JOURNAL
OF
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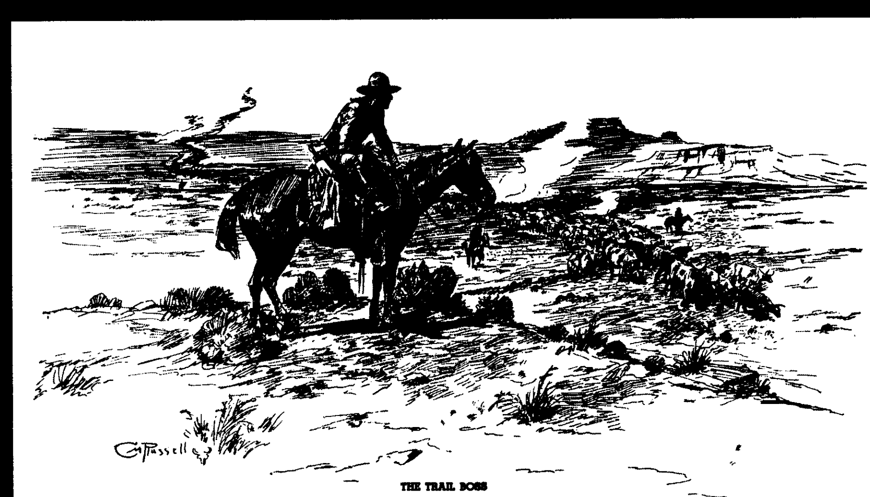

PUBLICATION OF THE
SOCIETY FOR RANGE MANAGEMENT

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MARCH 1978

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Denver, Colorado, U.S.A.
August 14–18, 1978

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SOCIETY FOR RANGE MANAGEMENT

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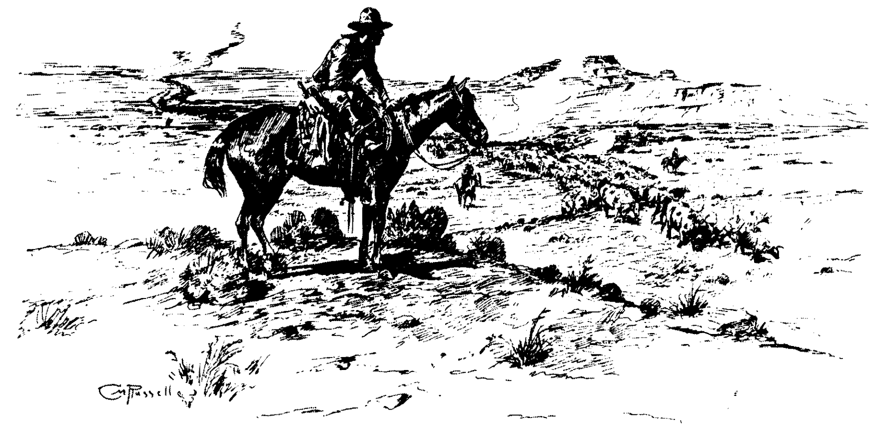

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The objectives for which the corporation is established are:

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

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

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

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

—*to promote professional development of its members.*

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

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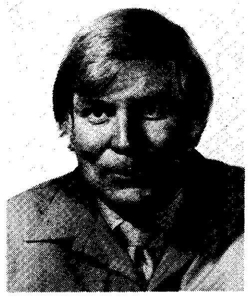
Food, Fiber, Fuel, and Fun from Rangelands



THADIS W. BOX

It has been a pleasure to serve as the thirtieth president of the Society for Range Management. In the beginning our Society was a small collection of dedicated people trained in forestry, animal science, agronomy, and ecology, and bound together only by a concern for and dedication to the management of the country's rangelands. In three brief decades it has developed into a group of well over 5,000 people with varying degrees of training in the field of range management. We, as a Society, speak for about 40% of the earth's surface. We are the major professional group that must produce the food, fiber, fuel, fun, all the goods and services that society wants from rangelands.

It may seem ludicrous that the thirtieth president of the Society for Range Management should begin his discussion with a definition of rangelands. However that may be, the concepts of rangelands are changing so radically today that a brief discussion is necessary.

The terms "range" and "rangelands" are of relatively recent origin. When John Wesley Powell (1878) wrote his treatise on the western rangelands, he did not even use the term, but talked of "pasturage lands." Soon after the turn of the century, descriptions of rangeland began to appear. The one included in the Senate report on the western range (U.S. Senate 1936) was typical:

> The western range is largely open and unfenced, with control stock by herding; when fenced, relatively large units are enclosed. It supports with few exceptions only native grasses and other forage plants, is never fertilized or cultivated, and can in the main be restored and maintained only through control of grazing. It consists almost exclusively of lands which, because of relatively meager precipitation and other adverse climatic conditions, or rough topography or lack of water for irrigation, cannot successfully be used for any other form of agriculture.
>
> In contrast the improved pastures of the East and Middlewest receive an abundant precipitation, are ordinarily fenced, utilize introduced forage species, . . . cultivation for other crops, and are often fertilized to increase productivity, and are renewed following deterioration.

This was the prevailing concept of rangelands prior to the formation of the Society for Range Management.

Several authors gave definitions of range management in the early years of our Society. Rangeland was called "the land upon which the animals graze" (Clawson 1950). Sampson (1952) described range as "large, naturally vegetated, mostly unfenced lands of low rainfall areas that are grazed by domestic livestock and game mammals." Dyksterhuis in 1955 stated that a satisfactory definition of range appeared to be "native pasture on natural grazing land." Stoddart and Smith (1955) did not define rangeland but chose instead to define range management. They called it the science and art of obtaining maximum livestock production from rangeland consistent with the conservation of natural resources.

Presidential Address from the 31st Annual Meeting of the Society for Range Management, San Antonio, Texas, February 8, 1978.

These definitions stressing livestock production and grazing from rangelands were the standard concept and definition of range until about the late 1950's and early 1960's. At that time rangeland began to be discussed as a particular classification of land with equivalent standings to that of forests or cropland. Most authors admitted that there were no specific characteristics that differentiated rangelands from either croplands or forests. Rangelands were described as being not suitable for croplands or intensive forests, their use being limited by aridity, rocks, shallow soils, rough topography, poor drainage, cold temperatures, and other physical features. Intensively managed pastures were also considered as range. Although most authors were reluctant to define rangelands, their descriptions were all similar. Range was recognized as a kind of land that can produce many goods and services. It is managed most effectively using principles of ecology rather than intensive agriculture or agronomic techniques (Stoddart, Smith, and Box 1975; Blaisdell et al. 1970; Colbert 1977).

The definition of range management has also changed over the years. When I was a student the definition I learned was from Stoddart and Smith (1955). Range management meant obtaining maximum livestock production from native vegetation. We were trained to produce a forage crop—native plants—and harvest it with animals—cattle, sheep, or goats. Range management today is defined as the science and art of optimizing the returns from rangeland in those combinations most desired by and suitable to society through the manipulation of range ecosystems (Stoddart, Smith, and Box 1975). Range management is involved in the production of many different goods and services, of which only one may be livestock products.

Unfortunately, many people still consider range as a use of land and not land itself. They equate range with livestock grazing. Even some agencies managing rangelands discuss the multiple uses of the land as timber, water, range, recreation, etc. Timber, water, and recreation are all goods or services and outputs of land. Range is the land itself. It can be used for the production of timber, forage, water, etc. Francis Colbert once said:

> I want to emphasize in the strongest possible way that range—or rangeland or range ecosystems—is a kind of land. It is not a land use.
>
> I must admit that the word "range" has always been associated with livestock grazing (a specific use) on uncultivated lands, and this is the connotation that is still prevalent, especially to the general public (if, in fact, the general public thinks of it as anything else than the kitchen stove!). Nevertheless, rangeland comprises at least 40 percent of the total land area, not only in this country but in the entire world, so I believe it's time that we made a serious effort to recognize range for what it really is: a kind of land—a major land resource—from which there is, and can be, obtained a wide variety of products and values, of goods and services.

If range is a particular kind of land, distinguished from cropland and forest, what are the goods and services that can be expected from rangelands now and in the future?

Food from Rangelands

The traditional product most often considered when rangeland is discussed is food—red meat. Although many of the outputs of ranges are measured in animal unit months, the ultimate product that society desires is meat for the table. American is a land that has for many decades been blessed with food surpluses. We are now in one of those cycles when we are embarrassed by high food production and low food prices. One has only to look at the world population growth to see that this embarrassing surplus of food is ephemeral and that shortages are bound to occur in the future.

As the human population grows, more and more cropland will be used to produce food for direct human consumption. The amount of meat in the diets may decrease but it will still be the desired source of high quality protein when it is available. Livestock will be raised on crop aftermath and on native plants. The rangelands of the world will surely become more important, although many people in our affluent society find it hard to accept. The current attitude toward grazing on public lands, for instance, will change when food is in short supply. A few years ago a major western newspaper carried two articles on a single page. One was an article dealing with the suit of the Natural Resource Defense Council against the Bureau of Land Management. The Council, and apparently a large part of the U.S. public, wanted to ban grazing from the public rangelands. On the same page was an article from Japan. Japan, for the first time in its history, had opened its national forests and national parks to grazing. Because it was short on meat, Japan was willing to allow a new use for its lands. Our country, with its abundance, was trying to restrict grazing. My point is that attitudes change as the situation changes, and I predict that the attitude toward grazing of livestock on public lands will change rapidly in this country. Food production will be a major goal for rangelands in only a few decades.

Grazing of domestic livestock for food production will be the major economic use of rangelands. Rangelands, as we have discussed earlier, are usually vegetated with shrubs, forbs, and grasses. They are vastly different from the succulent, irrigated pastures of the farming regions. If we develop criteria for using rangeland as an engineer would if he were to design a harvesting machine, we would probably not design a cow to graze the rangelands. We want an animal that can breed, have young, and the young reach market weight within one year on the scant forage of rangelands, go for long periods of time without water, and withstand the rigorous climate of range areas. That animal probably would be a sheep or goat, not a cow. The preferred red meat of most Americans is beef. However, if rangelands are called upon to produce meat most efficiently, the ranges will probably be grazed by something other than a cow beast.

Fiber and Rangelands

Rangelands will be called upon to produce additional fiber in the future. It takes about twice as much energy to produce a synthetic fiber as it does a natural one (Thomas, Curl, and Bennett 1976). If my estimates are correct, it will take most of our arable land to produce food for direct human consumption. Our clothing will be produced from synthetic fibers and from fibers from rangelands. Wool and mohair are already a standard crop from many of the range areas of the world. If we accept my criteria for the kind of animal that will graze rangelands, then it follows that not only will sheep and goats become more prevalent for food production but many of them will be dual-purpose animals, producing fiber as well.

It is not unlikely that industries producing fiber from native range plants may also develop. There are today a number of cottage industries in developing nations throughout the world that use yuccas, euphorbias, sisal, etc., to produce local fibers for baskets, ropes, and other useful materials. If efficient harvesting techniques could be developed, it is entirely possible that we may see fiber production from range plants become more important, at least locally.

An even greater possibility exists that wood fiber from low-value range plants could be used for the paper industry or for other products where wood cellulose is a building block. Literally thousands of tons of cellulose are left to rot each year after range improvement projects. Although such techniques are not economically feasible today, we may see the time when mesquite, piñon-juniper, sagebrush, and other low-value range plants are harvested during range-improvement projects and then processed into some other product useful to mankind. Although they are fiber plants, such range plants as guayle and jojoba, are now being studied for production of rubber and oil. If these industries develop on rangelands, they would release petro chemicals that could be used for the production of fiber.

Fuel from Rangelands

Many scientists now think that energy supply will be the ultimate limiting factor in the deveopment of the world. Regardless of the validity of that statement, it is apparent that an increasing energy shortage will develop in the next two or three decades until alternate sources of energy are found (Cook 1976). Until that alternate source of energy is developed, our nation will be dependent on fossil fuels. As the most desirable fossil fuels, oil and gas, are gradually reduced in availability, we will shift to the more abundant coal. Much of the nation's low-sulphur coal occurs under western rangeland, as does the uranium for nuclear energy, and as do valuable geothermal sites, etc. It is inevitable that the rangelands of America will fill a key role in supplying the energy for this country.

In order to extract the materials from which energy is ultimately developed, it will become necessary to disturb much of the rangelands. These lands are costly to rehabilitate, often requiring thousands of dollars per acre to reclaim land that has a surface value of only a few hundred dollars per acre (National Academy of Sciences 1974). However, when the cost of rehabilitation is related to the product removed, it is seldom more than a few cents per ton of coal removed to rehabilitate the land.

We as a society for range management have a two-fold responsibility in the rehabilitation of western energy lands. First, we must provide the necessary scientific research and professional expertise. Second, we must insist that options be kept open for future generations and that rangelands be rehabilitated on the basis of their value to society for the energy rather than the surface value of the rehabilitated land for farming or ranching.

Proposals for the development of energy plantations are now under study in several of the forested regions of our country, the theory being that a renewable resource, trees, can produce fuel for the heat generation of electricity. If such fuel plantations are feasible in forested areas, it seems logical that the waste products from range-improvement projects could be burned to produce electricity. The main problem would be in harvesting and transporting the wood products to generating sites. No one would suggest such a scheme under the current economic conditions. However, conditions could change.

Fun from Rangelands

Many range areas contain strikingly beautiful scenery. They produce wildlife herds that are valuable for viewing or recreational hunting and provide the basis for a growing recreation business.

Our cities are becoming more crowded and more unlivable. The search for solitude is a major goal of many people in the developed countries of the world.

The opening day of deer season each year finds hunters occupying almost every single acre of rangeland in the western states. In private land states such as Texas, hunting is already a business. The income derived from hunting leases may rival that from livestock or any other range product.

Hunting fees are not charged on public land, but the public demands that the land be managed for the production of wildlife. Anyone who has ever witnessed the opening day of deer season in Montana, Colorado, or Utah will agree that the production of wildlife is one of the most desired uses of rangeland. Although direct monetary return usually does not come to the land management agency from hunting, the restaurant owners, shopkeepers, and guides throughout the West have a direct economic return. The demand for hunting is likely to continue, even though the nationwide reaction against sport hunting is becoming stronger each year. The population continues to grow and Westerners are not likely to voluntarily give up the sport of hunting.

Picnickers, backpackers, campers, and others are finding that rangelands offer open spaces and a chance to get away from it all. Rock hounds now visit even the most remote and desolate areas of the public rangelands. Organized groups such as motorcycle racers or four-wheel-drive-vehicle clubs find rangelands a place to practice their sport, with the result that the uncontrolled use of off-road vehicles is now a major problem in range management.

Solitude remains one of the major objectives of many outdoor recreationists. The vast open spaces, deep canyons, and undeveloped areas of rangeland are also desirable for recreationists. Many range areas have high wilderness values and the conflict between wilderness users and other range users is likely to increase.

Other Rangeland Products

There will be products other than food, fiber, fuel, and fun produced from rangelands. Water will be increasingly more important. Timber, mining props, fence posts, and other wood products will be locally important.

Other uses may develop that we cannot predict at the present time. The point that I want to make is that rangelands will continue to produce a wide array of products, although in the foreseeable future the main product will continue to be animals and animal products. Grazing, though only a single range use, will probably be as important to range as timber production is to forest lands. The nature of the land and ecological principles dictate that rangelands are grazing lands. They evolved concomitantly with grazing and browsing animals and, for the foreseeable future, grazing land they will remain. If these predictions are true, what will be the role of the Society for Range Management in the next 30 years?

The SRM's Role in the Next 30 Years

The Society for Range Management has done well in the first 30 years. We have given birth to a new profession and raised it through adolescence. During the next 30 years we will nurture it in its early adult years. A major role will be leadership in the continuously changing definition of rangelands and range management. We will develop new concepts and apply knowledge gained in the past. On the one hand we will work toward applying the body of knowledge that has been developed in the first 30 years. On the other, we must push forward to new frontiers and pioneer new research. We as a professional Society should not simply react to the demands of the public. We must set the standards under which rangelands of the world will be used.

To do this we need to develop and constantly maintain a professional image. We must at all times be scientifically credible. We must speak from a position of strength backed by sound data and research. This will be difficult, because we have as a policy accepted all those into our Society who have an interest in rangeland. We have never claimed to be an exclusive or elitist group. We accept people on the basis of their concern for the condition of rangelands of the world. One of our major strengths has been the diversity of people and our mutual acceptance. This open attitude we must somehow keep. but at the same time we must become judgmental, especially of those in our midst who do not keep our code. This year we have begun a program of certification of consultants. Its standards are high. Not all who belong to the Society for Range Management will qualify, but those who do will have the stamp of approval of this Society. We have also initiated a program of accreditation of range schools. Again, not all will qualify, but those that do will meet a certain standard of excellence that we as a Society think is desirable for the management of rangelands. I predict that more such actions will be necessary in the future.

Our ability to balance love and judgment—accept all people on confession of faith but endorse their actions on stringent professional criteria—will determine how successful we will be in the next 30 years. It has been a pleasure being your president.

It is inevitable that the demands placed on the rangelands of the world will change and change rapidly in the next few years. If our Society can anticipate and direct those changes, then we will be successful. If we only react to them, we will slowly fade away, and my guess is that our absence will be noticed by no one.

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Taxonomic Determination, Distribution, and Ecological Indicator Values of Sagebrush within the Pinyon-Juniper Woodlands of the Great Basin

N. E. WEST, R. J. TAUSCH, K. H. REA, AND P. T. TUELLER

Highlight: Various sagebrush taxa are major understory components of most Great Basin pinyon-juniper woodlands. Improved understanding of their identification, distribution, and ecological indicator significance is necessary to interpret site differences for these ranges. Morphology within sagebrush taxa is so variable that chromatographic determination is more easily and objectively relied upon for identification. Big sagebrush is so widespread and likely genetically diverse that sub-specific designations are more helpful in reading site conditions. The various sagebrush taxa are found in particular situations in Great Basin woodlands. Climatic differences explain the basin-wide distributions much more than geologic, landform, or soil conditions. Soils and exposure become more important on the local scale. Presence of a particular sagebrush taxon within pinyon-juniper woodlands can be used for comparisons of site favorableness provided one understands the general distribution of the other sagebrush taxa.

Pinyon-juniper woodlands occupy about 7.1 million ha (17.6 million acres) within the Great Basin (Beeson 1974). It has been difficult to classify these woodlands into smaller units of landscape designed to satisfy management needs. One of the major problems that has impeded progress toward more detailed synecological classifications is the very low floristic diversity in these woodlands (West et al. 1978). The major species appear to be nearly ubiquitous. A search for discriminatory species forces one to look at the less abundant taxa. Less abundant taxa pose considerable sampling problems. Woody sagebrush (*Artemisia*), however, constitutes one major understory genus offering possibilities as differential indicators if sub-species of big sagebrush are distinguished. By relating sagebrush taxa, including the big sagebrush sub-species, to site similarities and differences, there seems to be some hope of including a major understory genus in synecological classifications that managers can use.

This report summarizes our current understanding of the geographic distribution of sagebrush taxa and their relationships to environmental factors within Great Basin pinyon-juniper woodlands. Our objective was to further synecological investigations in the woodlands and not to define the overall distribution of sagebrushes in the Great Basin. Additional sampling would be necessary to accomplish such broad goals.

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Manuscript received August 24, 1977.

Methods

Field Collection

Data were taken from a random selection of 66 of the approximately 200 mountain ranges of the Great Basin (West et al. 1978). We had three levels of sampling: rapid for 46 mountain ranges, intermediate for 17, and intensive for two.

On all mountain ranges we followed a strategy of locating stands on broad, even slopes falling in cardinal directions, and elevationally placing them at regular intervals up and down the slope from the 2,000-meter contour which is common to nearly all woodland belts. This technique was used to allow for direct gradient analysis (Whittaker 1973) of the data.

In establishing the upper and lower type boundaries, we determined that a stand had to have at least 25 pinyon and/or juniper trees per hectare (10/acre), and that, of these, at least one tree had to be of the mature form-size-age class (Blackburn and Tueller 1970). These criteria kept the sampling from extending too far into ecotones, yet allowed for a good coverage of the main woodland belt.

The sampling plot was 20 × 50 meters, oriented perpendicular to the contour. We recorded data on land form, soils, vegetation, and land use. Details of the data collected varied with different intensities of sampling (Beeson 1974; Nabi 1978); however, taxonomic vouchers of sagebrush were collected at each site.

Data Analysis

Sagebrush specimens were segregated morphologically following the work of Winward (1969) and Brunner (1973). However, chromatographic differentiation was also done following the methods and interpretations developed by Hanks et al. (1973) and Stevens and McArthur (1974). Specimens were number coded and the morphologic and chromatographic methods of determination were applied independently without knowledge of the taxonomic placement by the other method. Tabular comparisons of the results were then made. Chromatographic determinations were used as the most objective and repeatable identification of the taxa involved.

Distributions and environmental relationships were derived from the plot data.

Results and Discussion

Overall Occurrence

Of the 375 pinyon-juniper woodland plots on 66 mountain ranges from which we obtained data, 97% had at least trace amounts of some sagebrush. Only the McCullough Range in extreme southern Nevada failed to have sagebrush associated with the woodlands we sampled there. In 83% of the intermediate and intensively studied plots, sagebrush was found to be the dominant shrub in terms of relative shrub cover. (The rapid sampling utilized only cover abundance scales.) Thus, sagebrush taxa are both widespread and important under Great Basin pinyon-juniper woodlands.

Nine *Artemisia* taxa have been found as woodland understory components: mountain big sagebrush [*Artemisia tridentata vaseyana* Rydb.) Beetle]; basin big sagebrush [*A. tridentata tridentata* (Nutt.) Ward]; Wyoming big sagebrush (*A. tridentata wyomingensis* Beetle); black sagebrush (*A. nova* A. Nels.); low sagebrush (*A. arbuscula* Nutt.); silver sagebrush (*A. cana* Pursh); Louisiana sagebrush (*A. ludoviciana* Nutt.); pigmy sagebrush (*A. pygmaea* A. Gray); and fringed sagewort (*A. frigida* Willd.). The latter four species are only occasional components of Great Basin pinyon-juniper woodlands and will not be considered further.

We found that 81% of the plots which had sagebrush present had only one species or sub-species of sagebrush (Table 1). Conversely, 19% had more than one *Artemisia* taxon present. The relative abundances of the various taxa can be read from the diagonals of matrix in Table 1. Most of the co-occurrences involved two taxa. Only two plots we sampled had more than two sagebrush taxa represented. The different taxa, although often existing on adjacent sites, seem to have fairly closely circumscribed environmental requirements. Competitive exclusion of one taxa or the other from the "sagebrush niche" at each site is probably intense since there seem to be abundant opportunities for the light seed to be windblown across considerable distances.

Influence of Taxonomic Definitions and Methods

There is much dispute about the existence and identification of specific and sub-specific taxa in the genus *Artemisia*. The five most important taxa were once considered sub-species of *A. tridentata* (Hall and Clements 1923). These five taxa are placed in two species in some more modern taxonomic treatments (Holmgren and Reveal 1966). If more precise indicator values are to be developed for sagebrushes, plants must be delineated at the sub-specific level because species are so widely distributed, occupy a variety of sites, and probably possess considerable ecotypic variation.

The genus *Artemisia* is a polyploid complex with considerable morphological variability (Stebbins 1975). The necessity of going to the more objective chromatographic means of taxonomic placement is illustrated in Table 2, where morphological and chromatographic identifications are compared. Using chromatography as the final arbiter, we correctly identified to sub-species only 42.8% of the specimens when using morphological criteria. Only 78% of the species were apparently identified to morphologically based species designations. *A. arbuscula* was misidentified most often. At one time or another,

Table 1. Percentage occurrence and co-occurrence of various *Artemisia* taxa in Great Basin pinyon-juniper plots having at least one *Artemisia* plant. Principal diagonal of the matrix indicates the percentages of plots that have only one taxon present. Abbreviations such as *A.t.t.* = *Artemisia tridentata tridentata*, etc., correspond to the full names given in the left hand column.

Taxa	*A.t.t.*	*A.t.w.*	*A.t.v.*	*A.n.*	*A.a.*
A. t. tridentata	19.9	1.5	2.5	2.3	0.3
A. t. wyomingensis		13.6	1.8	3.0	0.8
A. t. vaseyana			32.4	3.8	2.8
A. nova				13.8	0.8
A. arbuscula					1.0

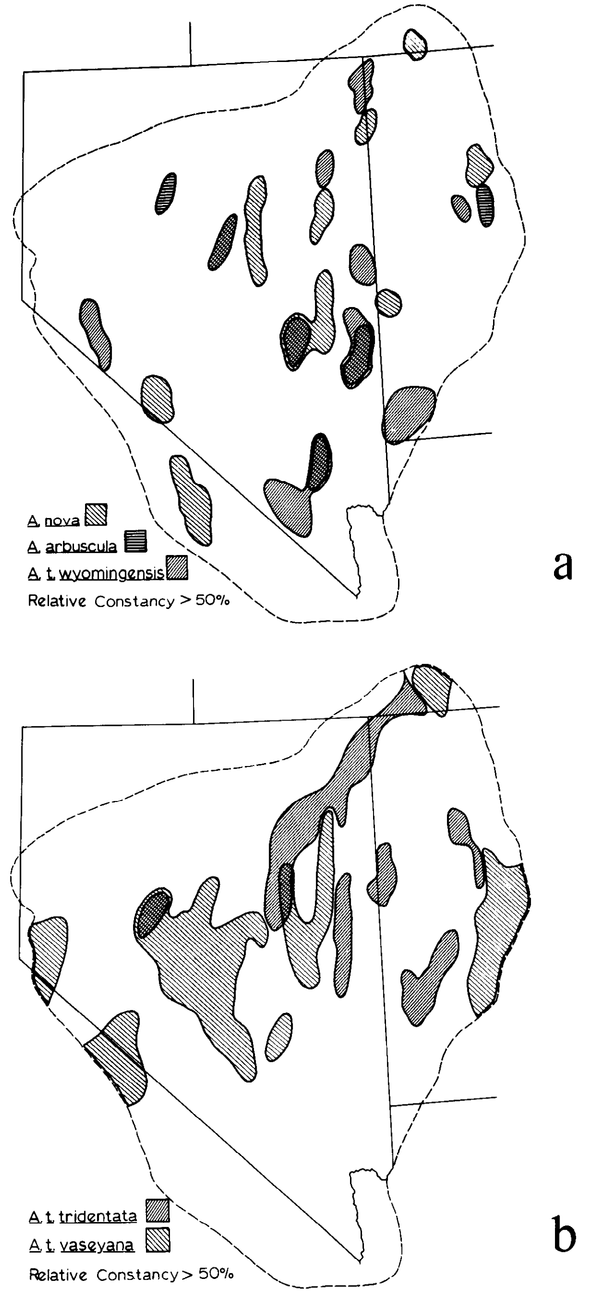

Fig. 1. *Portions of the Great Basin where various* Artemisia *taxa occur in greater than 50% of the pinyon-juniper plots sampled per mountain range: (a)* A. nova, A. arbuscula, *and* A. t. wyomingensis; *(b)* A. t. tridentata *and* A. t. vaseyana.

it was morphologically determined to belong in every other taxon. The overall "correct" placement of *A. tridentata* by morphological criteria at the species level, was 80%.
more restricted than morphological determinations of that taxon. The overall "correct" placement by morphological criteria of *A. tridentata,* at the species level, was 80%.

The biggest problems were encountered in determining the correct sub-species of *Artemisia tridentata* (Table 2). Only 32.6% of the specimens were correctly placed by morphological characteristics alone. The biggest problem was the identification of *A. t. tridentata* as *A. nova* or *A. t. vaseyana*.

We felt that our use of morphologically based taxonomy was as proficient as most range scientists could apply. It is likely that

Table 2. Matrix comparing *Artemisia* determinations by morphologic and chromatographic means (numbers of specimens identified to same taxon by the two different methods).

Morphological determinations	Chromatographic determinations					
	A. arbuscula	*A. nova*	*A. t. tridentata*	*A. t. wyomingensis*	*A. t. vaseyana*	Row totals
A. arbuscula	6	4	1	6	4	21
A. nova	8	76	40	17	7	148
A. t. tridentata	2	1	12	22	20	57 } 311 (57 + 96 + 158)
A. t. wyomingensis	2	1	23	57	13	96
A. t. vaseyana	7	2	36	61	52	158
Column totals	25	84	112	163	96	480
p (agreement)	.24	.90	.11	.35	.54	
			371 (*A. t. tridentata* + *A. t. wyomingensis* + *A. t. vaseyana*), p = .80			

Agreement at species level = 378; subspecies level = 203.
p = (percentage agreement) at species level = 64.5%; subspecies level = 42.8%.

phenotypic variation is so overwhelming as to defy writing a morphologic key that will allow correct identification of 90% or more of the specimens encountered. Chromatography as a taxonomic criterion is very easy to apply to this group and can be used with accuracy. Distributional analysis based on morphologically determined specimens was done as outlined in the following. The distributions obtained were much less ecologically explainable than when the chromatographically determined designations were used.

Artemisia identifications in studies where chromatography has not been used must be viewed with considerable caution. Chromatography is not a panacea, however, since hybridization creates individuals and populations that are hard to place in categories by any criteria. How greatly the concentration of the plant substances being separated varies from year to year and with different sites where the same genotype is involved is unknown.

Distribution

The first step in understanding indicator significance of taxa is to look at their natural distributions. From maps of current distributions we can determine if the taxa can be related to specific niches along environmental gradients.

Presence or absence of each taxon within sampled woodlands of a given mountain range offers little explanation by itself. All we could see from such maps was that greatest overlap of taxa occurs in the middle of the Great Basin. However, mapping the high relative frequencies (>50%) (Fig. 1) and the presence and absence (Fig. 2) of various combinations of taxa allows some generalizations to begin emerging.

Artemisia tridentata vaseyana, although the most common sagebrush in the Great Basin pinyon-juniper woodlands, is lacking in most western Utah woodlands (Fig. 2a). Only the higher and larger masses of mountains have *A. tridentata vaseyana* in their pinyon-juniper woodlands. *Artemisia nova* is generally absent in the woodlands of the southern Great Basin, in western Nevada and in western Utah (Fig. 2a). The exceptions involve mountains of higher and larger masses. *Artemisia arbuscula* is found widely scattered over the Great Basin, but only in the woodlands that reach higher elevations (Fig. 2b). *Artemisia tridentata tridentata* is generally absent in the woodlands of the southern Great Basin. *Artemisia tridentata wyomingensis* is absent from woodlands in the north and high central Nevada ranges (Fig. 2b).

Basin-wide variations in woodland composition is not strongly related to geology or landform (Beeson 1974; West et al.

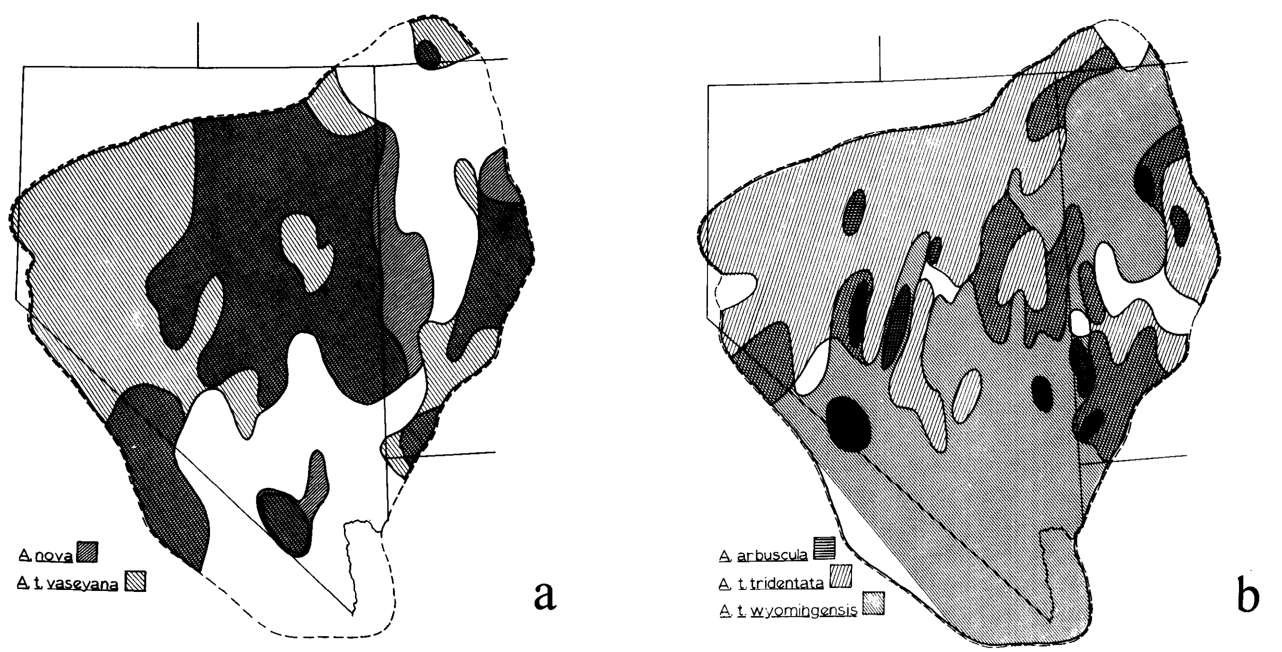

Fig. 2. *Portions of the Great Basin where various* Artemisia *taxa are present or absent in the pinyon-juniper woodlands on the mountain ranges sampled. Specific shading indicates the presence of a taxon: (a)* A. nova *and* A. t. vaseyana; *(b)* A. arbuscula, A. t. tridentata, *and* A. t. wyomingensis.

1978). Floristic variations in vegetation considered at a coarse focus are also not strongly related to soils over the basin as a whole. Analysis of basin-wide occurrences of the major *Artemisia* taxa in relation to higher level soil taxonomic categories showed no close correlation between sagebrush taxa and particular kinds of soils when the total set of data is looked at together.

General patterns of vegetation, soils and distribution of *Artemisia* taxa in woodlands seem to be more closely related to patterns of moisture and temperature (Beeson 1974; West et al. 1977). These aspects of climate in turn are influenced by physiography and storm systems (Houghton 1969). Cross-sections of the Great Basin show low, dry areas in the west, south, and east. The central plateau of eastern Nevada had a wetter and colder climate than elsewhere within the Basin (Wernstedt 1960; Houghton 1969).

