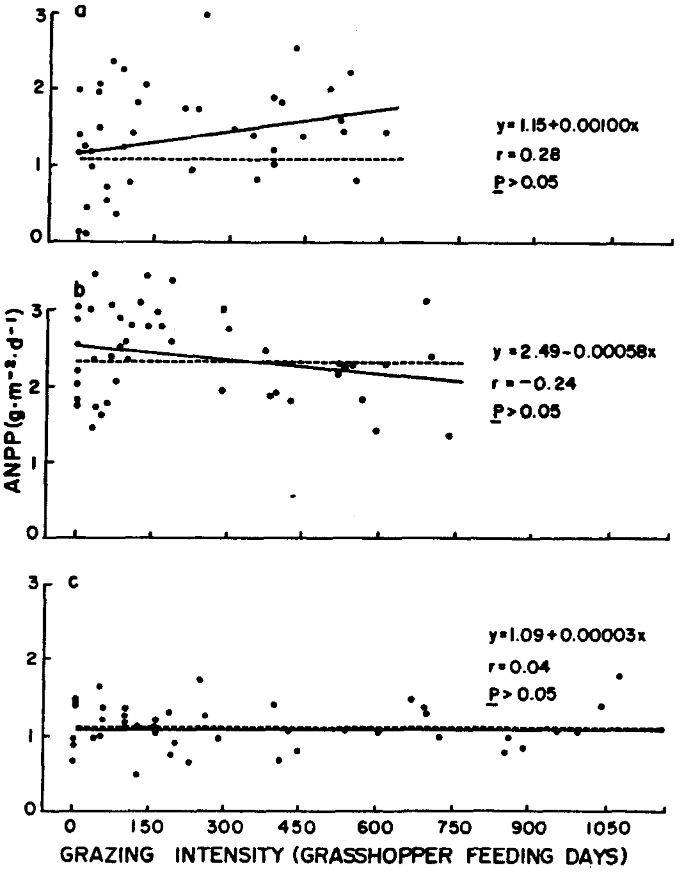

**Fig. 2.** *Blue grama aboveground net primary productivity (ANPP) on areas subjected to varying intensities of grazing during the periods (a) 20 June to 18 July 1979, (b) 24 July to 22 August 1979, and (c) 26 August to 6 October 1979. Dashed lines are means of controls; solid lines are linear regressions.*

15-cm layer was not included because of the unreliability of this method at shallow depths.

A nondestructive technique was used to estimate the aboveground standing crop of blue grama immediately before and after grazing. A square wood frame with an inner grid comprised of 16 strings set at 10-cm intervals along both axes of the frame was placed 4 cm above the ground. Basal cover of tillers was measured to the nearest millimeter along each string, for a total of 13.3 m of line measurements per quadrat. At alternate intersections of 2 strings, the nearest blue grama tiller was selected, and length (mm) of each blade was recorded. Vegetation on calibration plots was measured for blade lengths and basal cover, clipped at ground level, and oven dried at 60° C for 72 hours. Calibrations of the standing crop index (percent basal cover • mean total blade length per tiller) vs. plant biomass were obtained by using a least squares fit of a zero-intercept linear regression. This methodology is more fully described and representative calibration plots are given in Williamson et al. (1987).

Treatments were assigned randomly to the experimental units and consisted of caged and ungrazed (controls) or caged and grazed plots. In 1979, we utilized 6 control plots and 5 plots each of 8 levels of grazing intensity. Grazing intensities were based on stocking densities of 5, 10, 15, 20, 40, 60, 80, or 100 grasshoppers per cage. Based on analysis of the 1979 data, the experimental design for 1980 was modified to increase the number of control plots to 13. The treatment with 15 grasshoppers per cage was eliminated in the June 1980 experiment and, in addition, the treatment with 5 grasshoppers per cage was eliminated in July 1980.

Because weather-dependent grasshopper mortality occurred during the grazing period, a grazing intensity index, grasshopper feeding days, was computed as the product of length of the grazing event (days) and average number of grasshoppers in the cage during that period. Average number of grasshoppers per cage was determined by counting grasshoppers as they were placed on and removed from the plots, and assuming a linear decrease in density for those which disappeared by the time of removal. This was considered a reliable index of grazing intensity (or pressure) within an experiment but not between experiments. Use of this index assumes a linear correlation between total grasshopper feeding days and blue grama biomass removed, although this assumption may not be true at very high grasshopper densities (Hewitt et al. 1976).

Only 1 grazing event was conducted on each plot. The chronology of each experiment included: (1) nondestructive biomass measurements before grazing; (2) a 7- to 13-day grazing period, which was terminated when the most intensely grazed plots were 95% denuded; (3) nondestructive biomass measurements 2 to 7 days after grazing; (4) a 13- to 41-day regrowth period; and (5) a destructive biomass measurement. Grazing periods in the 5 experiments were: 10 to 17 June 1979; 12 to 20 July 1979; 11 to 24 August 1979; 15 to 26 June 1980; and 22 to 31 July 1980. Biomass harvests at the end of the regrowth periods were made on: 16 to 20 July 1979; 16 to 31 August 1979 (interrupted by cold, wet weather); 6 to 7 October 1979; 23 to 26 July 1980; and 13 to 14 August 1980. Mean ANPP (mass • area$^{-1}$ • time$^{-1}$) was calculated as in Hunt (1978) by dividing the change in biomass by the number of days in the regrowth period.

Since the presence of a parabolic curve was hypothesized (Fig. 1), response surface techniques were adopted to better define the actual response curve (Ostle and Mensing 1975). Individual linear regression analyses were conducted in which tests for differences between treatment means were followed by tests of the slope of the best fit least squares regression line. Before conducting the analyses, the data were examined for homogeneity of variance. Mean ANPP in each treatment and experimental data were compared. Student's t-test was used to test for individual differences between graphically identified treatment means (Ostle and Mensing 1975), using $\alpha = 0.05$ as the significance level. Finally, ANPP was plotted against grasshopper feeding days for each experiment, and the graphs were examined for lack of goodness of fit of a zero-slope line whose intercept was the mean value of the ungrazed plots.

## Results and Discussion

The mean biomass ($\bar{x}$±1 SD) prior to grazing on all experimental plots from the June, July and August 1979 and June and July 1980 experiments was 49.8 (±18.9) g • m$^{-2}$, 71.8 (±21.9) g • m$^{-2}$, 33.9 (±14.8) g • m$^{-2}$, 105.8 (±17.3) g • m$^{-2}$, and 136.6 (±26.2) g • m$^{-2}$, respectively. No significant effect of grasshopper grazing on ANPP of blue grama was found in the June and August 1979 sampling periods (Fig. 2a and 2c). In the latter case, cool weather apparently retarded feeding. In the two 1980 experiments, ANPP across all grazing intensities was significantly greater than ANPP of the ungrazed controls (Fig. 3).

In the case of the July 1979 experiment (Fig. 2b), there was evidence for the hypothesized (Fig. 1) grazing optimization curve. In this experiment, only 2 observations in the range of 100 to 300 grasshopper feeding days (corresponding to 20 and 40 grasshoppers per cage) were below the mean ANPP of controls, while 9 values were above the controls. In the range of 300 to 800 grasshopper feeding days (60, 80 and 100 grasshoppers per cage), only 3 values were above the mean control ANPP, and 8 values were

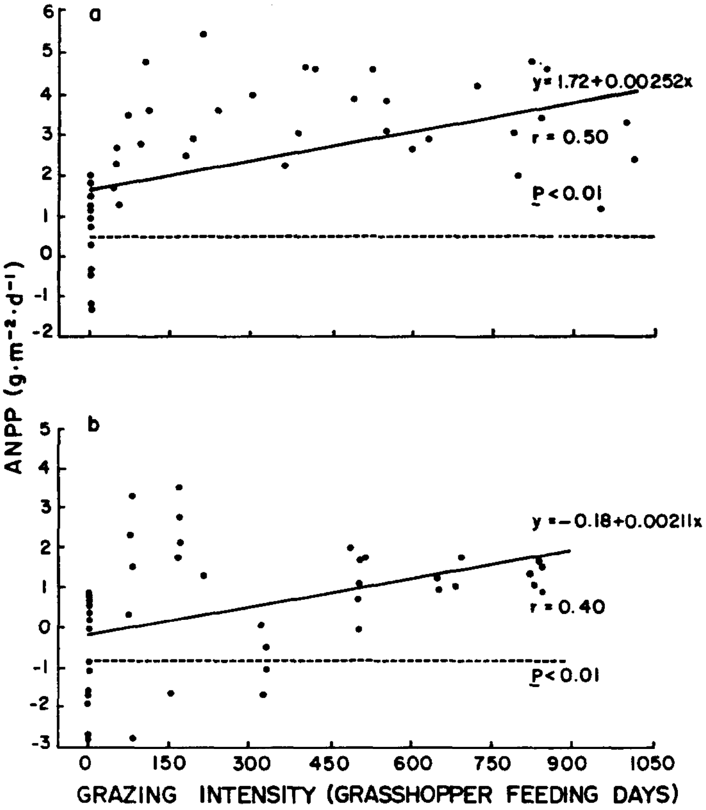

**Fig. 3.** *Blue grama aboveground net primary productivity (ANPP) on areas subjected to varying intensities of grazing during the periods (a) 28 June to 24 July 1980, and (b) 31 July to 13 August 1980. Dashed lines are means of controls; solid lines are linear regressions.*

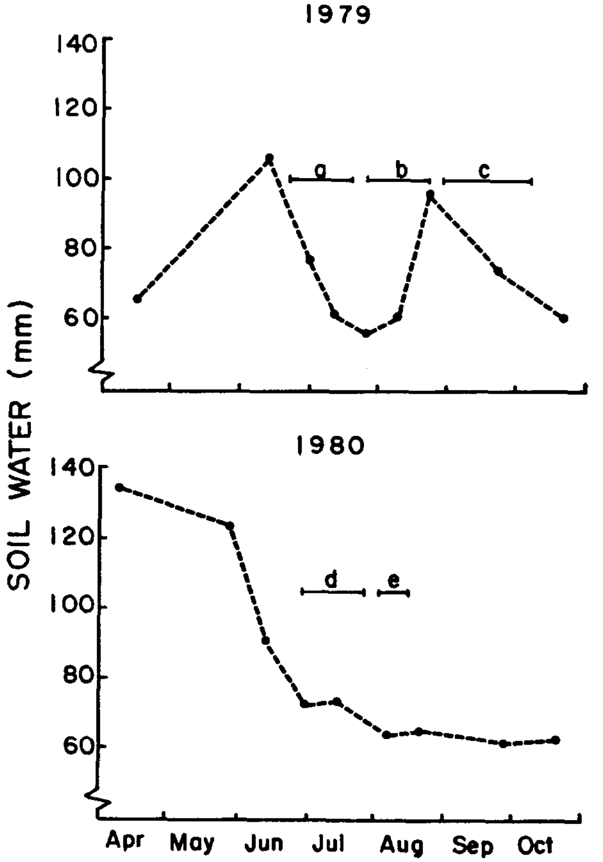

**Fig. 4.** *Soil water content from neutron probe measurements in the 15- to 60-cm soil section for the 1979 and 1980 growing seasons. Lines a, b, and c represent the duration of the regrowth period following the June, July, and August 1979 grazing experiments. Lines d and e represent the duration of the regrowth period following the June and July 1980 grazing experiments.*

below it. The means of these 2 sets of values were significantly different from each other (t = 3.36, 23 d.f., $P<0.01$). As with the 2 other 1979 experiments, ANPP across all grazing treatments did not differ significantly from that of the ungrazed controls.

The accuracy and precision of measurements of ANPP depend not only on changes in biomass but on length of the regrowth period. Thus, when determining mean daily rates of change, if some factor such as soil water or temperature is limiting, the calculated rate may be unrealistically reduced by including a time period when little or no growth is occurring. In the experiment with the longest regrowth period (41 days), and including a time period when temperature limited growth, ANPP was low with noticeably less treatment variability (Fig. 2c).

The within-year and between-year variability of ANPP (Figs. 2 and 3) indicates that weather effects should be considered when evaluating grazing effects. Soil water content in the 15- to 60-cm depth varied significantly within and between growing seasons (Fig. 4). Soil water content of the 15- to 60-cm section decreased from approximately 21% (95 mm) to 13% (60 mm) during the regrowth period in both the June and August 1979 experiments (Fig. 4, lines a and c). During regrowth in the July 1979 experiment (Fig. 4, line b), soil water content increased from 12% (55 mm) to 21% (95 mm). In the regrowth periods following both 1980 experiments, soil water content remained relatively constant at 16% (70 mm) and 14% (65 mm), respectively (Fig. 4, lines d and e).

Understanding the interactive effects of soil water content and grazing intensity is essential to understanding the relationship of grazing intensity and blue grama ANPP. Similar results between the June and August 1979 experiments and between the June and July 1980 experiments may be attributable to similar soil water content patterns in the respective regrowth periods. Maximization of productivity with a moderate amount of grazing may occur under certain soil water conditions. Hodgkinson (1976) found that *Danthonia caespitosa* plants which were completely defoliated once during the summer and not irrigated increased shoot yield, but similarly defoliated plants which were irrigated decreased shoot yield compared with undefoliated plants. After precipitation following dry conditions, production on lightly to moderately grazed areas frequently exceeds that on ungrazed or heavily grazed areas (McNaughton 1976, Heitschmidt et al. 1982). Thus, herbivore grazing optimization of shortgrass ANPP appears most likely to occur during recovery from a dry period.

Although this experimental work is based on a single grass species and a single herbivore species, it has broader ecological implications. In none of 5 experiments did a short-duration grazing event reduce ANPP of blue grama compared with ungrazed areas. When soil water content was moderate and constant through the regrowth period, all intensities of grazing resulted in equivalent ANPP that was significantly greater than ungrazed areas. This was an unexpected and interesting variation of the herbivore optimization curve. Following summer drought, light to moderate levels of grazing resulted in a significantly greater ANPP than did heavy levels of grazing.

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# Cattle nutrition and grazing behavior during short-duration-grazing periods on crested wheatgrass range

KENNETH C. OLSON, GERALD B. ROUSE, AND JOHN C. MALECHEK

## Abstract

**Daily changes in diet quality, ingestive behavior, and daily forage intake were investigated using crested wheatgrass [*Agropyron desertorum* (Fisch.) Schult. and *A. cristatum* (L.) Gaertn.] range in a 3-year study to provide an understanding of how the rapid defoliation that occurs under the high stocking density of short duration grazing (SDG) affects livestock nutrition. A 10-paddock short duration grazing cell was stocked with yearling Angus heifers. Grazing periods in paddocks varied from 1 to 4 days. Dietary quality was assessed daily within pre-selected paddocks by determining crude protein content and in vitro organic matter digestibility of extrusa samples collected from esophageally fistulated animals. Three variables of ingestive behavior were measured concurrently, including ingestion rate, biting rate, and grazing time. Daily forage intake was estimated by multiplying ingestion rate and grazing time. There were large daily changes in diet quality, ingestive behavior, and forage intake during the grazing period within particular SDG paddocks. Diet quality declined significantly during the 2 or 3 day grazing period in all 3 years. Although not as consistent throughout the study, ingestive behavioral responses changed significantly, indicating declines in forage intake during the grazing period on a particular paddock. Ingestive behavior was correlated with several characteristics of the sward that changed as it was defoliated. Ingestion rate decreased with herbage availability, apparently causing the animals to compensate by increasing biting rate or grazing time. Ingestion rate and biting rate decreased as nutritional quality of the sward declined, as indicated by decreased crude protein content and digestibility, and increased fiber content. Based on the system studied, grazing periods in SDG paddocks should be no more than 2 days to maintain high levels of livestock performance on crested wheatgrass range.**

**Key Words: diet quality, ingestive behavior, feed intake, crested wheatgrass, *Agropryon desertorum*, *A. cristatum*, sward characteristics, grazing management**

An important feature of short duration grazing (SDG) is the postulated effect of rapid rotation on dietary quality (Savory 1978). This purportedly allows animals to maximize selectivity and plants to regrow during the rest period, providing young and highly nutritious forage for the next grazing period. Thus, animal nutrition and resultant performance under SDG are hypothesized to be better than under traditional grazing schemes (Kothmann 1980). However, under the high stocking density in SDG paddocks, sward characteristics may change rapidly. For example, Heitschmidt et al. (1982) reported significant differences in crude protein content (CP) of available herbage before and after grazing in SDG paddocks. Thus, animal nutritional response, in terms of diet quality, ingestive behavior, and forage intake may also fluctuate in response to such changes.

Taylor et al. (1980) found no change in dietary CP over the course of 7-day grazing periods in individual paddocks of an SDG system, but dietary in vitro organic matter digestibility (IVOMD) declined significantly, presumably leading to decreased nutrient intake. They felt this could be overcome by using more paddocks and decreasing the length of grazing periods. Subsequently, Ralphs et al. (1986) repeated the trial with 3-day grazing periods on a similar site, and found that CP and IVOMD both declined significantly in the diets of sheep and cattle.

If management of SDG is to improve dietary nutrition and resultant animal performance, length of grazing periods in paddocks must be controlled so that fluctuating forage conditions do not develop that negatively impact animal nutrition. A scientific understanding of this and other principles of SDG is currently lacking (Kothmann 1984). Applying SDG as a scientifically founded program for grazing management requires that the principles upon which it is based be clearly defined, quantified, and validated. This includes understanding the sequence of events in the plant-animal interface that transpire from introduction of animals into paddock until they are rotated to the next paddock. Guidelines concerning the length of grazing periods in each paddock could then be developed to optimize animal nutrition by minimizing declines in diet quality or forage intake that may develop as the vegetation is defoliated. In addition, improved management may be obtained by better understanding which sward characteristics are responsible for changes in dietary nutrition. Sward-based criteria could then be developed to assist SDG managers in livestock rotation decisions. Therefore, the objectives of this study were to (1) determine if SDG causes changes, and the magnitude of those changes, in dietary quality, forage intake, and ingestive behavior during the grazing period of individual paddocks, (2) determine sward characteristic and ingestive behavior relationships under SDG, and (3) define management guidelines for length of grazing period in individual paddocks to maintain nutrient intake at high levels.

## Methods and Procedures

### Study Site

This study was conducted from 1983 to 1985 on the Tintic Experimental Pastures in Juab County, Utah. Average annual precipitation for the experimental area is 330 mm, distributed evenly through all seasons. The area is typical of Intermountain foothill range that is usually used for spring or fall grazing. Prior to this study, it had traditionally been used as spring or summer range. The SDG cell consisted of 10 equal-sized 8.4-ha (21 acre) paddocks arranged radially around a central watering and handling facility. The site was renovated in 1951 by removing unpalatable woody species, including big sagebrush (*Artemisia tridentata* Nutt.), rabbitbrush [*Chrysothamnus nauseosus* (Pallas)Britt.], and juniper trees (*Juniperus* spp. L.), and seeding to introduced wheatgrasses (*Agropyron* spp. Gaertn.) (Cook 1966). Most of the SDG cell was seeded to crested wheatgrass [*A. desertorum* (Fisch.) Schult. and *A. cristatum* (L.) Gaertn.], but a portion was seeded to intermediate wheatgrass [*A. intermedium* (Host)Beauv.]. The area dominated by intermediate wheatgrass was avoided as much as

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possible for sampling in this study. The study area was grazed with sheep until 1964 (Cook 1966). Because research efforts at this site were quiescent from 1964 to 1979, grazing history during that period is unknown. The area was grazed on a season-long basis with yearling heifers from 1979 to 1982 at an average stocking rate of 1.3 ha (3.3 ac) per animal unit month (AUM)[1]. During this study, the vegetation was dominated by crested wheatgrass with localized patches of western wheatgrass (*A. smithii* Rydb.). Big sagebrush and rabbitbrush were encroaching throughout the SDG cell and localized stands of juniper occurred.

## Grazing Management

The grazing season commenced on 22 April 1985 or 6 May 1983 and 1984, and ended on 13 June 1985 or 1 July 1983 and 1984. Dates varied among years because of differences in herbage availability.

The grazing cell was stocked with 90 yearling black Angus replacement heifers and 3 to 5 bulls, resulting in a stocking rate of 0.7 ha (1.7 acres) per AUM and a stocking density of 0.14 ha (0.35 acres) per animal unit (AU)[1]. This stocking rate was in accordance with the Bureau of Land Management allotment management plan for the study site. The heifers weighed 230 to 270 kg (500 to 600 lbs.) at the beginning of each grazing season.

Animals were moved among paddocks approximately every 3 days in 1983 and 1984. Two complete cycles were made through the grazing cell. In 1985, animals were moved approximately every 2 days during the first 2 cycles, and every day during a third cycle. Length of grazing period in specific paddocks was adjusted based on herbage availability (±1 day). When moved, the animals were rotated clockwise to the adjacent paddock. Animals were moved at midday to avoid interference with normal morning and evening grazing activity.

## Field Methodology

### *Dietary Quality*

Heifers with esophageal fistulae were used to collect samples of grazed forage for nutritional analysis. In 1983, three fistulated animals were used. In 1984 and 1985, this number was increased to 5 animals. Fistulated animals were contemporaries of the larger herd of heifers that grazed the experimental paddocks. In addition, they always grazed with the herd, and were thus accustomed to the vegetation, the other animals, and the grazing system.

Samples were collected in the early morning or when animals entered particular paddocks. Animals were fasted for 5 to 10 hours prior to sample collection to encourage grazing. Chacon and Stobbs (1977) found that bite size and diet quality were influenced more by stage of defoliation and individual animal variability than by fasting or diurnal variation in time of sampling, as long as fasting was less than 12 hours. Therefore, by keeping fast periods relatively short, we assumed there would be no measurable effects on experimental results. Fistula extrusa samples were frozen in the field immediately following collection by immersion in a dry ice-alcohol bath. Samples were then stored in a freezer until laboratory analysis.

Esophageal extrusa was collected whenever animals were in 3 preselected paddocks. These paddocks were spaced evenly around the grazing cell. As animals were moved around the grazing cell, this allowed the opportunity to record dietary response to defoliation as a function of advancing plant maturity and regrowth during the rest period. In 1983, extrusa was collected on the days cattle entered and left paddocks 3, 6, and 9. In 1984 and 1985, extrusa was collected on each consecutive morning that the heifers occupied paddocks 1, 4, and 7. In 1985, extrusa was also collected immediately after movement into the paddocks (i.e., at midday), to gain information on response to ungrazed swards.

### *Ingestive Behavior and Forage Intake*

Because measures of ingestive behavior make it possible to relate forage intake with sward structure and to make relatively instantaneous measures of forage intake (Stobbs 1974), it should be useful in developing a mechanistic understanding of animal response as the sward is rapidly defoliated under SDG. Therefore, 3 variables of ingestive behavior (ingestion rate, biting rate, and grazing time) were measured in 1984 and 1985.

Ingestion rate, or intake per unit time, was measured in conjunction with collection of esophageal extrusa. Extrusa collected during timed periods of sampling was weighed in the field immediately following collection. To improve the probability of collecting all forage ingested during an extrusa collection, foam rubber plugs were placed in the esophagus posterior to the fistula during collections in 1983, as recommended by Stobbs (1973a). However, animals were often observed to be disturbed by the presence of the foam rubber plug, and did not appear to graze normally. In 1984 and 1985, a cannula insert (Olson and Malechek 1987) was used in lieu of the foam plugs to facilitate total sample collection. Although evidence that the insert improves the probability of total sample collection is not available, the insert held the fistula lumen open, apparently making it the path of least resistance for boli. Additionally, use of the cannula did not affect animal behavior.

Biting rate was visually counted during the period of intense grazing in early morning, immediately prior to esophageal extrusa collections. Animals to be observed were selected in a stratified manner to maximize independence of samples. Consecutively observed individuals were separated by a distance that was deemed adequate to minimize possible effects of social facilitation on behavior. For a particular animal, time elapsed to prehend and ingest 100 to 200 bites was recorded with a stop watch while counts were made. Timing was interrupted during nongrazing intervals, such as when animals were disturbed by insects or walking.

Four intact animals were randomly selected from the herd and fitted with vibracorders to record grazing time. These instruments remained on the animals throughout the grazing season, and grazing time was recorded continuously.

Estimated daily forage intake was the product of ingestion rate and grazing time (Freer 1981).

### *Sward Characteristics*

Total aboveground herbaceous plant biomass was estimated by double sampling procedures (Pechanec and Pickford 1937). The harvested samples were dried for 24 hours at 60° C, weighed, and saved for laboratory analyses. Plant height was measured on 100 plants located on a pace transect positioned lengthwise through the center of the paddock. The height from the ground to the top of a randomly selected tiller in the tussock was measured. The tiller was measured as it stood naturally rather than manually straightening it to its maximum height. Forage bulk density was calculated by dividing biomass by plant height, and is expressed as g dry matter (DM) per $cm^3$. Data concerning sward characteristics were collected daily, immediately following esophageal extrusa collections.

## Laboratory Methodology

A subsample of each extrusa sample was used to determine DM and organic matter (OM) content (Harris 1970) to adjust ingestion rates to an OM basis. Another subsample of each frozen extrusa sample was freeze-dried and ground through a 1-mm screen. Extrusa samples were not composited across animals, days, or paddocks, because all these sources of variation were of interest. Ground samples were analyzed for Kjeldahl nitrogen (Harris 1970) and IVOMD by use of a cellulase technique (McLeod and Minson

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[1] AUM (animal unit month) and AU (animal unit) follow the standard definition wherein 1 animal unit equals a 454-kg cow with calf or the equivalent, and an animal unit month is the forage demand of 1 animal unit for 1 month.

1978). Crude protein was calculated as Kjeldahl nitrogen times 6.25.

Five oven-dried herbage samples from each sampling date were ground through a 1-mm screen and analyzed for nutritional characteristics by near infrared reflectance spectroscopy (NIRS) Marten et al. 1985). These analyses included crude protein, IVOMD, neutral detergent fiber, acid detergent fiber, permanganate lignin, cellulose, and hemicellulose (Goering and Van Soest 1970). A subset of 100 herbage samples were randomly selected for wet chemistry analysis to develop calibration equations for NIRS.

All results for extrusa and herbage nutritive characteristics are reported on an OM basis (Harris 1970).

### Data Analysis

Detection of significant daily changes in dietary quality and ingestive behavior was by least squares analysis of variance (ANOVA) using the Rummage statistical program (Bryce 1980). Statistical comparisons were not made between years because of differences in sampling schedules and grazing management. Mean separations were detected using LSD when ANOVA main effects were significant. Statistical significance was inferred at $P \leq 0.05$, unless otherwise stated. Replicates of the experimental range units (grazing cells) were not available. We recognize that this lack of replication of true experimental units limits the application of results to other swards. However, we feel that this study provides valuable insights concerning the relative effect of length of grazing period on diet quality and ingestive behavior.

To consider the relationship between sward characteristics and ingestive behavior, the correlation between each ingestive behavior variable and each sward characteristic was determined. Correlation coefficients ($r$ values) were considered statistically significant at $P \leq 0.10$.

Optimum length of stay in a paddock was inferred by considering daily changes in diet quality, forage intake, and ingestive behavior.

## Results and Discussion

### Daily Dynamics in SDG Paddocks

### *Diet Quality*

In 1983, CP and IVOMD ($P=0.56$) declined significantly from entry to day 3 (Table 1). These declines detected in the first year provided impetus for more intensive sampling on a daily basis in the ensuing years to better understand animal response to the rapid defoliation during the grazing of paddocks. In 1984, CP and IVOMD did not change from day 1 to day 2, but declined significantly by the third day (Table 1). In 1985, CP and IVOMD both declined significantly from entry into paddock to the first morning (day 1), but, like 1984, did not change from day 1 to day 2 (Table 1).

When comparing across years, no significant differences were detected between days 1 and 2 in 1984 and 1985. Apparently, animals attained a relatively high quality diet when they first entered a new paddock, as depicted at entry in 1985, but diet quality declined rapidly, with 18 to 20 hours. After that, diet quality was maintained for another day, as seen in both year's data. However, when the animals were left in the paddocks for a third day, as in 1984, diet quality declined appreciably.

This particular time sequence of declines in diet quality may be inherent to the study due to site characteristics and productivity. However, it can be concluded that the animal's ability to maintain selectivity for high quality forage decreases rapidly during the relatively short grazing periods under SDG.

**Table 1. Mean daily crude protein concentration and in vitro organic matter digestibility (IVOMD) of esophageal extrusa, ingestion rate, biting rate, grazing time, and daily forage intake by heifers during the grazing period within SDG paddocks.**

| Variables | Time | 1983 | 1984 | 1985 |
|---|---|---|---|---|
| Crude protein (%) | at entry | 14.87$^{a}$[1] | | 16.49$^{a}$ |
| | day 1 | [2] | 14.71$^{a}$ | 12.62$^{b}$ |
| | day 2 | | 14.23$^{a}$ | 11.75$^{b}$ |
| | day 3 | 11.35$^{b}$ | 13.05$^{b}$ | |
| IVOMD (%) | at entry | 68.19$^{a}$ | | 71.79$^{a}$ |
| | day 1 | | 68.32$^{a}$ | 67.10$^{b}$ |
| | day 2 | | 67.37$^{a}$ | 66.71$^{b}$ |
| | day 3 | 60.34$^{b}$ | 64.48$^{b}$ | |
| Ingestion rate (g OM/min) | at entry | | | 13.08$^{a}$ |
| | day 1 | | 10.80$^{a}$ | 9.85$^{b}$ |
| | day 2 | | 9.27$^{a}$ | 7.86$^{b}$ |
| | day 3 | | 9.43$^{a}$ | |
| Biting rate (bites/min) | day 1 | | 47.70$^{a}$ | 52.58$^{a}$ |
| | day 2 | | 52.10$^{b}$ | 52.53$^{a}$ |
| | day 3 | | 51.28$^{b}$ | |
| Grazing time (hrs/day) | day 1 | | 10.01$^{a}$ | 9.24$^{a}$ |
| | day 2 | | 10.07$^{a}$ | 10.12$^{b}$ |
| | day 3 | | 10.17$^{a}$ | |
| Bite size (g OM/bite) (IR/BR) | day 1 | | 0.23 | 0.19 |
| | day 2 | | 0.18 | 0.15 |
| | day 3 | | 0.18 | |
| Forage intake (kg OM/day) | day 1 | | 6.49 | 5.46 |
| | day 2 | | 5.60 | 4.77 |
| | day 3 | | 5.75 | |

[1] Means within years and variable differ ($P \leq 0.05$) when followed by different letters.
[2] Data not collected for that day within that year if blank.

### *Ingestive Behavior and Forage Intake*

**Ingestive Behavior in 1984.** Ingestion rate and grazing time did not change over days in a paddock (Table 1), while biting rate increased from day 1 to day 2, and then remained the same on day 3. Although bite size was not measured, a value can be calculated (bite size = ingestion rate/biting rate). Bite size apparently declined from day 1 to day 2, and remained unchanged on day 3 (Table 1). These calculated values for bite size and the actual means for ingestion rate, biting rate, and grazing time fall within the range of data reported in the literature for both temperate (Jamieson and Hodgson 1979a, 1979b) and tropical swards (Chacon and Stobbs 1976; Stobbs 1973a, 1973b, 1974, 1975). Animals apparently maintained ingestion rate by increasing biting rate as bite size declined due to defoliation of the paddock. Because ingestion rate did not decline, animals did not increase their grazing time. These results are consistent with those of Chacon and Stobbs (1976), who concluded that increases in biting rate or grazing time compensate for decreases in bite size as the sward is defoliated. However, these results disagree with those of Jamieson and Hodgson (1979a), who found that bite size, biting rate, grazing time, and daily forage intake all decreased as herbage availability decreased under intensive "rotational" grazing management (strip grazing). They concluded that animals did not increase biting rate or grazing time under strip grazing, as they did under continuous grazing (Jamieson and Hodgson 1979b), because they anticipated the move to fresh forage.

**Ingestive Behavior in 1985.** Ingestion rate declined significantly from sampling at entry to the paddock to the following morning (day 1), and subsequently remained unchanged (Table 1). Biting rate did not change between days 1 and 2. Grazing time increased significantly from the first to the second day in the paddock. Bite size appears to have declined slightly, but this is simply a reflection of the non-significant decline in ingestion rate from day 1 to day 2. Again, the range of data in this study is comparable to that of other studies of ingestive behavior done on a variety of swards (Jamieson and Hodgson 1979a, 1979b; Chacon and Stobbs 1976; Stobbs

1973a, 1973b, 1974, 1975).In contrast to 1984, animals increased grazing time in 1985, possibly to compensate for the decrease in ingestion rate that occurred following entry into a given paddock. Thus, animals used different components of ingestive behavior to compensate for apparent declines in bite size in each of the 2 years. This contrasts with the findings of Scarnecchia et al. (1985), who found that biting rate and grazing time increased simultaneously as a crested wheatgrass sward was defoliated under continuous grazing management. However, Scarnecchia et al. (1985) used a mature, primarily dormant sward, while this study was conducted during the growing season of crested wheatgrass. This seasonal effect would present a different sward structure with resultant implications to animal behavioral responses to that structure. These compensatory increases also contrast with Jamieson and Hodgson's (1979a) finding that biting rate and grazing time both declined as the sward was rapidly defoliated under strip grazing management.

**Forage Intake.** Daily forage intake was a direct reflection of ingestion rate (Table 1). Increased grazing time in 1985 apparently did not compensate for declining ingestion rate, thus having little effect on the decline in intake. It appears that sward characteristics that affect ingestive behavior can directly affect animal nutrient intake. Identifying and relating these sward characteristics to desired levels of ingestive behavior and intake should be useful in managing crested wheatgrass, particularly with SDG, to improve livestock performance.

## Correlation of Sward to Behavioral Variables

Relationships between ingestive behavior and sward variables were analyzed using simple correlation techniques (Table 2). These sward characteristics can be considered in 3 groups: (1) sward physical structure, including sward bulk density, aboveground biomass, and plant height; (2) positive nutritive characteristics, including crude protein and IVOMD; and (3) fiber components (including neutral detergent fiber, acid detergent fiber, permanganate lignin, cellulose, and hemicellulose) that are typically considered as inversely related to forage quality.