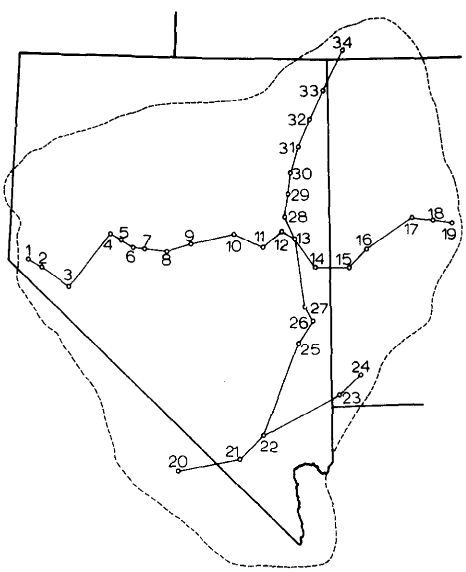

Fig. 3. *Map locations sampled for elevational scaling of* Artemisia *occurrence in pinyon-juniper woodlands of the Great Basin.*
List of Mountain Ranges in Figure 3: 1. Virginia Range, 2. Pine Nut Range, 3. Wassuk Range, 4. Clan Alpine Range, 5. Desatoya Range, 6. Shoshone Range, 7. Toiyabe Range, 8. Toquima Range, 9. Simpson Park Range, 10. Fish Creek Range, 11. White Pine Mountains, 12. Lower Egan Range, 13. Schell Creek Mountains, 14. Lower Snake Range, 15. Confusion Range, 16. House Range, 17. Sheeprock Mountains, 18. West Tintic Mountains, 19. East Tintic Mountains, 20. Panamint Mountains, 21. Spring Range, 22. Sheep Range, 23. Beaver Dam Mountains, 24. Pine Valley Mountains, 25. Wilson Creek Range, 27. Fortification Range, 28. Upper Egan Range, 29. Cherry Creek Range, 30. Spruce Mountains, 31. Pequop Mountains, 32. Toana Range, 33. Goose Creek Range, 34. Albion Mountains.

Relationships of *Artemisia* to environment, especially climate, are further illustrated by elevational considerations. Figure 3 indicates the locations of samples taken to examine these relationships. The first series (Fig. 4) is graphed by actual elevations and distances. The second series (Fig. 5) has simplified the patterns by graphing the percentage of plots where various sagebrush taxa occur. The relative elevational position of each has been maintained on the vertical scales. In both series the figures may be interpreted as cross-sections through a response surface to which the total data set could be fitted. Because data are available from very few climatic stations in the woodland belts, we must infer from elevations, slopes, and exposures that climatic relationships to *Artemisia* occurrences are likely.

Generally, the higher and larger mountains, and thus wettest and coolest of pinyon-juniper woodland sites in the central Great

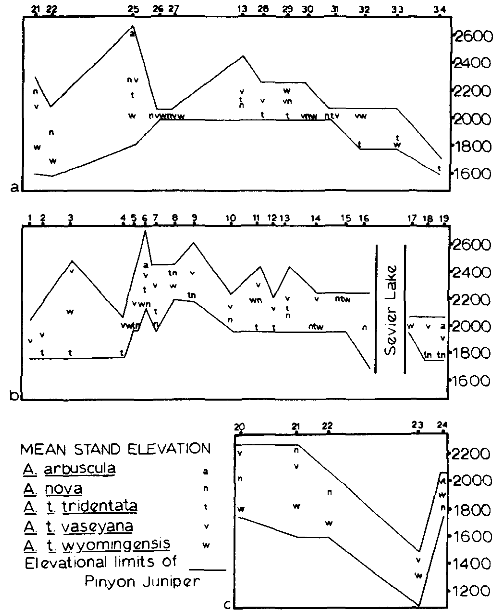

Fig. 4. *Elevation distribution of major* Artemisia *taxa in pinyon-juniper woodlands of the Great Basin: (a) south-north cross section of the Great Basin; (b) west-east cross section in the central Great Basin; (c) west-east cross section in the southern Great Basin. Numbers arrayed across the top of graphs are locations shown in Figure 3. Vertical scales are elevations (m).*

Basin have *A. tridentata vaseyana*. To the north and west, *A. tridentata vaseyana* increases in dominance until at the northwestern limits of the type it is the only woodland sagebrush present. *A. arbuscula* is widely scattered on cold, dry sites with shallow soils on the higher mountains all across the Great Basin. *A. tridentata tridentata* is lacking in the woodlands of the southern Great Basin. Where this taxon occurs on the northern ranges, it is on the relatively warmer, wetter sites wth deeper

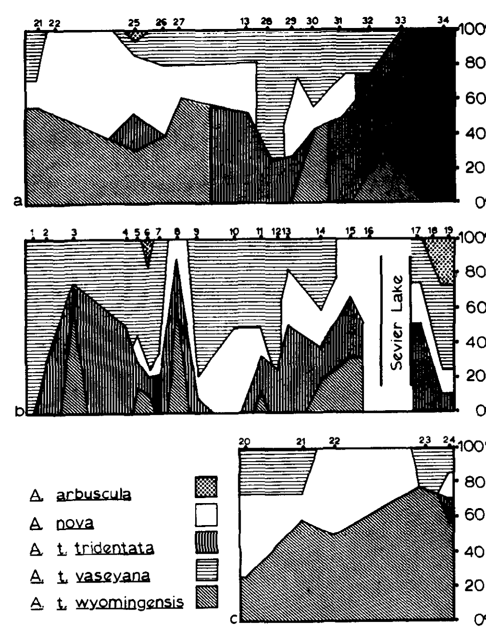

Fig. 5. *Relative altitudinal arrangement of percentage of plots occupied by various sagebrush taxa in the pinyon-juniper woodlands of the Great Basin: (a) south-north cross-section of the central Great Basin; (b) west-east cross-section of the central Great Basin; (c) west-east cross-section of the Southern Great Basin. Numbers arrayed across the top of the graphs are locations shown in Figure 3. Vertical scale is percentage of stands occupied, from lowest to highest elevations possessing woodlands.*

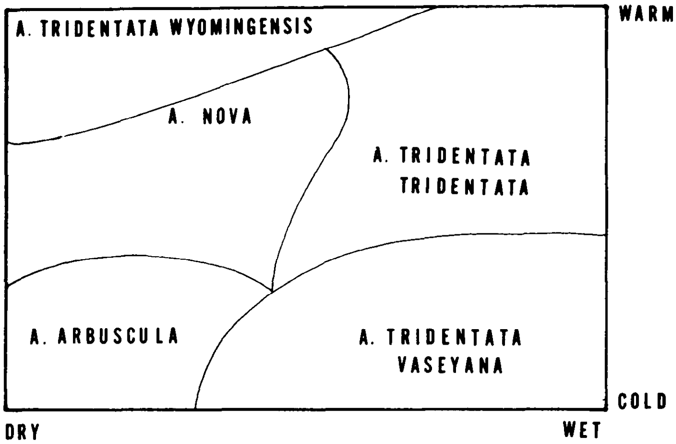

Fig. 6. *Generalized occurrences of major woodland sagebrush taxa in relation to relative gradients of temperature and moisture over the Great Basin as a whole.*

soils. *A. tridentata wyomingensis* is lacking in the woodlands of the northern Great Basin and high central Nevada ranges. It occurs in the driest, warmest woodland sites in the more southerly portions of the Great Basin. *A. nova* is generally absent from the more arid portions of the Great Basin in both western Nevada and western Utah, but occupies sites of intermediate favorableness elsewhere.

Ecological Indicator Values

The primary relationships of sagebrush taxa to effective moisture and temperature for the Great Basin woodland sites studied are summarized in Figure 6. *A. tridentata wyomingensis* occurs in the warmest and driest types of pinyon-juniper woodland. *A. nova* occurs in drier conditions where temperatures are intermediate. *A. arbuscula* is restricted to the coldest, driest woodland sites. *A. tridentata tridentata* occurs predominantly on the wetter, but still relatively warm woodland sites. *A. tridentata vaseyana* dominates woodland understory on the wettest, coldest sites.

The foregoing relationships characterize the coarse focus basin-wide patterns which appear to be largely responses to climate. In applying these generalizations, one must realize that environment is a complex of many interacting variables. Aspect may compensate for elevation in changing effective temperature and moisture. Slope, landform, and soils also alter the effective soil moisture levels. On particular mountain ranges and sites,

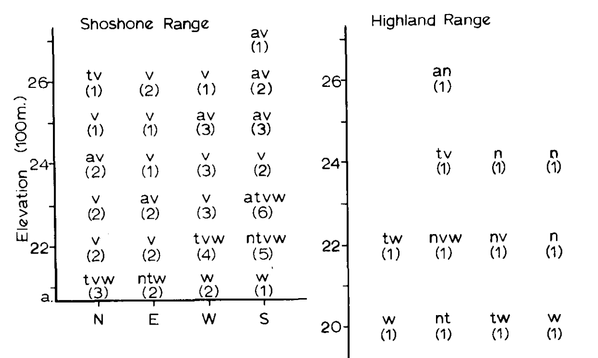

Fig. 7. *Distribution of major* Artemisia *taxa in relation to elevation (m, vertical scale) on the Shoshone (No. 6, Fig. 3) and Highland (No. 25, Fig. 3) Ranges and exposure (direction, horizontal scale).*

Table 3. Mean ($\bar{x}$) depth (cm) and standard deviation (s) of soil A horizon as related to taxa of *Artemisia* found in pinyon-juniper woodlands of Shoshone Mountains, Nevada, n=sample size.

	A. horizon depth (cm)		
Taxa	$\bar{x}$	s	n
A. arbuscula	25.6	12.2	11
A. t. vaseyana	32.2	17.2	42
A. t. tridentata	22.3	6.2	7
A. t. wyomingensis	19.3	5.6	9
A. nova	21.5	2.1	2

No differences are statistically significant.

geologic, micro-climatic, edaphic, or pyric factors definitely influence distribution of *Artemisia*. These kinds of interactions and site-to-site differences are illustrated and compared in the distribution patterns of *Artemisia* taxa found on the Shoshone Range of west-central Nevada and the Highland Range of east-central Nevada (Fig. 7). The Shoshone Mountains are typical of ranges located near the southwestern limits of pinyon-juniper woodlands. The Highland Range is located near the center of the Great Basin pinyon-juniper woodlands and borders the high central plateau region on its north and east sides and the Great Basin-Mojave Desert transition on its west and south slope. There is a 200 m elevational difference between the valley floors on the northeast and on the west.

Except on the lowest elevations and driest aspects, the sagebrush in the Shoshone Mountains is primarily *Artemisia t. vaseyana* with an occasional *A. arbuscula* (Fig. 7). *A. arbuscula* is generally on shallower soils than *A. t. vaseyana* (Table 3).

The Highland Range occurs in a warmer but climatically more complex region (West et al. 1978). Maximum precipitation occurs on the east slope. The north slope has been disturbed by mining activity. All *A. t. vaseyana* and all *A. nova,* except for one stand on the east slope, occur above 2,100 m (Fig. 7). Except for the climatically complex east slope, all *A. t. tridentata* and *A. t. wyomingensis* occur below 2,100 m (Fig. 7).

On both ranges there appear to be definite elevational and aspect controls on the distribution of sagebrush taxa. However, because of differences in the location of these ranges in the Great Basin and, as a result, differences in their general climates, the specific details of their distributions differ.

We conclude that one must understand the broader picture before precise indicator significance of each taxon can be worked out for local areas. In the absence of past climatic records, soils information and other inventory data on these ecosystems, we have to let plants tell us something of the effective environments on the wildlands they occupy. Sagebrush taxa, if identified by chromatography, appear to offer a major set of plant indicators that can be used to compare site favorableness within pinyon-juniper woodlands.

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Nutrition and Production of Domestic Sheep Managed as Manipulators of Big Game Habitat

JOHN C. MALECHEK, KURT J. KOTTER, AND CHARLES H. JENSEN

Highlight: Weight gains of ewes and lambs, forage intake, and dietary quality of ewes were evaluated from mid-May to early July on foothill ranges under two intensities and durations of grazing management. Dietary quality was poorer and forage intake was lower under heavy than under moderate stocking. Individual lambs gained somewhat less weight under heavy stocking but ewes were not affected. A short-term, rotational grazing scheme, as compared to season-long grazing, did not appear either beneficial or detrimental to sheep. Response of the plant community will be a major factor determining which grazing system provides the best winter range for big game, but heavy stocking was decidedly superior when lamb production was considered on a land area basis.

The concept of controlling livestock grazing for the specific purpose of directing plant community succession in a manipulative sense is well recognized (Lewis 1969). Applications have generally been in the realm of specialized grazing systems aimed primarily at increasing range carrying capacity for livestock (reviewed by Herbel 1974), and to a smaller extent in the control of undesirable woody plants (DeToit 1974) and as a tool in forest management (reviewed by Adams 1975).

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Recent research indicates an additional potential for using controlled livestock grazing in management of wildlife habitat. For example, Anderson and Scherzinger (1975) reported a three-fold increase in winter elk (*Cervus canadensis*) numbers following implementation of planned cattle grazing on pine-bunchgrass range in Oregon. In other studies, Jensen et al. (1972) suggested that judiciously applied sheep grazing during spring could effectively increase yields of important shrub species for subsequent winter use by big game animals.

Unlike the direct and immediate cost outlays for plant community manipulation by conventional means (e.g. mechanical, chemical, or controlled burning), use of the grazing animal as a management tool is generally expected to yield a return (from livestock products) while the manipulation program is in progress. Thus, productivity aspects of the manipulator animal population must be considered in the overall evaluation. The research described in this paper was designed to evaluate possible nutritional limitations to production of domestic sheep managed under grazing regimes designed to benefit winter habitat of mule deer (*Odocoileus hemionus*) and elk. The major treatment variables were intensity and duration of grazing by sheep.

A preliminary assessment of plant community responses to the grazing treatments imposed has been presented by Jensen et al. (1976). Additionally, Smith (1976) and Fulgham et al. (1977) have reported initial data on the winter diets and nutrition of mule deer in response to one of the sheep grazing treatments.

Methods and Materials

Study Site

Field research was conducted at Hardware Ranch, located approximately 40 km southeast of Logan, Utah. The area, situated at approximately 1,750 m elevation, is typical of much of the intermediate elevation foothill range type found throughout Utah and much of the Intermountain West.

Vegetation of the area is characterized by the dominant big sagebrush complex (*Artemisia tridentata* subsp. *tridentata* and *A. tridentata* subsp. *vaseyana*) and to a lesser degree by bitterbrush (*Purshia tridentata*). Other shrubs such as snowberry (*Symphoricarpos oreophilus*), little rabbitbrush (*Chrysothamnus viscidiflorus*), low sagebrush (*Artemisia arbuscula*), and serviceberry (*Amelanchier alnifolia*) are common. Important contributors to the herbaceous component include the forbs: Pacific aster (*Aster chilensis* var. *adcendens*), mulesears wyethia (*Wyethia amplexicaulis*), tailcup lupine (*Lupinus caudatus*), and arrowleaf balsamroot (*Balsamorhiza sagittata*). Common grasses include: beardless bluebunch wheatgrass (*Agropyron inerme*), Kentucky bluegrass (*Poa pratensis*), Sandberg bluegrass (*Poa secunda*), Junegrass (*Koeleria cristata*), and Great Basin wildrye (*Elymus cinereus*).

Annual precipitation in the area varies from 46 to 66 cm, with the major portion falling as snow. The frost-free period ranges from 90 to 130 days.

Soils of the study area are derived from quartzite and quartzite-calcareous sandstone and range in texture from loam to stony, silty clay loam. They have a relatively slow rate of permeability and a moderate runoff potential.

The study site had not been grazed by domestic animals for approximately 25 years preceding this research, but the area annually sustains moderate grazing use by elk and mule deer during winter and early spring.

Grazing Treatments

Experimental treatments consisted of four combinations of time and intensity of grazing applied to eight separate but adjacent pastures (Table 1). The grazing treatments were repeated in three successive years (1972–74). During the initial 2 years, each pasture was grazed by seven head of Columbia × Targhee ewes with their lambs and three yearling Targhee × Columbia × Suffolk esophageally fistulated wethers used as collector animals for nutritional determinations. The third year no fistulated animals were grazed and the number of ewes per treatment was increased to nine. Ewes and lambs were obtained from a local farm flock in 1972 and from a neighboring range sheep operation in 1973 and 1974.

The two stocking intensities defined as moderate and heavy were designed to achieve, respectively, about 35% and 70% mean utilization of the total available forage by the end of a particular grazing period. All herbaceous species and the current year's twigs of all shrubs except *Artemisia* species were considered as available forage for sheep. The two levels of utilization were achieved by constructing the pastures of various sizes, based on the results of a forage inventory of the area conducted the year prior to initiation of the study. Pastures varied in area from 0.6 to 6.5 ha each.

Initial assignment of ewe and lambs to treatments at the beginning of each grazing season was not entirely random, in that we attempted to achieve a uniform distribution of ewes with twin lambs among all treatments. During a particular year, ewes and lambs initially assigned to the two short-term treatments were moved to new pastures of like grazing intensity on the approximate calendar dates designated on the pasture schedule (Table 1), while animals assigned to the two season-long treatments remained in their respective pastures for the duration of each year's grazing season. Fistulated sheep were randomly assigned among the four pastures being grazed during a particular time period in the grazing schedule (Table 1).

All animals were identified by numbered ear tags and were weighed individually (following a 12-hour fast) at the beginning of the grazing season, at each date when animals in the short-term treatments were moved to new pastures (Table 1), and again at the termination of the grazing season.

Table 1. Grazing treatment design for comparing production and nutrition of sheep stocked to achieve moderate and heavy grazing intensities during short-term and season-long grazing periods.

Grazing treatment	Pasture schedule[1]	Pasture area (ha)	Stocking density (sheep da/ha)[2]	Season-long stocking rate (sheep/ha)
Short-term moderate	May 15–May 31	2.6	65	
	June 1–June 17	2.0	85	
	June 18–July 2	1.6	100	
	Total	6.2		1.6
Short-term heavy	May 15–May 31	1.3	130	
	June 1–June 17	1.0	170	
	June 18–July 2	0.8	200	
	Total	3.1		3.2
Season-long moderate	May 15–July 2	6.2	81	1.6
Season-long heavy	May 15–July 2	3.1	161	3.2

[1] Approximate dates of pasture entry and exit. As much as 10 days variation existed in initiation of grazing from year to year, depending on plant phenology and range readiness. Length of grazing season was constant over years.

[2] A sheep day is defined as one day of grazing used by the average 60-kg ewe and her lamb(s).

Nutritional Determination

Nutritional determinations were conducted only during 1972 and 1973. Fistulated animals were allowed a 5-day period for adjustment to prevailing pasture conditions before any samples were collected. Samples of ingested forage were collected via fistula early each morning during weekly periods of 5 days each. A daily sample collection interval for a particular animal varied from 20 to 40 minutes, after which the sample, wet with saliva, was transferred from the screen-bottom collection bag to a porcelain laboratory tray where it was thoroughly hand mixed. The sample was then bagged in polyethylene, labeled, and immediately transferred to a chest-type freezer where it was stored at −20°C until analysis.

Preparatory to laboratory analysis, each individual sample was hand-chopped while frozen and then freeze-dried. Dried material was then ground to pass through a 40-mesh screen in a Wiley laboratory mill. After grinding, individual daily samples were aggregated over 5-day collection periods for each fistulated animal.

Laboratory analyses for the initial year's samples included crude protein (N × 6.25) by the macro-Kjeldahl method (A.O.A.C. 1970), cell soluble components (Van Soest and Wine 1967), cell wall constituents (Van Soest 1963), ash, and dry matter (A.O.A.C. 1970). Estimates of digestibility were derived through in vitro fermentations according to the two-step method of Tilley and Terry (1963). Rumen liquor inoculum for fermentations was obtained by vacuum aspiration from two ruminally fistulated donor sheep maintained on a diet of native hay. Diet samples obtained during the second year of the study were analyzed only for crude protein and in vitro digestibility. Data from all chemical analyses, as well as from in vitro fermentations were corrected to an organic matter basis in view of probable salivary ash contamination of samples (Hoehne et al. 1967).

Daily forage intake was estimated during the study's initial year according to the following rearrangement of the standard digestion-balance equation.

$$I = \frac{F}{100 - D} \times 100$$

where: I = daily forage organic matter intake; F = daily fecal organic matter output; and D = percentage organic matter digestibility of the diet. Fecal output was estimated by total collection, using standard fecal collection bags (Harris 1968) on the fistulated wethers. Digestibility was estimated from in vitro determination on fistula extrusa, as described above. No attempt was made to adjust in vitro digestibility estimates to an in vivo basis, nor were the intake estimates made on wethers adjusted for additional energy demands of lactation in ewes. Thus both digestibility and intake data presented here can be interpreted only as relative indices for among-treatment comparison.

Statistical Analysis

Data on animal weight responses were subjected to analysis of variance procedures (Snedecor and Cochran 1967) using a multiple least-squares regression program for unbalanced data. Main effects isolated by the analysis included years, grazing intensities, and grazing durations, as well as second- and third-order interactions of these effects. Data on nutritional parameters were analyzed by the same least-squares regression program as above. Components of variation tested were the same as those for animal weight responses,

Table 2. Crude protein content (CP), in vitro digestibility (IVD), and organic matter intake (OMI) of diets selected by sheep under two intensities and durations of spring grazing.

Duration of grazing	Grazing intensity						Grazing duration means[3]		
	Moderate			Heavy					
	CP[1]	IVD[1]	OMI[2]	CP	IVD	OMI	CP	IVD	OMI
Short-term	17.9	64.0	49.7	17.1	56.7	35.9	17.5b	60.4a	42.8a
Season-long intensity	18.8	62.9	44.6	18.4	61.4	42.3	18.6a	62.1a	43.5a
Means[3]	18.4a	63.5a	47.2a	17.8b	59.0b	39.1b			

[1] Expressed as percentages of organic matter. Tabular values are means of 1972 and 1973.
[2] Expressed as g/kg body wt$^{0.75}$. Intake measured during 1972 only.
[3] For a particular nutritional attribute, means followed by different letters are significantly ($P \leq 0.05$) different. Intensity means are averages of short-term and season-long grazing durations, and grazing duration means are averages of moderate and heavy grazing intensities.

with the exception of organic matter intake and fiber constituents which did not entail a "years" component. The Studentized range test (Snedecor and Cochran 1967) was used to isolate significance of individual treatment means in both animal weight and nutritional analyses.

Results and Discussion

Forage Nutritional Quality and Intake

Animals in the short-term heavy treatment consumed forage with significantly ($P \leq 0.05$) less crude protein and with a lower digestibility than did those in any of the other three treatments (Table 2). This response was consistent during both 1972 and 1973; thus values presented in Table 2 are pooled means for the 2 years. Forage intake, measured only during 1972, was also lowest in the short-term heavy treatment (Table 2), while the three plant-fiber components were highest there (Table 3). In contrast, sheep in short-term moderate treatment consumed the most digestible forage and demonstrated the highest level of relative intake of all treatments, but protein content was highest in the season-long moderate treatment (Table 2). Dietary crude protein in all treatments was well above the 8% (dry matter basis) recommended for ewes during the first 10 weeks of lactation (N.A.S. 1968), even when measured levels (Table 2) were adjusted from an organic matter to a dry matter basis. None of the fiber components differed significantly ($P \leq 0.05$) among the short-term moderate or the two season-long treatments (Table 3).

Contrasts designed to separate the effects of grazing intensity from grazing duration indicated that, on the average, moderate stocking yielded diets significantly higher in crude protein, digestibility, and relative intake (Table 2) and lower in cell walls, cellulose, and lignin (Table 3) than did heavy stocking. Differences between the two grazing durations were not as distinct, however. Season-long grazing appeared to provide an advantage over short-term grazing in all of the forage quality parameters, as well as relative intake; but differences between the two regimes were statistically significant only for crude protein (Table 2) and cellulose (Table 3). Differences approached significance at the 5% level for both dietary lignin and in vitro digestibility.

Our findings on qualitative attributes of diets in relation to grazing intensity closely resemble those of Cook et al. (1965), who conducted a study in similar plant communities but slightly later in the growing season. They attributed depressions of dietary crude protein and digestibility and increases in fiber components under heavy stocking to obligatory consumption of more fibrous portions (e.g. stems and stem bases) of the plants that constituted the available forage. A similar study of grazing intensity conducted during winter on desert shrub range (Pieper et al. 1959) attributed such responses to a shift in plant selection from grasses to shrubs; however, such a dietary shift was not observed in either the Cook et al. (1965) study or in the diet selection study conducted by Iskander (1973) in conjunction with our nutritional evaluation.

Table 3. Cell wall (CW), cellulose (CEL), and lignin (LIG) in diets selected by sheep under two intensities and durations of grazing during spring, 1973. Values are expressed as percentages of dietary organic matter.

Duration of grazing	Grazing intensity						Grazing duration means[1]		
	Moderate			Heavy					
	CW	CEL	LIG	CW	CEL	LIG	CW	CEL	LIG
Short-term	39.8	21.5	6.4	46.5	23.5	9.0	43.2a	22.5a	7.7a
Season-long intensity	40.2	21.7	7.0	44.2	21.4	7.1	42.2a	21.6b	7.1a
Means[1]	40.0b	21.6b	6.7b	45.4a	22.5a	8.1a			

[1] For a particular fiber component, means followed by different letters are significantly ($P \leq 0.05$) different. Intensity means are averages of short-term and season-long durations, and grazing duration means are averages of moderate and heavy grazing intensities.

Reduction of forage intake under conditions of heavy grazing or limited food availability can often be related to the interaction of behavioral and nutritional factors. Arnold (1970) has presented compelling evidence that sheep faced with a diminished supply of palatable plants spend a disproportionately large amount of time seeking and regrazing such plants, sometimes at the expense of total forage intake. Nutritionally, the inverse relationship is well established between forage fiber content, particularly if highly lignified, and digestibility and intake (Montgomery and Baumgardt 1965). Cook et al. (1965), contrary to our findings, did not record reduced intake with increased levels of utilization. However, their heaviest utilization levels (30% for grasses and 29% for forbs) more nearly approximated levels we measured under moderate stocking (3-year mean: 29% for grasses and 39% for forbs) than under heavy stocking (3-year mean: 53% for grasses and 71% for forbs).

The slight nutritional advantage of season-long grazing over short-term grazing is difficult to assess causally and is probably of minor practical importance. For a given grazing intensity, the two durations were so designed that an equivalent amount of animal days of grazing (approximately 440) arose from equivalent areas of land (Table 1). Thus, when considered in total, season-long stocking rates under the two durations were equal; but the sequential pasture scheme employed under the short-term regime resulted in a higher animal density, and animals confronted conditions of heavily utilized forage on three occasions during each grazing season while those in the season-long regime faced such conditions once per season. Sheep in the season-long pastures were probably able to selectively utilize relatively nutritious plant regrowth during much more of the grazing season, whereas, the short time span and the recurring heavy utilization of forage in the short-term pastures provided no such nutritional advantage.

Animal Weight Responses

The farm flock ewes tested during 1972 lost weight under all treatment regimes (Table 4). They came onto the experiment from a dry-lot situation where they had been receiving concentrate feeds and alfalfa hay and all were in a relatively high state of body condition. Their lambs varied widely in age, and the consequent energy demand for lactation probably was equally variable. In contrast, the range ewes tested in 1973 and 1974 came to the experiment directly from lambing pens and

Table 4. Weight gains (kg/head) by ewes under two intensities and durations of spring grazing.

Duration of grazing	Grazing intensity: Moderate 1972	1973	1974	Means[2]	Heavy 1972	1973	1974	Means[2]	Grazing duration means[3]
Short-term	–2.6	3.0	2.3	0.9b	–2.7	4.8	3.0	1.7ab	1.3a
Season-long	–1.7	8.4	4.1	3.6a	–5.2	4.8	3.5	1.0b	2.3a
Year means[1]	–2.2c	5.7a	3.2b		–4.0b	4.8a	3.3a		
Intensity means				2.3a				1.4a	

[1] Within each grazing intensity category, year means having different letters differ significantly ($P \leq 0.05$).
[2] Means for the four intensity × duration treatment combinations having different letters differ significantly ($P \leq 0.05$).
[3] Intensity or duration means followed by common letters are not significantly different ($P \leq 0.05$).

were in low body condition relative to the 1972 animals. They gained weight under all treatments (Table 4). Averaged across all treatments, weight responses were −3.1, 5.3, and 3.2 kg per head for 1972, 1973, and 1974, respectively, and they all differed significantly from each other. We have no explanation for the greater gain in 1973 than in 1974, when comparable sheep were grazed.

The season-long moderate treatment yielded significantly higher weight gains by ewes than either the season-long heavy or short-term moderate treatments when all 3 years were considered (Table 4). However, when moderate grazing was compared to heavy grazing, and likewise, when short-term grazing was compared to season-long grazing, no statistical differences were evident.

Lambs' weight gains were relatively high in all treatments during all 3 years, with the season-long moderate treatment demonstrating a distinct advantage (Table 5). The two short-term treatments yielded intermediate gains; and the season-long heavy treatment tended to yield the least, although the 3-year means of the season-long heavy treatment and the short-term heavy treatment did not differ significantly.

Lamb gains differed among years, averaging 13.5, 15.3, and 17.0 kg/head for the three respective years. The relatively low gain during the initial year can be attributed, at least partly, to the pre-experiment husbandry of both ewes and lambs used that year. However, the reason for the relatively high gain in the final year is not evident, and it is not consistent with performance of ewes that gained the most during the second year.

The interaction of year and grazing intensity was significant, and can be seen in a comparison of year means in Table 5. Lambs under moderate grazing developed a 3 kg/head advantage over those under heavy grazing in 1972, a 1.5 kg/head advantage in 1974, but no discernible differences in 1973.

Animals assigned the two grazing durations did not respond uniformly within the two grazing intensities, as indicated by a significant intensity × duration interaction in the analysis of variance and by a comparison of the four intensity × duration means in Table 5. Lambs grazed season-long gained the most under moderate stocking, but heavy stocking appeared to overshadow any effects of either grazing duration tested.

The effects of stocking rate upon animal production have been studied widely, and it is commonly accepted that individual animal performance is depressed by stocking rates sufficiently high to elicit intraspecific competition for food (Heady 1975). We found no evidence from the present study to refute this hypothesis. Weight gains of both ewes and lambs, as well as forage intake and forage quality indicators, were lower under the heavy intensity than under the moderate intensity. Our findings also support the hypothesis that within the realm of realistic stocking rates, production expressed as a function of land area is highest under the relatively heavy stocking rates. We found lamb production to be highest under the short-term heavy treatment (57 kg/ha), followed by the season-long heavy treatment (50 kg/ha), and finally by the two moderate treatments (30 kg/ha).

Little research has apparently been done on grazing duration effects upon animal performance, despite mounting importance of the question in relation to designing specialized grazing systems. We had hypothesized that both individual animal performance and nutritional intake would be limited by the short-term grazing schedule, as instantaneous stocking denisty was higher there than under the season-long regime. Also, the shifts to unfamiliar pasture conditions twice during each grazing season would lead to temporary periods of behavioral and nutritional stress. All of our results on nutrition and production suggested small advantages to season-long grazing over short-

Table 5. Weight gains (kg/head) by lambs under two intensities and durations of spring grazing.

Duration of grazing	Grazing intensity: Moderate 1972	1973	1974	Means[2]	Heavy 1972	1973	1974	Means[2]	Grazing duration means[3]
Short-term	13.6	15.3	17.4	15.4b	12.2	15.5	16.8	14.8bc	15.1a
Season-long	16.4	15.3	18.2	16.6a	11.6	14.9	15.8	14.1c	15.4a
Year means[1]	15.0b	15.3b	17.8a		11.9b	15.2a	16.3a		
Intensity means[3]				16.0a				14.5b	

[1] Within each grazing intensity category, year means having different letters differ significantly ($P \leq 0.05$).
[2] Means for the four intensity × duration treatment combinations having different letters differ significantly ($P \leq 0.05$).
[3] Intensity or duration means having different letters differ significantly ($P \leq 0.05$).

duration, but only two nutritional parameters (crude protein and cellulose) differed statistically between the two time regimes imposed. Thus, we must conclude that duration of the grazing period is a much less important consideration in designing grazing systems than is the stocking rate. However, the grazing period employed in this study was confined to the spring season when forage quality and plant growth is generally considered as maximal. Different responses might be expected at other seasons.

In designing a spring grazing management program with the specific goal of manipulating vegetation to favor subsequent forage values for big game, plant community response must be given primary consideration over aspects of domestic animal production. Most range managers would logically expect some degree of sacrifice in livestock response where the primary management goal is plant community manipulation. However, results of this study indicate that this tradeoff need not be large. For example, if pending analyses of vegetational data indicate that heavy stocking yields the quickest and most desirable plant community response, the slight disadvantage imposed on individual animal performance (1.5 kg/head for lambs over the 49-day grazing season) is not great, especially in view of the decided advantage to heavy stocking if production per unit land area is considered.

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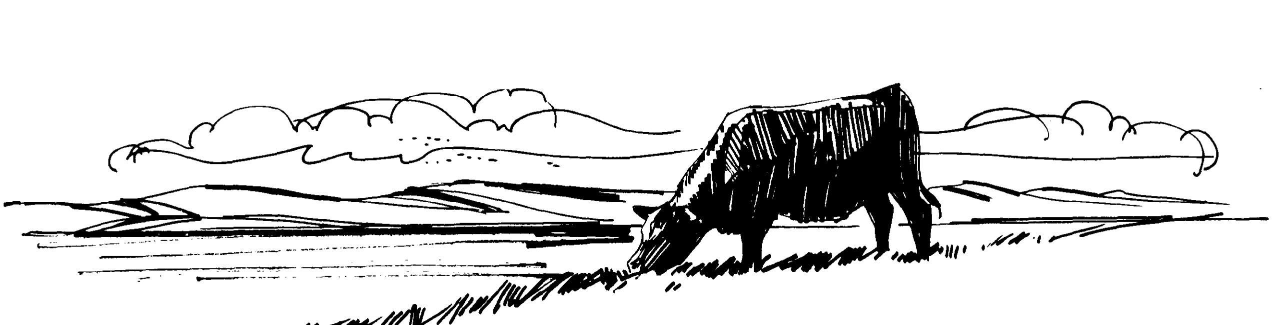

Vegetation Response to Contour Furrowing

J. ROSS WIGHT, E. L. NEFF, AND R. J. SOISETH

Highlight: Over an 8-year period, contour furrowing on a panspot range site increased average annual herbage production 165% (527 kg/ha), increased plant available soil water 107%, and reduced total basal cover 73% (from 15.72 to 4.22%). On a saline-upland site, contour furrowing increased available water but had no measurable effect on total herbage production and basal cover. Thickspike and western wheatgrass accounted for most of the increased yields on the contour-furrowed panspot site. High yields on the furrowed plots were due primarily to increased soil water resulting from increased overwinter recharge and reduced summer runoff.