**Table 2. Correlation coefficients (r) between ingestion rate (IR, g OM/min), biting rate (BR, bites/min), and grazing time (GT, hrs/day) and several sward characteristics for each year.**

| Sward characteristics | IR | BR | GT |
|---|---|---|---|
| 1984 | | r | |
| Bulk density (gm/$cm^3$) | .54* | –.21 | –.01 |
| Biomass (kg/ha) | .51* | –.31 | –.38 |
| Height (cm) | .38 | –.15 | .16 |
| Crude protein (%) | .42 | .15 | –.62 |
| IVOMD (%) | –.03 | .35 | .06 |
| Neutral detergent fiber (%) | .04 | –.34 | .20 |
| Acid detergent fiber (%) | –.003 | –.21 | .55 |
| Permanganate lignin (%) | .02 | .20 | .53 |
| Cellulose (%) | .04 | –.27 | .15 |
| Hemicellulose (%) | .09 | –.48* | –.22 |
| 1985 | | | |
| Bulk density (gm/$cm^3$) | .51* | –.44* | –.79* |
| Biomass (kg/ha) | .61* | –.31 | –.66* |
| Height (cm) | .19 | –.55* | –.77* |
| Crude protein (%) | .31 | .51* | .31 |
| IVOMD (%) | .16 | .38* | .19 |
| Neutral detergent fiber (%) | –.38* | –.63* | –.20 |
| Acid detergent fiber (%) | –.31 | –.22 | .11 |
| Permanganate lignin (%) | –.13 | .07 | .07 |
| Cellulose (%) | –.33* | –.51* | –.25 |
| Hemicellulose (%) | –.30 | –.73* | –.34 |

*significant at $P \leq .10$

Ingestion rate was positively correlated with physical characteristics, while biting rate and grazing time were negatively correlated. Results during both years were generally similar, although fewer correlation coefficients were significant in 1984, usually because of fewer samples, but also apparently because of weaker relationships. However, the signs and relative magnitudes of most correlation coefficients generally correspond across years. These results indicate that as biomass became more available, ingestion rate increased, while biting rate and grazing time decreased. This agrees with previously reported results (Allden and Whittaker 1970, Freer 1981, Short 1985). Thus, ingestion rate can increase as more forage is available and accessible. Changes in ingestion rate were inversely related to changes in biting rate and grazing time, as expected from results of Chacon and Stobbs (1976). The negative correlation between biting rate and plant height is consistent with the conclusion of Hodgson (1985) that animals take more bites and spend less time manipulating forage as the sward becomes shorter. Ingestion rate was more strongly correlated with biomass than with sward bulk density in 1985. These correlation coefficients were essentially equal in 1984. These results differ from the findings of Stobbs and Hutton (1974), and may reflect differences in structure of temperate and tropical grass swards. Tropical swards are typified as having much greater total biomass than temperate swards, but having a much lower sward bulk density and much higher stem content (Stobbs 1975, Whiteman 1980). Thus, sward bulk density rather than biomass availability probably first limits ingestive behavior in a tropical sward, while the opposite is true in a temperate sward.

Herbage CP and IVOMD indicate that increasing nutrient content and availability typically were positively related to all 3 behavioral responses. Correlations were significant only for biting rates in 1985, however. Increases in these nutrient characteristics is probably positively related to desirability, causing an animal to increase its rate of biting. They are also positively related to a high leaf content, thus allowing increased biting rate, because the animal spends less time manipulating stems out of its bite (Chacon and Stobbs 1976).

Fiber fractions tended to be negatively correlated with ingestive behavior variables. However, few of the correlations were significant. Increasing herbage fiber content signifies declining leaf:stem content because of selective defoliation of leaves or an increase in the proportion of stems as maturity advances (Chacon and Stobbs 1976). The resulting decrease in accessibility of available leaf can cause a reduction in ingestion rate and biting rate in an attempt to increase selectivity (Chacon and Stobbs 1976). Increasing fiber content also makes the plant material tougher, causing prehension of bites to become more difficult. This can also cause a decline in rates of ingestion and biting. Note the relatively strong correlation of biting rate to hemicellulose content in both years. Hemicellulose is a fiber matrix of branched-chain polysaccharides that bind the cellulose fibers of the cell wall together (Albersheim 1975), thus providing structural rigidity and strength to the plant cell walls. Therefore, increased hemicellulose is probably related to increased "toughness", causing the animal to expend more time and effort to prehend a bite. Visual observations indicated that the animals had to put a great deal more effort and time into tearing off individual bites as the sward matured.

## Management Guidelines for SDG Paddock Grazing Periods

Diet quality, ingestive behavior, and forage intake all changed rapidly as paddocks were grazed under the conditions of this study. Diet quality and ingestion rate both declined within the first day in a paddock, but then remained constant into the second day of grazing. However, significant declines occurred on the third day in 1984. Therefore, livestock should be moved among paddocks at least every 2 days during the rapid growth stage of crested wheatgrass. This time period may be specific to this study site, and other swards with different production capabilities may sustain nutrition over a different time period. However, regardless of site characteristics, it can be concluded that animals will have to be moved very rapidly when vegetation is actively growing. In addition, these rapid declines in intake and nutrition indicate elevated risk of loss in animal performance due to mismanagement. Moving the cattle a day late could seriously impact animal performance. In fact, animal performance, in terms of heifer growth, was greater relative to season-long grazing in 1985 compared to 1983 and 1984, possibly as a result of using 2-day rather than 3-day grazing periods (Olson and Malechek 1988). Thus, decision-making on a daily basis and the risks involved make SDG an extremely management-intensive form of grazing management. The correlations between ingestive behavior and some sward characteristics (Table 2) indicate that a predictive relationship could be developed between these variables, allowing the determination of optimum sward conditions to maintain a high level of animal nutrition. Animals could be moved whenever the sward was defoliated to a condition that limited dietary nutrition to a pre-selected minimal standard. Such a predictive model using this data was developed (Olson et al. 1986). However, because data were collected over a limited range of spatial and temporal conditions, this model currently has limitations that make it unsuitable for use as a management tool.

These management guidelines are based on animal nutritional responses, and intended to provide improved animal performance. They are not based on plant response and resultant effects on productivity of the crested wheatgrass sward.

## Conclusions

Diet quality significantly and rapidly decreased over the grazing period in all 3 years as the paddocks were defoliated (Table 1). Ingestion rate declined significantly during the grazing period in 1985, but not in 1984. Significant increases in biting rate during the grazing period in 1984 indicated that animals may have tried to compensate for a decline in bite size, thus maintaining constant ingestion rate. Biting rate did not change during the grazing period in 1985, thus allowing the decline in ingestion rate. Grazing time did not change during the grazing period in 1984, but increased significantly in 1985. Evidently, when ingestion rate declined, as in 1985, grazing time increased to compensate. The resultant effect was a decline in daily forage intake as the paddock was defoliated.

Significant correlations existed between sward characteristics and ingestive behavior. Physical structure of the sward, including aboveground biomass, sward bulk density, and sward height, was positively related to ingestion rate, and negatively related to biting rate and grazing time. This indicated that ingestion rate increased as forage became more available, and compensatory declines in biting rates and grazing time occurred. Further correlations indicated that increases in the nutritional value of the herbage, as indicated by increased crude protein and digestibility, and decreased fiber content, were associated with increased ingestion rate and biting rate.

Because of the rapid declines in diet quality and ingestion rate, it is recommended that paddocks be grazed for 2 or fewer days during the active growth period of crested wheatgrass.

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# Growth dynamics of fourwing saltbush as affected by different grazing management systems

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## Abstract

**Individual leaders of fourwing saltbush were permanently marked and their growth responses monitored during a 3-year study in a shortduration grazing system, a 4-pasture rotation system, and in ungrazed exclosures. Primary and secondary leader growth and numbers of secondaries were responses of interest. Plants continuously browsed by cattle were usually maintained in a hedged form and produced relatively little growth. There was little difference in growth responses between plants in the 4-pasture rotation and the shortduration system when the shortduration rotation cycle was 32 days. However, when the rotation cycle was increased to 64 days, there was a substantial increase of growth for plants in the shortduration system. Plants protected from browsing for 1 year also responded with progressively less leader production as length of protection time increased. We suggest fourwing saltbush plants respond to a 60-day deferment at the beginning of the growing season.**

**Key Words: *Atriplex canescens*, utilization, rest periods**

There is an increasing interest in the use of intensively managed grazing systems on private and public rangelands. This interest arises primarily from the need of ranchers for an increased net return on the invested dollar while maintaining rangeland resources. Quantifying the effects of different grazing management systems on individual plant responses can help define and refine basic ideas behind intensive grazing management.

Fourwing saltbush (*Atriplex canescens* [Pursh.] Nutt.), a common species on New Mexico rangelands, was monitored in the study. Fourwing can be an important browse species on mountain-shrub and desert-shrub regions of New Mexico, especially during the dormant period for herbaceous vegetation.

Many clipping studies have been designed to simulate intensity, frequency, and season of defoliation by herbivores. These studies can suggest guidelines for grazing systems, but several differences exist between the effects of clipping and grazing on plants (Culley et al. 1933, Jameson 1963). However, there are limitations using grazing animals because good control is not always possible.

Undesirable effects of herbage removal on aboveground parts of shrubs are generally in proportion to intensity of clipping or browsing (Bruce 1956, Marshall et al. 1955, Maggs 1959, Shepard 1971). Aldous (1952), Garrison (1953), and Young and Payne (1948) found proper use of shrubs varied from 20 to 75%, depending on species. DeBano (1957), Garrison (1953), and Shepard (1971) reported increases in lateral branching after removal of current annual twig growth from sagebrush and bitterbush. These workers indicate production by individual browse plants can be increased by defoliation if intensity of defoliation is not excessive. Buwai and Trlica (1977) and Trlica et al. (1977) found both detrimental and stimulating effects of removal on several shrubs, depending on intensity and phenological stages of the plant. Davis (1953) also found positive effects of proper defoliation decline after several years if the treatments are not continued. Pieper and Donart (1978) commented that few studies have been done on effects of defoliation on fourwing saltbush. However, these studies indicate fourwing saltbush responds similarly to other shrub species, depending on intensity and frequency of defoliation and phenological stage of the plant at time of defoliation (Buwai and Trlica 1977, Nord and Stalling 1976, Trlica et al. 1977).

In New Mexico, vigor and productive capacity of fourwing plants is usually reduced under a system of year-long grazing, and plants occurring in moderate to low densities in grassland areas need 1 season of rest every 3 or 4 years to maintain populations (Pieper and Donart 1978).

The primary objective of this study was to quantify the growth response of fourwing saltbush to several sequences of rest, deferment and browsing affected by a series of exclosures and grazing systems.

## Study Area

The study was conducted on the Fort Stanton Experimental Ranch, comprising about 10,600 ha in Lincoln County, southcentral New Mexico. Elevation varies from 1,950 to 2,250 m, with a general topography of level mesas, steep canyons, and rolling hills. Mean minimum temperature is –6.7° C in January, mean maximum is 28.8° C in July, and mean annual temperature is 11.1° C (Groce and Pieper 1967, Pieper et al. 1978). The frost-free period is approximately 160 days from early May until the middle of October (Lowance 1967). Mean annual precipitation for 1876 to 1982 was about 380 mm (USDC, NOAA 1982) with 60% occurring during the growing season (Pieper and Donart 1978). Monthly and

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**Table 1. Monthly and total precipitation (cm) in 1981, 1982 and 1983 and 78 year average.**

| Month | 1981 | 1982 | 1983 | 78 year average |
|---|---|---|---|---|
| January | T | 1.3 | 0.7 | 1.5 |
| February | 0.6 | 0.2 | 2.0 | 1.2 |
| March | T | 0.6 | 2.3 | 1.5 |
| April | 0.9 | — | 1.8 | 1.4 |
| May | 8.2 | 0.3 | 2.0 | 2.3 |
| June | 5.3 | — | 1.2 | 3.2 |
| July | 4.4 | 8.1 | 5.2 | 7.9 |
| August | 8.7 | 6.8 | 4.8 | 6.9 |
| September | 9.2 | 6.9 | 8.8 | 4.7 |
| October | 2.1 | 6.0 | 7.0 | 1.9 |
| November | 1.2 | 1.3 | 5.5 | 0.7 |
| December | — | 2.1 | 0.8 | 1.8 |
| Total | 40.7 | 33.6 | 42.1 | 35.0 |

total precipitation during the study, 1981 through 1983, is given in Table 1.

Fort Stanton lies in an ecological transition zone between the juniper-pinyon woodland and the grama-galleta steppe vegetation types (Kuchler 1964). Blue grama (*Bouteloua gracilis* [H.B.K.] Lag.) is dominant or co-dominant on the mesas and canyon bottoms, while pinyon (*Pinus edulis* Engelm.), juniper (*Juniperus* spp.), and wavy leaf oak (*Quercus undulata* Torr.) are dominants or co-dominants on canyon sides and at higher elevations (Pieper et al. 1971).

## Methods

Management System I was a 7-paddock, short-duration grazing cell that was completed in 1980. Stocking rate was 13 ha/AUY during the study, 1981–1983. Length of rotation cycles in 1981 and 1982 was 32 days during periods of rapid plant growth (June to August), and 64 days for periods of slow growth or dormancy. However, there was no period of rapid growth in 1983 because of late summer rains. Consequently, the rotation cycle was maintained at 64 days throughout the year.

Management System II was a 4-pasture (100 ha each) rotation grazing system initiated in 1969 (Pfister et al. 1984). Stocking rate was 15 ha/AUY in 1981, but was reduced to 22 ha/AUY in 1982 and 1983 for management reasons.

In Management System I, the short-duration grazing system, 1 paddock (139 ha) was chosen for observation of fourwing saltbush. One group of 10 plants was included in a 0.8-ha deer- and cattle-proof exclosure erected in 1969 and designated as the 20-year rest treatment (20-YR). A second group of 10 plants was included in a cattle-proof exclosure built in 1972 adjacent to the deer exclosure. The exclosure was removed in 1981 and plants were subjected to short-duration grazing during this study. Plants from the group were designated as the shortduration paddock 8 treatment (SD-8). Adjacent to the removed cattle exposure, a third group of 10 fourwing saltbush plant was chosen. These plants had been subjected to year-long grazing from 1969 to 1980 (Pieper and Donart 1978), and then short-duration grazing from 1980 throughout this study. This group was designated as the short-duration paddock 7 treatment (SD-7). Stock density in SD-7 and SD-8 was 0.5 AU/ha.

In Management System II, the 4-pasture rotation grazing system, only 2 of the 4 pastures were used. One group of 10 fourwing plants was chosen in each of the 2 pastures. One pasture was rested from February 1981 through February 1982, and grazed the remainder of the study. The other pasture was grazed continuously from February 1980 through February 1983, and rested until February 1984. Stock density in both pastures was 0.09 AU/ha in 1981 and 0.06 AU/ha in 1982–1983. In March 1982, one more group of 10 plants was chosen in each of the same 2 pastures. These were protected from cattle browsing to achieve the desired sequences and lengths of rest. For Management System II, treatment designations were assigned by year of the study (e.g., 1-year rest treatment [1-YR], 2-year rest treatment [2-YR], 3-yr rest [3-YR],

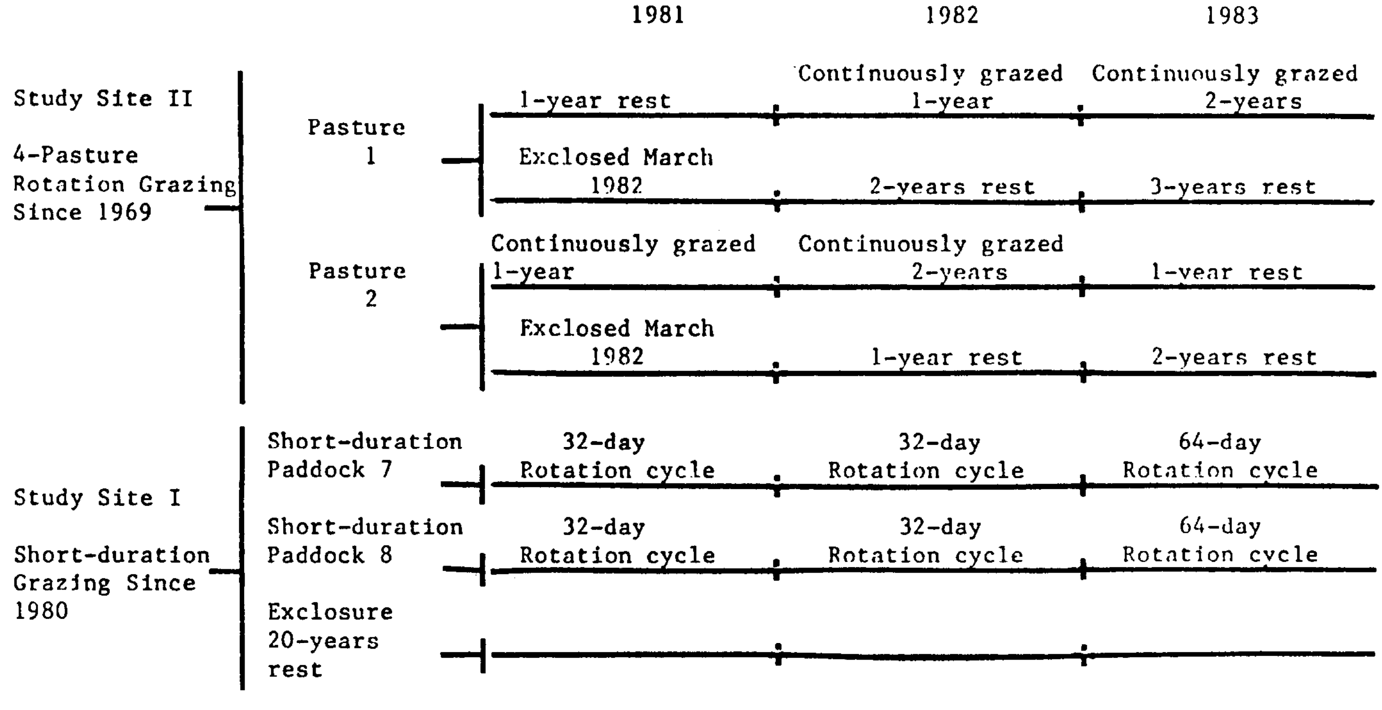

**Fig. 1.** *Treatment structure for fourwing saltbush study during growing seasons of 1981 through 1983.*

continuous-grazing, 1-year [CG-1] and continuous-grazing, 2-year [CG-2]) (Fig. 1).