Range forage production in arid and semiarid regions is closely associated with soil water availability, which is limited by precipitation amounts and runoff. Contour furrowing was one of the first land surface modification treatments applied to rangeland to reduce runoff. Since this treatment was introduced in the 1930's, it has been applied in a wide variety of furrow sizes and spacings. While optimum spacing is related to furrow size, spacings wider than 1.5 to 1.8 m have generally been ineffective (Bennett 1939; Barnes 1950). In the past 20 years, most contour furrowing has been done with the Arcadia Model B contour furrower developed by the U.S. Forest Service. Herbage yield responses to contour furrowing have ranged from none to increases of 100% or more and have been closely associated with the type of furrowing treatment and site characteristics (Wight 1976). In addition to increasing forage production, contour furrowing has been used extensively, primarily by the Bureau of Land Management, to reduce runoff and erosion on fine-textured, erodible rangelands.

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At present, contour furrowing is generally not used as a range improvement practice because unfavorable economics have discouraged its use by private landowners, and changes in management philosophies have restricted its use by the Bureau of Land Management and other land management agencies. However, on rangelands with high runoff and resultant low productivity, contour furrowing can significantly reduce runoff and increase forage production. More information is needed regarding long-term vegetation responses and site-treatment interactions. The purpose of this paper is to examine the vegetation responses of panspot and saline-upland range sites to contour furrowing. Vegetation responses were examined in terms of herbage production, species composition, and associated environmental factors. The results and data presented here are part of a cooperative study between the Agricultural Research Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, to evaluate contour furrowing effects on the vegetation and hydrology of fine-textured rangelands in southeastern Montana.

Site Description and Methods

This study was conducted about 29 km south of Ekalaka in the southeast corner of Montana. The climate is arid to semiarid continental with cold, relatively dry winters and warm summers. The long-time average annual precipitation is about 300 mm, with 80% of the precipitation received during April through September. Based on data from nearby weather stations, the precipitation during 1968–76 study was about 120% of the 76-year average and about 115% of the last 22-year average. The average frost-free season is 127 days.

The contour furrowing treatments were applied to panspot and saline-upland range sites, which are characterized by impervious saline-sodic soils with low forage productivity. The panspot soils are in the Bickerdyne and Bascovy series, fine or very fine, montmorillonitic, Borollic Vertic Camborthids. The saline-upland soils are in the Dilts series, clayey, montmorillonitic, acid, frigid, shallow Ustic Torriorthents. A dominant feature of these soils is low infiltration and high runoff. Neff and Wight (1977) estimated that approximately 40% of the late fall, winter, and early spring precipitation was lost by runoff.

Vegetation of the panspot site included thickspike wheatgrass (*Agropyron dasystachyum*), western wheatgrass (*A. smithii*), Sandberg bluegrass (*Poa secunda*), prairie Junegrass (*Koeleria cristata*), big sagebrush (*Artemisia tridentata*), and pricklypear cactus (*Opuntia* sp.). Small residual pedestals of coarse-textured materials had abundant blue grama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), and clubmoss (*Selaginella densa*). The saline-upland site was dominated by alkali sacaton (*Sporobolus airoides*) and Nuttall alkaligrass (*Puccinellia airoides*). Other species present were Nuttall saltbush (*Atriplex nuttallii*), broom snakeweed (*Gutierrezia sarothrae*), racemed poisonvetch (*Astragalus racemosus*), and *Eriogonum multiceps*.

Sixteen 0.8-hectare watersheds, twelve on the panspot range site with average slopes of 1 to 5% and four on the saline-upland range site with an average slope of 3%, were established in November 1967. Half of the watersheds at each site were contour furrowed with the Arcadia Model B contour furrower. Two pairs of offset disks 1.5 m apart formed two furrows approximately 50 cm wide and 15 to 25 cm deep. Rippers ahead of the disks fractured the soil to a depth of 25 to 40 cm. Intrafurrow dams were constructed about every 5 m. The furrow and the ridge portions represented about 40 to 60%, respectively, of the treated area. The treatments were applied in a randomized complete block design with treatments replicated six times on the panspot site and two times on the saline-upland site.

Annual herbage production was determined by clipping vegetation at ground level in eight randomly located 0.25- × 2-m quadrats or four 0.5- × 2-m quadrats in each watershed. Plots were clipped when vegetation reached peak standing crop, usually in late July or early August. No yield measurements were made in 1973 because of early grazing. Yields were determined separately for the dominant species and major species groups (i.e., grasses, forbs, and shrubs). Because of the difficulty in separating thickspike and western wheatgrass, the thickspike-western wheatgrass complex was harvested as a single category. No estimates were made of annual big sagebrush growth. Furrows and ridges were harvested separately in 1968, 1969, 1970, 1972, and 1976; in the other years, sampling quadrats were located to include a proportional amount of ridge and furrow. There was no measurable productivity in the furrows until 1971. Grazing was not a treatment but plots were grazed in 1969, 1971, and 1973 to remove accumulated residue.

Soil water was measured by the neutron scatter method to a depth of 120 cm periodically (biweekly to monthly) during the growing seasons at two locations in each watershed and included both ridges and furrows of the treated plots. Cm-days of available water was determined by plotting soil water content for the April 1 to July 31 growing season and measuring the area between the plot and a base line representing the water content below which water was unavailable to plants. This integrated area is an index reflecting both the amount and duration of available soil water. The base line or lower limit of soil water availability was determined as the lowest water content that occurred naturally in the field during the 9-year study. Because most of the root activity on these two sites is limited to the top 60 cm of soil profile, available soil water was determined for this zone only.

Nitrogen (N) and phosphorus (P) contents were determined annually on the mature thickspike-western wheatgrass plants.

Basal cover was determined for the years 1968–71 and again in 1974 with the point quadrat method. Species composition based on basal cover was determined in 1974. Point data were taken along six permanently located line transects at 5-cm intervals with a 20-point frame for a total of 1,200 points per plot. Only the basal hits are discussed in this paper. The percentage basal cover data were normalized by the transformation

$$X = \sqrt{X + 0.5,}$$

Table 1. Average annual herbage yields (kg/ha) and composition on check and furrowed plots for 1969–1976.

	Site					
	Saline-upland			Panspot		
Species	Check	Furrowed	Furrowed/ check	Check	Furrowed	Furrowed/ check**
Nuttall alkaligrass	23	80	3.47	—	—	—
Alkali sacaton	59	73	1.26	—	—	—
Thickspike-western wheatgrass	23	29	1.22	119	558*	4.64
Total grass	139	218	1.55	271	704*	2.60
Forbs	78	114	1.49	31	129*	4.00
Total	241	350	1.45	320	847*	2.65
Percent grass	58	62	—	85	83	—

* Means significantly different from the check (P=0.1).
**Furrowed/check data not analyzed statistically.

and analyzed statistically. All data were analyzed with a split-plot analysis of variance with furrowing treatments as the main plots and years as the subplots.

Results and Discussion

Herbage Production

The effect of contour furrowing on herbage production is shown in Table 1 and Figure 1. Except for the treatment year, contour furrowing generally increased herbage production on all plots. On the saline-upland site, yield increases due to contour furrowing were not significant (P = 0.1). However, with only two replications and two treatments, an analysis of variance was not very discerning. On the panspot site, furrowing increased average herbage production 527 kg/ha (165%).

Increases in the dominant forage species accounted for most of the yield increases on the contour-furrowed plots. Nuttall alkaligrass and alkali sacaton increased 247 and 26%, respectively, on the saline-upland site; and thickspike-western wheatgrass increased 364% on the panspot sites (Table 1). Blue grama and buffalograss, which represented about 25% of the basal cover on the nonfurrowed panspot site, accounted for only 17.8 and 1.7% of the total production on the check and furrowed plot, respectively. Forbs, which accounted for only 10 and 32% of the total production on the untreated panspot and saline-upland sites, respectively, responded to contour furrowing in about the same proportion as did the dominant grasses. The major forb response to contour furrowing on the panspot site in 1976 was a heavy infestation of yellow sweetclover (*Melilotus officinalis*).

N and P Uptake

Herbage quality as determined by N and P contents of thickspike-western wheatgrass was significantly affected by contour furrowing (Fig. 2). In 1968, both the N and P contents were higher on furrowed than on nonfurrowed plots, indicating a nutrient enrichment as disturbed soil and sod weathered and decomposed. However, during the next few years, N and P contents were generally lower in the furrowed than in the nonfurrowed plots, indicating a

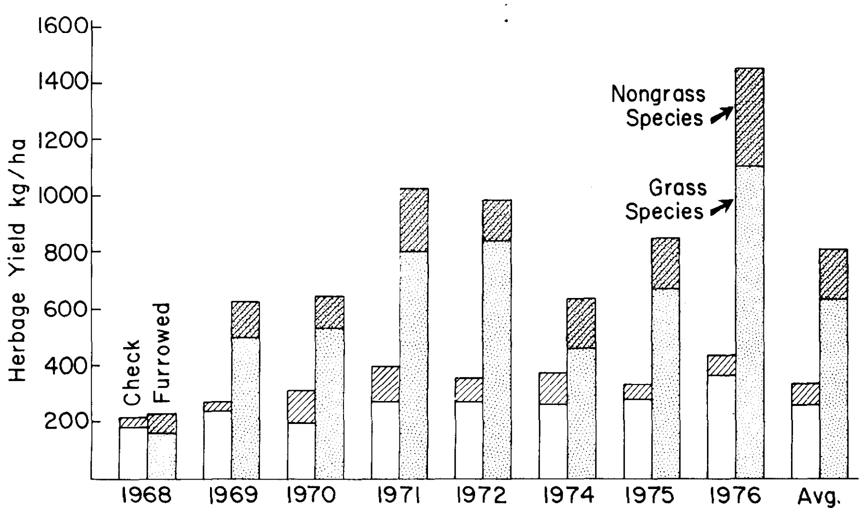

Fig. 1. *Herbage production under contour furrowing on panspot range site.*

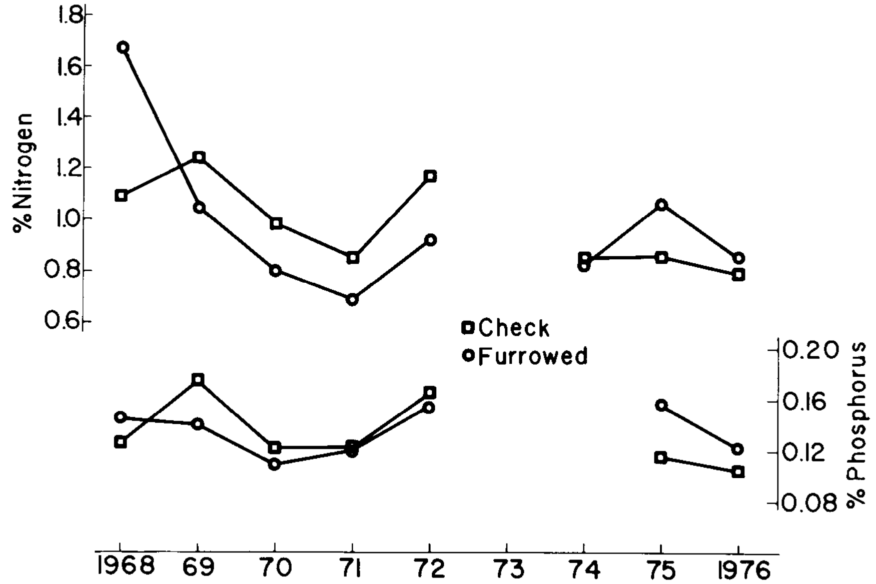

Fig. 2. *N and P content of thickspike-western wheatgrass under contour furrowing.*

dilution effect as the furrowed plots produced 2 to 3 times more vegetation than did the nonfurrowed plots. Also, decreases in N and P contents are associated with decreases in leaf:stem ratios as plants grow more vigorously. Although N and P contents were lower on the furrowed than on the nonfurrowed plots, total uptake of N and P was higher on the furrowed plots because of the increased production. As indicated in Figure 2, this situation again reversed itself in about 7 years, with the furrowed plots producing forage higher in N and P contents than did the nonfurrowed plots. After 7 years of increased soil water and productivity on the furrowed plots, the soil nutrients were probably cycling in greater quantities on the furrowed than on the nonfurrowed plots.

Species Composition

Except for the rapid establishment of tumblegrass (*Schedonnardus paniculatus*) in the furrows on the panspot site, the furrows revegetated slowly and for the first 3 years nearly all of the herbage was produced on the ridges (Table 2). However, within about 4 years the major forage species reestablished in the furrows and the furrow production was equal to or greater than that of the check plots but only about half that of the ridges. By 1976, furrow production was about 70% of ridge production on the panspot and saline-upland sites. The furrow production was two and a half times that of the check plots on the panspot site, but was not significantly different from that of the check plots on the saline-upland site. Thickspike-western wheatgrass accounted for most of the herbage production in the panspot furrows. On the saline-upland site, Nuttall alkaligrass was more productive in the furrows than on the ridges or check plots while alkali sacaton favored the ridges and the check plots more than the furrows.

Changes in percent composition 7 years after treatment are shown in Table 3. Most changes were beneficial, with the biggest changes occurring in the major forage species—Nuttall alkaligrass, alkali sacaton, and the thickspike-western wheatgrass. Tumblegrass and foxtail barley (*Hordeum jubatum*), which are of little forage value, also increased in the furrows of the panspot site. Foxtail barley was restricted almost entirely to those furrowed areas where water remained ponded for a considerable time. However, in 1976 tumblegrass and foxtail barley comprised only 2.0 and 1.2%, respectively, of the total grass yield.

Basal Cover

On the saline-upland site, only the basal cover of alkali sacaton and the shrubs was initially reduced by contour furrowing (Table 3). However, by 1974, there were no measurable differences in the check and contour-furrowed plots. On the panspot site, contour furrowing reduced the basal cover of nearly all species except thickspike-western wheatgrass and tumblegrass; these were increased. Contour furrowing reduced total basal cover from 15.72 to 4.28%, mostly due to a reduction in clubmoss from 9.38 to 0.36%. Disregarding clubmoss, the basal cover 7 years after treatment on the furrowed plots was still only about half that on the nonfurrowed plots (3.86 vs 6.35%). Blue grama and buffalograss were also significantly reduced by contour furrowing and accounted for much of the loss in total cover on the furrowed plots. Except for the first year after treatment on the saline-upland site, there were no measurable changes in shrub cover as a result of contour furrowing.

Soil Water

Increased soil water was the major beneficial effect of the contour furrowing treatments and was closely associated with changes in herbage production. In a previous paper, Neff and Wight (1977) reported that contour furrowing increased overwinter recharge 157 and 162%, respectively, on the saline-upland and panspot sites and

Table 2. A comparison of herbage production rates (kg/ha) in the furrows (F), ridges (R), and checks (C).

	1969			1972			1976			
Species	F	R	C	F	R	C	F	R	C	LSD
Saline-upland										
Nuttall alkaligrass	0	76	6	56	97	9	110	82	46	180
Alkali sacaton	0	2	66	0	87	40	79	211	100	121
Forbs	0	193	49	87	186	49	86	131	233	205
Total grass	0	155	102	182	355	123	188	292	178	97
Total yield	0	350	159	287	541	206	302	432	467	236
Panspot										
Thickspike-western wheatgrass	0	619	121	406	880	95	423	900	115	205
Foxtail	0	12	0	—	—	—	137	22	0	—
Forbs	0	188	22	97	55	27	388	312	31	185
Shrubs	0	28	10	3	10	17	0	9	40	32
Total grass	0	835	242	614	984	273	722	1364	365	207
Total yield	0	1051	274	714	1049	317	1111	1685	436	244

LSD (P=0.1) valid for within-year comparisons only.

Table 3. **Basal cover and composition of species and species groups on check and furrowed plots.**

	Basal cover %										Composition %	
	1968		1969		1970		1971		1974		1974	
Species	C[1]	F[2]	C	F	C	F	C	F	C	F	C	F
Saline-upland												
Thickspike-western wheatgrass	0.21	0.04	0.29	0.21	0.13	0.21	0.17	0.29	0.13	0.29	6.5	18.6
Nutall alkaligrass	0.17	0.21	0.25	0.25	0.04	0.17	0.08	0.29	0.08	0.21	4.4	13.8
Alkali sacaton	1.50	0.33*	0.71	0.17	0.83	0.21*	1.00	0.42*	0.71	0.50	52.0	32.4
Total grass	1.88	0.58*	1.29	0.75*	1.08	0.67*	1.29	1.08	1.08	1.17	74.9	77.1
Total forb	1.04	0.21	0.38	0.42	0.46	0.21	0.33	0.25	0.29	0.29	18.6	19.5
Total shrub	0.54	0.25*	0.21	0.04	0.04	0.00	0.00	0.00	0.13	0.04	6.5	3.3
Total cover	3.46	1.04*	1.88	1.21	1.58	0.88	1.63	1.33	1.50	1.50		
Panspot												
Thickspike-western wheatgrass	0.67	0.43	0.85	1.10	0.75	1.69*	0.63	2.40*	0.71	1.39*	5.4	35.5*
Blue grama	1.92	0.29*	1.64	0.32	2.46	0.60	1.58	0.35	1.82	0.61	15.8	14.6
Buffalograss	0.83	0.25*	0.97	0.26*	1.47	0.32*	0.88	0.42	1.29	0.17*	9.3	4.8
Sandberg bluegrass	0.58	0.18	0.53	0.47	0.81	0.26*	1.06	0.47*	1.08	0.57*	7.7	10.7
Tumblegrass	0.06	0.13	0.00	0.17*	0.00	0.13*	0.03	0.17*	0.04	0.26	0.2	6.2
Foxtail barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.42	0.0	1.2
Cactus	0.83	0.06*	0.65	0.07*	0.42	0.07*	0.57	0.07*	0.24	0.08	1.8	1.8
Clubmoss	9.03	0.19*	10.13	0.31*	8.38	0.11*	8.75	0.26*	9.38	0.36*	47.9	7.0*
Big sage	0.81	0.42*	0.74	0.60	0.53	0.47	0.57	0.36	0.32	0.21	2.2	4.6
Total grass	5.33	1.38*	4.67	2.54*	5.92	3.10*	4.53	4.13*	5.63	3.24*	46.2	77.1*
Total forb	10.92	0.50*	11.15	0.85*	9.10	0.54	9.50	0.69	9.74	0.71	51.0	16.4
Total shrub	0.85	0.65	0.82	0.78	0.64	0.57	0.61	0.46	0.36	0.28	2.7	6.5
Total cover	17.10	2.53*	16.64	4.17*	15.65	4.21*	14.64	5.28*	15.72	4.22*		
Total minus clubmoss	8.07	2.33*	6.51	3.86*	7.28	4.10*	5.89	5.01*	6.35	3.86*		

[1] C = check.
[2] F = furrowed.
* Means significantly different from the check (P=0.1).

that this increase accounted for about 60% of the herbage production increase on the contour furrowed plots. In this study, contour furrowing increased available soil water, measured as cm-days, 107 and 36%, respectively, on the panspot and saline-upland sites. A regression analysis of the available soil water and yield data indicated that during 1969–75, 67% of the yield variation was explained by soil water differences. However, in 1976, only 40% of the yield variation could be accounted for by available soil water differences. This was due in part to infestations of yellow sweetclover on some of the contour-furrowed sites which, in some instances, more than doubled herbage production. We suspect that the ability of sweetclover to fix atmospheric nitrogen was the main reason for the high sweetclover production, which reemphasizes the role of N in limiting the productivity of these range sites.

Conclusions and Application

The results of this study show that contour furrowing is an effective tool for increasing soil water and herbage production on panspot and saline-upland range sites. Species composition changes were beneficial for increased production of grazeable herbage.

Where the inherent productivity is very low, as on the saline-upland site in this study, increases in productivity up to 200% may not be economically feasible. On the panspot site, productivity levels were approaching the range of economic consideration, and treatment application decisions would have to be based on current cost-benefit ratios which are determined primarily by treatment costs, treatment longevity, and livestock values. With a furrowing machine and furrow construction such as discussed by Neff (1973) and Wight (1973), furrowing treatments should cost less than $50/ha ($20/acre).

In a previous study on a similar range site, Neff (1973) estimated that furrows lost over half of their water detention capacity within 10 years and had an effective life (at least 1.3 mm water detention capacity) of about 25 years. The furrows in this experiment were carefully constructed with an original water detention capacity of about 40 mm. After 10 years, the furrows were well stabilized and still had about 20 mm water detention capacity. Their effective life should extend well beyond 25 years. Also, as indicated by the data of Soiseth et al. (1974), the beneficial effects of contour furrowing should be autocyclic—i.e., as more water enters the soil, salinity decreases and herbage production increases, resulting in increased infiltration and nutrient availability which, in turn, favors increased herbage production. Thus, the beneficial effects of contour furrowing may last well beyond the actual effective life expectancy of the furrows.

The furrowed panspot site plots averaged 527 kg/ha more herbage than did the check plots. Assuming only 50% utilization of the additional forage and 370 kg dry matter/AUM for summer grazing (Cook 1970), contour furrowing would increase the carrying capacity by 0.71 AUM/ha per year. For AUM values of $3.00–$6.00, contour furrowing would be worth from $2.13–$4.26/ha (0.86–$1.72/acre) per year. The presence of a N-fixing legume, yellow sweetclover, in 1976, greatly enhanced the value of contour furrowing on the N-deficient soils. With a yield difference of 1,020 kg/ha between check and furrowed plots; contour furrowing would have been worth from $4.14–$8.28/ha per year ($1.67–$3.34/acre per year) in 1976. Also of value, but difficult to give monetary values, are the beneficial effects of contour furrowing for watershed protection and wildlife needs.

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Distribution of Food Reserves in Snowberry (*Symphoricarpus oreophilus*)

MELVIN R. GEORGE AND C. M. McKELL

Highlight: A study was conducted in northern Utah in 1974 to determine the distribution of nonstructural carbohydrates (NC) and lipids in snowberry (*Symphoricarpus oreophilus*). Snowberry biomass was sampled and partitioned into small roots, large roots, root crowns, old stems, new stems, and leaves, which were analyzed for NC and lipids. The results showed a generally larger pool of NC in stems than in belowground biomass. Lipids in snowberry remained relatively stable throughout the growing season and included relatively small amounts of those lipids most likely to enter metabolism. Thus, lipids apparently do not contribute significantly to the carbon reserve pool.

Plant food reserves are largely nonstructural carbohydrates (NC) but lipids may also be a source of reserve carbon (Cook 1966). Lipids have received little attention as potential food reserves in range plants but have been investigated in alpine plants (Bliss 1962; McCown and Tieszen 1972). Fluctuating lipid concentrations might indicate additional reserve potential because seasonal fluctuations of reserve compounds imply metabolic use and replacement. Conversely, seasonal constancy of lipid concentrations or qualities indicates that lipids are relatively unimportant as reserve compounds under normal conditions.

Seasonal trends in NC concentrations have been described for many range plants by various researchers (Cook 1966; White 1973), but few researchers have described NC distribution on a quantity basis. Priestly (1962) stated that it was desirable to determine the total quantity of carbohydrate reserves in plant storage organs rather than only the concentration of carbohydrate reserves.

Whereas concentration measures of carbohydrates have been used to illustrate the time sequence of reserve depletion and replenishment, they fail to give an accurate estimate of the amount of carbohydrate reserves in the plant. Reserve amounts can only be determined on an absolute basis, which requires an estimate of total plant biomass.

In this study, NC and lipids were determined both on a concentration and a quantity basis to show the distribution in selected plant parts, and to determine seasonal changes in lipid and NC quantities.

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Methods

Biomass of snowberry (*Symphoricarpus oreophilus* Gray) was collected in late April, mid-May and mid-August in 1974 near the Utah State University Forestry Summer Camp in Logan Canyon 42 km northeast of Logan, Utah. Plants and clones were excavated separately because they have different growth habits. A plant has a single stem at the ground surface with a correspondingly small basal area. In contrast, a clone has a large basal area because many single stems are connected underground by the root crown.

Auger samples were taken radially from plants and clones at several depths in each radial stratification to determine the soil volume that must be excavated to remove root biomass (Schuurman and Goedewaagen 1971). Roots did not extend beyond 31 cm from the stem of single plants or the outer stems of clones. Root depth was limited to 61 cm by the rocky soil at that depth and the claypan at 76–81 cm. Root material belonging to understory species and adjacent shrubs was identified and removed from the soil volume. The remaining root material was sieved, washed and floated from the soil using methods similar to those of McKell et al. (1961). All plant material was dried (80°C) and weighed to determine biomass.

Total biomass over the range of plant and clone sizes varied so greatly that the biomass was separated into four size classes: large clones (7 to 15.5 kg), small clones (2.5 to 7 kg), large plants (0.95 to 3.5 kg), and small plants (0.25 to 0.95 kg). Ten individuals in each size class were excavated. This sample size was great enough to insure a coefficient of variation of ±15% at the 90% level of probability.

During the three periods of biomass sampling, random samples of leaves, new stems, old roots, root crowns, large roots, and small roots (less than 6 mm in diameter) from four plants or clones were frozen in dry ice for analysis of NC and lipids. This sample size was adequate to insure that 95% of the observations fell within 10% of the mean.

Frozen plant samples were stored in a freezer and were later freeze-dried. The freeze-dried samples were ground in a Wiley Mill through a 40-mesh screen. The ground plant material was stored in desiccators.

The NC was extracted from the ground plant samples using 0.2 N sulfuric acid as described by Smith et al. (1964). This method hydrolyzed NC to reducing sugars, which were analyzed using the dinitrosalicylic acid method (Luchsinger and Cornesky 1962). Glucose was used as a standard. The product of this procedure has conventionally been called total available carbohydrates but this term is a misnomer according to Stoddart et al. (1975) and George (1976).

Lipid extractions were conducted by the method of Fonnesbeck and Harris (1974) that was similar to the method of McCown (1973). As a gross index to the availability of the total lipids, each extract sample was saponified using alcoholic potassium hydroxide. The amount of potassium taken up by the total lipid was an index of the amounts of triglycerides and their component compounds in the total lipid fraction. The saponified lipid was then titrated with a standard acid to determine the amount of potassium hydroxide (KOH) left after the completion of saponification. The saponification number is the number of milligrams of KOH consumed in the complete saponification of one gram of fat or oil (Clark 1964).

Duplicate laboratory analyses were conducted periodically to check methods and stock solutions. Duplicate analyses were also conducted if there was any reason for doubting some determinations.

Analyses of variance and F-tests were performed on all data. The calculated F values were tested at the 1 and 5% levels of probability. Duncan's new multiple range test (Duncan 1955) was used at the 5% level to separate means that differed significantly.

Results and Discussion

Biomass

The four size classes of snowberry biomass measured in late April, mid-May, and mid-August were not intended to estimate plant production, but only as a measure of the biomass of various plant parts at three important points along the seasonal NC cycle. The belowground and old stem biomass of the three smallest size classes (small clones, large plants, and small plants) did not change significantly over the three collection periods (Fig. 1). Even

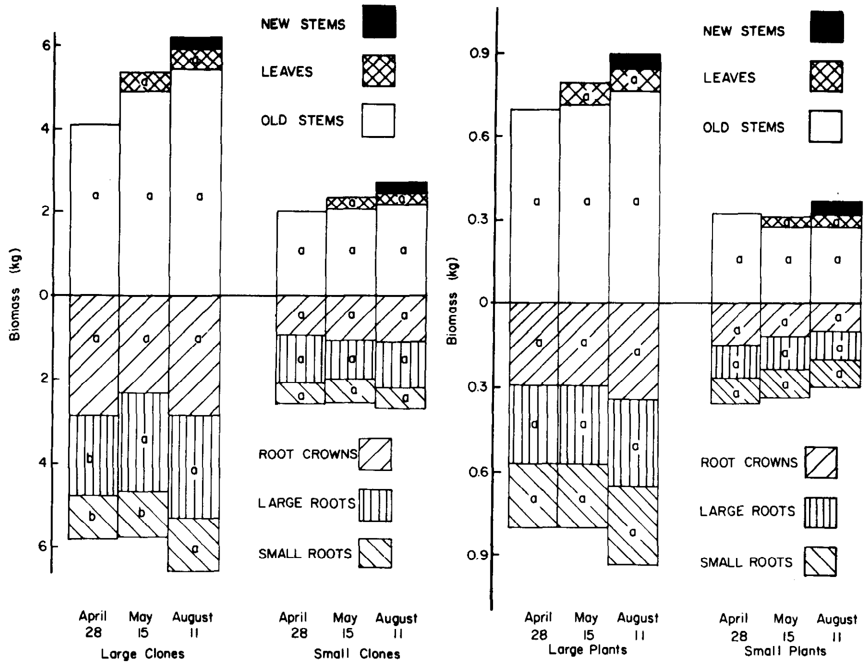

Fig. 1. *Biomass of various plant parts of snowberry. Means for the same plant part with the same letter are not significantly different (P> 0.05). 1a (left) large and small clones; 1b (right) large and small plants.*

the increase in biomass resulting from leaf production and stem elongation did not significantly increase the total biomass.

Increases in belowground biomass in large plants and large clones over the three collection dates may be attributed to natural variation and sampling error. On the first sampling date the soil was extremely wet and sticky, probably hampering root recovery. On the second sampling date, the soil consistency had improved but was still somewhat sticky. On the third collection date the soil was quite friable and root recovery was improved.

Lipids

Lipid concentration did not change significantly over the three collection dates in any of the plant parts except leaves (Table 1). Leaf lipid concentrations were 5.8% and 7.1%, respectively, for the second and third collection dates. Lipid concentrations in other plant parts were much lower. The National Academy of Science (1971) reported that other extracts of lipids were between 2 and 5% for snowberry browse.

Lipid concentration values were multiplied by biomass data to provide an estimate of the quantity of lipids in each plant part (Fig. 2). Although lipid concentrations did not change significantly over the three collection dates, their quantities varied because of changes in biomass.

The saponification number (mg KOH consumed/g of lipid) for the lipid fraction from small roots was significantly lower on May 15 than on April 28 and did not increase significantly by August 11 (Table 1). The saponification number in large roots was

Table 1. Mean lipid concentration (%) and saponification number (mg KOH consumed/g of lipid) for each plant part of snowberry on the three dates.

	Dates					
	4/28/74		5/15/74		8/11/74	
Plant part	Lipid (%)	Saponification number	Lipid (%)	Saponification number	Lipid (%)	Saponification number
Small roots	0.90 c[1]	51.40 bcd	0.93 c	19.40 e	1.09 c	44.92 bcde
Large roots	0.74 c	50.80 bcde	0.61 c	108.82 a	0.74 c	76.34 b
Root crowns	1.03 c	45.04 bcde	0.79 c	63.75 bc	0.91 c	55.56 bcd
Old stems	1.55 c	49.13 bcde	1.32 c	43.67 cde	1.33 c	36.09 cde
Leaves	—	—	5.84 b	45.66 bcde	7.09 a	36.41 cde
New stems	—	—	—	—	1.71 c	24.83 de

[1] All means for each chemical analysis followed by the same letter are not significantly different (P>0.05).

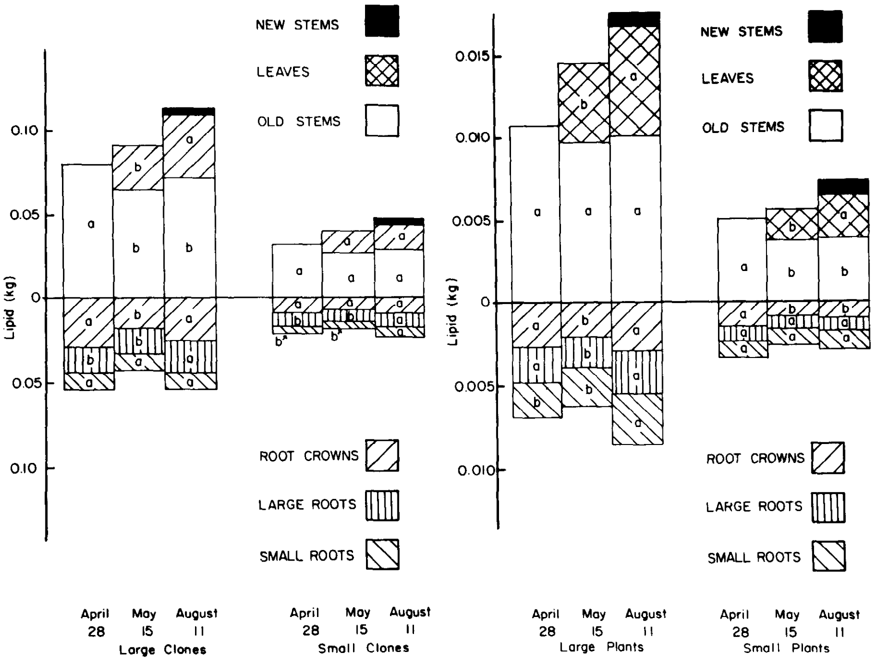

Fig. 2. *Lipid quantity in various plant parts of snowberry. Means for the same plant part with the same letter are not significantly different (P> 0.05). 2a. large and small clones; 2b. large and small plants.*

significantly greater on the second collection date than on the other two dates. Saponification numbers for root crowns and old stems remained unchanged over all three dates. The leaf saponification number did not change significantly from May 15 to August 11, and the new stem saponification number was similar to that found in old stems.

Saponifiable lipids, such as fats and phosopholipids, are more likely to enter metabolism and become an energy source than are nonsaponifiable lipids (Mooney and Chu 1974). Saponification numbers are an indicator of the proportion of the lipid fraction which might enter metabolism. For example, each mole of fat, with three fatty acid side chains per molecule, requires three moles of KOH for complete saponification. The low saponification numbers determined for lipids extracted from snowberry indicate that only part of the lipids are likely to enter metabolism. Clark (1964) reported saponification numbers of 183 to 207 for readily metabolizable lipids such as linseed oil, corn oil, almond oil, and olive oil. These numbers are twice as great as the highest saponification number determined for snowberry lipids. Mooney and Chu (1974) found only small amounts of carbon devoted to saponifiable compounds in *Heteromeles arbutifolia*. The lack of seasonal fluctuation and only partial availability of lipids indicate that they are probably not important food reserves under normal conditions.

Nonstructural Carbohydrates

Nonstructural carbohydrate concentrations in small roots and old stems varied significantly throughout the seasonal cycle of snowberry (Table 2). Donart (1969) reported similar findings for NC concentration in small roots.

Table 2. Mean nonstructural carbohydrate concentration (%) for each plant part of snowberry on three dates.

	Dates		
Plant parts	4/28/74	5/15/74	8/11/74
Small roots	11.52 c[1]	5.75 f	12.47 c
Large roots	4.89 f	5.03 f	5.07 f
Root crowns	5.72 f	5.72 f	5.52 f
Old stems	8.47 e	5.53 f	10.43 d
Leaves	—	25.88 a	17.28 d
New stems	—	—	10.01 d

[1] All means followed by the same letter are not significantly different ($p>0.05$).

The concentration of NC in large roots and root crowns was relatively stable throughout the seasonal cycle.

Significant variation in NC quantity was observed in small roots and old stems of all size classes (Fig. 3). Nonstructural carbohydrate quantity in large roots and root crowns remained stable except in large clones, where significant changes in large root biomass caused a change in large root NC quantity.