Sixteen primary leaders on all identified fourwing plants were marked at their base with acrylic paint during the second week of May each year. Growth measurements were taken every 12 to 15 days throughout the growing season until early October. Measurements included primary leader growth, numbers of secondary leaders per primary leader, and total secondary leader growth per primary leader.

Positive increments in growth were determined for each measurement date and summed over each growing season. Data were first analyzed within year using a completely randomized design with plants as replications. Whole model analysis indicated measurement date by treatment interaction terms were significant ($P \leq 0.001$) for each of the 3 years. Therefore, data were analyzed within year and measurement date. Where F tests were significant ($P < 0.05$), the LSD procedure was used for mean separations at the 95% level.

## Results and Discussion

### Growth Dynamics—1981

By late July, primary leader growth of fourwing saltbush was significantly greater in the 1-YR treatment (Table 2). Little additional growth was contributed by primary leaders after July, and

**Table 2. Cumulative mean growth (cm) by measurement date of primary leader length, secondary leader length per primary, numbers of secondary leaders per primary and total length (primary plus secondary length) for fourwing saltbush, 1981 through 1983.**

| Date/ | Mean primary length | | | Mean secondary length | | | Mean numbers of secondaries | | | Mean total length | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| treatment | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 |
| Mid-May | | | | | | | | | | | | |
| 1-YR[1] | 3.8a[2] | 2.5a | 8.2a | | | | | | | | | |
| 2-YR | —[3] | 2.0a | 4.6cd | | | | | | | | | |
| 3-YR | — | — | 5.2bc | | | | | | | | | |
| 20-YR | 2.4bc | 1.2bc | 3.5de | | | | | | | | | |
| SD-7 | 2.0c | 1.1bc | 6.1b | | | | | | | | | |
| SD-8 | 2.0c | 0.9c | 6.3b | | | | | | | | | |
| CG-1 | 3.0b | 1.2bc | — | | | | | | | | | |
| CG-2 | — | 1.4b | 3.1e | | | | | | | | | |
| Early June | | | | | | | | | | | | |
| 1-YR | 8.1a | 4.1a | 12.5a | | | | | | | | | |
| 2-YR | — | 2.5b | 7.5c | | | | | | | | | |
| 3-YR | — | — | 8.3c | | | | | | | | | |
| 20-YR | 4.3cd | 1.9b | 5.5d | | | | | | | | | |
| SD-7 | 6.1b | 1.8b | 10.9ab | | | | | | | | | |
| SD-8 | 5.5bc | 2.1b | 10.7b | | | | | | | | | |
| CG-1 | 3.7d | 1.7b | — | | | | | | | | | |
| CG-2 | — | 2.1b | 4.1d | | | | | | | | | |
| Late June | | | | | | | | | | | | |
| 1-YR | 13.2a | 9.8a | 17.5a | 3.1a | 3.0a | 1.5c | 2.3a | 1.2c | 0.8bc | 16.3a | 12.8a | 19.0b |
| 2-YR | — | 2.5cd | 11.1b | — | 0.0b | 0.7c | — | 0.0b | 0.3c | — | 2.5c | 11.8cd |
| 3-YR | — | — | 10.8b | — | — | 2.9bc | — | — | 1.7ab | — | — | 13.7c |
| 20-YR | 5.4c | 3.3c | 7.4c | 0.1b | 0.4b | 0.4c | 0.1b | 0.2b | 0.2c | 5.5bc | 3.7c | 7.8de |
| SD-7 | 6.6b | 3.4c | 17.8a | 0.0b | 0.2b | 6.0a | 0.0b | 0.1b | 1.9a | 6.6b | 3.6c | 23.8a |
| SD-8 | 6.2b | 6.4b | 16.9a | 0.0b | 3.0a | 4.8ab | 0.0b | 1.1a | 1.7ab | 6.2bc | 9.4b | 21.7ab |
| CG-1 | 4.3c | 1.7d | 0 | 0.1b | 0.0b | — | 0.1b | 0.0b | — | 4.4c | 1.7c | — |
| CG-2 | — | 2.8cd | 5.0c | — | 0.2b | 0.5c | — | 0.2b | 0.3c | — | 3.0c | 5.5e |
| Early July | | | | | | | | | | | | |
| 1-YR | 15.5a | 13.5a | 20.8a | 6.0a | 8.7a | 5.6abc | 2.6a | 2.0a | 2.5ab | 21.5a | 22.2a | 26.4a |
| 2-YR | — | 9.2b | 13.2c | — | 0.1b | 2.4d | — | 0.1b | 0.1c | — | 9.3b | 15.6b |
| 3-YR | — | — | 11.9cd | — | — | 3.8cd | — | — | 2.2abc | — | — | 15.7b |
| 20-YR | 5.9c | 4.7c | 8.8de | 1.1b | 1.3b | 1.8d | 0.6b | 0.6b | 0.8d | 7.0c | 6.0b | 10.6bc |
| SD-7 | 8.3b | 5.7c | 18.0ab | 2.6b | 1.5b | 7.6a | 1.0b | 0.7b | 2.8a | 10.9b | 7.2b | 25.6a |
| SD-8 | 8.5b | 12.5a | 17.1b | 2.2b | 8.8a | 6.0b | 0.9b | 2.7a | 2.3abc | 10.7b | 21.3a | 23.1a |
| CG-1 | 5.0c | 5.0c | — | 1.0b | 0.2b | — | 0.4b | 0.1b | — | 6.0c | 5.2b | — |
| CG-2 | — | 3.7c | 5.6b | — | 1.3b | 2.7bcd | — | 0.7b | 1.2bcd | — | 5.0b | 8.3c |
| Late July | | | | | | | | | | | | |
| 1-YR | 19.0a | 15.8ab | 22.7a | 14.6a | 12.9a | 9.2a | 3.6a | 2.4a | 3.3a | 33.6a | 28.7a | 31.9a |
| 2-YR | — | 17.9a | 14.acd | — | 1.9b | 3.5b | — | 0.6b | 1.4c | — | 19.8b | 17.6b |
| 3-YR | — | — | 12.1de | — | — | 3.8b | — | — | 2.2abc | — | — | 15.9bc |
| 20-YR | 6.4c | 5.2c | 9.2ef | 1.9b | 1.6b | 2.0b | 0.9b | 0.7b | 0.9c | 8.3bc | 6.8c | 11.2bc |
| SD-7 | 8.8b | 6.7c | 18.5b | 4.6b | 2.2b | 12.2a | 1.4b | 0.9b | 3.6a | 13.4b | 8.9c | 30.7a |
| SD-8 | 9.2b | 13.4b | 17.5bc | 4.0b | 10.3a | 9.7a | 1.4b | 3.2a | 3.0ab | 13.2bc | 23.7ab | 27.2a |
| CG-1 | 5.5c | 6.4c | — | 2.1b | 1.8b | 0 | 0.9b | 0.6b | — | 7.6c | 8.2c | — |
| CG-2 | — | 4.6c | 6.1f | — | 2.0b | 4.0b | 0 | 0.9b | 1.8bc | — | 6.6c | 10.1c |

**Table 2. Continued.**

| Date/ treatment | Mean primary length | | | Mean secondary length | | | Mean numbers of secondaries | | | Mean total length | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 | 1981 | 1982 | 1983 |
| Mid-August | | | | | | | | | | | | |
| 1-YR | 21.9a | 17.7ab | 23.7a | 23.2a | 16.6a | 11.6bc | 4.9a | 2.7a | 3.8a | 45.1a | 34.4a | 35.3a |
| 2-YR | — | 21.2a | 14.7cd | — | 2.8b | 3.9d | — | 0.6b | 1.6c | — | 24.0b | 18.6b |
| 3-YR | — | — | 12.9de | — | — | 4.9d | — | — | 2.8abc | — | — | 17.8b |
| 20-YR | 6.6c | 5.8c | 9.5ef | 3.4b | 2.0b | 3.4d | 2.1b | 0.9b | 1.5c | 10.0bc | 7.8c | 12.9b |
| SD-7 | 9.6b | 7.3c | 19.4b | 8.1b | 3.0b | 19.4a | 2.3b | 1.2b | 4.2a | 17.7b | 10.3c | 38.8a |
| SD-8 | 9.8b | 14.3b | 18.1c | 6.1b | 11.9a | 14.9ab | 2.0b | 3.5a | 3.6ab | 15.9bc | 26.2ab | 33.0a |
| CG-1 | 6.6c | 6.7c | — | 3.8b | 2.6b | — | 1.8b | 0.9b | — | 9.0c | 9.3c | — |
| CG-2 | — | 5.1c | 6.3f | — | 2.9b | 5.2cd | — | 1.3b | 2.1bc | — | 8.0c | 11.5b |
| Early October | | | | | | | | | | | | |
| 1-YR | 22.6a | 18.8b | 24.4a | 25.4a | 19.2a | 18.1a | 5.5a | 3.0ab | 4.0a | 48.0a | 38.0a | 42.5a |
| 2-YR | — | 23.2a | 15.3cd | — | 3.3c | 4.1b | — | 0.8c | 1.6c | — | 26.5b | 19.4b |
| 3-YR | — | — | 13.3de | — | — | 5.0b | — | — | 2.8abc | — | — | 18.3b |
| 20-YR | 6.9c | 7.9c | 9.8ef | 3.7b | 6.4bc | 3.5b | 2.3b | 2.2bc | 1.6c | 10.6b | 14.3c | 13.3b |
| SD-7 | 9.8b | 7.8c | 19.6b | 8.2b | 3.5c | 20.4a | 2.4b | 1.4c | 4.4a | 19.0b | 11.3c | 40.0a |
| SD-8 | 10.1b | 14.9b | 18.2bc | 6.2b | 13.0ab | 15.7a | 2.1b | 3.9a | 3.8ab | 16.3b | 27.9b | 33.9a |
| CG-1 | 6.9c | 7.1c | — | 4.0b | 3.5c | — | 2.0b | 1.3c | — | 10.3b | 10.6c | — |
| CG-2 | — | 5.8c | 6.7f | — | 3.5c | 5.6b | — | 1.7bc | 2.2bc | — | 9.3c | 12.1b |

[1] 1-YR = one year rest; 2-YR = two year rest; 3-YR = three year rest; 20-YR = 20 year rest; SD-7 = short-duration paddock seven; SD-8 = short-duration paddock eight; CG-1 = continuous grazing on year; CG-2 = continuous grazing two years.

[2] Different letters within measurement date and column indicate significant differences ($P \leq 0.05$).

[3] Dashes (–) indicate no data collected.

treatment means separated into 3 groups. The first group included plants with the least growth and occurred on plants in the CG-1 and 20-YR treatments. Plants in the SD-7 and SD-8 treatments produced intermediate primary growth and plants in the 1-YR treatment produced the most primary growth (Table 2).

Initiation of axillary buds that produced secondary leaders began in June in the 1-YR treatment, but plants in remaining treatments did not produce much secondary growth until July. By October, secondary leader growth and numbers of secondaries were greatest for plants in the 1-YR treatment. Secondary growth and numbers were not different for plants between the remaining treatments for any measurement date (Table 2).

From July until October, major contributions to total growth (primary plus secondary growth) was from secondary growth in all treatments, but this response was particularly evident in the 1-YR treatment. Secondary growth was not significantly different among the remaining treatments from July through October; however, fourwing plants in the SD-7 and SD-8 treatments tended to produce more growth than plants in the CG-1 and 20-YR treatments (Table 2).

### Growth Dynamics—1982

As in 1981, little additional growth was contributed by primary leaders after July. Plants in the 1-yr, 2-yr, and SD-8 treatments tended to produce the greatest primary growth while plants in the 20-yr, SD-7 and CG-1 and CG-2 treatments produced substantially lesser amounts of primary growth (Table 2).

Fourwing plants in the SD-8 treatment attained greater primary growth than might be expected as compared to the SD-7 treatment (Table 2). This can be explained because plants in the SD-8 treatment in 1981 were exposed to grazing after removal of the exclosure that had protected them for 9 years. During protection, plants had become decadent with long, brittle upper branches. When exposed to browsing by cattle, upper branches were easily broken at the base, leaving only older and stouter branches with few areas of active growth. However, enough leaders remained intact to maintain sample numbers. New areas of active growth began to appear in 1982, a response caused by breakage of the younger upper branches. These new areas of active growth were well down in and among older branches, making cattle access to them difficult. In 1982, leaders on plants in the SD-8 treatment were unbrowsed until they reached a substantial length and cattle were able to reach them. Fourwing plants in the SD-7 treatment were in a hedged condition because of continuous browsing since 1969. Therefore, most new leader growth on these plants was vulnerable to browsing as soon as it was a few centimeters long. Secondary leader growth began in June 1982, and plants in the 1-YR and SD-8 treatments produced significantly greater lengths and numbers of secondaries by August (Table 2). Secondary growth was greater than expected in the SD-8 treatment compared to the SD-7 treatment. Again, this was probably a result of position of new growth down in the main branches of the plants where the leaders were not accessible to browsing and more axillary buds were left intact to develop secondary growth.

In terms of total growth, plants in the 1-YR treatment produced significantly more than plants in the 2-YR and SD-8 treatments and these, in turn, produced more than plants in the remaining treatments (Table 2). These data indicate a trend of reduced vegetative growth on a per leader basis for fourwing plants that are protected from browsing for more than 1 year (Davis 1953).

### Growth Dynamics—1983

Because of late summer rains in 1983, the rotation cycle for the short duration grazing system (Management System I) was maintained at 64 days through the growing season rather than 32 days as in 1981 and 1982 (Fig. 1). This decision had a significant impact on study results.

By late June 1984, primary leader growth for fourwing in the 1-YR, SD-7 and SD-8 treatments was significantly greater than leader growth for the 2-YR and 3-YR treatments (Table 2). Plants in the 20-YR and CG-2 treatments produced the least amount of growth. This trend in early-season growth was maintained through the end of the growing season.

Secondary leader growth began in June and by October, secondary length was significantly greater in the 1-YR, SD-7, and SD-8 treatments (Table 2). Numbers of secondaries produced also followed this same trend; however there was a lack of separation among treatment means.

Total growth in June 1983 was greatest for plants in the 1-YR, SD-7 and SD-8 treatments, intermediate in the 2-YR and 3-YR treatments, and least in the 20-YR and CG-2 treatments (Table 2). This relationship was the same at the end of the growing season. However, means for the 2-YR, 3-YR, 20-YR, and CG-2 treatments were not statistically different.

An important point with respect to the data is that plants in the SD-7 and SD-8 treatments were subjected to 2 heavy defoliations during the 1983 growing season, but they still produced as much total growth on a per leader basis as plants in the 1-YR treatment. Because of the 64-day rotation cycle, fourwing plants in the SD-7 and SD-8 treatments received their first defoliation about 60 days after spring growth started. This 60-day deferment period allowed primary leaders to reach an average length of 11 cm before being browsed (Table 2). From general field observations, it was noted that leaders 10 to 15 cm long became slightly woody at their bases compared to shorter leaders, but they remained flexible compared to longer and older leaders. When cattle browsed plants in the SD-7 and SD-8 treatments, they removed terminal buds and younger tissue at the ends of leaders, leaving the woody portion of the leader intact. Therefore, axillary buds were left intact on plants, but the most rapidly growing tissue and terminal buds were removed. This probably reduced inhibition on axillary buds (Jameson 1963). However, if fourwing plants were browsed before leaders became woody at their bases, the entire leader was generally pulled off leaving very few axillary buds intact. This is what generally took place in the continuously grazed treatments (CG-1 or CG-2) and in the SD-7 and SD-8 treatments when the rotation cycle was too short (32-day rotation) to allow primary leaders to reach optimum length.

Conversely, if fourwing plants were rested 1 complete year, leaders became very long, woody, and brittle. When cattle browsed the plants the next year, these fragile leaders were easily broken off, thereby causing severe plant damage. This type of damage was noted twice during the study, once in 1981 in the SD-8 treatment when plants were browsed after 9 years protection and again in 1982 in the CG-1 treatment after plants had been rested in 1981 (Fig. 1). In addition, fourwing plants rested more than 1 year began to decline in growth of primary and secondary leaders and numbers of secondary leaders (Table 2). These data support findings of Davis (1953) and Buwai and Trlica (1977).

## Summary and Conclusions

Results of this study indicate continuous browsing of fourwing saltbush plants produced relatively little leader growth. A high percentage of primary leaders produced secondary leaders, but the plants were browsed so intensively and frequently that only a few secondary leaders developed on each primary. Secondaries were likewise browsed before much growth was produced.

Fourwing plants browsed under proper intensity and frequency produced as much leader growth as plants rested 1 complete year. The 60-day deferment after onset of spring growth, combined with periodic rest thereafter, allowed primary leaders to attain enough growth so cattle did not browse too intensively. Therefore, a greater number of axillary buds were left intact and produced secondary leaders of substantial length.

Fourwing plants rested for 1, 2 and 3 or more years produced progressively more flower stalks (Price 1985) and progressively less leader growth. Therefore, proper sequences and lengths of rest maintain the plant in a more productive vegetative state. Even continuously browsed plants produced as much leader growth as plants rested too long (20-YR).

In conclusion, browsing can stimulate growth of fourwing saltbush if the proper rest sequence is used. A short-duration grazing system can help achieve proper rest, but is not necessary. The key is to allow enough deferment in the early growing season. Any grazing strategy which provides at least 60 days deferment in the early growing season will allow for adequate growth.

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# Observation on cattle liveweight changes and fecal indices in Sudan

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## Abstract

**Changes in liveweight of sedentary and migratory herds of cattle in south Kordofan Province, Sudan, were determined monthly. Feces of these animals were analyzed for N and ADF during the same period. Both the sedentary and the migratory herds gained liveweights during periods August to September and November to February and lost liveweight during October and from March to July. Changes in liveweights were more highly related to fecal ADF concentrations ($r = -0.60, P<0.002$) than to fecal N concentrations ($r = -0.085, P<0.305$).**

**Key Words: cattle, sedentary, migratory, liveweights, fecal constituents**

Sedentary operations and transhumance are the 2 systems involved in liveweight production in many parts of the Sudan. These 2 systems are mainly practiced in the western provinces, including Kordofan and Dar Fur. In Kordofan transhumants migrate to the arid, sandier ranges of the north during the rainy season and return to specific locations in the clay-dominated ranges of the south in the Nuba Mountains during the dry season. The sedentary operators, on the other hand, remain in the clay-dominated ranges of the Nuba Mountains throughout the year, although they make local movements about these ranges.

Because the Nuba Mountain ranges are utilized by many sedentary and migratory livestock, it is important to know the quality of these ranges. One approach to determine this is through chemical analysis of feces voided by free-ranging ruminants.

High relationships between dietary N and fecal N have been reported by Raymond (1949), Hinnant (1979), Mould and Robbins (1981), Holechek et al. (1982), Bredon et al. (1983), and Mubanga (1983). These relationships resulted in the hypothesis that liveweights of cattle could be predicted from the N contents of their feces. The objective of the present study was to determine liveweight changes and chemical constituents of feces, including N and ADF, of the sedentary and the migratory herds in south Kordofan, Sudan.

## Study Area

This study was conducted at Kadugli Research Station in south Kordofan. South Kordofan lies within the savanna zone of the Sahelian belt, and can be classified as having a hot, semiarid climate. March is the hottest month at Kadugli with a maximum of 41° C and a minimum of 24° C. December and January are the coolest months with a maximum of 35° C and a minimum of 18° C. Rainfall varies from about 500 mm in the north to over 800 mm in the south. Rains occur in a single season (Khareef), primarily from June to September, although some rains also fall in May and October. A short, hot season (Deret) occurs after the rains from October to November, followed by cool, dry season (Shitta) from December to February. The main hot season (Saif) occurs from March to early June.

Bunderson et al. (1984) identified soil types in rangelands of south Kordofan. These soils included gravely grey soils: red, loamy soils; dark, heavy cracking clays; brown, coarse loamy clays; sandy clay and loams; very dark cracking clays; red noncracking clays; dark, medium cracking clays; redish-white loamy sands; brown noncracking clays.

Range productivities vary according to soil types, being highest in the very dark, heavy cracking clays and lowest in the brown, coarse sandy loams.

## Methods

Two herds of cattle were bought by the Western Sudan Agricultural Research Project (WSARP) at Kadugli Research Station. One herd of 80 cattle was kept in the fenced research farm (760.62 ha), where the dominant soils were dark cracking clays. This herd was stocked at 9 ha/head/year to simulate the sedentary system. The other herd of the same size was allowed to migrate with the transhumants to simulate their system.

Liveweights of 10 bulls selected randomly from each of the sedentary and the transhumant systems were determined monthly from November 1984 to November 1985. Cows were excluded from this selection to avoid changes in liveweights that might accrue from pregnancy, calving, or lactation rather than the nutritional value of the range forage.

Liveweights were determined monthly by confining the bulls overnight without food and water before weighing. Changes in liveweight per bull were calculated by subtracting the total starting monthly weight from the total ending monthly weight and dividing this difference in liveweight by the number of bulls in each herd.

Ten grab samples of feces were collected every 2 weeks from the selected bulls in the 2 herds for laboratory analysis. These samples were oven-dried at 50° C, pooled and analyzed chemically for N and ADF. Nitrogen was determined by the standard Kjeldahl N procedure. Acid-detergent fiber was determined according to the method described by Van Soest (1982). Monthly averages of fecal ADF and N for each herd were related to the monthly change in

**Table 1. Liveweight changes and chemical constituents of feces of sedentary and migratory cattle in south Kordofan, Sudan.**

| | Sedentary cattle | | | Migratory cattle | | |
|---|---|---|---|---|---|---|
| Month | Wt. change/ bull, kg | % fecal N | % fecal ADF | Wt. change/ bull, kg | % fecal N | % fecal ADF |
| November '84 | –4.61 | 1.64 | 57.95 | 5.85 | 1.45 | 53.98 |
| December '84 | –0.23 | 1.27 | 50.48 | 9.30 | 1.46 | 51.84 |
| January '85 | 1.64 | 1.52 | 50.32 | 18.39 | 1.61 | 52.70 |
| February '85 | 13.69 | 1.21 | 52.75 | 26.43 | 1.19 | 56.11 |
| March '85 | 0.31 | 1.12 | 57.53 | –4.56 | 1.15 | 59.43 |
| April '85 | –2.68 | 1.06 | 60.35 | –6.24 | 0.99 | 60.18 |
| May '85 | –1.36 | 1.09 | 60.62 | –19.04 | 1.09 | 60.68 |
| June '85 | –21.57 | 1.78 | 67.44 | –40.61 | 1.46 | 63.04 |
| July '85 | –16.43 | 2.04 | 64.22 | –13.38 | 1.50 | 63.83 |
| August '85 | 29.86 | 1.85 | 55.49 | 0.12 | 1.47 | 54.91 |
| September '85 | 20.78 | 1.56 | 57.83 | 43.43 | 1.21 | 56.17 |
| October '85 | –12.08 | 1.54 | 57.77 | –10.91 | 1.53 | 58.43 |

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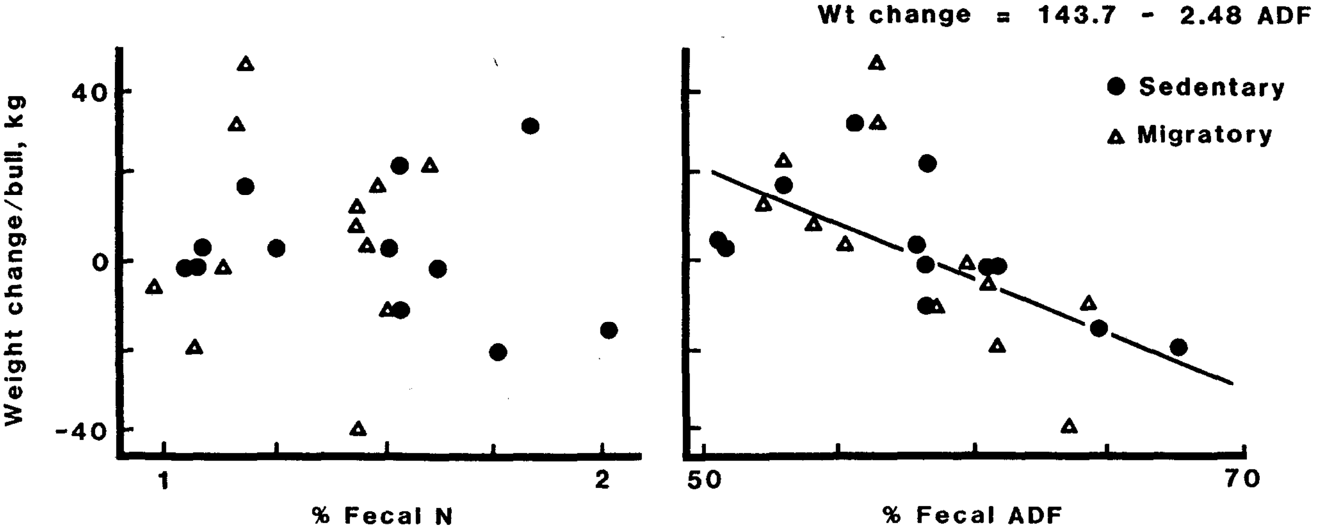

**Fig. 1.** *Relationships between liveweight change and fecal N or ADF of sedentary and migratory cattle in south Kordofan, Sudan.*

liveweight per bull by multiple regression analysis (Draper and Smith 1966).

## Results and Discussion

Seasonal changes in liveweight and chemical constituents of feces of the sedentary and the migratory herds are presented in Table 1. Liveweights changed during 4 seasons. The first and the longest season in which a decrease in liveweight occurred extended from March to July (Saif). Quantity and quality of range forage became limiting during the dry season. Bunderson et al. (1984) reported that diet selected by cattle during this season contained 5.9% crude protein; intake of dry matter, digestible dry matter, and crude protein were 4,472, 2,665, and 264 g g/head/day, respectively. Intake of crude protein barely met the maintenance requirements of cattle during Saif.

The second decrease in liveweight occurred in October. This decrease continued in November and December for the sedentary but not for the migratory cattle. The reason for this decrease is not clear as forage was abundant for the 2 herds in October. However, rainfall patterns differed in the 2 areas grazed by sedentary and migratory cattle during 1984 and 1985.

The 2 herds showed an increase in liveweights in 2 seasons. The first season was in late Khareef, August and September, when the 2 herds recorded maximum gains in liveweight. The second season (Shitta) extended roughly from November until February. Diet selected by cattle during the Khareef and Shitta contained 11.7% and 8.2% crude protein, respectively; intake of dry matter, digestible dry matter and crude protein during the same seasons were 5,311, 3,468, and 621 g/head/day for the Khareef and 6,318, 3,576 and 518 g/head/day for Shitta, respectively (Bunderson et al. 1984).

During the Khareef and Shitta the migratory herd gained slightly more liveweight than the sedentary herd. Gains by the 2 herds in these 2 seasons were offset by losses in Deret and Saif so yearly average change in liveweights were similar, suggesting that neither of the systems performed better than the other.

Two problems are involved in using change in liveweight to describe condition of free-ranging cattle (Lloyd et al. 1978). First there is no established normal liveweight from which variations may be allowed. Second, liveweight is not always an index of health because overweight animals may be undernourished while underweight animals may be well nourished. However, liveweight change may be a good index of health. In addition, liveweights could be affected by factors irrelevant to the nutritive value of range forage, such as reproductive stage, long distance movements, and parasites.

The relationships between liveweight change and fecal N or fecal ADF are presented in Figure 1. Relationships between liveweight changes and chemical constituents of feces were based on findings by previous investigators that weight gain (Holechek et al. 1982) and liveweight change (Squires and Siebert 1983) were significantly related to fecal N, and that fecal N and dietary N were highly correlated. However, fecal ADF was more highly related to liveweight change ($r = -0.60$, $P < 0.002$) than was fecal N ($r = -0.085$, not significant). The inverse relationship between liveweight change and fecal ADF could indicate that energy, not protein, appeared to control gain in liveweight. Van Soest (1982) reported that ADF was inversely related to digestible energy and intake of forages.

Our finding is in contrast to the work of Squires and Siebert (1983), who found that fecal N was significantly and directly related to changes in liveweight of cattle. Van Soest (1982) questioned the relationship between fecal N and dietary N because there was no evidence of potentially digestible feed protein in feces. He argued that protein in feces was quantitatively insoluble and was either keratin, Millard products (nitrogen rendered indigestible through heating of forages), or bound N and therefore resistant to peptic digestion. Therefore fecal N had no relationship to digestible dietary N.

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# Economic consequences of alternative stocking rate adjustment tactics: a simulation approach

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## Abstract

**An economic analysis of alternative stocking rate adjustment tactics is performed using a simulation model which emulates the annual decision-making situation of a rancher. The model includes variation in livestock prices and annual forage production. The manager's decisions are based on the availability of forage at 4 decision points in the year, the expected growth between the current decision point and the next, and the expected portion of the forage that is to be harvested through grazing. Livestock are bought and sold to adjust the stocking rate to equal the expected available forage for grazing. Results are obtained for 3 different stocking tactics based on 4 levels of expected forage production and livestock utilization set at the May decision point. The results reflect the differences in net returns over variable costs and the differences in annual cow investment capital associated with each tactic. The results indicate that the tactics using a maximum stocking rate of 3.6 ha/au offer the most reasonable compromise between mean and variance of net returns. The tactic with no limit on stocking rate provides the possibility of obtaining higher average annual net returns than tactics with limited stocking rates, but the variation in annual returns is considerably greater and the annual cow investments costs are higher.**

**Key Words: cow/calf production, net returns, simulation model**

Cattle producers face 2 principal sources of uncertainty: prices and weather. The rancher must manage within the constraints of these uncertainties while trying to meet the production, marketing, and financial objectives of the firm.

Grazing management is a tool used to meet ranch firm objectives. Grazing management, broadly defined, is the manipulation of grazing animals to achieve desired results (Society for Range Management 1974). Although various grazing management strategies may be implemented to alter the temporal and spatial distribution of various kinds or classes of grazing animals, the major decision affecting level of production achieved is stocking rate. Through the timely adjustment of stocking rate, management can effectively buffer the adverse effects of uncertainty relative to forage availability and livestock prices. The ability to adjust may help the firm survive the occurrence of an undesirable event, such as drought, and may thus decrease the risk of an undesirable outcome. The objective of this study was to develop and illustrate the use of a simulation model to analyze the economic implications to a ranch business of using alternative decision rules (tactics) to adjust stocking rate in accordance with annual fluctuations in forage availability.

Several approaches have been used in the past to determine the economic consequences of stocking rate decisions made by producers. Halter and Dean (1965) used Bayesian decision theory in a payoff table framework to analyze the consequences of alternative stocking rates in the foothills of California. Whitson (1974) used simple and multiperiod quadratic programming to model a representative ranch and derive sets of efficient income variance plans, while simultaneously incorporating time and uncertainty into the firm manager's decision environment.

In this study, simulation offers a way to assess long-term effects of alternative tactics for adjusting stocking rate in accordance with variations in forage production and to simultaneously include the impacts of variations in cattle prices on the outcome. Simulation allows the results of the alternative tactics to be monitored through time to determine which tactics create the greatest variance in cattle numbers and how these changes impact the mean and variance of net returns to the rancher's capital, land, and management.

## Materials and Methods

### Study Area

Data for this study were collected at the 2,900-ha Texas Experimental Ranch located in Throckmorton County. Climate in the area is highly variable with warm, wet springs and falls, hot summers, and mild winters. Average annual precipitation is 682 mm. The frost free growing season averages 233 days and exends from March to November.

The principal range sites on the ranch are clay loam, clayey upland, clay slopes, and bottomland. The herbaceous vegetation is a mixture of mid and shortgrasses. Dominant perennial species are sideoats grama [*Bouteloua curtipendula* (Mixnx.) Torr.], a warm-season midgrass, buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.], a warm-season shortgrass, and Texas wintergrass [*Stipa leucotricha* Trin. and Rupr.], a cool-season midgrass. Japanese brome (*Bromus japonicus* Thunb.) is the dominant annual grass. For a detailed description of the study site see Heitschmidt et al. (1985).

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## Model Development

The decision making environment of the ranch firm manager is, to a large degree, the result of weather-induced fluctuation in forage production and the strategies, tactics, and practices set by the manager. Management of grazing involves in part the estimation of the forage that will be available between 2 points in time (decision points) and the setting of a stocking rate that will allow the available forage to be economically utilized by his grazing animals. Thus, if the manager can reasonably estimate the forage that will be available between decision points and the amount that can be captured through livestock grazing, he can determine the stocking rate adjustments needed to efficiently utilize the forage available.