Leaf quantity decreased between May and August. This was primarily because of a drop in NC concentration from 25.9 to 17.3% (Table 2). New stems had NC concentrations similar to those measured in old stems in August. New stem NC quantity represented a statistically insignificant increase in total biomass NC quantity on an annual basis. Nonstructural carbohydrates were determined at the end of dorman-

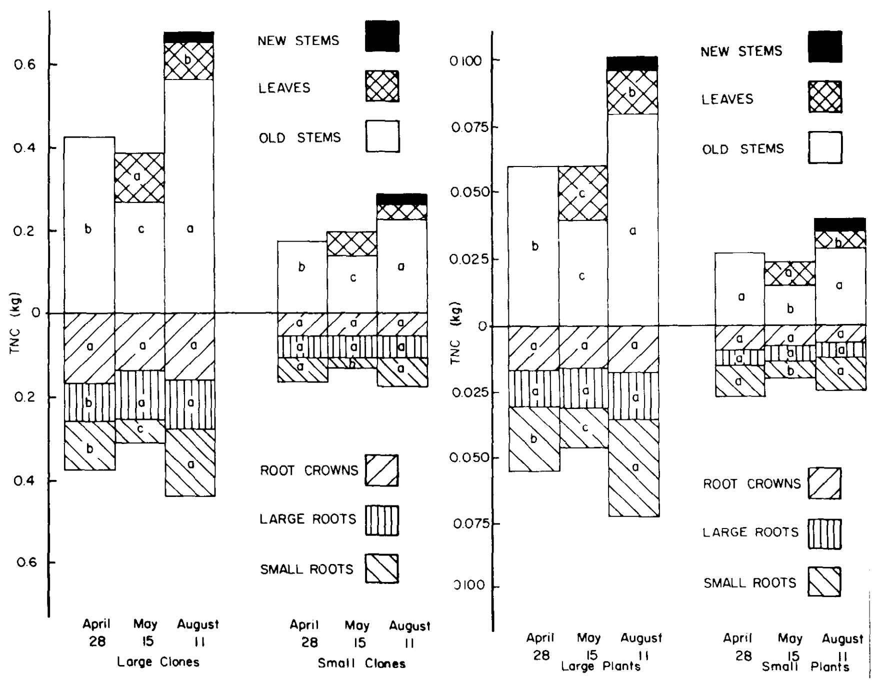

Fig. 3. *Nonstructural carbohydrate quantity in various plant parts of snowberry. Means for the same plant with the same letter are not significantly different (P> 0.05). 3a. large and small clones; 3b. large and small plants.*

cy, at the approximate NC low and again at the annual NC maximum following replenishment with photosynthates. Snowberry reached a maximum level of NC in each of its plant parts before entering dormancy. During dormancy the NC pool was partially depleted. Near the end of dormancy buds below the snow and litter level broke dormancy and began elongating even though the soil surface was still covered with snow. Thus, depletion of NC during dormancy was not used exclusively for respiration. When the buds in the stems began to swell, indicating the end of dormancy, the NC quantity measured in perennial plant parts was 21 to 25% lower than the NC quantity measured at the summer maximum in large plants and large and small clones. The NC quantity in perennial plant parts of small plants was only 7.5% lower at the end of dormancy than at the summer maximum.

From the onset of bud swelling in late April, NC was further depleted as the plant began spring leaf production. Carbon reserve depletion was at its lowest point by mid-May or early-June. The NC quantities in perennial plant parts were 41 to 46% lower than the summer maximum in all four size classes. From June until mid-August, NC was replenished in all plant parts. Stem growth occurred during this period as well as limited flower production and seed set.

From a seasonal aspect, the distribution of NC changes between aboveground biomass and belowground biomass. Old and new stem NC quantity was greater than the belowground NC quantity in mid-August in all four size classes, but only in large clones and large plants on the first collection date. In contrast, belowground NC quantity was greater than old and new stem NC quantity in mid-May.

McConnell and Garrison (1966) found that bitterbrush roots maintained the greater quantity of reserve carbohydrates except in June and July when the NC depletion point was reached. Sprague and Sullivan (1950) found that although roots had lower concentrations of carbohydrate reserves than other storage organs in some grasses, the total quantity of carbohydrates stored in roots was greater because of the greater mass of roots. In snowberry the mass of old stems is less than the mass of total roots, but the higher NC concentration of old stems shifts the NC quantity balance to the stems, except at the annual NC low points.

Nonstructural carbohydrate concentration fluctuation is commonly considered an indicator of the relative contribution of NC by each plant part, but this ignores the importance of plant parts where NC concentration shows little seasonal change. Little seasonal NC concentration fluctuation could indicate rapid replacement of NC from another source, or a small contribution of NC to plant metabolism. George (1976) showed that NC concentration in large roots and root crowns decreased in response to defoliation. In the present study, small roots and old stems showed seasonal variations in NC concentration but large roots and root crowns did not. Large roots and root crowns together usually contained a greater NC quantity than small roots. A large NC pool could make an important contribution to metabolism without showing a significant decrease in NC concentration. In many studies NC concentration in small roots is most responsive to changes in NC sources and sinks. The inference is that the plant is in a vulnerable state when NC concentrations drop from the annual maximum to the spring depletion point. This interpretation ignores any NC in larger roots and root crowns, which may moderate the effect of NC concentration decreases in small roots.

Conclusions

Lipids did not fluctuate on a seasonal basis and only a small proportion of the lipid compounds was available for plant metabolism in snowberry. Therefore, lipids are believed not to be important as food reserves in snowberry under normal conditions. The NC quantity balance shifts from the aboveground biomass to the belowground biomass when reserves are at their lowest level in mid-May. This may indicate that aboveground biomass contributes more carbohydrate reserves during spring leaf production than belowground biomass. Finally, the tendency to imply plant carbohydrate status from one sensitive plant part, such as small roots, should be avoided because it ignores the contribution of other plant parts to the whole plant NC pool.

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Factors Influencing Productivity of Two Mule Deer Herds in Utah

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Highlight: Doe-fawn counts show that the mule deer herd on the LaSal Mountains of southeastern Utah produced over 38% more fawns per doe than the Henry Mountain herd over a 9-year period. Carcass weights of animals from the LaSal herd were generally greater for all age classes. Observed reproductive differences appear to be unrelated to the incidence of diseases, parasites, or predation. Furthermore, winter ranges are nearly equal in forage quantity and quality on the two ranges. Summer range vegetation on the LaSal Mountains, however, produced more forage of better quality than did similar community types on the Henry Mountains. LaSal summer ranges produced 2,149 kg/ha fresh weight of available forage while similar ranges on the Henrys produced only 1,314 kg/ha. Forbs account for 52% of the forage on LaSal summer ranges but only 12% of the forage on ranges of comparable elevation on the Henrys. The data suggest that the characteristics of the forage found on the summer range, especially the quantity and quality of forbs, exert important influences on productivity of these herds.

During the 1950's, Utah experienced high populations of mule deer (*Odocoileus hemionus*), and a general deterioration of habitat results. In an attempt to correct this condition, the Utah State Division of Wildlife Resources and federal land management agencies embarked on a program to reduce mule deer and livestock numbers to the carrying capacity of the range. Management tools implemented to reduce deer numbers included building access roads, issuing permits for special hunts, and extending hunting seasons. The effect of that program on herd size varied by herd unit. Some herds maintained a high reproductive rate and special controls are still being used to keep such herds in balance with their ranges. Other herds have not responded to reduced hunting pressure; production of fawns appears to be low and herd size has remained static. Because of such apparent differences in productivity, this study was initiated to quantify reproductive differences between two herds and identify factors that might be responsible for observed differences.

The LaSal and Henry Mountain deer herds were selected for their apparent differences in fawn production. Both areas are geologically similar, and each is an isolated mountain system rising from the surrounding desert. There is little movement of deer into or out of either herd unit. Research objectives were to determine: (1) fawn production for the two herds; (2) carcass weight by age-class for the herds; and (3) factors responsible for any differences observed.

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Pertinent Literature

Nutritional status of does at critical periods during the year has been found to have an effect on deer productivity. Julander et al. (1961) stated that "successful breeding depends largely upon thrifty condition of the deer at rutting time." Longhurst et al. (1952) noted: "Rate of ovulation seems to be strongly affected by the level of nutrition just prior to and during the rut."

The diet of the doe during the time of gestation has been found to have an effect upon the size of the newborn fawns (Verme 1963). Verme also found the survival of fawns to be closely related to their size at parturition. In late winter, a doe reaches her lowest nutritional ebb (Hagen 1953). Wood (1962) found that in Idaho "the primary cause of high early fawn loss . . . (was) poor doe condition during parturition." Yoakum (1965) reported that "fawns born of does that are in poor condition will often be in poor condition when dropped and handicapped for survival. Under such austere conditions fawns do not live past their first week."

After giving birth to her young, the doe has a new energy demand placed upon her, that of lactation. Verme (1962) believed that "undernourished does delay milk production or fail to produce milk." If a herd is to increase rapidly, the production of twins is essential, and, according to Yoakum (1965), "does on poor range often cannot give enough milk for twin fawns."

Deer weights show a correlation with quantity and quality of food available (Hosley 1956). The size of deer of the same age and sex will vary in response to quality and quantity of forage available to the herd during the year (Severinghaus and Cheatum 1956). According to Swank (1958), mature body size is affected by diet from birth to 5 or 6 years of age. Any shortage of food during this period will result in smaller body size. Murphy and Coates (1966) showed that a reduction of protein content in the diet reduced body weight and chest girth.

Study Areas

The study areas are located in southeastern Utah (Fig. 1). The LaSal Mountains are located east of Moab in Grand and San Juan counties. The Henry Mountains are south of Hanksville in Wayne and Garfield counties. The two areas are about 117 km apart. Both are laccolithic mountains of similar geologic age (Butler 1920; Hunt et al. 1953). Precipitation averages somewhat higher (about 10%) on the LaSals than the Henrys for comparable vegetation zones (Pederson 1970).

The LaSal herd unit encompasses approximately 221,374 ha. The highest point on the LaSals is Mount Peale at 3,876 m elevation. The Henry Mountain area includes approximately 72,886 ha; the highest point on the range is Mount Ellen at 3,500 m.

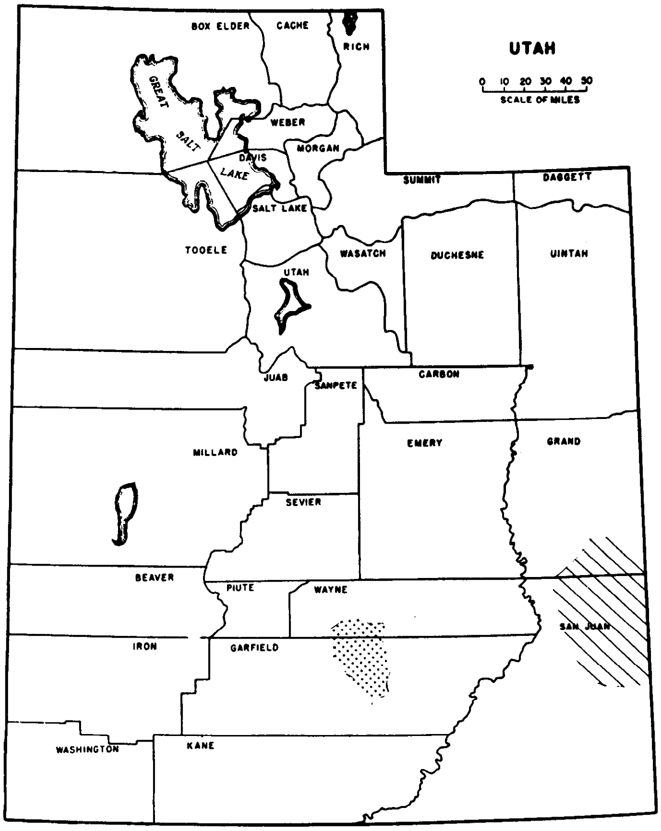

Fig. 1. *Location of study areas: outlined areas designate the Henry (left) and LaSal Mountains (right).*

Methods and Procedures

To determine population structure, hunter kills were aged by the tooth replacement and wear method (Robinette et al. 1957). Preseason sex ratio and fawn/doe counts were made over a 9-year period starting on September 15 and running to the day prior to the opening of hunting season (approximately October 20). Special attention was given to single and multiple fawns. Observations were made along the same routes each year. All counts were made by the senior author except those for the 1972–75 period on the Henrys.

Mortality was ascribed to the following causes: winter loss, predation, illegal kill, disease, and parasites. Hunter harvest was also considered, being divided into hunter kills and wounding loss. Winter loss, predator kills, and illegal kills were looked for whenever field work was conducted on an area. Nineteen deer were taken for intensive necropsy during April and May of 1968 and 1969. Blood from those animals was tested for Rocky Mountain spotted fever, tularemia, brucellosis, Q fever, and plague. Fetal counts were made on all does collected.

Hunter harvest data were obtained from the Utah Division of Wildlife Resources annual big game harvest questionnaire sent to license holders at the conclusion of each hunting season. We estimated wounding loss to be 15% of legal hunter harvest following Robinette and Olsen (1944). Deer weights were taken in hunting camps on each mountain during the regular hunts of 1967–1969.

Major vegetational studies were conducted between June and August 1967. Summer forb production was measured in July 1967–69. An average of 200 m of transect was sampled per vegetation type on each mountain range. Cover of woody plants was obtained from canopy intercept along a steel tape stretched taut along each transect. Herb and browse production were estimated in plots that paralleled the full length of each transect. Herb estimating plots were 30 cm and browse plots were 1.3 m wide. For convenience, estimates were made in 3-m segments along both herb and browse transects.

A forage palatability index (FPI) was computed for each vegetational type. A palatability rating was assigned to each species (e.g., 1=poor, 2=fair, 3=good). Ratings for all major species are reported in Pederson (1970). The rating value for each species was multiplied by the relative contribution of that species in total production. These composite values were summarized for all species in each vegetative type and divided by 100 to produce the FPI. FPI values were calculated separately for grasses, forbs, and shrubs in each vegetative type. The higher the FPI, the better the palatability of forage for that type.

During summer, 1967, a pellet-group transect (Julander et al. 1962) consisting of 100 plots, each 9.3 m^2, was examined along each vegetative transect to establish use of range types by livestock and big game. In addition, permanent pellet-group transects on winter ranges were used to help determine deer numbers and range use.

Differences between herd and range parameters on the two mountain ranges were tested for significance wherever possible. Differences were analyzed using a *t*-test designed for independent samples (Snedecor and Cochran 1967).

Results

Reproduction and Growth

Reproduction

For the 9 years of record, the average productivity of the LaSal herd was about 38% greater than that of the Henrys (Table 1). Differences between herds were consistent in all years. With about 84 fawns per 100 does, the LaSal herd is somewhat more productive than the average herd in Utah and the average herd in the Southeast Region, where the LaSal and Henry mountains occur. The Henry Mountain herd was far below average productivity for both the region and the state. Over half (52%) of the does on the Henry Mountains were judged to be barren during the period (1967–1969; only 31% were so judged on the LaSals (Pederson 1970). These figures include the yearling age-class. An average of 26% of the does on the LaSals were accompanied by twins just prior to the October hunting season

Table 1. Nine years of herd productivity as determined from doe:fawn counts taken in autumn just prior to the October hunting season. Sample size is shown in parentheses (doe/fawn).

	Fawns per 100 does									
	Year									
Herd unit	1967	1968	1969	1970	1971	1972	1973	1974	1975	Average
	(194)	(104)	(62)	(151)	(146)	(329)	(191)	(280)	(170)	
LaSal Mountains	96(187)	94(98)	89(55)	91(138)	75(101)	73(242)	95(183)	73(205)	75(124)	84.3
	(155)	(114)	(134)	(105)	(108)	(148)	(94)	(123)	(60)	
Henry Mountains	63(98)	48(55)	63(85)	61(64)	73(79)	56(84)	70(66)	53(66)	65(92)	61.3
Southeast region	83	79	77	87	84	74	71	74	79	78.6
State average	83	83	81	83	84	75	71	75	73	78.6

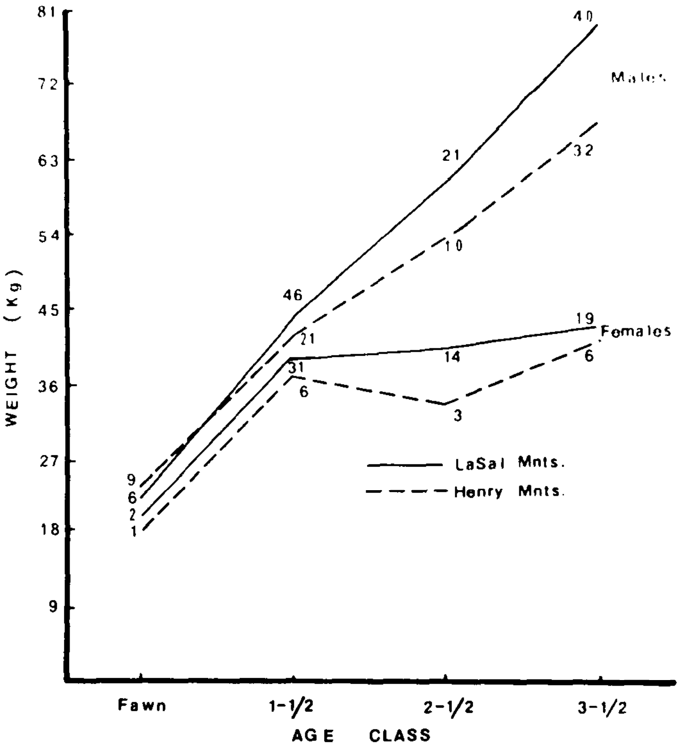

Fig. 2. *Age-eviserated body weight relationships for male and female deer of various age classes from the LaSal and Henry Mountain levels. Numbers along each curve indicate the number of animals weighed to produce the average value plotted for each sex and age class. Weights were taken during October in both areas.*

during the 1967–69 period, but only 11% of the does on the Henrys had twins during that period (Pederson 1970).

Supplementary reproduction data were obtained from does taken for necropsy. Those data show a 2.0:1 fetus/doe ratio from the LaSal Mountain herd and a 1.6:1 ratio from the Henry Mountain herd. Although the sample was small (5 does per mountain range), the trend is in the same direction as the autumn fawn/doe counts.

Body Condition

During the hunting seasons 1967–69, a total of 190 animals from the LaSal area and 82 from the Henry Mountain herd were weighed (Fig. 2). Where 6 or more weights were obtained per age-class for each herd, weight differences between herds were tested for significance. The LaSal deer were significantly heavier in the 2½ and 3½ age-classes for male animals. In the fawn and yearling age-classes, observed differences were not statistically significant.

The decline in body weight of does on the Henry Mountains (Fig. 2) between the 1½ (N = 6) and 2½ (N = 3) age-classes was unexpected and may be an artifact of a small sample. Nevertheless the majority of the does on the Henrys appear to mature their first fawn while they are in the 2½ year age-class, and poor range conditions may contribute to severely depleted body reserves of young nursing mothers. Fawns from the Henrys are almost as large as fawns from the LaSals, but it should be noted that 64% of the fawns are singles on the Henrys while singles account for only 40% of the fawns on the LaSals. LaSal does thus support more twins and still produce larger fawns on the average than Henry Mountain does.

Health and Mortality

Diseases and Parasites

A total of 19 deer (11 from the LaSals and 8 from the Henrys) were taken for detailed necropsy analysis. Blood of all animals tested negative for plague, brucellosis, tularemia, Rocky Mountain spotted fever, and Q fever. Eight parasites (5 ecto- and 3 endo-) and a nonmalignant skin tumor were observed on the animals sampled (Pederson 1970). Seven of the parasites were found on animals from both areas. Cattle lice (*Linognathus* spp.) were present on animals from the LaSal herd only. Although there are minor variations in percentage of animals infected by various parasites in the two herds, the differences do not appear to be significant.

Winter Mortality

Winter losses of deer on both areas were observed at the time vegetative transects were run, each spring when the browse transects were evaluated, and at other times as we travelled over the areas. During the years of this study, 5 possible winter losses were found on the Henrys and 7 on the LaSals. Since approximately 15 man-days per year were spent on the winter ranges of each mountain range, there is little likelihood that any major winter losses were missed.

Table 2. Harvest data (averages) for the LaSal and Henry Mountain deer herds for the period 1965–1974. Data were extracted from the Big Game Harvest Reports (1965–1974) of the Utah Division of Wildlife Resources. Animals harvested per unit area are reported in terms of area of summer range, since the limits of winter range were set by arbitrary boundary lines and not by deer use.

	Average for site	
	LaSal Mountains	Henry Mountains
No. of hunters	3.886	252
Total kill	2,554	122
% hunter success	66	48
No. hunters/km²	8.0	4.0
No. deer harvested/km²	5.2	1.9

Hunter Harvest

Harvest data (Table 2) demonstrate greater hunting pressure and greater hunter success on the LaSals as opposed to the Henry Mountains. There was almost 40% greater success per unit effort of hunters on the LaSals as opposed to the Henrys. The high hunter success on the LaSals during the period 1965–74 has been maintained despite preseason hunts, either-sex hunts, and female-only extra permits. During the same period, the Henrys have received only short season hunts, buck-only hunts and, in recent years, closed seasons and yet have shown no significant improvement in hunter harvest or fawn production.

Other Mortality Factors

Other factors affecting mortality include predation, kills by vehicles, entanglement in fences, fights, falls, and illegal kills. From extensive experience on the two mountain ranges, we do not consider any of these variables to differ significantly between ranges but quantitative data are lacking.

Vegetation

On the LaSals, 2,942 m of transect were analyzed to determine composition and production of summer range vegetation. A total of 3,883 m of transect was evaluated on the summer range of the Henry Mountains. The difference in actual length of transect was due to the greater density and number of species of plants on the LaSals; transects there required more sampling time. A summary of the range types and their area and production on the two mountain ranges appears in Tables 3 and 4.

As shown in Table 3, the proportion of major vegetative types is quite similar on the winter ranges of the two mountain systems. The apparent difference in desert shrub vegetation is an artifact of the method of delineation of the sample area. Desert shrub vegetation extends far beyond the boundary used to delimit the Henry Mountain area.

Table 3. Aerial extent of the major vegetative complexes encountered on the LaSal and Henry Mountains.

	LaSal Mountains		Henry Mountains	
Vegetation complex	Total area (ha)	%	Total area (ha)	%
Winter range				
Desert shrub	35,510	21	8,236	12
Pinyon-juniper-sage	106,502	61	47,884	72
Mountain brush	22,948	13	8,962	13
Reseeded and agricultural	7,796	5	1,534	3
Total	172,756	100	66,616	100
Summer range				
Mountain brush	14,323	29	3,445	55
Ponderosa-mountain brush	12,277	25	1,373	22
Conifer-aspen	21,212	44	1,297	20
Rock	806	2	155	3
Total	48,618	100	6,270	100

In contrast, summer ranges differ widely in composition on these mountains. In relative terms, the mountain brush zone is larger and the conifer-aspen zone is smaller on the Henry Mountains (Table 3). The conifer-aspen zone is especially important as a source of succulent forage in the late summer in this region (Julander et al. 1961).

In respect to forage production, both winter and summer ranges are more productive on the LaSals than the Henrys (Table 4). LaSal winter and summer ranges are 23 and 64%, respectively, more productive than similar ranges on the Henry Mountains.

It should be noted too that the forb/shrub ratio differs widely on these mountains. For LaSal summer ranges, the forb/shrub ratio is about 2/1; on the Henrys the ratio is 1/6 (see Table 4). Composition of forage on the winter ranges differs far less than on the summer ranges of the two areas.

Forage palatability is another important parameter in range evaluation. Forage palatability indices are reported for winter and summer range in Table 5. Overall winter forage palatability is somewhat higher on the Henry Mountains, but the situation is reversed on summer ranges. Not only are LaSal summer ranges more productive, but their forage palatability (particularly for forbs) is superior to that of the Henrys. Pederson (1970) reported greater species diversity for the LaSals than the Henrys (270 versus 176 species). Most of the enrichment in species diversity on the LaSals is contributed by forbs.

Pederson (1970) has shown that forb production was consistently higher on LaSal summer ranges than on the Henrys in the 1967–69 growing seasons. Year to year variation in forb production on the summer ranges was positively correlated with precipitation in the growing season.

The 9-year trend for utilization of browse on four winter-range transects on each mountain (Table 6) shows browse to be utilized more heavily on the LaSal than the Henry Mountains. Although the precipitation is lower on the Henry Mountains,

Table 4. Annual production of "available" forage in the various vegetational complexes on the two mountain ranges. Averages reported are weighted to show the value for the entire winter or summer range complex.

	Forage production[1]	Percent contributed by		
Vegetative complex	(kg/ha)	Grasses	Forbs	Shrubs
Winter range				
LaSal Mountains				
Desert shrub	675	10	14	76
Pinyon-juniper-sage	1,072	17	17	66
Mountain brush	3,328	19	18	63
Weighted average	1,300	17	17	66
Henry Mountains				
Desert shrub	407	15	2	83
Pinyon-juniper-sage	1,254	17	5	78
Mountain brush	609	28	5	67
Weighted average	1,058	18	5	77
Summer range				
LaSal Mountains				
Mountain brush	2,003	17	67	16
Ponderosa-mountain brush	1,064	23	44	33
Conifer-aspen	2,868	21	47	32
Weighted average	2,149	21	52	27
Henry Mountains				
Mountain brush	1,522	14	12	74
Ponderosa-mountain brush	1,232	16	15	69
Conifer-aspen	850	3	8	89
Weighted average	1,314	13	12	75

[1] Forage weights shown are fresh weight during the height of the growing season. Air-dry weight is approximately 40% of the figures shown.

average twig length usually is longer than for the same species on LaSal winter ranges. This apparently indicates better species vigor on Henry Mountain ranges.

Discussion

Our search for possible causes of the observed differences in reproductive rate between the LaSal and Henry Mountain deer herds has not offered support for hypotheses that disease, parasites, or predators are responsible. Likewise the evidence suggests that harvest rates are not responsible. Winter range differences also seem inadequate to account for the greater reproductive rate of the LaSal herd. Although Henry Mountain winter ranges are somewhat drier and less productive [about 20% less yield than on the LaSal Mountains (Table 4)], forage quality (Table 5) and plant vigor (Table 6) actually appear to be slightly better than on the LaSals. Deer use of winter ranges (Table 6) also seems to be lighter on the Henrys as opposed to the LaSals.

In contrast with the foregoing variables, summer range conditions differ markedly between these mountain ranges.

Table 5. Forage palatability indices (FPI) for the winter and summer ranges.

	Forage palatability index (FPI)[1]			
Type	Grass	Forbs	Browse	Total vegetation
LaSal Mountains				
Winter ranges	1.92	1.45	1.99	1.89
Summer ranges	1.00	1.94	1.59	1.64
Henry Mountains				
Winter ranges	1.74	1.50	1.98	1.91
Summer ranges	1.00	1.68	1.48	1.44

[1] Values reported are the average for all vegetative types. The total vegetation FPI is not a simple average of that for grasses, forbs, or shrubs, because the index is weighed by production of each group.

Table 6. Deer utilization of browse as determined from transects on winter ranges of the two study areas. Data for all transects are averaged for the 9-year period, 1967–1975. The browse species analyzed on each transect is noted in parentheses.

	% Utilization	Average twig length (cm)	Deer days use/ha
LaSal Mountain transects			
Pine Ridge (Putr)[1]	39	6.3	40
Amasa's Back (Cemo)[1]	35	6.3	37
Brumley Ridge (Cost)[1]	68	9.0	99
Melroy Ridge (Putr)[1]	34	5.5	54
Henry Mountain transects			
Horn Mountain (Cemo)[1]	16	9.7	22
Horn Mountain (Putr)[1]	20	8.3	17
Side Hill (Cemo)[1]	9	8.3	35
Bull Mountain (Putr)[1]	4	4.8	5

[1] Cemo = *Cercocarpus montanus;* Cost = *Cowania stansburiana;* Putr = *Purshia tridentata.*

Table 7. Average content (%) of nitrogen and phosphorus in five major forage species[1] in each of three plant lifeform categories on the LaSal and Henry Mountains.

	Nitrogen	Phosphorus
Grasses		
LaSal Mountain	1.50[a]	0.13[a2]
Henry Mountain	1.09[b]	0.22[a]
Forbs		
LaSal Mountain	1.77[a]	0.18[a]
Henry Mountain	1.87[a]	0.19[a]
Shrubs		
LaSal Mountain	2.16[a]	0.19[a]
Henry Mountain	1.54[b]	0.19[a]

[1] All of the aboveground tissue of herbs and current year growth (i.e., leaves and annual twig growth of shrubs) was taken in late July 1976.
[2] Superscript letters indicate significance of difference ($P<0.05$ or better) of averages for a specific plant lifeform nutrient element between mountain ranges. Pooled averages that differ significantly have different superscripts.

LaSal summer ranges produce over 60% more herbage per unit area on the average than Henry Mountain summer ranges (Table 4). The composition of summer range forage is dramatically different on the two mountains. Forage on the LaSal ranges is composed of over 50% forbs; the comparable figure for the Henrys is 12%. LaSal summer ranges produce 1,117 kg/ha of fresh weight forbs per year while Henry Mountain ranges produce only 158 kg/ha. Thus, LaSal summer ranges provide over seven times more forb biomass per unit area than comparable ranges on the Henrys.

As mule deer are known to feed heavily on forbs during the summer season (Kufeld et al. 1973), the striking difference in forb production on the two mountains deserves further consideration. Studies on other ranges demonstrate that forbs are good sources of nitrogen, calcium, phosphorus, potassium, carotene, and energy (Stoddart and Greaves 1942; Cook and Harris 1950; Dietz et al. 1962; Cook 1972; and Harner and Harper 1973). Chemical analysis of major grasses, forbs, and shrubs on the LaSal and Henry Mountain summer ranges substantiate those results for nitrogen and phosphorus (Table 7).

Since the vegetation of the Henrys is dominated by shrubs (Table 4), mule deer probably turn to these plants for a significant portion of their summer forage needs. Shrubs are known to be low in digestible energy (Cook 1972; Wallmo et al. 1977), and does feeding on shrubs are likely to have difficulty meeting the energy demands of daily maintenance, lactation, and weight gains required to compensate for winter losses. Cook's (1972) data suggest that stress will be most severe in late summer. Data presented by Wallmo et al. (1977) implied that mature animals that do not gain weight in the summer will not survive the winter in regions where the winter diet is dominated by shrubs. They concluded that Colorado mule deer feeding on browse in the winter experience a dietary energy deficiency which can only be compensated by the intake of more digestible herbaceous forage in the summer.

The shrub-dominated forage of the Henry Mountain summer ranges also may be deficient in protein (Table 7). A recent experimental study of the effects of dietary protein on mule deer productivity has been reported by Robinette et al. (1973). They concluded that diets that were rich in protein resulted in larger body size and a large increase in reproductive rate.

Swank (1956) concluded that mule deer populations in Arizona are largest where deer spend the summer in open ponderosa pine forests with a heavy understory of herbaceous material. Dietz et al. (1962) stated that "a general decline in the quality of summer range would almost certainly be reflected by a corresponding decline in numbers and condition in the associated deer herd."

All of the foregoing studies and data from our study area support our hypothesis that summer range conditions are related to the greater productivity of mule deer on the LaSal Mountains. Before more firm conclusions can be drawn as to the cause(s) of the reproductive differences observed, seasonal dietary studies are needed. Ideally, one would like to know the average dietary intake of a doe in each of these herds and the reproductive consequences of that diet.

Currently we have no firm evidence concerning the origin of the reproductive differences observed in autumn counts of fawns/100 does on the two mountain ranges. We are unable to say whether the observed differences arise from differentials in conception rates or from fawn mortality or both. Future studies should attempt to determine the relative importance of conception rates and fawn mortality in producing the observed differences in productivity.

If summer range condition is an influential variable controlling herd productivity, management techniques for improving forage production and quality should be developed. Much evidence suggests that the relative importance of shrubs has increased through recent decades as a consequence of natural plant succession, overgrazing, and suppression of wildfires in the Intermountain West (Harper and McNulty 1977; West and Tueller 1972; Cottam 1961). Range improvement procedures capable of increasing forbs at the expense of shrubs on summer ranges include late autumn aerial seeding of adapted forbs under aspen and oak canopies, anchor chaining of decadent aspen groves and closed oak stands to induce stand regeneration (Plummer et al. 1968), and controlled fire in areas formerly dominated by aspen but now controlled by noncommercial quality conifers (Kleinman 1973).

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Predation on Range Sheep with No Predator Control

J. KENT McADOO AND DONALD A. KLEBENOW

Highlight: A Great Basin band of open range herded sheep was monitored intensively for losses between June 8 and September 29, 1976, in an area where organized predator control had not been employed for the preceding 9 years. Verified losses due to all causes totalled 69 (4.4% of the band), of which 59 (86%) were due to predation. Forty-eight of the predator losses were lambs, a 6.3% loss of the lambs in the herd. Eleven adults were killed by predators.

Ninety percent of the predator losses were attributed to coyotes (*Canis latrans*), 2% to bobcats (*Lynx rufus*), and 8% to predators of undetermined species. Physical condition was determined for 41 of the sheep attacked by predators: 93% were healthy and 7% were in poor condition. Predation intensity varied from approximately one loss every 6 days in June to almost one per day in August and September.

The efficiency of government-conducted predator control programs in curtailing sheep losses on western ranges has been questioned in recent years by the sheep industry, environmentalists, and the control agencies. Many ranchers feel that toxicants, banned by Executive Order in 1972, were efficient in keeping coyote numbers down and thereby reducing depredations. Current methods which have replaced toxicants are believed by most operators to be much less efficient.

Wagner (1972) questioned the common procedure of evaluating predator control programs by comparing the cost of such programs with the economic loss represented by depredations on livestock (sheep). Inherent in this mode of comparison is the assumption that, without control, predator numbers would be greater and depredations much higher.

Recently, the U.S. Fish and Wildlife Service, responsible for predator control in many western states, has conducted several studies to determine the extent of predation in areas without control. Research was conducted on a Montana ranch in 1974 (Henne 1975) and 1975 (Munoz 1976), and on a New Mexico ranch in 1974 and 1975 (DeLorenzo and Howard 1976). These studies reported much higher losses than are apparently typical of most western range operations (Presnall 1948; Nielson and Curle 1970; Reynolds and Gustad 1971; Early et al. 1974a and b; Magleby 1975; Klebenow and McAdoo 1976). However, results could have been influenced by variables other than the lack of predator control. In the Montana and New Mexico studies, sheep were grazed in large fenced pastures, unherded. Nearly half of the sheep in the West are grazed on open range (Gee and Magleby 1976), and usually watched by herders.

Although no control was the goal during the Montana and New Mexico studies, it probably was not achieved in either case. Predator control was employed in both of the Montana studies during the 5-month period after lambs were shipped. No control was employed during the New Mexico study, but adjacent ranches intensified control efforts, and the researchers believed this may have influenced results.

With these problems in mind, the operation chosen for this study was one in which sheep were herded on open range, and in an area where predator control had not been conducted by government agencies for the preceding 9 years. According to George Roberts, the rancher whose sheep we studied, little or no commercial trapping occurs on his summer range (the study area).

Since the rancher cooperated by branding a separate bunch of sheep for research purposes and agreed to herd these sheep in a manner "typical" of sheep operations in the Great Basin area, he was reimbursed by the Fish and Wildlife Service for all verified predator losses. The study began shortly after the sheep arrived on summer range (June 8, 1976), and was terminated when market lambs were separated out to be fattened on alfalfa (September 29, 1976).

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Study Area and Sheep Management

The area on which the study band ranged was located on the west slope of the Sweetwater Mountains (about 32 km northwest of Bridgeport, California, and 14 km southwest of the Nevada State line), on the Bridgeport District of the Toiyabe National Forest. Elevation on this 5,700-ha area varied from 2,100 to 3,000 m.

The area was dominated by northern desert shrub, mountain brush, and pine forest type vegetation. Big sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), snowberry (*Symphoricarpus* spp.), and serviceberry (*Amelanchier alnifolia*) were the common shrubs in the area. Grasses and forbs included bluebunch wheatgrass (*Agropyron spicatum*), bottlebrush squirreltail (*Sitanion hystrix*), bluegrass (*Poa* spp.), lupine (*Lupinus* spp.), and arrowleaf balsamroot (*Balsamhoriza sagittata*).

Mountain mahogany (*Cercocarpus ledifolius*) occurred in stands along some ridge tops. In addition, groves of aspen (*Populus tremuloides*) and patches of willow (*Salix* spp.) were common along stream bottoms and adjacent slopes. Stands of lodgepole pine (*Pinus contorta*) occurred at higher elevations, primarily on north slopes.

Terrain varied from gently rolling hills and almost flat terraces, to very steeply sloping canyons. Three small streams flowed through the area.

The climate is characterized by long, cold winters and warm, dry summers. Annual precipitation, primarily in the form of snow, falls mostly during the winter and spring.

The initial study band consisted of 238

ewes and 312 lambs (550 sheep total). Although such a small band is not typical of western range operations, original intent was to keep the flock small in order to facilitate reimbursement of the rancher in the event that predator losses should skyrocket under the "no control" study conditions. However, on July 28, 1976, the study band and another band from the same operation mixed, resulting in a band consisting of approximately 1,240 ewes and 1,125 lambs (2,365 sheep total). Since losses had been minimal to this point, a decision was made to study this larger band of more representative size, rather than attempt to separate out the original band.

Throughout the study period, the sheep were open-herded as recommended by the U.S. Forest Service. The herder was requested to bed the sheep as is typical of western range operations. Also, propane "cannons" used by other herders in this operation to avert coyotes were considered nontypical, and were not used near the study band. However, the herder did carry a rifle and pistol, and shot at predators, since this practice is typical of most western operations.

Methods

Research personnel made at least two searches daily for carcasses, wounded animals, and lost or strayed sheep. An investigator accompanied the herder at dawn each morning as the sheep were moved off bedding areas. These bedding grounds and surrounding vicinities were checked thoroughly for losses by making several transects afoot and glassing all open areas. Dogs were also used successfully for searching out losses in heavy cover.

Day-use areas (where sheep grazed, watered, and rested) were routinely checked each afternoon in conjunction with moving the sheep toward bedding areas. Areas of dense vegetation were often rechecked at mid-day (when shadows are few) for possible losses overlooked earlier.

Strays and incapacitated animals were located by making trips into areas previously occupied by sheep. In addition, the periphery of the band was checked daily for the slower moving wounded, crippled, or diseased animals.

After a carcass was located, the objective was to determine whether the animal had been attacked and killed by a predator, or had died from other causes. Techniques for verifying causes of death have been described by Rowley (1969, 1970), Wiley and Bolen (1971), Bowns et al. (1973), and McAdoo (1975). Primarily, the presence or absence of puncture wounds, in conjunction with subcutaneous hemorrhages, free blood, and bloodstains were the bases for differentiating between predator-caused losses and other losses.

Nondeath losses included strays and wounded animals. Only those strays which were permanently abandoned were recorded. Since buyers will not accept animals which have survived attacks by predators, animals so wounded were also recorded as losses. Most of these animals apparently die eventually from shock, infection, or biological stress (Bowns 1976).

Wounds, types of consumption patterns, tracks, droppings, sightings of predators in the area, and other kill-site evidence were used to determine the predator species involved in each attack on sheep. Predator identification has been discussed by Rosko (1948), Gier (1957), Rowley (1969), Bowns et al. (1973), and McAdoo (1975).

Victims of predator attacks were examined for any external abnormalities (swollen joints, broken bones, general emaciation, etc.). Lacking any external evidence of a weak condition, the health of a lamb was judged by its relative size compared to other lambs at that time.

Two major (corral) counts of sheep, when the bands were organized at shearing time (June 8, 1976), and again when the market lambs were separated out (September 29, 1976), permitted a comparison between verified and actual losses. Also, during the period when the small band was being studied (June 8–July 27), four accurate field counts were made. After mixing with the other band, the resulting larger band did not easily lend itself to field counts.

Results

A total of 69 losses (due to all causes) was verified. Fifty-nine (86%) were due to predation, and ten (14%) to miscellaneous causes (Table 1). Miscellaneous losses included two old ewes which died of undetermined natural causes, five lambs which died from disease, and three stray sheep (2 ewes, 1 lamb). The 59 predator losses included eight lambs which were wounded but not killed outright. One of these was taken to the ranch for treatment and died within 3 days. Four apparently died within 2 days of observation since they were never again observed in the band. The other three were wounded later in the study and were considered to have died eventually.

The determination of the predation rate was complicated by the quadrupling of band size which resulted when the original study band mixed with another in late July. Before mixing, 1.6% of the original band was lost to predators; and after mixing, 2.1% of the newly formed band fell prey. Based on the average size of the band for the study duration, an overall predation rate of 3.8% was incurred, and 0.6% of the band was lost to miscellaneous causes (Table 1). Predators killed 6.3% of the lambs.

The mixing of the initial study band with another band also complicated the determination of verification success. The last count made of the small band (one week before mixing occurred) indicated that 100% of all losses to this time had been accounted for. The next count obtained was the count of the larger mixed band at termination of study (September 29).

Early summer counts obtained at shearing were available for both the initial study band and the band with which it was later mixed. Therefore, it was possible to compare the number of verified losses for the composite band which occurred after mixing to the number of losses based on counts. However, the final count at shipping indicated that 53 more losses were verified than the counts indicated. Apparently, an incorrect count at shearing of the band with which the initial study band eventually mixed was the cause of this discrepancy. Because of this counting error, verification success could not be accurately determined. We believe we found most of

Table 1. Domestic sheep losses (no.) and predation intensity verified from a Great Basin range band during the summer of 1976.

		Verified losses						
	Length of period	Predation		Miscellaneous		Totals		Predation intensity (1 loss/
Time period	(days)	Ewes	Lambs	Ewes	Lambs	Ewes	Lambs	no. days)
June (6/8–6/30)	23	—	4	—	2	0	6	1/6
July (7/1–7/31)	31	—	6	1	1	1	7	1/5
August (8/1–8/31)	31	5	20	1	1	6	21	1/1
September (9/1–9/28)	28	6	18	2	2	8	20	1/1
Totals	113	11	48	4	6	15	54	1/2 (Avg.)
Total ewes plus lambs		59 (86%)		10 (14%)		69 (100%)		
Percent of total band		3.8		0.6		4.4		

the dead sheep, possibly even 100% of the losses.

Predation intensity, a measure of predation frequency based on verified losses, has been expressed as one predator loss per X number of days (Table 1). Predator losses varied from approximately one loss in 6 days during June, to one loss in 5 days for July, to almost one loss per day in August and September. During the entire study, the band incurred an average predation intensity of nearly one loss every 2 days.

Of the 59 predator losses verified, 53 (90%) were attributed to coyotes (*Canis latrans*), 1 (2%) to a bobcat (*Lynx rufus*), and 5 (8%) to predators of undetermined species (Table 2). Black bears (*Ursus americanus*) and mountain lions (*Felis concolor*) were present in the study area, but no depredations by these species were verified.

Table 2. Verified sheep losses (from a Great Basin range band) attributed to different predators during the summer of 1976.

Predator	Sheep losses	
	Number	% of total
Coyote	53	90
Bobcat	1	2
Bear	0	0
Lion	0	0
Undetermined	5	8

Table 3 lists the estimated physical condition of 41 sheep which were attacked by predators. Thirty-eight (93%) of these sheep were classified as healthy; three (7%) were in poor condition. Two of these were relatively small lambs attacked in July, and the other was a large wether which had been observed previously limping and lagging behind with a swollen front leg joint. The physical condition for 18 losses was considered nonassessable. These sheep had been consumed to such an extent by predators and/or scavengers that accurate assessments were not possible.

Discussion

Predation was the major cause of sheep losses during the study. Several studies have shown predation on western ranges to be the primary cause of summer sheep deaths (Bowns et al. 1973; Early et al. 1974a and b; Henne 1975; Klebenow and McAdoo 1976; Munoz 1976). Generally speaking, sheep are in good physical condition during the summer period, and except for instances when herders lose many strays, predation can be expected to be the major cause of loss during this time.

Table 3. Physical condition of 41 predator losses verified from a Great Basin range sheep band during the summer of 1976.

Condition of sheep	Losses	
	Number	% of total
Healthy	38	93
Poor	3	7

The 3.8% predation rate on the total herd and 6.3% loss of lambs to predators in our Great Basin study are much lower than those reported during "no control" studies in New Mexico and Montana. DeLorenzo and Howard (1976) reported 15.6% and 12.1% losses of lamb crops to predators in two consecutive years in New Mexico. Henne (1975) reported that predators killed 29.3% of the lamb crop on a Montana ranch during 1974, and the following year Munoz (1976) reported a loss of similar magnitude (24.4%) on the same ranch. More than 16% of the total flock was killed each year during these two studies.

The relatively short duration of our study (compared to the above-mentioned studies) may partly account for the difference in results. If the equivalent 4-month time periods (June through September) are considered for each of the above studies, a more valid comparison can be made. From data reported by DeLorenzo and Howard (1976), we calculated lamb losses (to predators) of 8.8% and 5.6% for the summers of 1974 and 1975, respectively, in their New Mexico study. Similar calculations, using data reported by Henne (1975) and Munoz (1976), showed summer predation rates on lambs of about 14% and 13% (in 1974 and 1975, respectively), during their studies in Montana. Except for the 1975 summer period of the New Mexico study, these loss rates are all higher than the 6.3% loss of lambs to predators during our "no control" study.

When an analysis of each of the "no control" studies is made, the obvious difference between ours and the others is that of sheep management. During our study, sheep were herded daily by a herder, to and from grazing, watering, salting, and bedding areas. This is typical of many large operations which graze sheep on public lands in the Great Basin. The other studies involved sheep being grazed "unherded" within large fenced pastures on private land. Perhaps the presence of a herder as he moves the sheep with dogs twice daily, shouting and whistling, shooting at predators sighted, often staying with the sheep for several hours at a time, is in itself a deterrent to predation.

Other factors, such as predator density, natural prey density and/or availability, could also be partially responsible for the differences in predation rates between each of the "no control" studies. However, these parameters were not measured and no valid comparisons can be made.

Attempts were made during the study to simulate herding as is practiced commonly in the Great Basin. However, in the process of encouraging the herder not to use his propane cannon or bring his sheep to camp each night, he may have derived the idea that his band should be essentially ignored at night. On 28 occasions (during August and September), his sheep were bedded in multiple (2 to 5) bunches, 0.5 to 2.5 km apart (Table 4). Twenty-nine sheep were attacked by coyotes during these multiple bunch nights.

Table 4. Comparison of sheep killed on nights when band was bedded in one bunch versus nights when band was bedded in multiple bunches 0.5 to 2.5 km apart.

Number of bunches	Number of nights	Number of kills	Number of kills/ night
Multiple (2–5)	28	29	1.04
One	30	20	0.67

This is an average of 1.04 sheep killed per night, compared to 0.67 sheep killed per night during the one-bunch nights of these same months. Apparently, leaving the sheep bedded in more than one group at night increased exposure to predators and thus increased predator losses. Peripheral bunches received little or no protection afforded by the herder and his dogs.

Herd size was determined by computing the average size of the band during the study, since the original bunch mixed with another during late July. The question arises: Which is more vulnerable to predation, a small band or a large one? Perhaps no conclusive answer can be given. However, in light of observations made during the study, we believe that a relatively small band in a given area may suffer a number of predator losses similar to a larger band in the same area, though predation rate for the small band would be greater. During the period before the herds mixed, our small band (550 head) incurred nine predator losses, compared to six losses observed by the herder for the larger band (1,815 head) with which we mixed. However, the herder was using a propane cannon at this time and no doubt herding more intensively, complicating the comparison.

The late summer predation increase observed in our study has also been reported by several researchers on other western ranges (Rosko 1948; Bowns et al. 1973; Klebenow and McAdoo 1976; Terry Rock personal communication, Saskatchewan Dep. of Natural Resources, Saskatoon). This increase was forecasted by ranchers and herders. Carcasses of predator losses verified in late summer were utilized to a greater extent by coyotes than those found earlier in the summer, and were fed on extensively by pups (judging by tracks and feces near kills). The growing pups are more active in late summer, and we believe that the resultant increased food requirement is a cause of the peak in predation intensity at this time of year.

The majority of sheep attacked by predators were healthy. Henne (1975), Klebenow and McAdoo (1976), and Munoz (1976) reported similar findings. Domestication has bred out natural defense and/or escape mechanisms in sheep (Kupper 1945; Howard 1974). There is no reason to believe that predators are forced to select unfit individuals among an introduced species which, even when healthy, are highly susceptible as prey. Since coyotes are attracted by movement of prey (Fox 1971), more active, healthier animals can be expected to be attacked most often. Field observations of coyotes chasing sheep (Henne 1975; McAdoo 1975) indicated that coyotes tend to pursue a fast-moving animal which breaks away from the herd.

We believe that our study area came as close to being free from the influence of predator control as is possible for an area of sheep-grazed public land. The nearest government control took place during winter and spring in valleys approximately 30 to 60 km from the study area, and consisted primarily of intensive aerial shooting and some trapping. Commercial trapping was apparently negligible on the study area, and was probably inconsequential (though unmeasured) in the outlying vicinities of lower elevations.

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Use of Infiltration Equation Coefficients as an Aid in Defining Hydrologic Impacts of Range Management Schemes

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Highlight: Based on infiltrometer data from 13 pinyon-juniper sites in Utah, the relationship of selected rangeland vegetation characteristics and soil physical properties to the various infiltration coefficients contained in three well-known algebraic infiltration equations was determined. Coefficients in Kostiakov's equation were related more to vegetation factors than to soil factors while coefficients in Philip's equation were more related to soil factors than to vegetation factors. The single coefficient in Horton's equation was somewhat intermediate, representing both vegetation and soil influences. It is conceivable that changes in rangeland use activities or intensity of use may be detected through changes encountered in infiltration coefficients, with emphasis on either vegetation or soil factors or both, depending on the equation or model used.

The relationship of infiltration in native and "disturbed" rangeland plant communities to soil and vegetation parameters has been of interest to hydrologists for many years. Many devices have been designed to measure infiltration rates, and these range from ring-type infiltrometers to sprinkling-type devices that attempt to duplicate certain characteristics of natural rainfall.

Based on actual measurements, various researchers have found that the results of infiltrometer trials may be expressed in terms of specific models or equations. Examples include Kostiakov's equation (1932), Horton's equation (1940), and Philip's equation (1957). Each of these equations contains various coefficients, most of which are speculatively related in some (perhaps unidentified) way to factors that may be controlling the infiltration process. The objective of this study was to determine, to the extent possible, the relationship of selected rangeland vegetation characteristics and soil physical properties to the various infiltration coefficients contained in the three well known algebraic infiltration equations mentioned above. This objective is especially pertinent in terms of possible interpretations of long- or short-term temporal changes in infiltration rates as a function of specific management plans, and especially in those circumstances where supplemental soil and vegetation data are minimal or completely lacking.

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Available Infiltrometer Data

All infiltrometer data were collected using the Rocky Mountain infiltrometer (Dortignac 1951). Plots (0.23 m^2) were run with soils at field capacity to start (prewet and allowed to drain). Samples were collected at selected time intervals during each infiltrometer run, and infiltration was assumed to be the difference between rainfall applied and runoff. Rainfall application rates generally exceeded 7 cm/hour and represented relatively low probability short-term high intensity convectional thunderstorms of approximately 30-min duration.

Infiltrometer data from approximately 500 infiltrometer plots covering 13 pinyon-juniper (*Pinus* spp.-*Juniperus* spp.) plant communities (250 mm to 325 mm annual precipitation) scattered throughout Utah were utilized for this study. For 12 of these sites, the following vegetation and soil information was available for each infiltrometer plot: bare soil (%); total vegetal crown cover (%); soil <2 mmd (%); silt plus clay (0–7.5 cm depth %); total porosity (0–7.5 cm depth %); noncapillary porosity (0–7.5 cm depth %); and bulk density (gms/cc 0–7.5 cm depth) (Williams et al. 1972). For site 13, vegetation cover and yield data were available plus soils data from both undisturbed 7.5-cm diameter soil cores and disturbed samples from both the 0–2.5 cm depth and the 0–7.5 cm depth. These data were as follows: total yield of vegetation on plot (kg/ha); bare ground (%); water-stable sand-sized aggregates (%); sand + sand-sized aggregates (%); silt (%); clay (%); saturated hydraulic conductivity (cm/hour); total porosity (%); capillary porosity (%); and bulk density (gms/cc) (Busby 1977).

Analysis Procedure

The three infiltration equations included in this analysis were as follows:

$$f = cnt^{n-1} \quad \text{(Kostiakov 1932)} \quad (1)$$

$$f = f_c + (f_o - f_c)e^{-kt} \quad \text{(Horton 1940)} \quad (2)$$

$$f = \frac{30S}{\sqrt{t}} + A \quad \text{(Philip 1957)} \quad (3)$$

where:

f = infiltration rate, in length/hour;
t = time (min) elapsed since simulated rainfall began;
c, n, k, s, and A = coefficients;
f_c = the constant rate approached by f asymptotically as time continues, in length/unit time;
f_o = initial infiltration capacity, when $t_o = 0$.

Equations (1) and (2) are strictly empirical while the Philip equation was derived based on the physics of flow through unsaturated porous media. In this latter instance, the first term of equation (3) describes the uptake of water by porous media via capillary forces and dominates infiltration when time is small, while the second term, A, describes the ability of the soil to transmit water due to gravity forces and becomes increasingly important with time.

Each of the three equations was fit to infiltration data from each plot on a given pinyon-juniper site and, based on the least squares fit, values were determined for each of the five coefficients. A stepwise multiple-regression analysis was then used to determine the relationship of the various vegetation and soil parameters to the five infiltration coefficients.

Results and Discussion

The amount of variance associated with each infiltration coefficient as explained by the seven vegetation and soil parameters (% crown cover and % bare soil were included as a quadratic function) on 12 of the pinyon-juniper sites is shown in Figure 1. R^2 values for c range from 0.35 to 0.98 ($\bar{x}$ = 0.85); for n from 0.25 to 0.96 ($\bar{x}$ = 0.61); for k from 0.30 to 0.79 ($\bar{x}$ = 0.54); for S from 0.37 to 0.92 ($\bar{x}$ = −0.75); and for A from 0.23 to 0.83 ($\bar{x}$ = 0.64). Two examples of the ability of the seven parameters to explain variance associated with the five infiltration coefficients are shown in Figures 2 and 3 for different pinyon-juniper sites.

Significant soil and vegetation parameters for each infiltration coefficient, as defined in a pooled analysis (the 12 pinyon-juniper sites combined) were as follows:

Infiltration coefficient	Significant soil or vegetation parameter (.05 level)	Variance explained (%)
c	(% crown cover)^2	70
	total porosity (%)	12
	% soil <2 mmd	8
n	(% bare soil)^2	34
	(% crown cover)^2	33
	% soil <2 mmd	9
k	bulk density	32
	(% crown cover)^2	24
	% noncapillary porosity	9
S	% soil <2 mmd	55
	bulk density	25
	(% crown cover)^2	7
A	% soil <2 mmd	55
	% silt + clay	6
	bulk density	5

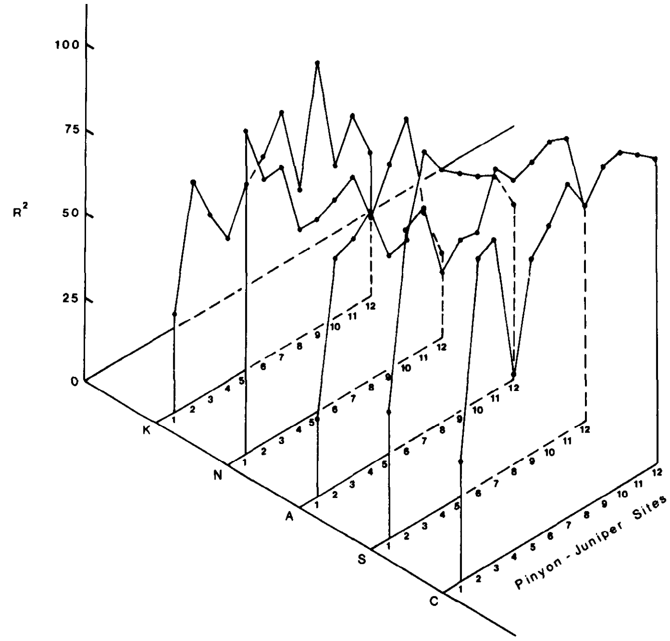

Fig. 1. *Amount of variance (R^2, %) associated with each infiltration coefficient as explained by seven vegetal and soil parameters on 12 pinyon-juniper sites in Utah.*

Analysis of data from pinyon-juniper site 13, a site on very uniform sandy loam soils in southeastern Utah, was somewhat disappointing. As previously mentioned, besides vegetation data, detailed soil data were available for each plot from undisturbed soil cores and disturbed samples collected from both the 0–2.5 cm and the 0–7.5 cm soil depths. However, R^2 values representing both sets of data indicates inadequate fit of the multiple regression model to any of the infiltration coefficients (maximum R^2 = .08; Fig. 4).

Discussion

The five infiltration coefficients studied were not related in a totally consistent way to any of the soil and vegetation parameters measured on infiltrometer plots. R^2 values for the various coefficients (as defined by multiple regression analyses) ranged

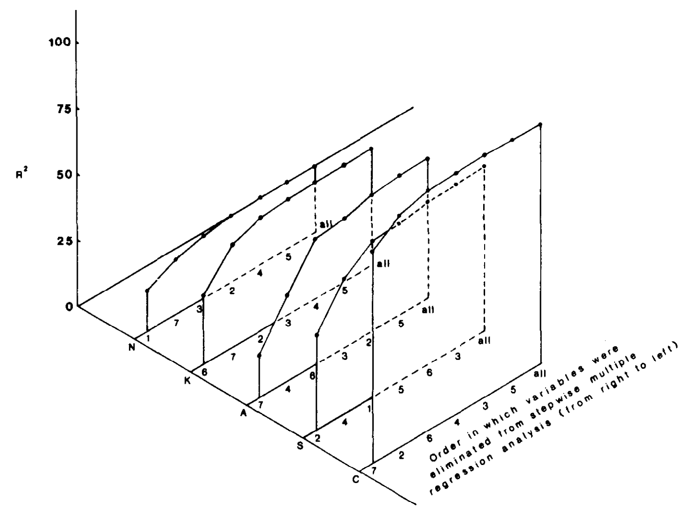

Fig. 2. *Amount of variance (R^2, %) at pinyon-juniper site 11 associated with each infiltration coefficient as explained by the following factors: X_1 = total porosity; X_2 = bulk density; X_3 = non-capillary porosity; X_4 = silt + clay; X_5 = soil <2 mmd; X_6 = (bare soil)^2; and X_7 = (crown cover)^2.*

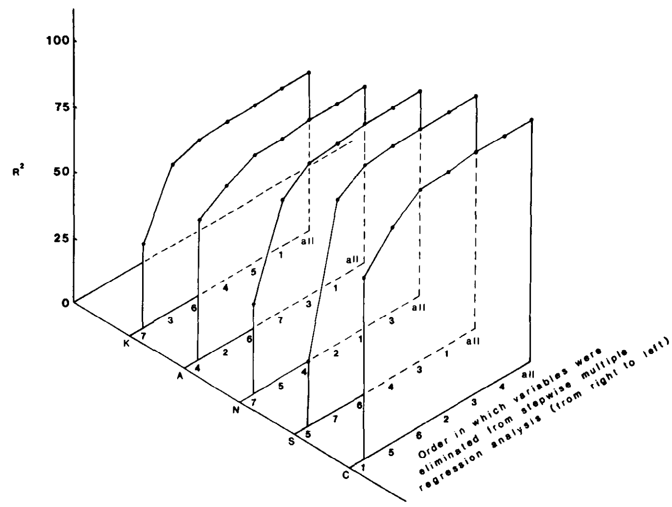

Fig. 3. *Amount of variance (R^2, %) at pinyon-juniper site 1 associated with each infiltration coefficient as explained by the following factors: X_1 = total porosity; X_2 = bulk density; X_3 = non-capillary porosity; X_4 = silt + clay; X_5 = soil <2 mmd; X_6 = (bare soil)^2; and X_7 = (crown cover)^2.*

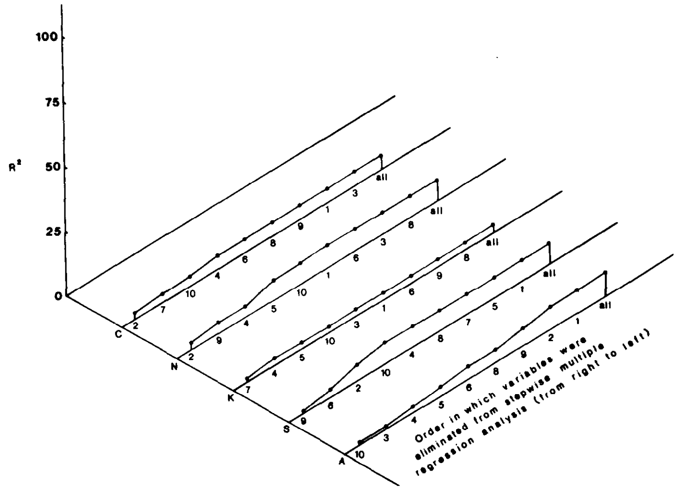

Fig. 4. *Amount of variance (R^2,%) for data from the 0-7.5 cm soil depth at pinyon-juniper site 13 associated with each infiltration coefficient as explained by the following factors: X_1 = kg/ha vegetation on plot; X_2 = bare ground; X_3 = water stable sand-sized aggregates; X_4 = sand + sand size aggregates; X_5 = silt; X_6 = clay; X_7 = hydraulic conductivity; X_8 = capillary porosity; X_9 = total porosity; and X_{10} = bulk density. Data from the 0–2.5 cm depth looked nearly identical.*

from 0.02 to 0.98 over 13 pinyon-juniper sites scattered throughout Utah. Based on an analysis of data pooled over 12 sites it appeared that coefficients in Kostiakov's equation were related more to vegetation factors than to soil factors, while coefficients in Philip's equation were more related to soil factors than to vegetation factors. The single coefficient in Horton's equation was somewhat intermediate, representing both vegetation and soil influences.

It is recognized that both soil and cover factors interact in a complex and highly variable way to determine the rate at which the infiltration process takes place on a given site (other things being equal). Assuming that the Rocky Mountain infiltrometer provides a valid measure of infiltration rates, then it is obvious that on most sites other unmeasured soil and vegetation properties were also acting to control the behavior of the various coefficients. Because vegetative cover is often relatively sparse on semiarid rangeland sites, it was anticipated that soil physical properties would be extremely important in all attempts at modeling the infiltration process. However, based on this study, it appears that some models may be more sensitive to vegetation or soil protective cover and resultant impact on the infiltration process than to the input of soil parameters. It is therefore conceivable that changes in rangeland use activities or intensity of use may be detected through changes encountered in infiltration coefficients, with emphasis on either vegetation or soil factors or both, depending on the equation or model used. Obviously, as was reflected in the R^2 values, changes in infiltration coefficients may at times not reflect changes in any of the soil or vegetation parameters included in this study.

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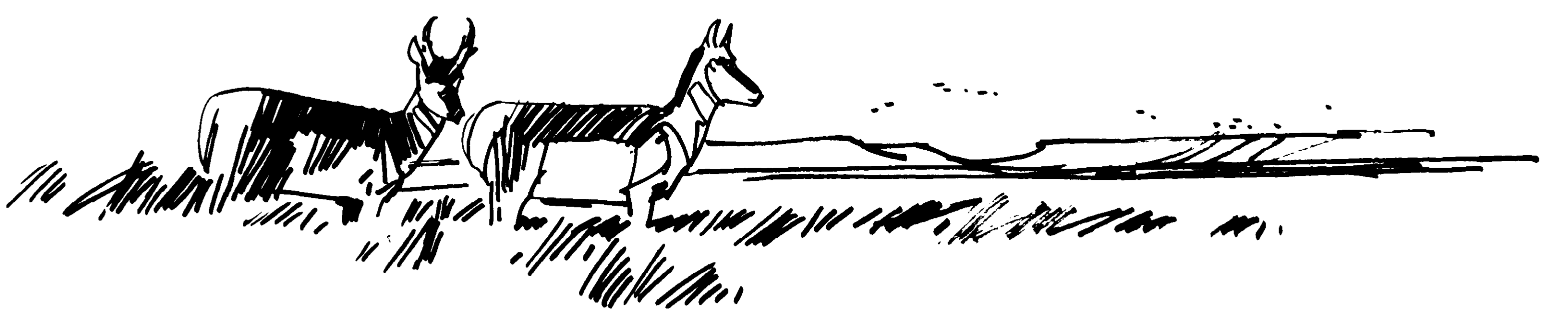

Estimation of Plant Biomass from Quadrat Data Using the Lognormal Distribution

GARY C. WHITE

Highlight: This paper introduces a new method of estimating plant biomass from a series of randomly located quadrats. A mixture of the binomial and lognormal distributions provide a more realistic probability density function than the commonly used normal distribution. Point and interval estimators are derived using the method of Maximum Likelihood (ML). Example calculations illustrate the method.

This paper introduces a new method of estimating plant biomass based on a series of randomly located quadrats. For a particular taxon, a series of biomass weights, $x_1,\ldots,x_n$, are measured on n quadrats. The x_i are assumed observations of the random variable X. Two characteristics of these data are:

1) the taxon does not occur on every quadrat, so many of the x_i values are zero; and,
2) the distribution of positive values is highly skewed to the right (Fig. 1).

The usual method of estimating the biomass and a confidence interval is as follows:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$s^2 = \left[\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2/n\right]/(n-1)$$

$$95\%\ \text{C.I.} = \bar{x} \pm t_{(n-1;0.05)}\ s/\sqrt{n}$$

where $\bar{x}$ is the estimated mean biomass,

s^2 is the estimated $\text{Var}(x_i)$, assumed constant for all x_i,

$s/\sqrt{n}$ is the estimated $\sqrt{\text{Var}(\bar{x})}$, and

$t(n-1;0.05)$ is a 0.05 level t-statistic with $n-1$ degrees of freedom.

$\bar{x}$ is an unbiased estimate of E(X). However, the construction of the 95% confidence interval is dependent on X being normally distributed for finite n. For large n, the Central Limit Therom can be used to justify the use of the normal distribution. Unfortunately, biologists seldom have sample sizes compatible with this assumption, but basically claim a normal distribution for the random variable X to construct the confidence interval. This may result in too short an interval estimate and give the estimate of biomass an illusion of preciseness. The purpose of this paper is to present a method of estimating biomass and an appropriate confidence interval based on realistic distributional assumptions about the observed x_i.

Maximum Likelihood Estimation with the Lognormal Distribution

A realistic representation of the distribution of X (biomass weights) is as follows:

$$P[X < 0] = 0,$$
$$P[X = 0] = \delta,$$
$$P[X > 0] = 1-\delta$$

δ is then the proportion of zero values in the sample. Positive values of X are assumed to be lognormally distributed. The assumption of lognormality is more realistic than the assumption of normality because this distribution has a range from 0 to

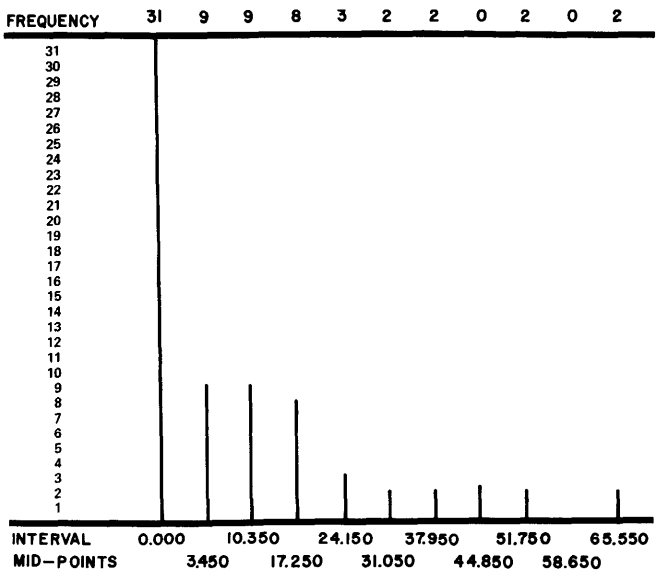

Fig. 1. *A typical frequency distribution of biomass weights measured on randomly located quadrats. The first frequency represents the quadrats with zero biomass.*

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infinity; hence there is no probability that negative values will be observed. Also the lognormal distribution is skewed to the right. A second justification for the application of the lognormal distribution is based on the "law of proportionate effect." This law applies to a process of change where the random variable at any step of the process is a random proportion of the previous value of the random variable (Rustagi 1964). A random variable which is the result of a continued series of such proportional effects tends to be lognormal. For the weight of wet biomass of a species observed on a quadrat, possible proportionate effects may be rainfall, mineral content of the soil, or any of the other environmental parameters affecting the species growth. A competing probability density function might be the gamma distribution. However, the gamma distribution cannot be justified with the law of proportionate effect as can the lognormal distribution. Other skewed distributions such as the negative binomial and the Poisson are not reasonable because they assume X is a discrete variable, while biomass is clearly a continuous variable. Estimation for $X > 0$ will now be considered under the lognormal distribution, $\Lambda(\mu,\sigma^2)$.