The model was designed (Fig. 1) to project a cow/calf ranching firm's cattle investment capital requirements and net returns over variable costs over time. Projections were based on costs and returns from weaned calf sales, as affected by adjustments in stocking rate and supplemental feeding practices coupled with random variations in product prices.

Decision points were 15 March, 30 May, 30 August, and 31 October. All decisions were based on amount of graminoid standing crop present. The 15 March decision concerned the date that feeding of winter supplement would be terminated (15 March vs. 30 March). All other decisions centered on stocking rate adjustments near the time of peak live standing crop (30 May), near the end of the period of summer dormancy (30 August), and near the end of the growing season (31 October). Decision rules regarding stocking rate adjustments and production variables and penalties were determined based on forage and livestock production data from the ranch.

Livestock production variables were followed through time to present a revenue figure based on yearly calf sales. Total variable costs were obtained annually, so annual net returns over variable costs could be calculated. Since stocking rate adjustments change the number of breeding cattle on a ranch at any point in time, annual changes in cow transactions above normal culling provide an indication of the costs associated with the buying and selling of cows for each alternative tactic. To allow comparison over time without inflationary influences, prices for all classes of livestock were adjusted using the producer price index to equal 1984 dollars. Therefore, both the net returns and the losses and gains in cow investment capital resulting from cow transactions above the normal culling rate are presented in 1984 dollars.

## Forage Standing Crop

Forage standing crop on each of the 4 dates was predicted using 36-years of weather data from Throckmorton (USDC 1950–1985) and linear models that were developed using climatic and standing crop variables during the period from 1981 through 1984. The standing crop data were collected on a clay loam site in a 16-paddock, 1-herd rotational grazing treatment stocked at a heavy rate (Heitschmidt et al. 1987a). The linear models were developed by examining correlation coefficients between various variables and reported standing crops at the 4 decision times in the year, and by examining the correlation coefficients between standing crops within a year. The final equations selected were:

$$SC1 = 152.566 + 98.342\,X_1 + 216.193\,X_2 \qquad [1]$$
$$R^2 = 0.688 \quad df = 11$$

$$SC2 = 42.912 + 175.04\,X_3 + .4509\,SC1 \qquad [2]$$
$$R^2 = 0.851 \quad df = 11$$

$$SC3 = 599.889 + 30.141\,X_4 \qquad [3]$$
$$R^2 = 0.656 \quad df = 11$$

$$SC4 = -349.268 = 31.353\,X_5 + 0.891\,SC3 \qquad [4]$$
$$R^2 = 0.597 \quad df = 12$$

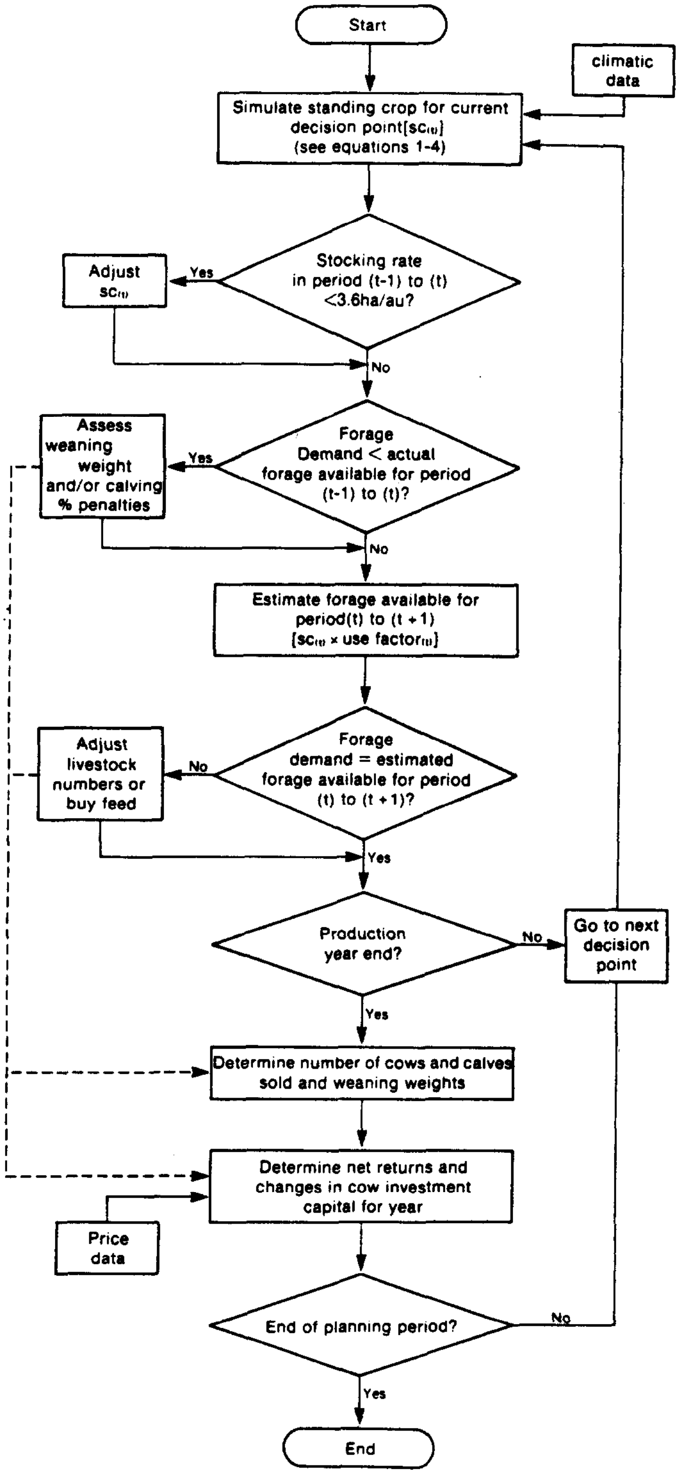

Fig. 1. *A flow diagram of the model.*

where:

$SC1$ = graminoid standing crop (kg/ha) for 15 March.
$SC2$ = graminoid standing crop (kg/ha) for 30 May.
$SC3$ = graminoid standing crop (kg/ha) for August 30.
$SC4$ = graminoid standing crop (kg/ha) for 31 October.
$X_1$ = total rainfall (cm) for Jan., Feb., and Mar.
$X_2$ = average minimum temperature (c) in Feb.
$X_3$ = total rainfall (cm) for Mar. and Apr.
$X_4$ = total rainfall (cm) for May and June.
$X_5$ = total rainfall (cm) for Sept. and Aug.

Predicted standing crops at time t were adjusted to reflect the effects of different rates of stocking from time t-1 to time t. For the purposes of this study it was assumed the effects of stocking rate were directly proportional to forage demand as demonstrated by Heitschmidt et al. (1987a). In general, adjustments were made based on forage demand/animal unit estimates as reported by Olson (1984). Estimates were based on previously published (Heitschmidt et al. 1987) and unpublished cow and calf weights and forage organic dry matter digestibility estimates at the ranch (Heitschmidt et al. 1987b). For the purposes of the model, organic dry matter intake/cow was set at 13.66, 13.15, 11.65, and 9.63 kg/da for the periods between 15 March and 30 May, 30 May and 30 August, 30 August and 31 October, and 31 October and 15 March, respectively. Estimated intake/calf was set at 4.92 kg/da for the period from 30 August to 31 October. Intake/calf prior to 30 August was assumed to be negligible.

For the model to satisfactorily meet the objectives of this study, an estimate of the amount of forage available for consumption between 2 decision points was required to establish decision rules. Although considerable effort was expended in an attempt to model the varied biological processes that would affect standing crop at any given decision point (senescence, trampling, herbivore, etc.), it became apparent during the process that this was not necessary (Riechers 1986). We reasoned that producers make most stocking rate decisions based upon amount of standing crop present at a given time and his/her perception of amount of standing crop that will be present at some future time. Moreover, we recognized that with yearlong grazing regimes, such as cow/calf operations, most stocking rate decisions made prior to the end of the growing season are influenced by that producer's perception of what the standing crop will be at the beginning of the next growing season. In other words, the decision to adjust rate of stocking in late June is influenced by the producer's perception of not only its impact on standing crop in late August and October, but also its potential

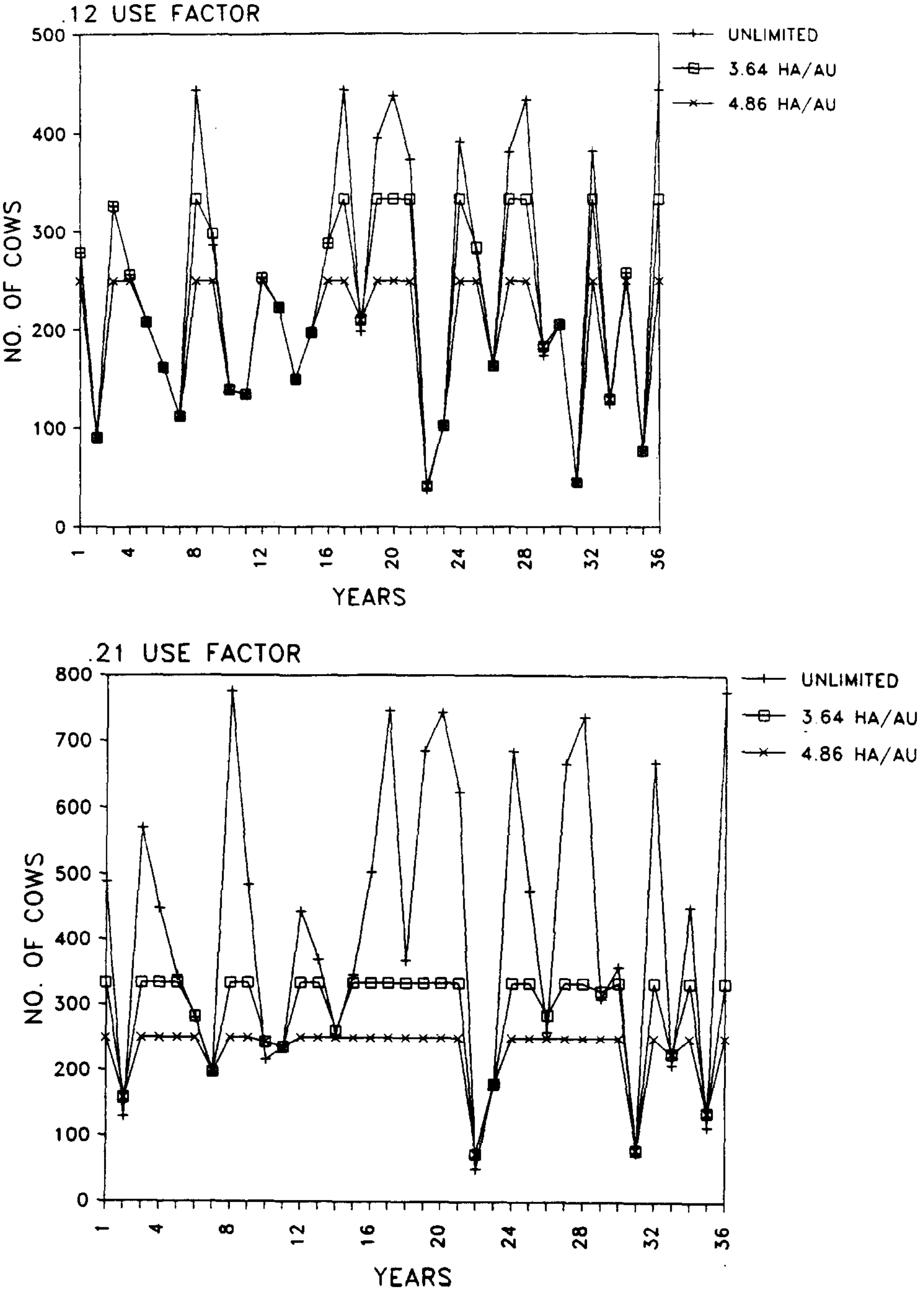

**Fig. 2.** *Cow numbers on the ranch after the May decision point for the 3 tactics at 2 use factors.*

impact on standing crop the next spring.

To effectively model these considerations into the decision making process, we began by again examining the standing crop data from the heavily stocked rotational grazing treatment from which the standing crop predictive equations were derived. Because stocking rate in this treatment was high, available standing crop at the end of the winter dormancy periods from 1982 through 1984 was usually perceived to be near zero relative to a cow's ability to harvest the residue. Average graminoid standing crops across the 3 years were about 775, 1,250, 1,250, and 950 kg/ha on 15 March, 30 May, 30 August, and 31 October, respectively (Heitschmidt et al. 1987a). We then assumed net standing crop losses between decision points were equal to the forage demand of the grazing animals as shown to be true on an annual basis by Heitschmidt et al. (1987a). Estimated disappearance/forage demand values averaged about 250, 300, 250, and 325 kg/ha across the 3 years for the periods from 15 March to 30 May, 30 May to 30 August, 30 August to 31 October, 31 October to 15 March, respectively.

The forage disappearance values between times t and t+1 were then divided by the standing crop estimate at time t. These values for the 3 years averaged 0.32, 0.24, 0.20, and 0.34, respectively, for the periods beginning on 15 March, 30 May, 30 August, and 31 October. We then ran a series of simulations using these values to estimate the maximum amount of forage available for consumption between 2 decision points. Based on the output from these simulations, we adjusted these "use factor" estimates as necessary to develop an acceptable level of realism in the model. Final use factors selected were 0.25, 0.50, and 0.70, respectively, for the March, August, and October decision points. Four use factors were used for the May decision point because the model was found to be quite sensitive to use factors at this critical decision point. Use factors for May were 0.12, 0.15, 0.18, and 0.21.

It should be emphasized that the inclusion of use factors in the model was required to establish realistic decision rules at each decision point. They did not affect estimates of amount of standing crop present at the next decision point if rate of stocking remained unchanged. They simply limited the magnitude of any upward adjustment in stocking rate. For a more detailed description concerning standing crop estimation procedures, see Riechers (1986).

### Livestock Production

Estimates of the livestock production parameters used in the model (production/au and production/ha) were based on research reported by Heitschmidt et al. (1987c). Normal weaning weights for both August and October were set at 220.2 and 252.4 kg, respectively. The 90-day breeding season began 1 April, and a weaning percentage of 80 was used under normal circumstances. The model, however, incorporated 4.5 kg reductions in weaning weights for each period when forage availability was less than demand based on the number of cattle actually present during the period. The model also incorporated a 3% reduction in weaning percentages when forage shortages were encountered during the October–March, and March–May periods reflecting the impact of cow condition at the beginning of the breeding season. Alternatively, if cow numbers were reduced in June, the weaning percent was increased by 5% since most of the cows sold in June would be those without calves.

### Costs and Prices

Prices of inputs and outputs are another source of uncertainty facing the management of agricultural firms. Changes in prices have a direct impact on the net revenues and cash flows at the firm level. The inclusion of variations in both prices and standing crop insured the integrated effect of sources of uncertainty on the financial condition of a cow-calf firm could be addressed in the simulations.

Standard variable cost budgets were developed based on production estimates from 4 grazing treatments at the ranch (Conner and Chamberlain 1985). Normal net replacement costs for females, based on a 333 head base herd, a 2% death loss, and an 11% culling rate were included in the annual variable cost budgets. The annual variable net replacement cost per cow was calculated by subtracting the average cost of replacements from the yearly revenue obtained through the selling of cull cows. The viable net replacement cost of replacements was set a $15.03 per cow based on the above assumptions. This permitted the cost differences associated with the alternative decision rules to be more accurately reflected in annual net returns and annual changes in cow investment capital.

The variable cost budgets also reflected the cost of purchasing

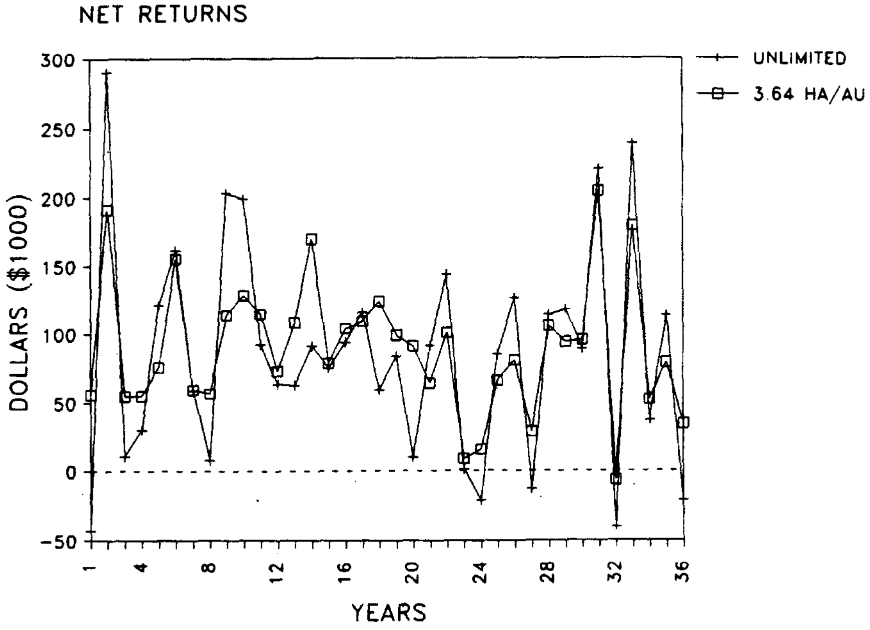

**Fig. 3.** *Annual net returns over variable costs for unlimited and 3.6 ha/au stocking tactics at the 0.21 use factor over the 36 year period (1950-1985).*

and feeding when forage conditions warranted such feeding based on internal decision rules in the model. The additional costs were based on the number of cows kept through the winter and the number of days the animals were fed. It was assumed that each cow would be fed a 20% CP range cube at a rate of 1.36 kg/day for 90 days with the option to supplement for 15 extra days made at the March decision point if specified forage conditions were encountered. The cost of supplement was set at $0.24/kg. (Conner and Chamberlain 1985). Without the 15 days of supplemental feeding the variable cost per cow was $88.57. Each year the model calculated total variable cost by multiplying the variable cost per cow times the number of cows on the ranch after the May decision point.