Estimation of the parameters of the lognormal distribution has been extensively studied by Finney (1941), Aitchison and Brown (1969), and Bradu and Mundlak (1970). Let $y_i = \log(x_i)$ so that y_i has the normal probability density function

$$f(y)dy = \frac{1}{\sigma\sqrt{2\pi}} \exp[-(y_i-\mu)^2/2\sigma^2]dy.$$

Define $\alpha = E(X)$, and $\beta^2 = \mathrm{Var}(X)$ (for $X > 0$). The minimum variance unbiased estimators of α and β^2 are respectively

$$\hat{\alpha} = \exp(\bar{y})g_n(1/2\, s_y^2),$$

$$\hat{\beta}^2 = \exp(2\bar{y})[g_n(2s_y^2) - g_n(\frac{n-2}{n-1} s_y^2)]$$

where

$$\bar{y} = \sum_{i=1}^{n} y_i/n,$$

$$s_y^2 = \sum_{i=1}^{n} (y_i-\bar{y})^2/(n-1)$$

and the function

$$g_n(t) = 1 + \frac{n-1}{n} t + \frac{(n-1)^3 t^2}{n^2(n+1)2!} + \frac{(n-1)^5 t^3}{n^3(n+1)(n+3)3!} + \ldots.$$

The function $g_n(t)$ was first derived by Finney (1941) to correct the bias of the ML estimator of α:

$$\hat{\alpha}_{MLE} = \exp(\bar{y} + s_y^2/2)$$

because

$$E[\hat{\alpha}_{MLE}] = E(X)\bullet\exp\left[-\frac{(n-1)}{n}\frac{\sigma^2}{2}\right]\bullet\left(1-\frac{\sigma^2}{(n-1)}\right)^{-(n-1)/2}$$

This result assumes s_y^2 defined as above, and not the ML estimator of s_y^2. The ML estimator is consistent but has positive bias for finite samples.

The series $g_n(t)$ is slow to converge but is easily programmed for solution by computer:

$$(j^{th}+1)\text{ term} = j^{th}\text{ term}\bullet\left\{\frac{(n-1)^2 t}{n\, j\,(n+2j-1)}\right\} \quad (j = 2,3,\ldots)$$

The function $g_n(t)$ is tabled for $-2 \leq t \leq 2$ and for increments of n up to 5000 by Bradu and Mundlak (1970).

Bradu and Mundlak (1970) give an exact expression for $\mathrm{Var}(\hat{\alpha})$:

$$\mathrm{Var}(\hat{\alpha}) = \exp(2\mu)\,[\exp(2\sigma^2/n)\; G_n(\frac{\sigma^2}{2} - 1/2\,\frac{\sigma^2}{n}) - \exp(\sigma^2)]$$

where $G_n(t) = \exp(2t)\, g_n(2(n+1)t^2/n^2)$, a useful relation provided by Evans and Shaban (1974), and $\bar{y}$ and s_y^2 are estimates substituted for the unknown parameters μ and σ^2.

The E(X) is often estimated with a geometric mean. However, note the resulting estimate is biased low, because the factor $g_n(1/2\, s_y^2)$ is always greater than unity for $s_y^2 > 0$. Hence the geometric mean is not an appropriate estimator, and should not be used with lognormal data.

With the above summary of parameter estimation for the lognormal distribution, estimators for quadrat data where zero values occur will now be considered. Zero values represent the case where the species did not occur on the quadrat.

Let the population be such that there is a proportion δ of zero values and the distribution of positive values in lognormal, $\Lambda(\mu,\sigma^2)$. If X still denotes the corresponding random variable then

$$P[X < 0] = 0$$
$$P[X = 0] = \delta$$
$$\text{and}\quad P[X > x] = \delta + (1-\delta)\,\Lambda(\mu,\sigma^2) \qquad (x > 0).$$

We then write that X is $\Delta(\delta,\mu,\sigma^2)$ (Aitchison and Brown 1969). The multiplication property of the lognormal distribution also holds for the delta distribution (Aitchison and Brown 1969), i.e., if X_1 and X_2 are Δ-variates, then X_1X_2 is also a Δ-variate. Therefore the same arguments that justify the use of the lognormal distribution for positive values can be used to justify the delta distribution as a representation of both zero and positive values.

Suppose a sample of size n is taken from $\Delta(\delta,\mu,\sigma^2)$, and that n_0 zero values occur, and the remaining $n_1 = n-n_0$ positive values are $x_i (i=1,\ldots,n_1)$. Let

$$\bar{y} = \sum_{i=1}^{n_1} y_i/n_1 \qquad (n_1 > 0),$$
$$= 0 \qquad (n_1 = 0),$$

and

$$s_y^2 = \frac{1}{n_1-1}\sum_{i=1}^{n_1}(y_i-\bar{y})^2 \qquad (n_1 > 1)$$

$$= 0 \qquad (n_1 = 0,1)$$

The likelihood function of the sample is derived from a mixture of the binomial and lognormal distributions:

$$\binom{n}{n_0}\, \delta^{n_0}\,(1-\delta)^{n_1}\frac{1}{(\sigma\sqrt{2\pi})^{n_1}}\exp\left\{-\frac{1}{2\sigma^2}\sum_{i=1}^{n_1}(y_i-\mu)^2\right\}$$

Aitchison and Brown (1969) show that n_0/n, $\bar{y}$, and s_y^2 are jointly sufficient estimators for δ, μ, and σ^2, and so any function of n_0/n, $\bar{y}$, and s_y^2 is a most efficient estimator of its expectation. To obtain the most efficient estimators of $\kappa = E(X)$ and $\rho^2 = Var(X)$, functions of n_0/n, $\bar{y}$, and s_y^2 must be found whose expectations are κ and ρ^2. These estimators, $\hat{\kappa}$ and $\hat{\rho}^2$, are given by Aitchison and Brown (1969):

$$\hat{\kappa} = \frac{n_1}{n} \exp(\bar{y})\ g_{n_1}(1/2\ s_y^2) \qquad (n_1 > 1)$$

$$= \frac{x_1}{n} \qquad (n_1 = 1)$$

$$= 0 \qquad (n_1 = 0)$$

and

$$\hat{\rho}^2 =$$

$$\frac{n_1}{n}\exp(2\bar{y}) \left[g_{n_1}(2s_y^2) - \frac{n_1 - 1}{n-1} g_{n_1}\left(\frac{n_1 - 2}{n_1 - 1} s_y^2\right) \right] \qquad (n_1 > 1)$$

$$= \frac{x_1^2}{n} \qquad (n_1 = 1)$$

$$= 0 \qquad (n_1 = 0)$$

For large n

$$Var(\hat{\kappa}) = \frac{\alpha^2}{n} \left\{ \delta(1-\delta) + 1/2(1-\delta)^2\ (2\sigma^2 + (\sigma^2)^2) \right\}$$

Note that this formula differs slightly from that given by Aitchison and Brown (1969).

A 95% confidence interval on the estimated biomass is then calculated based on the asymptotic normality of the ML estimator:

$$\hat{\kappa} \pm 1.96\sqrt{Var(\hat{\kappa})}$$

The above estimator, $\hat{\kappa}$, is the average biomass per quadrat, and will be termed the delta estimator in the remaining sections. The term ''delta'' was provided by Aitchison and Brown (1969), and is a poor name because of confusion with other mathematical and statistical procedures of the same name. Also no information is provided with this name that the distribution is actually a mixture of the binomial and lognormal distributions.

Example Calculations

A sample data set for alfalfa *(Medicago)* will be used to illustrate the calculations. Thirty-nine samples were taken (n=39) with 6 positive values (n_1=6, n_0=33). The positive values are 0.5, 1.5, 2.0, 5.0, 5.5, and 6.5. Thus $\bar{y}$ = 0.932 and s_y^2 =0.983. Using these values the estimate of α is 3.74, $\hat{\beta}^2$ = .13.67, and $\hat{V}ar(\hat{\alpha})$ = 4.46. The estimates derived from the delta distribution are $\hat{\kappa}$ = 0.576 and $\hat{V}ar(\hat{\kappa})$ = 0.059. A 95% confidence interval is then [0.010–1.052].

Results and Discussion

Occasionally, the estimates from the delta distribution are much larger than those from the usual method, although both are based on exactly the same data. In these cases the frequency distribution of the positive values is usually highly skewed, with several very large values. This is particularly common when sampling shrubs. Many quadrats with zero biomass values occur, and also several quadrats with very large biomass values. An example is a series of 30 quadrats for sagebrush *(Artemesia tridentata)*. Nineteen positive values occurred, with $\bar{x} \pm \hat{S}E(\bar{x})$ being 806±292, while $\hat{\kappa} \pm \hat{S}E(\hat{\kappa})$ was 3260±3026. The lognormal distribution tends to weight large positive values more heavily, because there is a larger probability that such extreme values will occur with this distribution over the normal distribution.

The two estimators provide very similar point and interval estimates when few zero values occur, and when the frequency distribution of the x_i's is not highly skewed. An example of this is a series of 29 quadrats taken on miscellaneous grasses (Graminae). No zero values occurred, and $\bar{x} \pm \hat{S}E(\bar{x})$ was 161±9 while $\hat{\kappa} \pm \hat{S}E(\hat{\kappa})$ was 162±11.

Although the usual method often provides the smallest standard errors, these are probably negatively biased due to the normality assumptions made. That is, the interval estimate constructed with this standard error will include the true biomass less often than expected because of incorrect assumptions, and provide an illusion of preciseness. If the frequency distribution of the positive values is truly lognormal, the unbiased modified maximum likelihood estimates derived from the delta distribution are known to be the minimum variance estimates.

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Effect of Removal of Standing Dead Material on Growth of *Agropyron spicatum*

RONALD H. SAUER

Highlight: Standing dead was clipped from clumps of bluebunch wheatgrass, with no other disturbance. Clumps without dead material, compared to those with, had less green material and shorter leaves but did not differ in height or number of flowering culms or head lengths. Standing dead appears to be beneficial to bluebunch wheatgrass.

Agropyron spicatum (bluebunch wheatgrass), in the ungrazed condition, grows in clumps with a dense accumulation of dead culms and leaves, collectively known as standing dead. Standing dead modifies the environment of young leaves, and to a lesser degree older leaves, by intercepting sunlight and reducing air movement. Reduced light intensity may decrease photosynthetic activity. On the other hand, reduced air movement may favor a reduced vapor pressure deficit at the leaf surface and reduced water stress in plant tissues, compensating perhaps for the reduced light intensity. This report describes the effect on bluebunch wheatgrass of the removal of standing dead without the removal of live material. The results of this research are relevant to ecosystems studies focusing on the effect of standing dead on the growth of bluebunch wheatgrass.

Grazing studies have dealt with the effect of removal of both live and dead material from rangeland grasses during the growing season (Rickard et al. 1975; Mueggler 1972, 1975; Wilson et al. 1966; Heady 1950). In contrast, this study addresses the effect of removing dead material early in the season before growth initiation of new leaves.

Study Area and Methods

The study site is the Arid Lands Ecology Reserve located on the United States Energy Research and Development Administration's Hanford Reservation in southcentral Washington. The site occupies a gently sloping, east-facing slope on the Rattlesnake Hills at an elevation of approximately 390 m (1,300 ft). The vegetation is classified as the *Artemisia tridentata/Agropyron spicatum* association (Daubenmire 1970). The soil is a silt loam with very few rocks in the upper 2 m of profile. Precipitation is approximately 200 mm (8 inches), most of which comes in fall, winter, and early spring. Growth is arrested in summer by drought and in winter by cold. Most species grow in the period between January and June when soil water content and temperatures are simultaneously conducive to growth.

Seventy-three clumps of bluebunch wheatgrass were randomly selected and individually identified in an area approximately 100 m by 20 m. On January 14, 1976, no live leaves were present and 35 clumps were clipped to the crowns with scissors. The material from each clipped clump, all dead, was bagged, dried in a 60°oven, and weighed. By June 15, 1976, growth had stopped and all 73 clumps were clipped. The live and dead material was hand separated and oven dried as before. The weights of the dead material were added for the January and June harvests.

Leaf length, number and height of flowering culms per clump, head length, and basal area were measured in the field before clipping. Leaf length was estimated by measuring the total length of 18 leaves randomly chosen from the periphery and center of each clump. Height of flowering culms and head length were estimated by measuring up to 18 flowering culms and the length of the attached seed head. The total number of flowering culms was recorded for each clump. Leaves and flowering culms were measured from the soil surface to the end of the unbent structure. Basal area (length × width) was estimated by measuring the longest and shortest dimension of each clump.

These data were analyzed in three steps. First, averages for leaf length, height of flowering culms, and head length were calculated for each clump. Second, the distribution of the data for all parameters (leaf length, height of flowering culms, head length, basal area, number of flowering culms, and live and dead weight) was tested for normality using all clumps because the *t*-test (Snedecor and Cochran 1967) requires the data to have a normal distribution. Basal area, number of flowering culms, leaf length, and live and dead weights were transformed to a normal distribution using natural logs. Third, basal area was noticeably different between the treatments for reasons unknown and unrelated to the treatments (clipping height left the growing points undamaged). Accordingly, the effect of basal area on the other parameters was statistically removed from the other parameters as follows: A regression equation using all clumps was calculated for each parameter using that parameter as the dependent variable and basal area as the independent variable. The regression equation was used to calculate estimated values of each parameter, which were subtracted from the observed values to obtain residuals. The residual values were used in the *t*-test to compare treatments within parameters.

Results and Discussion

The untransformed means and standard errors for all parameters are summarized in Table 1. The standard errors are descriptive only and are not to be used to determine significant differences because the untransformed data does not have a normal distribution. Removing standing dead material decreased the weight of the new generation of leaves and culms by 28%, decreased the loss of standing dead by 21%, decreased leaf length by 25%, but did not significantly change the number of flowering culms per clump, the height of the flowering culms, or the head length.

There are several possible explanations for the measured changes following removal of standing dead. The decrease in live weight suggests that any increase in photosynthetic rate with increased light intensity is offset by a decreased carbon

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Table 1. Means and standard errors for the seven parameters measured in the two treatments. Data here are not transformed to a normal distribution and thus standard errors are not to be used to determine significant differences.

	Treatment	
Parameter	Without standing dead N=35	With standing dead N=38
Live (gm/clump)	11.2 ± 1.4	15.6 ± 1.9*
Dead (gm/clump)	35.4 ± 5.3	27.9 ± 3.8*
Leaf length (cm)	19.8 ± .4	26.5 ± .6**
Number flowering culms	7.6 ± 1.7	15.0 ± 3.5
Height flowering culms (cm)	23.8 ± 2.8	27.1 ± 3.3
Head length (cm)	4.0 ± .4	3.7 ± .4
Basal area (cm²)	366.4 ± 43.0	448.1 ± 67.9

*Treatments different at = .05.
**Treatments different at = .001.

dioxide absorption rate because of greater air movement and subsequent increased plant water stress. In other words, in intact clumps, the effect of reduced light intensity is more than compensated for by the possible sheltering effect of standing dead in this arid environment.

The greater growth of bluebunch wheatgrass clumps shaded with dead material contrasts with results of studies on wheat (Fischer 1975) and potatoes (Sale 1976) in which shade reduced yield. These results are also in contrast to the increase in bluebunch wheatgrass shoot production, leaf length, length and number of flowering culms, and head length following a wildfire in this same pasture (Uresk et al. 1976). Since fire removes standing dead, it appears that fire may have more of a growth stimulating effect than previously thought because simple removal of standing dead decreases growth. The wildfire mentioned above reduced competition for the bluebunch wheatgrass by removing all *Artemisia tridentata* (big sagebrush) shrubs and some weaker individuals of other perennial species. Reduced competition has been found to increase growth in bluebunch wheatgrass (Mueggler 1972). Ash deposition and associated higher early season soil temperature from the darkened surface may also account for some of the increased growth of bluebunch wheatgrass in the burned area (Kozlowski and Ahlgren 1974).

Decomposition of dead material proceeds most rapidly during the January-to-June growing season (Wildung et al. 1975) and the unclipped clumps were also probably losing dead material during this time. The 21% differences in standing dead between the two treatments is probably close to the percentage of dead material lost through fragmentation and decomposition.

The decrease in leaf length on the clipped clumps may be an effect of higher light intensity acting to constrain cell elongation, or simply a reflection of less leaf weight.

The small differences between treatments for height and number of flowering culms and length of seed heads indicate that reproductive performance was not affected by the removal of standing dead.

These data suggest that standing dead is beneficial to bluebunch wheatgrass and is not a deterrent to growth.

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Impact of Herbivores on Arid and Semiarid Rangeland Ecosystems—

Proceedings of the Second Workshop of the US/AUSTRALIA RANGELANDS PANEL—Adelaide, 1972.

We have received a small number of copies of the above **Proceedings** on consignment from the Australian Rangeland Society, publishers of the Second Workshop. These copies are available from the *Society for Range Management, 2760 West Fifth Avenue, Denver, Colo. 80204,* for approximately $7.50 (US dollars). The publication contains the contributions of the 10 United States and 23 Australian scientists participating in the Second Workshop.

Also available from the SRM Denver headquarters is a limited supply of ***Arid Shrublands—Proceedings of the Third Workshop of the US/AUSTRALIA RANGELANDS PANEL, Tucson, Ariz. 1973. ($3.00 postpaid)***

Germination Responses of Three Forage Grasses to Different Concentrations of Six Salts

T. R. MILLER AND S. R. CHAPMAN

Highlight: Both total germination and rate of germination of three species of perennial grasses were affected by concentration of six salts. A significant salt by species interaction was detected, and species differed in their response to concentrations, but both the salts and specific cations and anions affected all three species in the same way.

In many areas of the Western United States, Canada, and elsewhere worldwide, the reclamation of saline soils is becoming a major environmental-conservation concern. The problem is extremely complex, but one important facet is developing repeatable methods of screening seed stocks for tolerance to salts, so that salt tolerant lines can be identified and selected.

Dewey (1962) has suggested that germination provides a fair measure of general salt tolerance. Ayers and Hayward (1948) state that no generalization can be drawn between salinity tolerance during germination and tolerance at other development states. Pearson et al. (1966) reported that salinity slows the rate of germination, but does not reduce total germination; and Donovan and Day (1969) noted that germination is affected by both salt concentration (the osmotic pressure) and by the type of salt. Germination of alkali sacaton was reduced more by MgCl than by KCl or NaCl and more by KCl than NaCl (Hyder and Yasmin 1972).

In our study, we sought to determine the impact of salts and their concentrations on the germination of three species of perennial grasses.

Materials and Methods

Seeds (caryopses) of three species of perennial grass—tall wheatgrass (*Agropyron elongatum*), tall fescue (*Festuca arundinacea*), and Reed canarygrass (*Phalaris canariensis*)—were germinated in each of three concentrations, determined by electrical conductivity (4, 10, and 16 mmhos) of each of six salts (NaCl, Na_2SO_4, $MgCl_2$, $MgSO_4$, KCl, and K_2SO_4) in the dark in a germinator with 15–25°C alternating temperatures (16 and 8 hours, respectively). One hundred seeds of each species were placed in separate, standard germination boxes on blotters that had been saturated with one of the six salt solutions. Blotters were wetted with distilled water as necessary throughout the 14-day study period. The design was a randomized complete block with blocking in time; the same germinator was used for each of two successive replications. Germination was scored daily. A seed was deemed to be germinated when both radicle and plumule growth were evident.

Total germination and rate of germination (RG) were analyzed. Rate of germination was calculated following Carleton et al. (1968) as:

> $\Sigma(X_{i+1} - X_i)/N_{i+1}$ where X_{i+1} and X_i are the number of seeds germinated on any given day, and on the previous day, respectively, and N_i is any given day of the experiment. Day 1 was the day the experiment was started.

Results and Discussion

For total germination, statistically significant variation ($p \leq .05$) was detected for differences among species and among salt concentrations and for the species × concentration interaction. Other effects, including blocks, salts (and their components cations, anions, and the anion × cation interaction), and the interactions species × salt, salt × concentration, and species × salt × concentration, were statistically nonsignificant. The significant species effect was due to significantly lower germination of Reed canarygrass compared with tall wheatgrass and tall fescue (Table 1). For all species germination was not significantly reduced between the distilled water check and a 4-mmhos salt solution (Fig. 1). In the salt solutions, germination decreased in a linear fashion from 73% at 4 mmhos to about 59% at 16 mmhos (Table 1). The significant interaction is

Table 1. Mean number of seeds germinated and rate of germination for three species, for six salts, and for three concentrations of salts, measured by electrical conductivity.

	Seeds germinated		Rate of germination	
Species	Salt[1]	Control[2]	Salt[1]	Control[2]
Tall wheatgrass	80.8[a]*	89.0[a]	12.3[a]	14.1[a]
Tall fescue	77.1[a]	87.0[a]	10.8[a]	13.2[a]
Reed canarygrass	41.7[b]	56.5[b]	5.8[b]	7.9[b]
Salt		66.8[a]		9.5[a]
NaCl		67.4[a]		9.5[a]
Na_2SO_4		65.5[a]		9.7[a]
Mg_2Cl_2		66.9[a]		9.6[a]
Mg_2SO_4		67.1[a]		9.8[a]
KCl		67.2[a]		9.7[a]
K_2SO_4				
Concentrations				
4 mmhos	73.4[a]		11.3[a]	
10 mmhos	68.4[b]		9.7[b]	
16 mmhos	58.6[b]		7.9[c]	

[1] Mean of six salts at three concentrations.
[2] Mean of distilled water control.
* Means in the same column for each effect (species, salts, or concentrations) with a letter in common are not significantly different ($p \leq .05$, Duncan's multiple range test).

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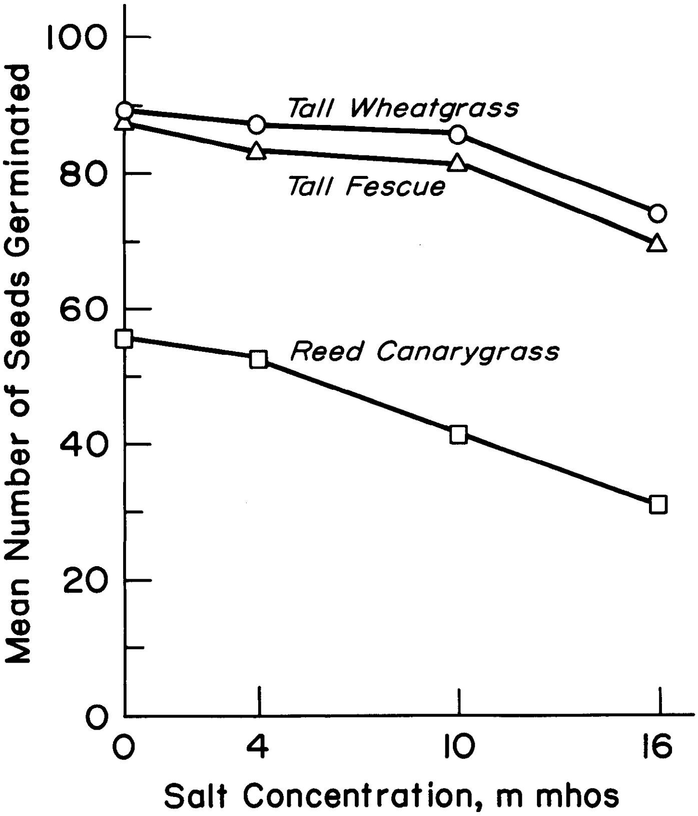

Fig. 1. *Relationship between number of seeds germinated in 14 days and salt concentration for three species of perennial grass.*

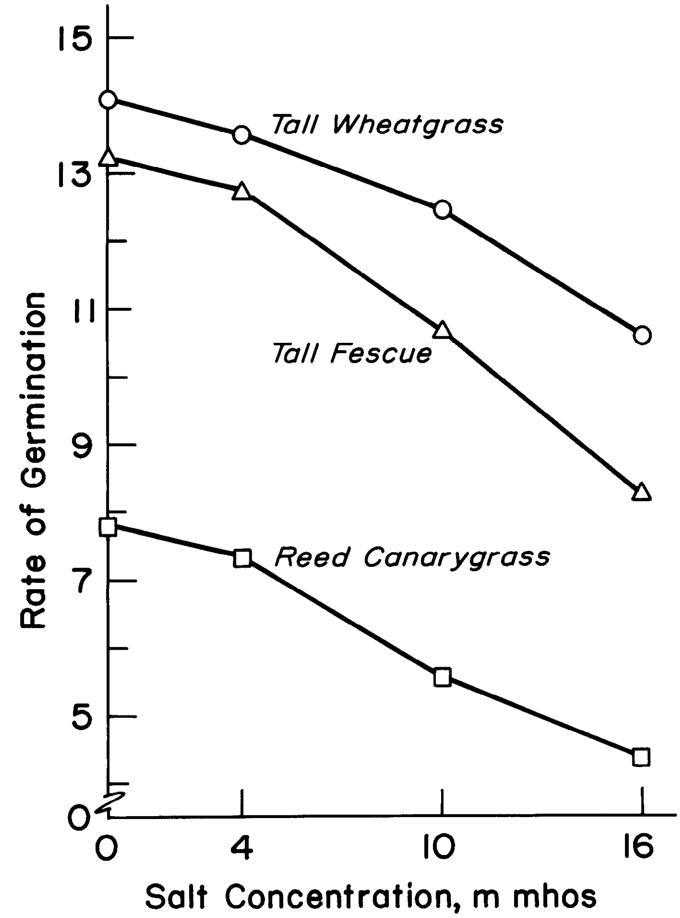

Fig. 2. *Relationship between rate of germination in a 14-day period and salt concentration for three species of perennial grasses.*

attributed to the constant decline in germination of seeds of Reed canarygrass from 4 to 16 mmhos salt concentration compared to the virtually uniform response of both tall wheatgrass and tall fescue from 4 to 10 mmhos salt concentration and then a uniform decline of each of these from 10 to 16 mmhos concentration (Fig. 1).

The analysis of rate of germination presented a picture comparable to that of total germination with respect to significant effects. The only difference was the unexplained, significant block effect in the rate study. Rate of germination decreased with increasing salt concentrations and Reed canarygrass had a significantly slower rate than tall wheatgrass and tall fescue, which were comparable (Table 1). The cause of the significant species × concentration interaction is not as evident for rate of germination as it was for total germination. The reduction in rate of germination was nearly linear over the three concentrations for tall fescue; the reduction in rate was less for both Reed canarygrass and tall wheatgrass from concentrations of 10 to 16 mmhos (Fig. 2).

From this study we conclude that although species differed with respect to their response to concentrations of salts, screening for salt tolerance would be done equally effectively with any of the six salts used.

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An Economic Analysis of Retention of Yearlings on Range and Potential Effects on Beef Production

DAVID B. HEWLETT AND JOHN P. WORKMAN

Highlight: Optimum range livestock marketing schemes were developed for two typical Utah ranch sizes (150 and 300 head of brood cows) using linear programming analysis. Based on average Utah cattle prices for 1970–75, the range livestock management alternative which maximized net ranch income for both ranch sizes was to reduce the cow herd 25% and use the released feed to retain all steer calves for sale as yearlings. Optimum disposition of heifer calves was sale at weaning time. The reduction in breeding herd to accommodate retained yearlings would decrease the number of feeder livestock marketed. Potential decreases in U.S. beef production from 1 to 4% were estimated if 25 to 100% of the ranches in the 11 western states adopted the optimum management alternative. These reductions would result in an increase in United States wholesale beef prices of 1 to 6%.

Recent high prices for heavy feeder cattle relative to those paid for lightweight feeder calves has stimulated new interest in range livestock management alternatives for marketing yearlings rather than weaner calves. The extremely high feed grain prices since 1974 have made it cheaper for feeders to purchase livestock gain from ranchers than to produce the gain in a feedlot (Stenquist 1975). If the time of low feed grain prices and huge feed grain surpluses is indeed over (Brunk 1975; Nielsen 1975), feedlot operators may come to prefer grass-fed yearlings to lightweight calves. Considering these factors, it was hypothesized that Utah ranchers might find it more profitable to market grass-fed yearlings than the traditional weaners.

This study was designed to investigate various Utah range livestock production options and evaluate their effects on net ranch income. A majority of those who have investigated the profitability of retaining ownership of beef calves to sell as yearlings have used a budgeting technique that compared a cow-yearling operation retaining all calves to a cow-calf operation selling all calves. In contrast, we used linear programming to develop an optimum combination of various livestock marketing alternatives that would maximize net ranch income. We also estimated the effects on beef supply and price which might result if our optimum management strategies were widely adopted.

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Methods

Linear programming was used as the optimization procedure because it allowed us to simultaneously examine a large set of input and production constraints and determine the most economically efficient mix of production activities from among all available alternatives. Linear programming techniques have been shown to be well suited to aiding decisions concerning the allocation of scarce resource. between management alternatives in order to maximize income or minimize cost (Agrawal and Heady 1972; Beneke and Winterboer 1973; Jameson et al. 1974).[1]

Two typical Utah ranch sizes (150 and 300 head of brood cows) described by Roberts and Gee (1963), were modeled and called 150RANCH and 300RANCH for easy reference. Inventory and budget data for these two ranch sizes from Workman (1970) and Roberts and Gee (1963) provided the basic input for the analysis.[2] Resource constraints were formulated from forage balance charts and typical feed use patterns of the two ranch sizes as determined by Abdalla (1976). Total feed (pasture, range, hay, barley, crop aftermath, and federal permits) available to the 150RANCH was 2,472 animal unit months (AUM) and 4,993 AUM for the 300RANCH.

Ranch Management Options

The cattle production alternatives we considered were similar to those used by Leistritz and Qualey (1975) with the addition of options 3, 5, and 6 as follows:

1. Baseline (current) operation: cow/calf operation, all homegrown calves except replacement heifers sold November 1.
2. Cow/short-yearling operation, weaner calves wintered and sold April 1.
3. Same as No. 2 with additional calves purchased November 1, wintered, and sold April 1.
4. Cow/long-yearling, calves wintered, summered on range and sold October 1.
5. Same as No. 4 with additional calves purchased November 1, sold October 1.
6. Same as No. 4 with additional calves purchased April 1, sold October 1.

For the baseline cow-calf operation, weaning weights of calves were 380 lb for heifers and 400 lb for steers. The calf crop was 80% and 15% of the breeding herd was replaced annually. The 150RANCH ran one bull for 25 cows with a 4-year active life. The 300RANCH ran one bull for 20 cows with a 3-year active life. Short-yearling steers

[1] Readers desiring detailed discussions on linear programming techniques, uses, and limitations are referred to these authors.

[2] These data were gathered from numerous ranches and then composited according to the size categories of 50, 150, 300, and 500 head of brood cows. The 150 and 300 head size were chosen for the study as most representative of the majority of Utah's ranches.

weighed 490 lb on April 1 and short-yearling heifers weighed 470 lb. Sale weights of long-yearlings were 740 lb for steers and 680 lb for heifers.

Costs of Production

Cattle prices used were 6-year (1970–75) average prices paid at the North Salt Lake Stockyards, Salt Lake City, Utah (Table 1). Analyses at 1973 and 1975 prices were also included for comparison with the average price situation and to provide samples of the effects market fluctuations have on ranch income. Since current budget data for cattle ranching enterprises in Utah were not available, costs of production for the two Utah ranch sizes for 1968 (Workman 1970) were updated to 1976. Cash costs of production for short and long yearlings were calculated from Kearl (1969). Federal indices of prices paid by farmers for production items of both farm and non-farm origin (United States Department of Agriculture 1976) were used to update all price data to May 1976.

Table 1. Average price ($/cwt) paid for cattle in Utah 1970–1975, North Salt Lake Stockyards.[1]

	300–400 lb November 1		400–500 lb April 1		600–700 lb October 1	700–800 lb October 1
Year	Steers	Heifers	Steers	Heifers	Heifers	Steers
1970	$34.78	$31.52	$39.50	$34.96	$22.85	$30.06
1971	40.66	36.17	36.37	32.75	30.95	33.59
1972	54.00	45.90	40.38	37.77	38.67	39.96
1973	61.38	52.00	60.75	52.16	40.25	46.19
1974	30.76	25.56	52.41	46.81	24.69	27.73
1975	34.30	24.26	30.63	23.60	32.06	35.88
Avg	$42.65	$35.90	$43.34	$38.00	$31.58	$35.57

[1] Averages are based on price information from weekly issues of *Market News*, published in Ogden, Utah, by the Livestock Div. of the Agr. Market. Serv., U.S. Dep. Agr.

For optimization purposes, only variable costs that affect the optimum allocation of resources were included. Thus, fixed costs such as depreciation, taxes, and insurance were not included even though they must be paid from what is reported here as net ranch income. These costs remain the same regardless of the type of operation.

Total per unit costs for the 150RANCH cow-calf, short-yearling, and yearling activities were $112 to $118, $45, and $31 to $37, respectively, depending on the proportion of Federal rangeland grazed. For the 300RANCH total costs were $125 to $132, $45, and $31 to $37 for the cow-calf, short-yearling, and long-yearling activities, respectively. The higher production costs for the 300-RANCH cow-calf activity were due primarily to higher per unit expenditures for feeds and veterinary services (Workman 1970).

A baseline solution was first obtained by restricting the optimization procedure to the calf production activity to allow for later comparison with optimization solutions. Then the other five activities were added to the models and an optimum strategy was developed for each ranch size.

Possible reductions in beef produced in Utah and the 11 western state region were evaluated at four arbitrary levels of rancher adoption of the optimum strategy. Assuming that all ranches in the region are currently cow-calf operations selling weaner calves, the decrease in the number of calves produced as a result of required reductions in breeding herds to accommodate yearlings was calculated for situations where 25, 50, 75, and 100% of the total operators adopted the optimum strategy. The required reduction in herd size to adopt the optimum strategy was assumed to be that required by the two representative Utah ranch sizes.

The number of calves marketed was calculated as the number of beef calves weaned in the state or region minus 15% for replacements (Abdalla 1976). The percent reduction in herd size, multiplied by the number of calves marketed by either 25, 50, 75, or 100% of the ranches in the state or region, was used as the number of calves which would not be marketed at these four levels of rancher adoption. To determine the effect of the potential decreases in calves on U.S. live weight beef production, it was assumed that all calves and yearlings are currently fed to 1,100 pounds for slaughtering. The decreased number of calves multiplied by 1,100 pounds is the maximum possible reduction in U.S. beef production due to rancher adoption of the optimum strategy in Utah and the region.

The effect of a possible 11-western-state reduction in beef production on U.S. wholesale beef prices was evaluated by using the concept of price elasticity of demand. The price elasticity of demand is the percentage change in the quantity purchased, divided by the percentage change in the price of the product (Leftwich 1973). Workman et al. (1972) calculated the price elasticity of demand for beef in the U.S. to be -0.67. This value indicates that the quantity of beef purchased would decrease by 0.67% as the result of a 1% price increase. The inverse of the price coefficient,

$$\frac{1}{-0.67} = -1.49,$$

shows that a 1% decrease in the quantity of beef produced would cause a 1.49% increase in the price of beef (Workman et al. 1972). Thus, the percentage change in the price of beef resulting from rancher adoption of the optimum strategy is -1.49 times the percentage change in the quantity of beef produced.

Results and Discussion

Solutions to Baseline Cow-Calf Operations

For the 150RANCH model, the baseline solution resulted in a breeding herd of 159 cows. Spring range was the most limiting resource, with other resources becoming constraining almost simultaneously. The capital requirement (total annual cash costs) was $14,420, and net ranch income was $2,148.

Spring range was also the factor that limited the 300RANCH baseline cow-calf operation to 294 head of brood cows. Capital requirement was $28,879, and net ranch income was only $849. This low net return was due to the significantly higher costs of production on the 300-head ranches than on the 150-head ranches. Solutions for the baseline cow-calf operations of both ranch sizes are summarized in Table 2.

Table 2. Organization of the baseline solutions for the cow-calf operations for the two ranch sites.

Item	150RANCH	300RANCH
Cows	159	294
Bulls	7	15
Replacement heifers	24	44
Livestock marketed		
Cull cows	24	44
Steer calves	64	118
Heifer calves	40	73
Limiting resource	Spring range	Spring range
Operating capital requirement	$14,420	$28,879
Net ranch income	$ 2,148	$ 849

Optimum Strategies

Ideally, ranch organizations should be changed each year to employ the specific production and marketing strategies that would maximize net ranch income for that particular year, thereby maximizing long-term net ranch income. However, since prices cannot be foreseen for enough in advance to allow ranchers to make the necessary decisions, and since a constantly changing ranch organization would be unrealistic, an optimum strategy based on average price data is an appropriate means of maximizing long-term net ranch income.

The income-maximizing ranch organization for the 150-RANCH combined cow-calf and long-yearling options. The sale of heifer calves at weaning and the retention of all steer calves for sale as long-yearlings resulted in a net ranch income of $2,268, approximately 6% over that of the baseline cow-calf operation. Capital requirements decreased by $483 and a herd of 120 brood cows supplied the calves for the operation with no purchases of additional weaner calves or short yearlings. Spring range was the most limiting resource. Optimum production and marketing strategies for both ranch sizes are presented in Table 3.

Table 3. Organization of the optimum strategy for ranch operations for the two ranch sites.

Item	150RANCH	300RANCH
Cows	120	222
Bulls	5	11
Replacement heifers	18	33
Livestock marketed		
Cull cows	18	33
Heifer calves	30	55
Long yearling steers	48	89
Limiting resource	Spring range	Spring range
Operating capital requirement	$13,937	$27,334
Net ranch income	$ 2,268	$ 2,049

Sensitivity analysis of the optimum solution indicated that the 150RANCH solution would be sharply affected by a drop in price for long-yearling steers. If the gross return for these yearlings were lowered by only $1.06 to $262.16, while all other factors were held constant, net ranch income from the optimum solution would be almost identical to that from the baseline cow-calf operation. This sensitivity to decreased yearling prices was also reflected by the small ($120) difference in net ranch income between the baseline cow-calf and optimal solutions. The choice between the baseline cow-calf and the optimum cow-calf long-yearling operation may therefore be simply a matter of rancher preference. Lower prices of yearlings, however, might be accompanied by proportionately lower calf prices, in which case the long-yearling option could remain optimal.

The optimum strategy to maximize net ranch income for the 300RANCH was the same as for the 150RANCH. Sale of all heifer calves at weaning and retention of all steer calves for sale as long-yearlings increased net income by $1,200. Operating capital decreased $1,545. The 222 head of brood cows provided all calves for retention and no calves or short-yearlings were purchased. Spring range was again the most limiting resource.

Sensitivity analysis of the 300RANCH optimum solution indicated that it is more stable than the 150RANCH solution in the event of yearling price decreases. With other factors held constant, the gross return for long-yearling steers would have to drop by $13.54 (to $249.68) before the solution changed. This stability is also reflected in the large difference between net ranch incomes from the optimal solution and from the baseline cow-calf operation (Tables 2 and 3).

Analysis Using 1973 Prices

During 1973, Utah cattle prices were considerably higher than the 1970–75 average, with lightweight weaner calves bringing exceptionally high prices. Our analysis using 1973 prices yielded a much different optimum ranch organization than we obtained with 1970–75 average prices.

Optimum ranch organization for the 150RANCH became the baseline cow-calf operation. The resulting net ranch income of $9,340 was 19% higher than the $7,855 which would have been earned if the 1970–75 average price optimum strategy had been employed at 1973 prices.

Optimum ranch organization for the 300RANCH was also essentially the baseline cow-calf operation except that the larger ranch had a slight excess of winter feed, allowing five short-yearling steers to be retained. The net ranch income of $14,076 was 14% greater than the net ranch income ($12,306) that would have been generated at 1973 prices using the 1970–75 average price optimum strategy.

Analysis Using 1975 Prices

In 1975, Utah cattle prices exhibited a rare situation. Lightweight feeder calf prices were considerably below average while those 700- to 800-lb yearlings were not only slightly above average but were actually *higher* than calf prices.

With these conditions, the retention of heifers became profitable on the 150RANCH, and 26 yearling heifers displaced 17 cows, which reduced the breeding herd to 103 cows. As in the original optimum strategy, all steers were retained as long-yearlings. Net ranch income was $2,105. The baseline cow-calf operation, however, would have suffered a loss of approximately $1,450, since 1975 calf prices were too low to cover all production costs.

A similar optimum was indicated for the 300RANCH. The 48 heifer calves not needed for cow herd replacement were retained, displacing 30 cows and reducing the breeding herd to 192 cows. Net return was $2,108, while the baseline cow-calf operation would have lost approximately $5,600.

First-year Cash Flow

During the first year in which an operation switches from the baseline cow-calf operation to a cow-calf/long-yearling strategy, there may be a decrease in cash flow from retaining steer calves. On the 150RANCH, 39 cows must be culled to provide the feed for the 48 retained steer calves. Based on an income of $187.60/head for the 39 cull cows sold and a foregone income of $170.60/head for the 48 steer calves not sold, net decrease in cash flow for the initial year would be $872. This decrease is partially offset during the ensuing production year, however, by a $483 decrease in required operating capital.

On the 300RANCH, 72 cows are culled and 89 steer calves retained, resulting in a $1,676 decrease in initial-year cash flow. This decrease is almost entirely offset by a $1,545 reduction in operating capital required the following year. Additionally, the extremely heavy culling of the cow herd in the first year may well result in an improved calf crop percentage the following fall and a rapid improvement in cow herd quality.

Effects on Beef Production and Price

The 25% decrease in breeding herd to accommodate retained yearlings specified by the 1970–75 average price optimum would result in fewer feeder cattle going to market in Utah and in the region (Table 5). The reduction in regional beef production (Table 5) was used to calculate the associated change in U.S. wholesale beef price. Total liveweight beef production in the United States for 1975 was 40,680,069,000 lb (Abdalla

Table 4. Reduction in number of beef calves marketed in Utah and the western region resulting from 25, 50, 75, or 100% of all ranches adopting the optimum strategy.

Adoption level (%)	Reduction in beef calves marketed (head)	
	Utah	Western Region
25	15,619	347,863
50	31,238	695,726
75	46,857	1,043,589
100	62,476	1,391,452

Table 5. Decrease in the pounds (liveweight) of beef produced in Utah and the western region resulting from 25, 50, 75, or 100% of all ranches adopting the optimum strategy.

Adoption level (%)	Reduction in beef production (pounds)	
	Utah	Western Region
25	17,180,900	382,649,300
50	34,361,800	765,298,600
75	51,541,600	1,147,947,900
100	68,722,500	1,530,597,200

1976). At 25, 50, 75, and 100% optimum strategy adoption at the regional level, total U.S. beef production would be reduced by approximately 0.94, 1.88, 2.82, and 3.76%, respectively. Based on the elasticity coefficient of −1.49, if 15% of the ranchers in the region adopted the optimum strategy the price of beef would increase by 1.4%. Regional rates of optimum strategy adoption of 50, 75, and 100% would result in U.S. beef price increases of 2.8, 4.2, and 5.6%, respectively. Based on the assumptions that: (1) all ranches in the region are presently purely cow-calf operations marketing only weaner calves and (2) that all calves and yearlings marketed from these ranches are fed to slaughter weights of 1,100 lb, these estimates should only be viewed as the *maximum* possible effects on beef price and production if ranches shifted to the cow-calf/long-yearling organization.

The range livestock industry might benefit in two ways by shifting to the optimum strategy. First, marketing steer calves as yearlings would increase net ranch income over that produced by traditional cow-calf operations, and second, the inelastic demand for beef in the United States would mean that the herd size decreases required to accommodate retained yearlings would ultimately bring an increase in beef prices.

Summary and Conclusions

Optimal livestock production and marketing strategies for both ranch sizes called for a combination of cow-calf and long-yearling options. Heifer calves were to be sold at weaning, while the cow herd was reduced by approximately 25% to accommodate retention of all steer calves for 11 months after weaning.

Although optimal strategy net ranch income was higher for the 150RANCH than the 300RANCH, the increase in net ranch income over the baseline cow-calf operation was greater for the 300RANCH than the 150RANCH. The differential was due to higher original costs per cow incurred by the 300RANCH, which meant higher savings when cows were replaced with yearlings. The fact that net ranch income was higher for the 150RANCH than for the 300RANCH should not be construed as indicating a need for a 50% size reduction by the large ranch. More efficient management should give the 300RANCH a net ranch income at least double that of the 150RANCH.

Our analysis using the exceptionally high 1973 weaner calf prices defined a cow-calf operation as the optimum for both ranch sizes. Net ranch income was several times higher than that earned at 1970–75 average prices. In 1975, however, not only were cattle prices much lower than the 1970–75 average, but long-yearlings brought more per pound than did weaner calves. Optimization at 1975 prices therefore required retention of all calves for sale as long-yearlings. Cow-calf operations would have meant losses for both ranch sizes in 1975.

Widespread adoption of the cow-yearling strategy identified as optimum could result in a small (1 to 4%) reduction in U.S. beef production, which could lead to an increase in beef prices to consumers of from 1 to 6%.

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Will Mesquite Control with 2,4,5-T Enhance Grass Production?

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Highlight: Both honey mesquite density and percent of plants dead the year of aerial spraying with 2,4,5-T proved to be major factors influencing perennial grass production. Sites with sparse honey mesquite stands and very dense stands (over 50% canopy cover) yielded little extra grass after 2,4,5-T application. Heavy mesquite foliage probably prevented adequate leaf coverage with 2,4,5-T in dense stands, and in sparse stands mesquite competed little with the herbaceous plants. Increased perennial grass production of about 540 lb/acre/year would be necessary over a 5-year period to break even with a $4.60/acre aerial application of 2,4,5-T. With honey mesquite cover of 30%, a plant kill over 80% the year of application was required to provide a 540 lb/acre/year grass increase. However, a 90% kill would provide nearly 750 lb/acre/year extra perennial grass. Thus, paying particular attention to optimum environmental factors and proper timing for the 2,4,5-T application can pay big dividends.

In a series of publications entitled *Grassland Restoration*, Smith and Rechenthin (1964) pointed out that honey mesquite (*Prosopis glandulosa*) is the most common and widely spread "pest" plant in Texas. About 25% of the state's grasslands are infested with honey mesquite, with 16 million acres so densely covered as to seriously suppress grass production. The question is, "How much reduction constitutes seriously suppressed grass production?" Although Agricultural Extension Service demonstration plots and yield comparisons between sprayed and unsprayed pastures conducted by Soil Conservation Service personnel under Federal cost-share programs indicate increased forage production following honey mesquite control with herbicides, quantitative research accounts of forage increases are relatively scarce. Fisher et al. (1959) reported increased steer gains of 31 lb/head in pastures cleared of honey mesquite at Spur, Tex. Sale of animal products is ultimately the means whereby we measure direct monetary benefits of a range improvement practice; however, grazing studies to evaluate benefits of a brush control program are time consuming and costly. Consequently, it is necessary to utilize indirect means of measuring animal productivity increases by measuring forage increases. Prior to 1970, the major published research on increased forage production following herbicidal control of mesquite was conducted on the Santa Rita Experimental Range in Arizona. Forage production was inversely related to the number of velvet mesquite (*P. velutina*) trees (Martin 1966). Herbicidal control of velvet mesquite with 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid)] doubled grass production on sprayed native range and tripled Lehman lovegrass (*Eragrostis Lehmanniana*), as compared to that produced on unsprayed areas (Cable and Tschirley 1961).

Limited results led us to believe that honey mesquite control with herbicides in Texas would not provide yield increases of the magnitude reported from Arizona. First year results from near Matador, Tex., showed a 46% forage increase following honey mesquite spraying with 2,4,5-T (Robison et al. 1970). This extra forage increased beef production only 1.5 lb/acre, primarily because users maintained the same stocking rates on sprayed and unsprayed pastures. Following interviews with ranchers in the eastern part of the Texas Rolling Plains, Workman et al. (1965) reported that grazing capacity on upland sites was increased from 22 to 17 acres/AU/year, and from 20 to 16.5 acres/AU/year on bottomland sites.

In 1970, we began studying herbage yields from areas sprayed aerially with 2,4,5-T and from comparable unsprayed areas in the Texas Rolling Plains.

Study Area and Methods

This study was conducted in the Rolling Plains land resource area of West Texas. One location was near San Angelo in Tom Green County; one near Spur in Kent County; and one near Post in Lynn County.

At all locations, the basic herbicide mixture was 0.5 lb of 2,4,5-T (ester) in 1 gal diesel oil and enough water to bring the total spray solution to 4 gal/acre. The Tom Green County location was on a clay loam, and herbicide was applied on June 27, 1969. The pasture in Kent County was sprayed on May 26, 1970. For this location, we selected five variations in topography, in soils, and in honey mesquite density in each study pasture, pairing the sites as evenly as possible. Soils varied from clay loam to clay. Lynn County sites sprayed on July 6, 1971, constituted the third location. The soils of this location were clay loam to sandy clay loam.

Depending on uniformity of understory vegetation, from 9 to 25 woven wire cages, 5 ft in diameter, excluded livestock grazing from vegetation to be sampled for yield. Since 80% of the yearly growth is achieved by July in these areas (Hiermann 1973), we measured standing crop each year in July or August. Cages were relocated for next year's growth at sampling. One 4.8-ft^2 plot was clipped from each cage.

Herbage yields in Tom Green County were obtained for the 6 years, 1970 through 1975, and in Lynn and Kent counties yields were obtained 1971 through 1974.

Percent canopy cover of honey mesquite was determined from transects 1 ft wide and 100 ft long (from 2 to 12 transects per site). Honey mesquite mortality was determined from 25 permanently

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Table 1. Perennial grass yields in oven-dry lb/acre following aerial 2,4,5-T application to honey mesquite on Texas Rolling Plains rangeland from 1970 to 1975.

		Year after spraying									
		2 mo. after		1st		2nd		3rd		4th	
Site	Initial canopy cover (%)	Unsprayed	2,4,5-T sprayed	Unsprayed	2,4,5-T sprayed	Unsprayed	2,4,5-T sprayed	Unsprayed	2,4,5-T sprayed	Unsprayed	2,4,5-T sprayed
Shallow redland[1]	5			120	330	820	1000	1960	2080	1590	1210
Deep hardland[2]	12			1070	680	1060	1140	1760	2040	1060	1600
Deep hardland[3]	21	640	1850	2040	2530	1370	1640	560	840	—[4]	—[4]
Valley[1]	28			330	1290	2320	1990	2340	2670	1670	1710
Deep hardland[1]	34			390	1050	820	990	940	1420	—[4]	—[4]
Deep hardland[1]	36			480	2480	1490	2030	810	1220	1190	1580
Deep hardland[1]	54			540	770	1880	1270	580	990	—[4]	—[4]

[1] Kent County.
[2] Tom Green County.
[3] Lynn County.
[4] Plots lost due to mechanical disturbance.

marked trees/site. Initial mortality was measured during the October following spraying. If a tree had no sprouts anywhere, it was considered initially dead. A second check for sprouts was made during the fall following the second growing season after spraying.

Buffalograss (*Buchloe dactyloides*) and tobosagrass (*Hilaria mutica*) were dominant perennial grasses on the study sites. Other grasses commonly occurring were: vine mesquite (*Panicum obtusum*), Hall's panicum (*Panicum hallii*), blue grama (*Bouteloua gracilis*), three-awns (*Aristida* sp.), sand dropseed (*Sporobolus cryptandrus*), and Arizona cottontop (*Digitaria californica*). Texas wintergrass (*Stipa leucotricha*) was a minor component on some sites. Although Texas wintergrass and some winter annuals were occasionally present and sampled, the summer sampling sequence undoubtedly underemphasized their importance.

To ascertain if herbicidal control of honey mesquite can be justified, an example using yearling cattle is included. Assumptions in the example are: (1) cost of application will be repaid in 5 years using an interest rate of 10%; (2) steers weighing 400 lb can be purchased for $0.39/lb and resold 1 year later at $0.37/lb; (3) a yearly steer gain of 275 lb; (4) 1.5 lb/day of protein supplement costing $0.08/lb will be fed for 100 days; (5) $16.00/head for other variable costs including death loss, salt and mineral, veterinary and medicine, hauling and marketing, etc.; and (6) interest on operating costs of $18.00/head.

Correlation analysis was used to relate mesquite infestation to expected perennial grass yield increases.

Average Perennial Herbage Response

Aerially spraying honey mesquite with 2,4,5-T significantly ($P \leq 0.05$) increased perennial grass production in all three counties (Tables 1 and 2). It is apparent that while average grass yield increases for all counties due to 2,4,5-T spraying were significant, grass response on some sites was nonsignificant.

At those sites with 200 or fewer trees per acre, a high proportion were controlled with 2,4,5-T, but increased grass production was so low that it is unlikely that one could afford the treatment. Conversely, herbicide application to the most dense stand of honey mesquite (1,360 trees/acre) provided no perennial grass increase at all. However, this was because no trees were actually killed, and 56% of them had resprouted at the stem base by October of the year sprayed. Yield of honey mesquite basal sprouts the first year after spraying on this site was greater than the honey mesquite current year's top growth on a similar unsprayed site. We believe the heavy honey mesquite foliage resulted in poor leaf coverage with 2,4,5-T and subsequently in low root kill. Neither herbicidal treatment of sparse honey mesquite infestation of poor plant kill provide sufficient forage increases to warrant use of 2,4,5-T at today's cost of application. In this study we attempted to define those parameters that will delineate the point at which it is economical to use an herbicide for honey mesquite control.

Correlation analysis indicated that the two best predictors of increased forage production in this study were (1) the percentage of honey mesquite canopy cover before spraying and (2) the percentage of honey mesquite trees with no basal stem sprouts in the fall of the year sprayed. Table 3 may be used as a guide to the percentage kill necessary for a given degree of honey mesquite infestation to provide enough increased grass to justify the herbicide treatment. The amount of extra grass required will depend on current costs and returns. To illustrate, suppose the increased grass production necessary to justify spraying mesquite is 500 lb. The values in Table 3 indicate that one would need to get more than a 60% root kill during the first year in a pasture with 50% mesquite cover in order to provide the needed 500 lb of grass. However, a 90% kill at a site with 16 or 17% canopy cover should increase grass yields the same 500 lb/acre. These data also strongly indicate that mesquite infestations with less than 10% canopy

Table 2. Differences in perennial grass yields due to aerial application of 2,4,5-T to honey mesquite on Texas Raolling Plains rangeland from 1970 to 1975.

					Grass yield differences (year after spraying)					
Site	Initial canopy cover (%)	Trees/ acre	Root kill 1st year (%)	Root kill 2nd year (%)	2 mo. after spraying	1st	2nd	3rd	4th	Average
Shallow redland[1]	5	165	80	28		210	180	120	−380	30
Deep hardland[2]	12	206	85	40		−390	80	280	540	130*
Deep hardland[3]	21	630	80	40	1210	490	170	280	[4]	540*
Valley[1]	28	425	68	4		960	−330	330	40	250
Deep hardland[1]	34	625	65	8		660	170	480	[4]	440
Deep hardland[1]	36	665	92	12		2000	540	410	390	840*
Deep hardland[1]	54	1360	44	0		230	−610	410	[4]	10
Means	27	582	76	19		594	29	330	148	320

[1] Kent County.
[2] Tom Green County.
[3] Lynn County.
[4] Plots lost due to mechanical disturbance.
* Indicates that honey mesquite sprayed with 2,4,5-T resulted in significantly ($P \leq 0.05$) more perennial grass prodduction over the years sampled.

Table 3. Expected annual increases in perennial grass yield (lb/acre) in relation to degree of mesquite infestation and proportion of mesquite controlled in west Texas.[1]

Honey mesquite trees unsprouted (%) fall of year sprayed	Honey mesquite canopy cover (%)				
	10	20	30	40	50
40					
50				30	200
60			70	250	420
70		120	300	470	650
80	160	340	520	690	870
90	390	560	740	920	1090
100	610	780	960	1140	1310

[1] Yield increases (y) were determined by the formula Y = 17.6 (% canopy cover) + 22.2 (% root kill) − 1787. (R^2 = 0.78).

cover will seldom provide significant grass increases regardless of proportion of trees killed. An example, using 1977 prices, is given under the management implications section.

Longevity of Conrol

Mesquite control is expected to give maximum increased grazing capacity the first 2 or 3 years after spraying (Workman et al. 1965). Our results also showed the greatest grass response from 2,4,5-T spraying for 5 of the 7 locations studied occurred the first year after treatment.

Fisher et al. (1959) reported that with root kills of 30 to 50%, mesquite sprout growth is seldom great enough for retreatment within 4 years. Except for the Tom Green County location, our data do not extend beyond 4 years. However, for the Tom Green County site, mesquite canopy cover was 12% on unsprayed pastures compared to only 5% on sprayed plots in July, 1976, 7 years after spraying. Increased grass yields were 240 and 200 lb/acre for the 5th and 6th years, respectively. These are well above the 4-year average of 130 lb for the site (Table 2). Evidently, with root suppression of 75% or greater the year of spraying, significant grass yield increases can be obtained for more than 4 years after spraying.

Relationship of Mesquite Density to Mesquite Canopy Cover

Figure 1 shows the curvilinear relationship between canopy cover and honey mesquite density for this study. Canopy cover values, in combination with honey mesquite mortality in the year of 2,4,5-T spraying, was used in Table 3 rather than number of trees because it gave a slightly higher multiple correlation coefficient (R = 0.88 vs R = 0.80).

Management Implications

The question, "Do I have enough honey mesquite to justify the expenditure for chemical control?" is best answered by measuring increased livestock products to see if the increase can pay for an herbicide application strictly from increased forage. However, a major incentive for brush control is the accompanying labor savings in gathering and checking livestock, easier detection of crippled and diseased animals, etc. Some speculate that this aspect alone is worth $1.00/acre.

Aerial application of 2,4,5-T (0.5 lb/acre in 4 gal/acre total volume) currently costs about $4.60/acre. If this cost must be repaid in 5 years, at 10% interest, the annual payment would be $1.21/acre. To break even, this requires that the increased forage provide extra animal products worth $1.21. The question then becomes, how much forage increase does it take to provide this much extra beef?

Average grass standing crop in July on all untreated sites for the years of this study was 1,120 lb/acre. Sims et al. (1976) reported that forage disappearance per yearling steer per day

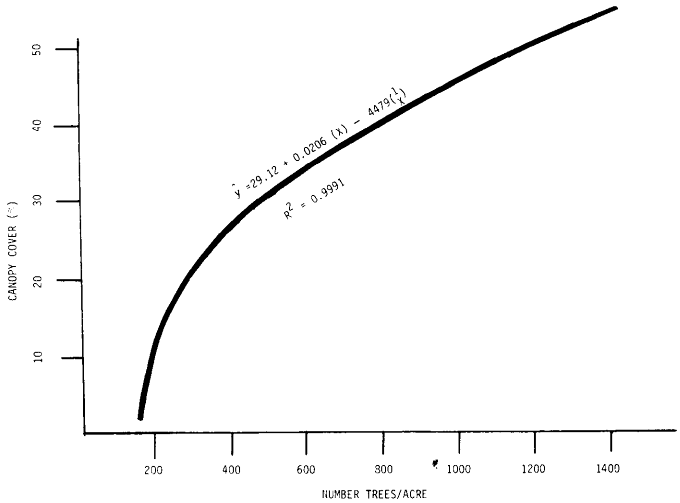

Fig. 1. *Relationship of honey mesquite canopy cover to density in the Rolling Plains of Texas.*

varied from 20 to 30 lb/head/day under moderate and light stocking rates in eastern Colorado. Using a conservative value of 30 lb/day for a yearling steer and reserving 30 lb of forage to maintain plant vigor, then each yearling steer will require 1,800 lb of forage/month; or, the untreated range would require 19.3 acres/yearling steer annually. The locations sprayed with 2,4,5-T produced an average of 1,450 lb/acre of grass which would then require only 14.9 acres/yearling steer. Using the assumed production costs and returns given in the methods section, return per steer would be $47.75 or $2.47 return/acre before treatment and $3.20/acre after herbicide treatment. The $0.73/acre increase would not make the $1.21 payment. To allow enough increased stocking to make the $1.21 annual payment, 540 extra lb/acre are needed or a total grass yield of 1,660 lb/acre. Using Table 3 as a guide, a 30% canopy would require over 80% root kill to give this much extra grass. Consequently, it is important to get a high percent kill the year of herbicide application, so particular attention should be given to getting optimum conditions for applying the herbicide.

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Relationships of Soil Salinity, Ash, and Crude Protein in *Atriplex canescens*

BRUCE L. WELCH

Highlight: The relationships of soil salinity, ash, and crude protein were determined in seven natural populations of fourwing saltbush (*Atriplex canescens*). The correlation coefficient between soil salinity and ash was −0.31 and between ash and crude protein, −0.33. Ash content ranged from 11.9% to 18.7%; the overall mean was 14.8%. Soil salinity directly beneath the plants varied from 234 parts per million (ppm) to 4,229 ppm. Crude protein ranged from 8.9% to 22.4%; the overall mean was 14.9%. Some of the populations contained significantly higher levels of crude protein than others. Also discussed is the difference in ash accumulation of *Atriplex* spp. growing in soil as opposed to those growing in nutrient solutions.

Atriplex canescens (fourwing saltbush) varies greatly in protein and ash content. The National Academy of Sciences (1958) reported that ash ranged from 5.6% to 24.2% and that crude protein ranged from 7.8% to 24.2%. It is generally believed that ash content increases as soil salinity increases (Ashby and Beadle 1957; Black 1968). Although Beadle et al. (1957) found "no close correlation" between soil salinity and ash content in Australian saltbushes, it is not known whether a high ash content has a depressing effect on protein content. I undertook this study to correlate soil salinity to ash content in fourwing saltbush and to determine what effects ash content might have on crude protein content.

Materials and Methods

Vegetative samples consisting of current-year growth of leaves and stems were collected during mid-August from native *Atriplex canescens* populations at seven different sites. Five plants were picked at random for each population. The seven population sites were: (1) Orem, Utah; (2) sand dunes near Delta, Utah; (3) Dividend, Utah; (4) Delle, Utah; (5) Vale, Oregon; (6) Helper, Utah; and (7) Wales, Utah.

Soil samples were collected directly beneath each plant. The first 2.5 cm of soil was removed and a composite sample of the next 28 cm was taken for determining total soluble salt content (Richards 1954). Holmgren and Brewster (1972) and Pearson (1965) have reported that between 50% and 80% of the root mass of desert shrubs was contained within the first 30 cm of soil, although roots were at a depth of 135 cm. The majority of the feeder roots were in the sampling zone.

The vegetative samples were first dried at 100°C for 48 hours and then ground to a fine powder in a Wiley mill. The powdered samples were stored in airtight containers and placed in a laboratory freezer until needed for chemical analysis. Ash content was determined in the manner reported by the Association of Official Agricultural Chemists 1965. Crude protein was determined by the Kjeldahl method. Soil salinity was determined by analyzing a sample of soil extract for total soluble solids (Chapman and Pratt 1961; Richards 1954).

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Results

Soil salinity directly beneath fourwing saltbush plants varied from 307 ppm for the Delta sand dune population to 1,693 ppm for the Vale population (Table 1). Variation within populations was high. The coefficient of variation (c.v.) for the Vale population was 84%. The remaining coefficients of variation were in the 20% to 65% range.

Ash content ranged from a low of 13.3% for the sand dune population to a high of 16.0% for the Delle population (Table 2). The overall mean for ash was 14.8% with a range of 11.9% to 18.7%. These findings are in close agreement with the findings of Nord and Green (in preparation). The within-population variation for ash content was much less than for soil salinity. The coefficient of variation for each population was below 10% except that for the Dividend population, which had a c.v. of 14.1%.

The correlation coefficient between soil salinity and ash was a nonsignificant −0.31.

Crude protein ranged from a low of 11.6% for the Orem

Table 1. Soil salinity (ppm) of a composite 28-cm soil sample taken directly beneath fourwing saltbush plants at seven different locations.

	Soil salinity (samples)							
Locations	1	2	3	4	5	$\bar{X}$[1]	*S.D.*[2]	% *C.V.*[3]
Delle, Utah	849	532	750	419	411	592	± 198	33.4
Wales, Utah	621	708	650	759	1,102	768	± 194	25.3
Dividend, Utah	471	486	1,408	677	283	665	± 438	65.9
Orem, Utah	893	484	787	577	679	684	± 162	23.7
Helper, Utah	743	428	493	366	451	496	± 145	29.0
Vale, Oregon	1,264	864	4,229	951	1,159	1,693	± 1,426	84.2
Delta, Utah	419	275	255	234	350	307	± 76	24.8

[1] $\bar{X}$ = Mean.
[2] *S.D.* = Standard deviation.
[3] *C.V.* = Coefficient of variation.

Table 2. Mid-August ash content (% dry matter) of current-year growth of leaves and stems of seven populations of fourwing saltbush.

	Ash content (samples)							
Populations	1	2	3	4	5	$\bar{X}$[1]	*S.D.*[2]	% *C.V.*[3]
Delle, Utah	15.3	17.4	14.4	17.4	15.6	16.0	± 1.3	8.1
Wales, Utah	16.0	16.7	15.2	14.9	15.5	15.7	± .7	4.5
Dividend, Utah	18.7	13.5	17.2	14.5	14.2	15.6	± 2.2	14.1
Orem, Utah	16.1	14.6	14.3	14.2	15.7	15.0	± .9	6.9
Helper, Utah	13.0	13.7	15.3	14.4	16.3	14.5	± 1.3	9.0
Vale, Oregon	12.5	14.6	12.7	12.6	14.0	13.3	± .9	6.8
Delta, Utah	11.9	13.6	14.4	13.0	13.5	13.3	± .9	6.8

[1] $\bar{X}$ = Mean.
[2] *S.D.* = Standard deviation.
[3] *C.V.* = Coefficient of variation.

Table 3. Mid-August crude protein content (% dry matter) of current-year growth of leaves and stems of seven populations of fourwing saltbush.

	Crude protein (samples)							
Populations	1	2	3	4	5	$\bar{X}$[1]	*S.D.*[2]	% *C.V.*[3]
Delle, Utah	13.5	14.4	16.3	13.3	14.1	14.3 ± 1.2		8.4
Wales, Utah	18.0	15.9	15.0	15.0	17.3	16.2 ± 1.4		8.6
Dividend, Utah	13.6	12.2	12.3	15.5	14.8	13.7 ± 1.5		10.9
Orem, Utah	14.8	10.3	12.6	8.9	11.4	11.6 ± 2.3		19.8
Helper, Utah	18.3	16.9	15.5	15.2	16.9	16.6 ± 1.2		7.2
Vale, Oregon	13.3	13.0	15.8	14.4	13.9	14.1 ± 1.1		7.8
Delta, Utah	13.8	22.4	13.0	18.3	20.5	17.6 ± 4.1		23.3

[1] $\bar{X}$ = Mean.
[2] *S.D.* = Standard deviation.
[3] *C.V.* = Coefficient of variation.

population to a high of 17.6% for the Delta sand dune population (Table 3). The overall mean for crude protein was 14.9% with a range of 8.9% to 22.4%. Within-population variation for crude protein was not as great as soil salinity, but slightly higher than ash. Five populations had a c.v. less than 11%, while the remaining two were near 20%.

The correlation coefficient between ash and crude protein was a nonsignificant −0.33. The results of an analysis of variance and Duncan's multiple range test used to detect significant differences of crude protein content among populations are given in Table 4. The Delta sand dune population, although it contained the highest amounts of crude protein, was not significantly different from the Wales or Helper populations, but was significantly higher than the Delle, Vale, Dividend, or Orem populations.

Discussion

From my study and that of Nord and Green (in preparation), it appears that the ash content of fourwing saltbush (14.8%) is much lower than that of other saltbushes. Goodin and McKell (1970) reported that the ash content for big saltbush (*Atriplex lentiformis*) and cattle saltbush (*A. polycarpa*) was 31.6% and 21.3%, respectively. The National Academy of Sciences (1958) reported that shadscale (*A. confertifolia*) contained 21.7% ash. A later report by this Academy (1964) listed the ash content of shadscale as 23.3% and nuttal saltbush (*A. nuttallii*) as 21.5%. Nord and Green (in preparation) found that the ash content of Gardner saltbush (*A. gardneri*) ranged from 23.5% to 25.3%. Beadle et al. (1957) reported that the ash content of three Australian saltbushes (*A. vesicaria, A. nummularia,* and *A. inflata*) ranged from 24.4% to 38.2%.

Fourwing saltbush may be tolerant to higher levels of soluble salts than those reported by Hansen (1962). He found 1,300 ppm to be the maximum level. I found a healthy plant growing in a soil containing 4,229 ppm of soluble salts. At Gordon Creek, an experimental planting near Helper, Utah, healthy fourwing are growing in a soil containing 5,000+ ppm of soluble salts.

Table 4. Analysis of variance and Duncan's multiple range test for crude protein content among seven populations of fourwing saltbush.

A. Analysis of variance

Source	Degrees of freedom	Mean squares	F[1]
Populations	6	21.02	4.89
Error	28	4.3	

B. Duncan's multiple range test

Populations[2]						
Orem	Dividend	Vale	Delle	Wales	Helper	Delta
(means in % dry matter)						
11.6	13.7	14.1	14.3	16.2	16.6	17.6

[1] Significant at the 0.05 level.
[2] Any two means not underscored by the same line are significantly different at the 95% level.

The lack of a relationship between ash content and soil salinity came as a surprise to me. I had supposed that the relationship of ash content to salinity of nutrient solution would be the same for the soil. As salinity increases, ash content increases. However, this does not appear to be the case. The Beadle group (Beadle et al. 1957; Ashby and Beadle 1957) studied ash content of three saltbushes from two angles: (1) soil salinity as opposed to ash and (2) nutrient solution salinity as opposed to ash. In the first case, they noted "no close correlation between the two" (Beadle et al. 1957). In the second, they found that ash content increased as salinity increased (Ashby and Beadle 1957), but they did not recognize the conflict between the two culture media—soil as opposed to nutrient solution. Ash content of fourwing saltbush is independent of soil salinity.