Under the modeled setting, all calves were sold through an auction market either in August or October. Weaned steer prices were randomly drawn from average August steer prices at the Amarillo market from 1960 through 1980. Annual prices for steers sold in months other than August and for the other classes of animal sold in August and other months were derived either through linear correlation or through the use of average price differences compared to August. If the correlation between the August steer prices and the price of the class in question was not significant ($P<0.05$), an average price difference between the August steer price and the class based on the 20 years of price data was used to calculate the price for the class at any point in time.

The model allowed sales above normal culling to occur at the May, August, or October decision points. These transactions reflected the need to alter stocking rates in order to balance perceived forage availability with demand as mediated by the alternative decision rules. The model allowed livestock purchases to occur only at the May decision point. Cows purchased to capture available forage were assumed to weigh 454 kg and were bought at the cow price generated for the May decision point plus a standard $10 per head marketing charge.

**Simulations**

The economic consequences of 3 different stocking rate tactics were simulated on a total land area of 1,215 ha. The first tactic set stocking rate at a maximum limit of 4.9 ha/au (250 head). The second tactic set the maximum limit of 3.6 ha/au, (333 head) and no maximum was set in the third tactic. No minimum levels were set for any of the simulated tactics. The simulation of the third tactic began at a stocking rate of 3.6 ha/au, since that was the base stocking rate used in the grazing treatment from which the forage data were derived. Results were contrasted between the 3 tactics and within the 3 tactics for the 4 May use factors.

## Results and Discussion

With the unlimited stocking tactic, the maximum number of cows reached 776 head when the May use factor of 0.21 was used, 665 cows when the 0.18 use factor was used, 554 cows when the 0.15 use factor was used, and 443 cows with the 0.12 factor was used (Fig. 2). The lowest cow numbers at any point in time also occurred using the unlimited stocking rate tactic: When the 0.15 use factor was used for the May decision the cow herd reached a low of 36 head as compared to 37, 41, and 49 cows when the 0.12, 0.18, and 0.21 use factors were used, respectively. The lowest cow numbers for the 2 limited tactics were 41, 51, 62, and 72 for the 0.12, 0.15, 0.17, and 0.21 May use factors, respectively. The difference in cow numbers for the 3 tactics at both the lowest and highest use factors indicates the response to available forage.

The simulations showed that the unlimited stocking tactic required winter supplement be fed an additional 15 days (16–30 March) 34% of the time as compared to 30% of the time for the 2 limited strategies. The option to wean calves early (August) was not invoked over the 36-year period for the 2 limited tactics under any of the May use factors. However, the unlimited tactic invoked the penalty 3% of the years at the 2 lowest use factors and 19% and 27% of the years at the 0.18 and 0.21 May use factors, respectively. The weaning weight reduction was encountered in about 25% of the years for all tactics.

The average annual net returns over variable costs for each tactic are presented in Table 1. Average net returns for all May use factors increased as the maximum allowable stocking rate increased. When the maximum stocking rate was changed from 4.9 ha/au to 3.6 ha/au, annual net returns increased an average of 21% and relative variation increased 8%. Comparing the differences between the 3.6 ha/au tactics and the unlimited stocking tactic annual returns averaged across all use factors, increased an average of 9% and variation increased an average of 15%. Figure 3 depicts the annual variation between these 2 tactics over the 36-year period relative to net returns over variable costs.

**Table 1. Means, standard deviations, and the coefficient of variation for the net returns over variable costs over the 36 year period (1950–1985), based on different stocking rate tactics and use factors in May.**

| May Use Factor | Stocking tactic | Mean | Std Dev | C.V. |
|---|---|---|---|---|
| | | ——dollars—— | | |
| | Max. 4.9 ha/au | 61,469.18 | 37,768.77 | .61 |
| 0.12 | Max. 3.6 ha/au | 70,743.96 | 48,370.81 | .68 |
| | Unlimited | 75,889.02 | 58,688.05 | .77 |
| | Max. 4.9 ha/au | 66,373.85 | 37,330.38 | .56 |
| 0.15 | Max. 3.6 ha/au | 79,491.20 | 50,583.41 | .64 |
| | Unlimited | 88,692.81 | 67,817.71 | .76 |
| | Max. 4.9 ha/au | 69,279.42 | 35,057.98 | .51 |
| 0.18 | Max. 3.6 ha/au | 85,742.09 | 50,808.58 | .59 |
| | Unlimited | 93,186.67 | 71,388.02 | .77 |
| | Max. 4.9 ha/au | 71,011.11 | 33,323.96 | .47 |
| 0.21 | Max. 3.6 ha/au | 89,481.06 | 49,185.59 | .55 |
| | Unlimited | 95,555.16 | 78,621.48 | .82 |

The effects of May use factors on net returns varied among tactics. Annual net returns increased and coefficients of variation (relative variation in net returns) decreased continuously for both limited stocking tactics as the May use factor was increased from 0.12 to 0.21. However, for the unlimited stocking rate tactic, average annual net returns increased and relative variation remained constant as the May use factor was increased from 0.12 to 0.18. As the use factor was increased from 0.18 to 0.21, however, average annual net returns increased 3% and relative variation increased 5%.

The probabilities of net returns falling below $27,000.00/year ($22.22/ha) for 1 or more years and 3 or more years in any given 10-year period are presented in Table 2. The threshold value of $27,000.00 represents the minimum net returns required to meet the rancher's living expenses and service debts. This is slightly less than the annual ownership costs for the ranch as shown by Conner and Chamberlain (1985). The probabilities of net returns falling below the critical level were based on 27 ten-year periods obtained by grouping the 36 years of primary results. Years 1–10 were grouped then years 2–11, etc., until the group with years 27–36 was reached.

The net returns under any of the stocking tactics or any of the May use factors never fell below the critical level 5 or more years out of any 10-year period. Averaged across all of the May use factors, there was little difference between the 4.9 ha/au and 3.6 ha/au tactics in terms of the probability that annual income would fall below the threshold level in at least 1 or 3 years out of every 10

**Table 2. Probability that in any 10 year period net returns over variable costs will fall below $27,000 in 1 and 3 or more years for 3 stocking tactics and 4 May use factors.**

| May use factor | Stocking tactic | Number of years in ten: One | Number of years in ten: Three |
|---|---|---|---|
| | | Percent | Percent |
| | Max. 4.9 ha/au | 81.5 | 40.7 |
| 0.12 | Max. 3.6 ha/au | 74.0 | 37.0 |
| | Unlimited | 81.5 | 37.0 |
| | Max. 4.9 ha/au | 48.1 | 29.6 |
| 0.15 | Max. 3.6 ha/au | 48.1 | 29.6 |
| | Unlimited | 77.8 | 37.0 |
| | Max. 4.9 ha/au | 51.9 | 3.7 |
| 0.18 | Max. 3.6 ha/au | 51.9 | 29.6 |
| | Unlimited | 81.5 | 29.6 |
| | Max. 4.9 ha/au | 51.9 | 3.7 |
| 0.21 | Max. 3.6 ha/au | 51.9 | 3.7 |
| | Unlimited | 81.5 | 29.6 |

years. Averaged across the 3 heavier use factors, the probability of the annual income (net returns) falling below $27,000.00 in at least 1 out of every 10 years was much greater for the unlimited than limited stocking tactics.

When the May use factor was changed from 0.12 to 0.15, the probabilities of net returns falling below the threshold level in at least 1 out of 10 years was substantially reduced for both limited stocking tactics. This indicated inefficient utilization of the forage resource at the 0.12 level. Because the probability of falling below the threshold level in 1 year out of 10 remained virtually unchanged for the unlimited tactic regardless of the May use factor, a producer could utilize the forage at a greater rate in May without increasing risk. The probability of falling below the critical level generally decreased over all the stocking rate tactics as the May use factor was changed from 0.12 to 0.21 which showed that by using a flexible stocking rate to enhance harvest efficiency, the probability of low net returns decreased.

**Table 3. Means, standard deviations, and the coefficients of variation for the annual capital investment costs of cow transactions above normal culling for 3 stocking tactics and 4 use factors over the 36 year period (1950–1985).**

| May use factor | Stocking tactic | Mean | Standard deviation | C.V. |
|---|---|---|---|---|
| | | dollars | dollars | |
| | Max. 4.9 ha/au | –546.16[1] | 56,999.00 | –104.36 |
| 0.12 | Max. 3.6 ha/au | –449.77 | 78,358.28 | –174.22 |
| | Unlimited | 1,446.22 | 99,686.15 | 68.93 |
| | Max. 4.9 ha/au | –646.07 | 50,645.40 | –78.39 |
| 0.15 | Max. 3.6 ha/au | –906.26 | 76,347.84 | –84.25 |
| | Unlimited | 413.76 | 109,447.45 | 264.52 |
| | Max. 4.9 ha/au | –297.02 | 43.017.44 | –144.83 |
| 0.18 | Max. 3.6 ha/au | –1,089.96 | 70,553.26 | –64.73 |
| | Unlimited | 153.02 | 111,826.60 | 730.78 |
| | Max. 4.9 ha/au | –208.46 | 37,152.44 | –178.23 |
| 0.21 | Max. 3.6 ha/au | –961.93 | 63,521.07 | –66.04 |
| | Unlimited | 1,489.28 | 117,971.95 | 79.21 |

[1] Negative annual costs indicate that, on the average, more investment capital was received from the sale of cows than was expended to purchase cows.

**Table 4. Probability that in any 10 year period accumulated cow investment capital will fall below zero in 1, 3, 5, 7, and 9 or more years for 3 stocking tactics and 4 May use factors[1].**

| May use factor | Stocking tactic | Number of years in ten: One | Three | Five | Seven | Nine |
|---|---|---|---|---|---|---|
| | | Percent | Percent | Percent | Percent | Percent |
| | Max. 4.9 ha/au | 70.4 | 55.6 | 44.4 | 37.0 | 18.5 |
| 0.12 | Max. 3.6 ha/au | 77.8 | 63.0 | 55.5 | 37.0 | 18.5 |
| | Unlimited | 88.8 | 66.6 | 55.5 | 37.0 | 22.2 |
| | Max. 4.9 ha/au | 85.2 | 48.1 | 37.0 | 29.6 | 18.5 |
| 0.15 | Max. 3.6 ha/au | 63.0 | 55.5 | 44.4 | 37.0 | 18.5 |
| | Unlimited | 88.8 | 74.1 | 59.3 | 37.0 | 25.9 |
| | Max. 4.9 ha/au | 85.2 | 66.6 | 51.8 | 37.0 | 18.5 |
| 0.18 | Max. 3.6 ha/au | 85.2 | 48.1 | 44.4 | 33.3 | 14.8 |
| | Unlimited | 92.6 | 70.4 | 51.8 | 40.7 | 25.9 |
| | Max. 4.9 ha/au | 74.0 | 66.6 | 51.8 | 40.7 | 22.2 |
| 0.21 | Max. 3.6 ha/au | 85.2 | 51.8 | 37.0 | 25.9 | 14.8 |
| | Unlimited | 92.6 | 77.8 | 59.2 | 44.4 | 25.9 |

[1] Accumulated cow investment capital refers to the sum of annual receipts from sales and/or expenditures for purchases of cows over the 10-year period. When accumulated investment capital becomes negative in any given year, the total capital expended to purchase cows for that and all previous years in the period exceeds the total capital received from sales of cows. Thus, the lower the probability of accumulated investment capital becoming negative, the less likely that the rancher would have to borrow money to maintain the desired herd size.

Tables 3 and 4 summarize the losses and gains to capital investment caused by cow transactions above normal culling. These transactions above normal culling indicate the investment capital costs associated with buying and selling cows for the breeding herd to match forage demand with available supply. The average annual cow investment costs, their associated standard deviations, and the resulting coefficients of variation are presented in Table 3. Negative annual costs indicate that, on the average, more investment capital was received from the sale of cows than was expended to purchase cows. Table 4 gives the probabilities associated with the accumulated investment capital costs being negative in at least 1, 3, 5, 7, and 9 years out of any 10-year period.

The tactics with upper stocking rate limits had negative average annual investment capital costs across all May use factors. The unlimited tactic showed a positive average annual investment cost regardless of May use factor. This indicated that for the limit tactics there would be capital investment inflows to the ranch and for the unlimited tactic there would be investment capital outflows. The unlimited stocking tactic resulted in equal or greater probabilities that accumulated annual investment capital would be negative in at least 1, 3, 5, 7, and 9 out of 10 years, compared to both the limited stocking tactics regardless of the level of the May use factor.

For the use factors of 0.12 and 0.15 the 4.9 ha/au maximum tactic generally results in equal or lower probabilities that accumulated investment capital will be negative in at least (x) years out of 10, except when (x) is equal to 1 and the use factor for May is 0.15 when compared to the 3.6 ha/au tactic. Further comparison of the limited tactics indicate that the 3.6 ha/au tactic results in equal or lower probabilities that accumulated investment capital will be negative in at least (x) years out of 10 when the use factor is 0.18 and 0.21, the only exception being when (x) equal 1 and the use factor equals 0.21.

## Conclusions

For the management regimes presented in this study, average annual net returns increased as the maximum stocking rate allowed increased; however, the variation in annual net returns also increased. Based on the annual net returns estimates, an argument favoring the use of a maximum stocking of 3.6 ha/au can be developed. The argument is based on the tactic's average net returns and relative variation of returns. Also, in all but 1 instance (0.18 use factor) this tactic has the lowest probability of net returns falling below the critical level in 1 or 3 years out of 10.

Considering the average annual capital investment changes associated with the 2 tactics where stocking limits are set, the average decrease in annual capital investment was greater under 3 of the 4 use factors when the 3.6 ha/au tactic was utilized. On the other hand, the unlimited tactic caused average annual investment costs to increase as the use factor increased.

Under the environment simulated, the model does not clearly identify a unique optimal tactic. It does present information on the net returns and capital requirements which might be expected under different tactics and forage use levels while incorporating forage changes and price movements. The model can be modified to incorporate more decision times or changes in the decision, different rates, changes in livestock management and changes in annual forage production. These modifications would need to be incorporated if the model were to be used in other regions since the model was site specific. The model could be improved by incorporating the tax implications for the different capital investment requirements associated with the alternative tactics. As presented, however, the model does provide important aids in the development of more refined decision making guidelines and tools for intensively managed grazing systems. Refinement of decision tools in this area will hopefully lead to software decision aids which will be available to the decision maker on the ranch. A manager will then have the tools necessary to estimate the economic consequences of his or her actions before making stocking rate adjustments.

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# Leafy spurge and the species composition of a mixed-grass prairie

JOYCE W. BELCHER AND SCOTT D. WILSON

## Abstract

**The relationship between leafy spurge (*Euphorbia esula* L.) and the species composition of mixed-grass prairie was examined on both a large scale, within a 200-km² area, and on a local scale, within a single infestation. On the large scale, cover values of 8 of the 10 most common species varied significantly ($P<0.05$) between native prairie and spurge-dominated vegetation. Cover values of all common native species were negatively correlated with cover of leafy spurge. Within a single infestation of leafy spurge, the frequency of 5 common native species decreased significantly with leafy spurge. Most native species were absent where leafy spurge was most abundant and species richness declined from 11 outside the infestation to 3 at the center. Ninety-five percent of leafy spurge infestations within a 374-ha area were associated with anthropogenic disturbances (vehicle tracks, road construction and fireguards) which removed native plant cover and exposed mineral soil. These observations corroborate experimental studies which show that leafy spurge establishes more readily in disturbed soil and indicate that the result of such disturbances is the replacement of native species with leafy spurge.**

**Key Words: effects on native grass, species richness, diversity, standing crop, disturbance**

An important Eurasian invader of mixed-grass prairie is leafy spurge (*Euphorbia esula* L.), a perennial capable of vigorous vegetative growth and domination of large areas (Selleck et al. 1962). The biology (Selleck et al. 1962, Raju et al. 1963, Best et al. 1980, Galitz and Davis 1983), control (Bowes and Molberg 1975, Messersmith and Lym 1985), and economic impact (Messersmith and Lym 1983) of leafy spurge have been described, but the effect of leafy spurge on the species composition of native prairie has not been examined.

The major objective of this study was to describe the relationship between leafy spurge and the species composition of mixed-grass prairie. This was done at 2 levels. First, the effect of leafy spurge over a large area was determined by sampling vegetation along eight 400 m long transects in a 200-km² area. Second, the species composition of native prairie as a function of the abundance of leafy spurge was examined within a single infestation of leafy spurge.

Soil disturbance by humans promotes the establishment of Eurasian plant species, such as leafy spurge, in North America (Baker 1986). Best et al. (1980) showed experimentally that 45 times more seeds of leafy spurge establish on bare mineral soil than in undisturbed vegetation. Bare mineral soil appears to be a suitable seed bed, allowing leafy spurge seedlings to establish without interference from neighbors. Therefore, as a secondary objective, we examined whether spurge infestations in a native grassland were associated with soil disturbance.

## Study Area and Methods

### Study Area

The study was conducted in the largest remnant (25 km²) of mixed-grass prairie in Manitoba, Canada, located about 30 km SE of Brandon (49° 39′N, 99° 30′W). Mixed-grass prairie is the most extensive grassland type in North America, originally covering $1.43 \times 10^6$ km², 38% of all North American grassland (Lauenroth 1979). The natural vegetation of the area is described by Bird (1927) and Coupland (1950). Native prairie is dominated by blue grama (*Bouteloua gracilis* [H.B.K.] Lag. ex Steud.), sedge (*Carex obtusata* Lilj.), porcupine grass (*Stipa spartea* Trin.), and little bluestem (*Andropogon scoparius* Michx.; nomenclature follows Scoggan 1957). In the study area, prairie is interspersed with areas dominated by Eurasian plant species, including leafy spurge, Kentucky bluegrass (*Poa pratensis* L.), and smooth brome (*Bromus inermis* Leyss.).

### Large-scale Effects

The relationship between leafy spurge and native prairie species over a large area was measured at 8 sites scattered over 200 km². Five sites were characteristic of native prairie and 3 were dominated by leafy spurge. All sites were similar in terms of soils, and topography. The native prairie sites had never been cultivated, although 4 sites had a history of occasional use for military training; the fifth was undisturbed. Two of the leafy spurge sites were previously used for intensive military training using tanks and the third had been cultivated.

A 400 m long transect was established at each site. Five sampling stations separated by 100-m intervals were located along each transect. Vegetation was sampled during 1–4 Sep. 1987 in each of four $1 \times 0.5$-m quadrats placed 10 m N, E, S, and W of each station. Cover values of plant species were recorded using Daubenmire's scale and converted to mean equivalent percent (Mueller-Dombois and Ellengberg 1974). The mean cover of each species was calculated for each transect. The covers of the 10 most abundant species were transformed (arcsine-square root) to reduce heteroscedasticity and examined with *t*-tests for significant variation between native and spurge-dominated vegetation. A correlation matrix was computed for these same species.

### Effects within a Single Infestation

The relationship between leafy spurge and native prairie species was measured within a single infestation of leafy spurge centered on a vehicle trail in otherwise undisturbed native prairie. The colony was sampled during 28–31 July 1986 by running a primary transect 25 m along the trail. Ten secondary transects, each 25 m long, ran perpendicular to the primary transect. These were placed at random 1-m intervals along the primary transect. Five sampling stations along each secondary transect were similarly selected. In total, 50 sampling stations were examined.

A $40 \times 40$-cm quadrat, divided into a $4 \times 4$-cm grid, was placed at each sampling station. A 1.7-mm diameter pin was dropped at 20 random points within the quadrat and all species touched by each pin were recorded. The frequency of each species was calculated as the proportion of points at which it occurred. Native species richness is the total number of native species recorded in each quadrat.

Standing crop was measured at each sampling station by clip-

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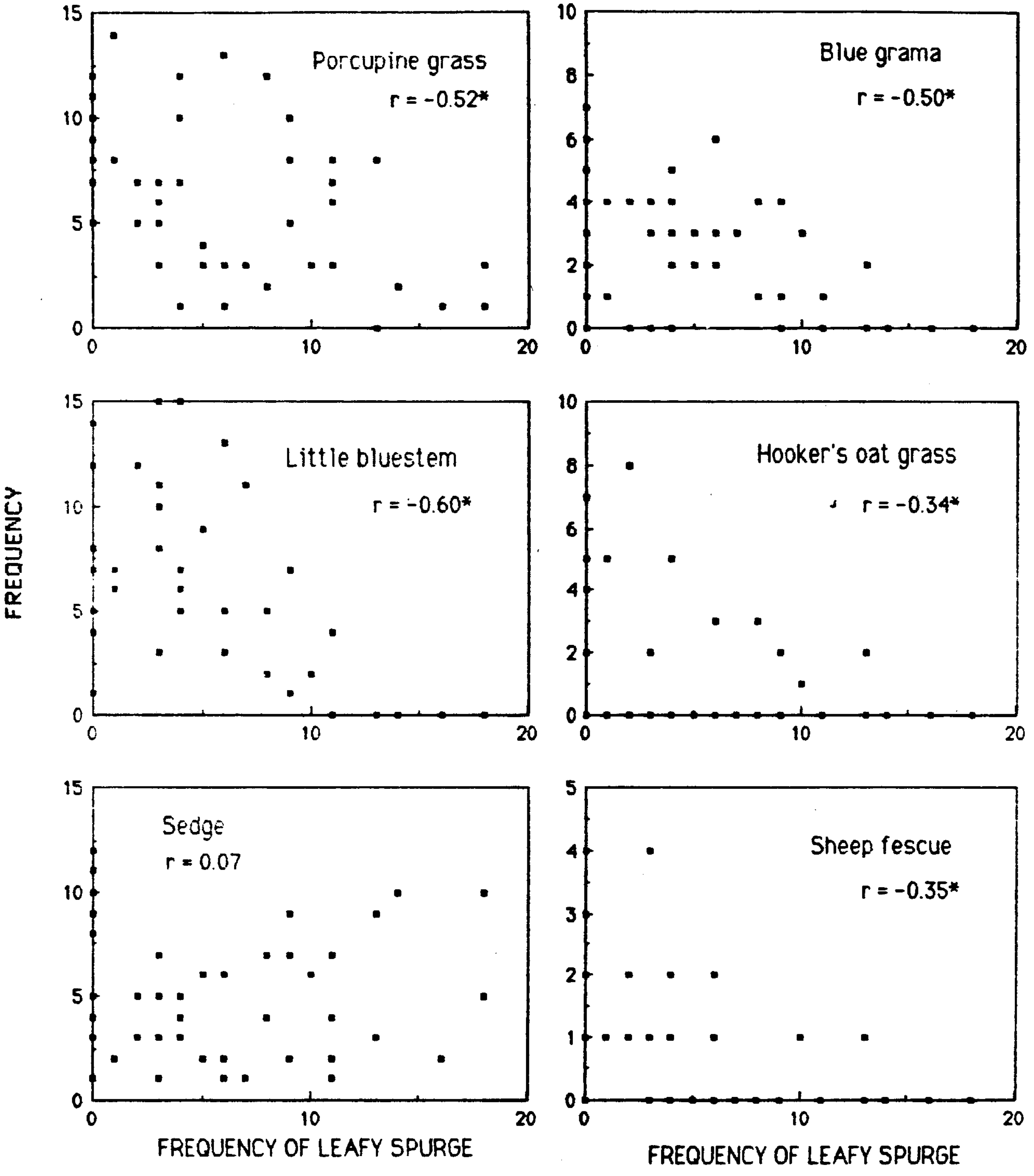

**Fig. 1.** *Frequencies of the 6 most common native species of mixed-grass prairie as a function of the frequency of leafy spurge within a single infestation. * indicates $P<0.05$.*

ping and collecting all aboveground biomass within a 20 by 20-cm quadrat. Samples were dried to constant mass at 100° C and weighed. Below-ground biomass was sampled using a soil core (5 cm diameter, 5 cm deep) removed from the center of each clipped quadrat. Roots were separated from the soil by washing and sieving in a 2-mm sieve. Root samples were dried and weighed as above.

The influence of leafy spurge on community composition was tested by calculating correlations between the frequency of leafy spurge and the following variables: native species richness, species diversity (H′), the frequency of 6 common species (porcupine grass, little bluestem, blue grama, Hooker's oat grass, sheep fescue, and sedge), and above and below-ground biomass.

### Association with Soil Disturbance

Every infestation of leafy spurge within a 274-ha prairie bounded by roads and fireguards was visited. We noted whether the infestation was centered on a trail, road or fireguard, or tracked vehicle turn, or not associated with any disturbance.

## Results

### Large-scale Effects

Eight of the ten most common species varied significantly in cover between native prairie and vegetation dominated by leafy spurge (Table 1). The 3 most common alien species, Kentucky bluegrass, smooth brome, and leafy spurge, were not found in native vegetation. Most of the common native species were present in stands of leafy spurge, but in significantly lower numbers. The native grass little bluestem was not recorded in leafy spurge stands. The cover values of common native species were negatively correlated with those of common alien species in 20 out of 21 cases (Table 2), indicating replacement of native species by alien species. Species richness in native prairie (mean = 23.5 species per transect) was significantly higher than in stands of leafy spurge (14.7) ($t=7.04$, $P<0.01$).

**Table 1. Cover values (per cent, $\bar{x}$ ± SD) of the most abundant species in native prairie and vegetation dominated by leafy spurge. Values are means for 100 quadrats in native prairie and 60 quadrats in leafy spurge-dominated vegetation sampled in a 200 km² area.**

| | Native prairie | Vegetation dominated by leafy spurge |
|---|---|---|
| Native species: | | |
| Blue grama** | 31.8 ± 15.7 | 2.0 ± 3.7 |
| Sedge** | 31.4 ± 12.7 | 15.0 ± 14.7 |
| Porcupine grass** | 30.8 ± 11.8 | 10.2 ± 10.0 |
| June grass* | 8.0 ± 5.6 | 4.0 ± 5.8 |
| Little bluestem** | 9.3 ± 9.3 | 0 |
| Creeping cedar | 9.1 ± 12.5 | 3.0 ± 6.5 |
| Pasture sage | 5.0 ± 4.0 | 4.1 ± 3.9 |
| Alien species: | | |
| Leafy spurge** | 0 | 33.0 ± 24.0 |
| Kentucky bluegrass** | 0 | 28.8 ± 25.9 |
| Smooth brome** | 0 | 18.8 ± 16.5 |

*cover significantly different between native prairie and vegetation dominated by leafy spurge at $P<0.05$; **: at $P<0.01$.

### Effects within a Single Infestation

The frequencies of the 5 dominant native grasses were significantly and negatively correlated with leafy spurge; 4 species were absent where leafy spurge was most abundant (Fig. 1). Sedge showed no variation with leafy spurge frequency. Native species richness decreased significantly with increasing leafy spurge (Fig. 2). Seven to 11 species were found outside the patch but 4 species existed where leafy spurge was most abundant. Species diversity also decreased significantly with leafy spurge (Fig. 2). Neither above- nor below-ground biomass varied significantly with frequency of leafy spurge ($r = 0.13$, $0.04$, respectively; $P>>0.05$), suggesting that native species were simply replaced by spurge without variation in the capacity of the soil to support phytomass.

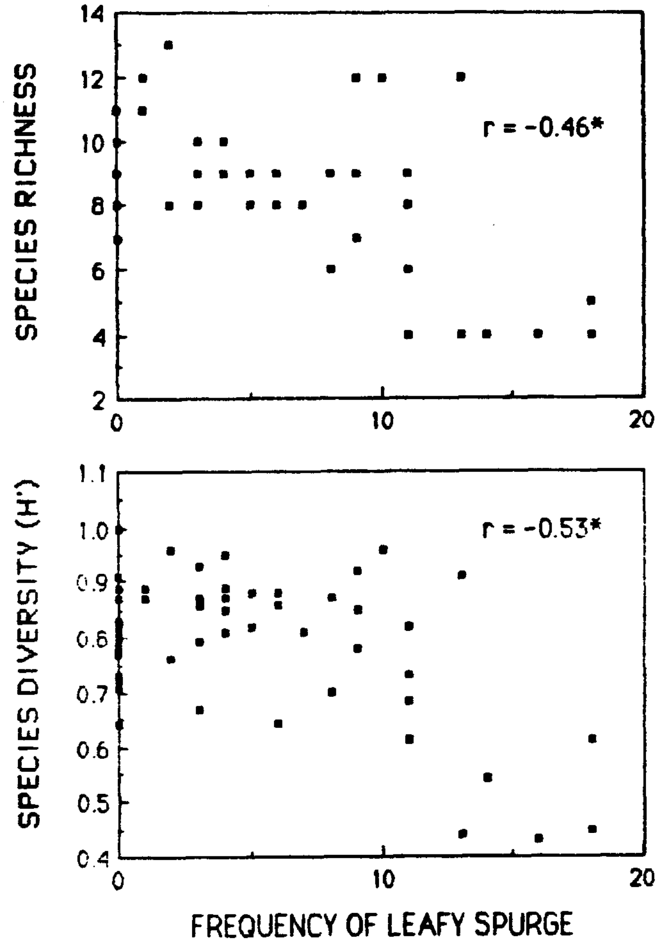

**Fig. 2.** *Species richness and species diversity as a function of the frequency of leafy spurge within a single infestation.* * *indicates* $P<0.05$.

**Table 2. Correlation matrix (r values) for the 10 most abundant plant species. Values are from 160 quadrats sampled in a 200 km² area.**

| | Native species | | | | | | | Alien species | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Blu gra[1] | Sedge | Por gra | Jun gra | Lit blu | Cre ced | Pas sag | Lea Spu | Ken blu | Smo bro |
| Native species: | | | | | | | | | | |
| Blu gra | 1.00 | | | | | | | | | |
| Sedge | 0.54** | 1.00 | | | | | | | | |
| Por gra | 0.38** | 0.46** | 1.00 | | | | | | | |
| Jun gra | 0.28 | 0.25 | 0.10 | 1.00 | | | | | | |
| Lit blu | 0.38** | 0.21 | 0.62** | 0.19 | 1.00 | | | | | |
| Cre ced | −0.08 | −0.14 | 0.35* | 0.14 | 0.32* | 1.00 | | | | |
| Pas sag | 0.11 | −0.01 | −0.08 | 0.16 | −0.09 | −0.18 | 1.00 | | | |
| Alien species: | | | | | | | | | | |
| Lea spu | −0.67** | −0.48** | −0.60** | −0.46** | −0.51** | −0.20 | −0.26 | 1.00 | | |
| Ken blu | −0.54** | −0.56** | −0.51** | −0.33* | −0.48** | −0.23 | 0.09 | 0.52** | 1.00 | |
| Smo bro | −0.64** | −0.31* | −0.54** | −0.39* | −0.46** | −0.08 | −0.31* | 0.62** | 0.43** | 1.00 |

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

[1] Species names in full: blue grama, sedge, porcupine grass, June grass, little bluestem, creeping cedar, pasture sage, leafy spurge, Kentucky bluegrass, smooth brome.

### Association with Soil Disturbance

Eighty-three colonies of leafy spurge were found. The majority of these (49) were centered on trails, fireguards and road construction. Thirty were centered on disturbances caused by tracked vehicles turning. The remaining 4 colonies were not associated with visible soil disturbance. No colonies were associated with natural soil disturbances such as those caused by pocket gophers.

## Discussion and Conclusions

Leafy spurge was clearly related to a decline in the abundance of the dominant species in native prairie, both on a large scale and within a single infestation. The only species that were significantly positively correlated with leafy spurge were the Eurasian species smooth brome and Kentucky bluegrass. This relationship might occur either because leafy spurge established in soil cultivated in preparation for the sowing of these grasses or because Eurasian agricultural species readily invade disturbed soil. Table 2 suggests that leafy spurge is one member of a community of Eurasians and that this community is associated with a decline in the cover of native prairie plants.

Leafy spurge alone can have a negative effect on native prairie, as demonstrated by the results from the sampling of a single infestation in which smooth brome and Kentucky bluegrass were not encountered (Fig. 1). The absence of 4 of the 5 common native species (little bluestem, blue grama, Hooker's oat grass, and sheep fescue) where leafy spurge was most frequent may result from shading by the relatively tall leafy spurge.

In our study area, 79 out of 83 leafy spurge infestations were centered on trails, roads, and plowed fireguards. Therefore, an important but unconsidered method of decreasing the number of infestations of leafy spurge on native prairie would be to reduce disturbances which expose mineral soil. Although disturbances at the study site resulted primarily from vehicle traffic and fireguard construction, the same principle may apply to more common disturbances such as overgrazing, road construction, and cultivation. Considerable attention has been given to chemical control of leafy spurge, but it appears that the occurrence of leafy spurge could also be reduced by limiting soil disturbances which promote its establishment.

Leafy spurge poses a considerable threat not only to the economic use of prairie for rangeland (Messersmith and Lym 1983), but also to its conservation as native vegetation.

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