I had thought that ash content of fourwing saltbush could be lowered by growing these plants on a nonsaline soil. Lowering the ash would be accompanied by an increase in crude protein, but as the data of my study show, crude protein is independent of ash.

Another interesting point of my study is that the sand dune population contained the highest levels of crude protein. Fourwing saltbush from this population has been described by Stutz et al. (1975) as a gigas diploid with a seedling and new twig growth rate nearly twice that of the tetraploids. I believe a comprehensive study of this plant is merited.

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Food Habits of the Black-tailed Prairie Dog in Western South Dakota

CAROL A. SUMMERS AND RAYMOND L. LINDER

Highlight: Five major plant species were important in stomach and pellet samples of prairie dogs from two different "towns" in western South Dakota: buffalograss (*Buchloe dactyloides*), scarlet globemallow (*Sphaeralcea coccinea*), threadleaf sedge (*Carex filifolia*), blue grama (*Bouteloua gracilis*), and western wheatgrass (*Agropyron smithii*). Seasonal differences for spring and summer diets were not significant ($P>0.05$). During winter pricklypear cactus (*Opuntia polyacantha*) and western wheatgrass increased in importance in diets and the other major species declined in importance. Three species important in the range but not important in the diet were threeawn (*Aristida fendleriana* and *A. longiseta*), prairie dogweed (*Dyssodia papposa*), and horseweed (*Conyza ramosissima*).

The black-tailed prairie dog (*Cynomys ludovicianus ludovicianus*) is characteristic of the short-grass prairie (Koford 1958) and in 1919 occupied about 100 million acres in the United States (Nelson 1919). Early studies concluded that prairie dogs competed with cattle (Nelson 1918; Bell 1920; Taylor 1920), and as a result, a campaign was launched to reduce competition by controlling prairie dogs (Bell 1920). By 1960 (U.S. Dep. of Interior 1963) the number of acres occupied by prairie dogs was reduced to about 1.5 million acres.

The degree of competition between cattle and prairie dogs is not known. Merriam (1901) calculated that forage consumption of one cow was equivalent to that of 257 prairie dogs. Taylor and Loftfield (1924) concluded that the Zuni prairie dog (*Cynomys gunnisoni zuniensis*) could destroy as much as 80% of the forage through feeding and clipping vegetation. The objectives of this study were to determine plant species eaten by prairie dogs and to relate the availability of plant species to preference in the feeding habits of prairie dogs.

Study Area

Two prairie dog towns were studied in southwestern South Dakota. Town 11 is located in the Buffalo Gap National Grasslands adjacent to the Badlands National Monument. Town Burns Basin is located in the Badlands National Monument. Two major vegetative types occurred within the boundaries of both towns.

Composition of the buffalograss vegetative type in Town 11 was mostly grass (95% of the cover). Buffalograss (*Buchloe dactyloides*) (68%) and threeawn (*Aristida fendleriana* and *A. longiseta*) (12 %) were the most abundant grasses in the summer. The two major grasses on blue grama vegetative type on Town 11 were blue grama (*Bouteloua gracilis*) (41% of the cover) and buffalograss (27%). Forbs made up 14% of the vegetative cover.

Threeawn (33%) and buffalograss (19%) were the important grasses in the threeawn vegetative type of Burns Basin. The important forbs were scarlet globemallow (*Sphaeralcea coccinea*) (8%), plaintain (*Plantago aristida*, *P. patagonica*, and *P. spinulosa*) (5%), prairie dogweed (*Dyssodia papposa*) (9%), and horseweed (*Conyza ramosissima*) (10%). Plant cover for the dogweed vegetative type on Burns Basin was primarily composed of forbs (84%). The two major grass species were threeawn (7%) and tumble grass (*Schedonnardus paniculatus*) (5%). The major forb was prairie dogweed (62%). Other important forbs were scarlet globemallow (7%) and plaintain (6%).

Method

Stomachs were removed from prairie dogs collected at four randomly selected, active burrows in each vegetative type during two collection periods, May 14–22 and August 1–14, 1973. Forty stomachs were collected in May and 56 in August; five fresh pellets were also collected from each burrow during each collection period. Fourteen stomachs were also obtained from June 24 to July 4, 1973, and eight on December 20, 1973, from Town 11.

Stomach and pellet samples were thoroughly mixed in water for 1 minute, washed over a 0.1-mm screen, and oven dried at 60°C. Dried stomach and pellet samples were ground over a 1.0-mm screen in a Wiley Mill. Five slides were prepared from each sample using the procedure described by Cavender and Hansen (1970). A compound, binocular microscope at 125 magnification was used to analyze the slides. Twenty locations were observed per slide. A location was considered that area of the slide that was outlined by the microscope field using the prescribed magnification. The initial location on the slide was randomly selected, and the remaining 19 locations were systematically observed. Fragments that were recognized as epidermal tissue were recorded for each location. Individual trichomes that were not adjoined to a fragment of epidermal tissue were disregarded.

Species of grasses and sedges were identified by the occurrence, position (over or between veins), and the shape of such specialized leaf and sheath epidermal structures as macrohairs, microhairs, prickle hairs, papillae, stomata, long cells, short cells, and silica bodies (Summers 1976). Diagnostic characteristics for leaf and stem material of forbs were the occurrence, shape, and position of certain epidermal structures: trichomes, stomata, subsidiary cells, crystals, cell walls, and cuticle. Most leaf and aboveground stem fragments could be recognized using these diagnostic characteristics. However, belowground stem material and root material were impossible to differentiate into species so these plant parts were recorded as "root-stem material." Seed fragments were not divided into species but rather recorded as "seed material."

Frequency percentages were recorded for each plant species, and percentages were converted to relative density as described by Sparks and Malechek (1968). Diet data were summarized as mean dry weight percentages (relative density) for each plant species in each vegetative type. Mean dry weight percentage for vegetative types did not include root-stem or seed material so that dry weights could be compared with availability (cover percentages) of each species.

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To estimate food availability, vegetation was surveyed at each burrow during the two main collection periods in May and August 1973. Fifteen randomly selected plots (31 × 31 cm) were measured in four concentric circles (3, 6, 9, 12 m) around the burrow. Ocular estimates of plant cover were made for all plant species. Aerial parts of plants were projected onto the surface of the ground. Total plant cover was estimated in addition to coverage of individual species. The percentage of area covered was recorded with a scale from Daubenmire (1959). The midpoint in each class of the scale was used as the estimate for coverage for a species. These values of percentage of total area covered for each species were converted to percentage of plant area covered using the total plant coverage measured in the plot.

Results and Discussion

A nested analysis of variance (Schultz 1955; Mendenhall 1968) showed no significant differences ($P>0.05$) in the plant taxa of prairie dog stomachs collected from burrows among vegetative types, between vegetative types within towns, and between May and August collection periods. However, contents from stomachs were significantly different between towns ($P<0.05$). The range survey showed no significant difference ($P>0.05$) in vegetation among concentric circles; but differences in vegetation were significant ($P<0.05$) among burrows, between vegetative types, between towns, and between seasons.

Seven plant species made up the major (greater than 5%) food items in prairie dog stomachs throughout the year (Table 1). Although food habits did not change significantly between spring and summer, a change did occur in December when pricklypear and western wheatgrass were of greater importance.

Grasses made up 65% of the mean annual diet and forbs 34%. Kelso (1939) reported 62% grasses and 34% forbs, with western wheatgrass (12%) and sixweeks fescue (9%) as the important grasses. He did not find buffalograss, blue grama, or sedge important anytime during the year. Koford (1958), Smith (1958), and Tiletston and Lechleitner (1966) listed western wheatgrass, blue grama, and buffalograss important plant species in the diet during the growing season. Lerwick (1974) in Colorado concluded that 88% of the diet was composed of grasses and sedges from May through September. Favorite species eaten by prairie dogs were blue grama, needleleaf sedge (*Carex eleocharis*), dropseed (*Sporobolus cryptandrus*), and scarlet globemallow (Lerwick 1974). Lerwick (1974) stated that prairie dogs did not consume buffalograss even though it was a dominant grass in the study area. He found that many annual forbs common in the range were not eaten.

Smith (1958), Koford (1958), Tiletston and Lechleitner (1966), and Kelso (1939) mentioned the importance of prickly-

Table 1. Percentage of dry weight (relative density) for plant species in stomach samples of black-tailed prairie dogs collected from Town 11 and Burns Basin in 1973.

	Percent dry weight				
Plant species	December (8)[a]	May (40)	June-July (14)	August (56)	Annual (118)
Total grasses and sedges	57	65	74	66	65
Total forbs	43	35	25	33	34
Major species					
Agropyron smithii	38	10	12	5	16
Bouteloua gracilis	2	9	13	11	9
Buchloe dactyloides	8	22	34	29	23
Carex filifolia	8	16	4	10	9
Opuntia polyacantha	32	tr[b]	1	1	8
Plantago spp.	1	9	5	1	4
Sphaeralcea coccinea	11	21	15	26	18
Others	1	9	16	18	11

[a] Sample size in parentheses.
[b] Trace = less than 1%.

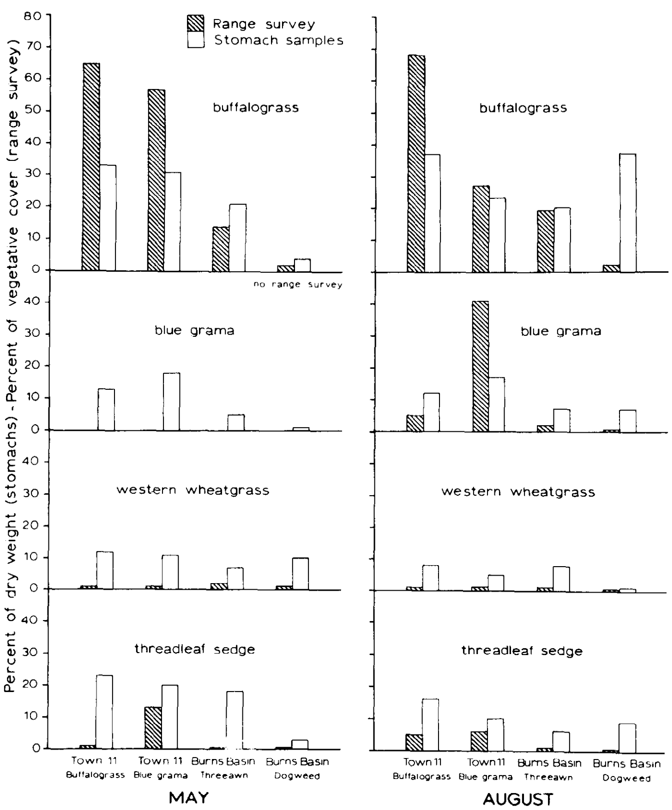

Fig. 1. *A. Comparison of the percentage of dry weight of vegetation in stomachs and percentage of vegetative cover in the range survey in the four vegetative covers for May and August.*

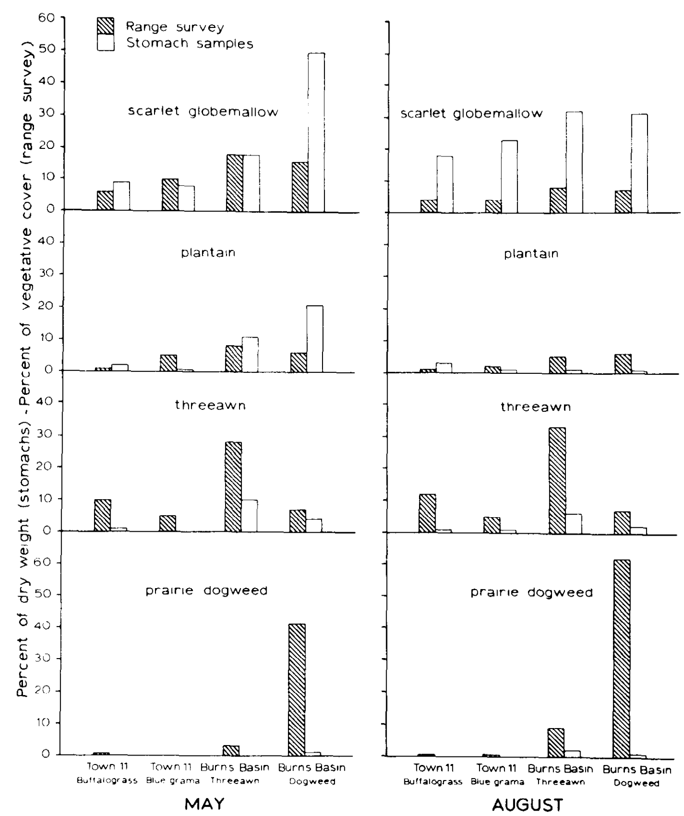

Fig. 2. *B. Comparison of the percentage of dry weight of vegetation in stomachs and percentage of vegetative cover in the range survey in the four vegetative covers for May and August.*

Table 2. Percentages of dry weight (relative density) for plant species in stomach and pellet samples collected from town 11 and Burns Basin for May 12–22 and August 1–14, 1973.

	Percent dry weight			
	Town 11		Burns Basin	
Plant species	Stomachs (58)[a]	Pellets (16)	Stomachs (38)	Pellets (16)
Total grasses and sedges	80	95	51	83
Total forbs	20	5	48	17
Root-stem and seed material	6	1	10	1
Buchloe dactyloides	31	28	21	28
Carex filifolia	17	19	9	10
Bouteloua gracilis	15	15	5	6
Sphaeralcea coccinea	14	4	33	14
Agropyron smithii	9	19	7	14
Aristida spp.	1	2	6	9
Munroa squarrosa	3	1	tr[b]	4
Schedonnardus paniculatus	2	7	2	11
Sporobolus cryptandrus	2	3	2	1
Plantago spp.	2	tr	8	1

[a]Sample size in parentheses.
[b]Trace = less than 1%.

pear cactus as a green winter food item. This was true in the present study as well. Digging for roots of grasses and forbs in late fall, winter, and early spring was mentioned in each of the studies cited above. We did not find an increase in root-stem material from August to December.

Smith (1958) and Koford (1958) found that seed material became important food items in the summer months. Lerwick (1974) found that seed material on one of his sites became important during the dry period; but, on the other site, seed material remained unimportant. In this study seed material constituted less than 5% of the stomach contents throughout the seasons studied. Although Smith (1958) and Kelso (1939) mentioned the importance of insects in spring, we found no insect material in the stomachs collected.

When percentage of dry weight in the stomach samples was compared to percentage plant cover for the range survey, it was found that occurrence of plant species in the diet differed from their occurrence in the range. All major plant species except buffalograss occurred more frequently in the diet than they occurred in the range survey (Fig. 1). The prairie dogs did not utilize threeawn, prairie dogweed, and horseweed. These three species were important in Burns Basin vegetative types.

A paired *t*-test (Mendenhall 1968) showed that the differences were not significant ($P>0.05$) in mean relative densities of plant species between stomach and pellet samples collected from Town 11 and Burns Basin (Table 2). Todd and Hansen (1973) also found no significant differences between rumen and pellet samples of bighorn sheep in Colorado. It appears that pellet samples could be substituted for stomach samples, and a valid index of the important foods would be obtained. However, we evidently underestimated minor species of forbs in pellets. Seventeen minor species of forbs (totaling 6%) were found in the stomach samples from Burns Basin; pellet samples had five minor species (2%). On Town 11, 13 minor forb species (4%) were found in stomach samples and only 3 species (1%) in pellet samples.

Conclusions

In both stomach and fecal pellets, the same five plant species were important for spring and summer in all vegetative types of the two study areas, even though the vegetative composition was different on the areas. The five important species were buffalograss, scarlet globemallow, threadleaf sedge, blue grama, and western wheatgrass. Three species that were important in the range but were not important in feeding were threeawn, prairie dogweed, and horseweed. Insect matter did not occur in the stomachs, and seed material made up less than 5% of the food material. Results of the study did not differ greatly from other studies except that buffalograss made up the greatest percentage of the stomach contents.

While the importance of pricklypear cactus and western wheatgrass increased during the winter, the importance of buffalograss, blue grama, threadleaf sedge, and scarlet globemallow decreased. Root material occurred in low incidence in all seasons.

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Longevity of Leafy Spurge Seeds in the Soil Following Various Control Programs

G. G. BOWES AND A. G. THOMAS

Highlight: Although picloram provided adequate control of leafy spurge (*Euphorbia esula* L.) for a minimum of 3 years, from 3,500 to 11,000 viable seeds remained in the soil, providing a source for rapid reestablishment of the infestation. Continuous sheep grazing for 8 years prevented annual seed set and reduced the size of the soil seed bank from > 3,500 to 15 seeds/m², greatly reducing the chance of reestablishment from seed. Combining the data from the various treatments indicated that the average annual loss from the soil seed bank is 13% of the original population. This means that even though an initial application of picloram kills most of the vegetative portion of the plant, a repeat treatment is necessary to greatly reduce the number of seeds in the soil seed bank to prevent reestablishment by seed.

Leafy spurge (*Euphorbia esula* L.) is an introduced weed from Europe which was reported in Massachusetts as early as 1827 (Gussow et al. 1942). It is now found in most of Canada and in the United States south to Pennsylvania, Illinois, and Nebraska (Fernald 1950). Numerous reports have described leafy spurge as a weed of cropland, pastures, and rights-of-ways (Anderson 1956; Mitich 1969; Selleck et al. 1962). Anderson (1956) estimated that 3,640 ha of land were infested with leafy spurge in western Canada. This estimate may be conservative because Selleck et al. (1962) reported more than 3,960 ha in one-third of the settled portion of Saskatchewan. In 1962, Selleck et al. (1962) speculated that there were 14,160 to 16,190 ha of land infested with leafy spurge in Canada. No recent estimates of the acreage infested in Saskatchewan are available. However, in neighbouring North Dakota, the plant was reported to cover 202,340 ha in 1969 and to be spreading at a rate of 3,360 ha per year (Mitich 1969).

The rapid spread and the difficulty of controlling this weed are due in part to its methods of reproduction. Leafy spurge can reproduce and spread vegetatively from roots as well as by seeds. The effectiveness of the root system for vegetative reproduction is well documented by Selleck et al. (1962). However, the importance of seeds in plant establishment has not been adequately investigated. The seeds are scattered by a special mechanism. The seed capsules break open with an explosive force often propelling the seeds up to 4.6 m from the parent plant, thus effectively dispersing them (Bakke 1936). Each flowering shoot normally produces from 10 to 50 fruits and each fruit usually contains 3 seeds, but larger plants will produce hundreds of seeds per plant (Bakke 1936).

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Many biological and chemical control methods have been used on leafy spurge. Smothering leafy spurge patches with straw has been attempted but proved ineffective because new shoots appeared around the edge of the piles (Batho 1938; Muenscher 1930). The straw piles must be left in place for 3 to 4 years to kill the roots below the center of the pile ((Batho 1938). Close grazing of leafy spurge with sheep has been recommended and used as a control measure for over 35 years (Batho 1938; Bibbey 1952; Helgeson and Thompson 1939; Muenscher 1930; and Wood 1945). In order to achieve control with sheep, the pasture must be continually grazed during the growing season. Chemical control methods have had some degree of success. Repeat applications of 2,4-dichlorophenoxy acetic acid (2,4-D) in the spring and fall for 3 or 4 years have given satisfactory weed control (Helgeson and Jansen 1959). More recently, a single application of 4-amino-3,5,6-trichloropicolinic acid (picloram) has given satisfactory weed control for 3 to 5 years, but the population rapidly recovered (Bowes and Molberg 1975).

All these control methods were designed to deplete carbohydrate reserves in the leafy spurge root system by preventing shoots from appearing above ground for at least 3 years. It is not known if the shoots appearing after these short-term control methods originated from perennial roots or seeds. If seedlings are important in the recovery of the population following control methods, the survival characteristics of leafy spurge seeds in the soil become important. However, none of the studies mentioned above have taken into account the amount of viable seeds in the soil either before, during, and after the various treatments. The following experiment was designed to estimate the amount of viable seeds remaining in the soil following the prevention of seed set with chemicals and sheep for 1 to 8 years.

Materials and Methods

Seeds were recovered from the soil at three separate locations that were chosen to represent a range of time since the initiation of control procedures. Two locations received a herbicide treatment and the other location was grazed by sheep. At the Moose Jaw location (50°22'N and 105°46'W) the potassium salt of picloram was applied at the recommended rate of 2.2 kg/ha on June 5, 1975. Two years previous, July 1973, picloram had been applied at the same rate on leafy spurge in an area 22 km east of Regina, Sask. (50°25'N and 104°22'W) at the Jameson location. At both locations, the degree of control was satisfactory. In the fall of 1967, ten dense patches of leafy spurge had been permanently marked in a pasture area near Mortlach, Sask. (50°26'N and 105°59'W). The area was not grazed prior to 1967 but was continuously grazed with sheep from the spring of 1968 until the termination of the experiment. The number of leafy spurge shoots/m² was recorded once or twice a year under four wire exclosures, each 1.2

× 1.2 m, which were randomly placed near the permanent markers. The exclosures were moved once a year at the time of the earliest counts but were not moved after the spring of 1974.

Ten soil samples, 20 × 20 cm and 2.5 cm in depth, were obtained on October 30, 1975, from each of the sheep grazed pasture, picloram treated areas at Jameson and Moose Jaw, and adjacent untreated areas. On October 29, 1976, ten additional samples were obtained from the picloram treated and from the adjacent untreated area near Regina. Leafy spurge seeds were separated from the dry sandy soil of the Regina and Mortlach locations with a series of sieves. The Moose Jaw soil had a higher clay and organic matter content so it was necessary to wash the soil through the sieve. Only whole seeds were hand-picked from the remaining debris at all locations. When the embryo dies and decays, the seed coat splits apart. Any seeds of this type were obviously nonviable and were not selected. From the date of collection until the commencement of germination tests in February, all samples were stored at −12°C.

Percent germination was determined by placing 50 seeds in 100 × 20-mm glass petri dishes on 2 layers of No. 1 Whatman filter paper moistened with 5 ml of water. Three replicates of 50 seeds were randomly selected from each of the 10 soil samples per location. When there were fewer than 150 seeds per soil sample, all seeds were used for germination (Mortlach location only). Environmental conditions for the alternating, cool + alternating, and hot + alternating temperature portion of the germination sequence are presented in Table 1. Optimum temperature for germination and the sequence of cold and hot conditions used to stimulate the germination of dormant seed were determined in previous experiments (unpublished data). The germination test was conducted in a germinator with a programmable light and temperature sequence. During the hot phase (40°C) of the sequence, the seeds were kept dry in small envelopes in a temperature controlled oven. In all other cases, water was added when necessary to the petri dishes. The number of seeds with radicals longer than 2 mm were recorded twice a week during the alternating (30 day/10 night) part of the sequence. After the hot + alternating phase, the seeds were examined and sorted into two groups. Those with a well-formed white embryo were classed as firm seeds and assumed to be viable. The remainder of the seeds were hollow or had a brown shrivelled embryo and were considered nonviable. This method of determining viable and nonviable seeds was confirmed on a random sample using the tetrazolium test (Grabe 1970).

Table 1. Light and temperature sequences used in germination tests.

Temperature sequence	Duration (wk)	Photoperiod (hr) light	Photoperiod (hr) dark	Temperature (°C) day (8 hr)	Temperature (°C) night (16 hr)	Moisture level
Alternating	4	8	16	30 ± 1	10 ± 1	wet
Cool +	4	0	24	2 – 5	2 – 5	wet
Alternating	2	8	16	30 ± 1	10 ± 1	wet
Hot +	4	0	24	40 ± 2	40 ± 2	dry
Alternating	2	8	16	30 ± 1	10 ± 1	wet

Results of the germination test are presented on a percentage basis. Total germination is the summation of the alternating, cool + alternating, and hot + alternating portions of the temperature sequence. Germination data were subjected to angular transformation prior to analysis of variance and Student-Newman-Keul multiple range test (Zar 1974).

Results

The density of leafy spurge remained high following 3 years of continuous sheep grazing (Fig. 1). The following year there was a drastic reduction in the shoot density which remained low during the duration of the experiment. From the fourth year until the end of the experiment, the few remaining shoots were observed to be perennial. The exclosures were not moved after

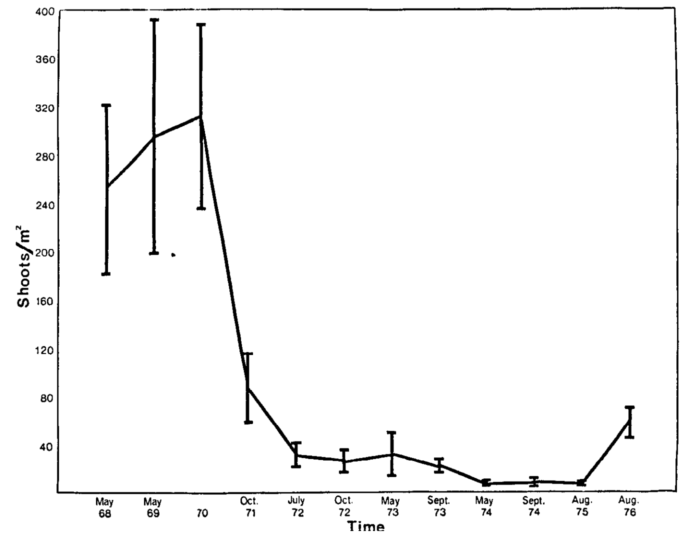

Fig. 1. *Shoot density of leafy spurge with continuous sheep grazing (shoots/m² with standard deviations).*

1974 and the population of leafy spurge started to reestablish from roots in 1976.

The large seeds of leafy spurge were easily recognized and separated from the debris after the sieving and cleaning process. This method yielded a large number of seeds representing the seed reserve in the soil (Table 2). The size of these seed banks varied considerably from location to location. Two to three times as many seeds were recovered in 1975 than in 1976 from untreated plots at the Jameson location. On the other hand, the numbers of seeds recovered in 1976 from Jameson and Moose Jaw untreated locations were similar. The herbicide treatment with picloram prevented seed set for 1 year at the Moose Jaw location and 3 and 4 years at the Jameson location. This elimination of seed input into the soil was reflected by fewer seeds recovered in the picloram treated than in the untreated areas. However, only during 1975 at the Jameson location was the difference statistically significant. The lowest number of seeds were found on the Mortlach location where sheep had grazed continuously for 8 years.

Only a portion of the recovered seed population germinated when placed in a suitable environment (Table 2). The greatest germination response occurred during the alternating temperature sequence for all treatments. A cool + alternating temperaure sequence increased the germination total but the hot + alternating temperature sequence had no effect. Seed recovered during 1976 was not subjected to a hot temperature sequence. There was considerable variation in the percentage of seed that germinated on the untreated sites. The seeds recovered during 1976 at Jameson had a much higher percentage germination than did the 1975 seed sample. During the alternating portion of the temperature sequence, the number of seeds that germinated in picloram treated areas was less than the untreated but this was only statistically different for seeds recovered during 1975 at Jameson. A similar relationship was found during the cool + alternating portion of the temperature sequence. Less than 1% of the seeds germinated at Mortlach during all parts of the temperature sequence.

The seeds that did not germinate were either firm or nonviable. Most of the firm seeds were viable as confirmed by the tetrazolium test performed on nongerminating seeds collected during 1975 from the 1975 picloram treated location (Table 3).

Table 2. Numbers of recovered leafy spurge seeds, percentage of seeds germinating, firm and nonviable and seeds capable of germination.

Location	Treatment	Sample date	Treatment date	Number of seeds/m²	Germination of leafy spurge seed (%)[2] Temperature sequence (°C) Alternating	Cool	Hot	Total	Firm seeds	Nonviable seeds	Seeds[3] capable of germination /m²
Moose Jaw	Untreated	1975		7043 b	56 d	5 b	0.4 ab	61 d	8 b	31 c	4860
	Picloram	1975	1975	6073 b	53 d	5 b	0.2 ab	58 d	15 e	27 bc	4433
Jameson	Untreated	1975		17823 d	29 c	16 c	0.8 ab	46 c	39 d	15 ab	15150
	Picloram	1975	1973	14053 c	12 b	6 b	0.6 ab	19 b	62 e	19 abc	11383
Jameson	Untreated	1976		6128 b	66 d	20 c		85 e	4 b	11 a	5454
	Picloram	1976	1973	4515 b	57 d	15 e		73 e	5 b	23 bc	3522
Mortlach	Grazed	1975	1967	1133 a	0.2 a	0.2 a	0 a	0.4 a	0.9 a	99 d	15

[1] Means followed by the same letter are not different at the 0.5 probability level.
[2] Alternating = 30/10°C for 4 weeks; Cool = 2–5°C for 4 weeks followed by 30/10°C for 2 weeks; Hot = 40°C for 4 weeks followed by 30/10°C for 2 weeks.
[3] (Percentage of seeds germinating + percentage firm seed) × number of seeds recovered/m².

In the untreated areas, the percentage of seeds classed as firm varied considerably among the four locations (Table 2). The seeds recovered from picloram treated plots at Moose Jaw, 1975, and Jameson, 1975, had a significantly larger percentage of firm seeds than the untreated. Compared to the other locations, the percentage of firm seeds following continuous grazing with sheep for 8 years was very low. A comparison of picloram treated and untreated areas indicated that the proportion of nonviable seeds in the samples was similar on three of the four locations, the exception being Jameson, 1976. The proportion of nonviable seeds in the sample might be expected to be similar on the two treatments since only whole seeds were selected.

After 8 years of continuous grazing at Mortlach, the number of seeds capable of germination was only 15/m² while at the other locations over 3,500 were capable of germination if subjected to a suitable environment (Table 2). Preventing seed set for 1 to 4 years with picloram reduced the number of seeds capable of germination in the soil seed bank.

Discussion

To achieve long-term control of leafy spurge, the shoots coming from perennial rootstocks and the soil seed bank must be drastically reduced. Three or more years of continual sheep grazing were necessary to greatly reduce the shoot density of leafy spurge. However, 5 to 10 shoots/m² were still growing from perennial rootstocks after 8 years (Fig. 1). These few shoots did not increase in number until the second year after the pressure from continuous sheep grazing was removed. It is not known how many years are necessary for the leafy spurge density to reach the pre-1968 level. The control at the Moose Jaw site averaged 2 shoots/m² during 1976 (unpublished data), which was similar to that reported for the Jameson site (Bowes and Molberg 1975). Therefore, during the first 3 to 4 years of a leafy spurge control program, picloram was as effective as sheep grazing in reducing the density of leafy spurge.

Regardless of the degree of control of shoots obtained from herbicide application, there are many leafy spurge seeds in the soil at the end of the first 3 to 4 years of a control program (Table 2). The ability of these seeds to germinate varies with the site from which they were collected (Table 2 and Selleck et al. 1962). Regardless of the variability between locations, the most important factor was the length of time seed set was prevented. Most seeds collected from the soil following the elimination of seed set for 8 years were either hollow or contained a shrivelled embryo. Our results indicated that ample seeds were available for reestablishment of leafy spurge following a single application of picloram (Table 2). However, if the initial application of picloram is followed by a repeat treatment 3 to 5 years later, then the amount of seed remaining in the soil should be similar to the area grazed with sheep.

To determine the rate of change in the numbers of seeds in the soil bank, a seed depletion curve was constructed using data from various locations (Fig. 2). The number of seeds capable of germination on treated areas was expressed as a percentage of the untreated plots. It was assumed that the rate of depletion in the soil was similar on all sites. An arithmetic regression equation was the best fit, which meant the average annual loss from the soil seed bank was linear and was in the amount of 13%. This figure was less than the annual depletion rate of 20% found by Roberts (1969) for natural populations of seeds in uncultivated soils in England.

The trend to a lower percentage germination and higher percentage of firm seeds on picloram treated areas (Table 2)

Table 3. Percentage germination and percentage firm and nonviable seeds of leafy spurge in the soil seed bank 3 years after treatment with picloram (Jameson 1975 location).[1]

Germinating seeds	37 ± 4*
Firm seeds	48 ± 4
Nonviable seeds	15 ± 3

[1] Mean plus standard deviation based on ten samples.

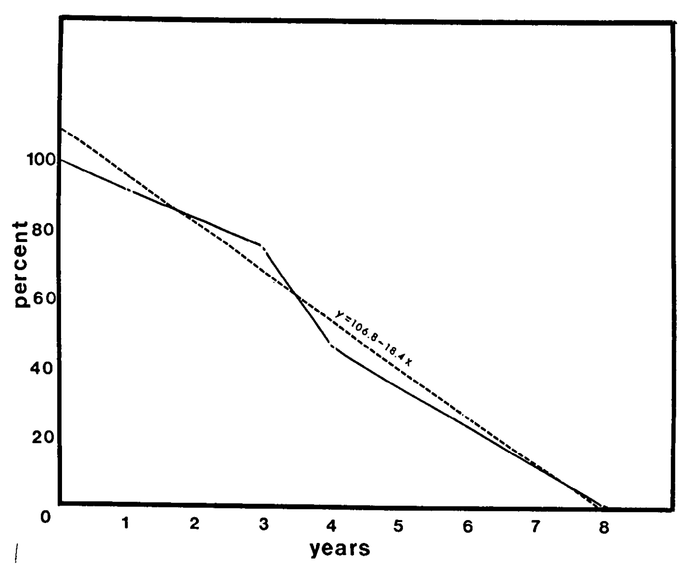

Fig. 2. *Total number of seeds capable of germination on picloram treated areas expressed as a percentage of the untreated areas.*

suggested that the chemical may have been toxic to a part of the embryo vital for germination, that the chemical may have induced dormancy in the seed, or that the germination characteristics of the seed changed with age. Laboratory investigations revealed that the germination of leafy spurge seeds in 0, 63, 125, 250, 500, and 1,000 ppb of picloram was 70, 73, 62, 75, and 68%, respectively, which was statistically nonsignificant at the 5% probability level. Picloram did not inhibit the germination process through chemical injury or by inducing dormancy. Picloram has been found by others to inhibit the germination of very susceptible species such as soybeans (*Glycine max* (L.) Merr. var Lee) and to a lesser extent safflower (*Carthamus tinctorius* L.), whereas radish (*Raphanus sativus* L.) and grass species were unaffected (Chang and Foy 1971; Scifres and Halifax 1972). It is not surprising that picloram did not inhibit germination since only very susceptible species are affected. Tetrazolium tests on the ungerminated seeds collected during 1975 from the 1973 picloram treated area revealed that most of the seeds were viable (Table 3). This suggests that seeds remaining in the soil bank for several years germinate under a different set of environmental conditions. The specific requirements which promote germination of these dormant seeds are unknown.

The conclusions drawn from the experiment are that there are many viable seeds present for reestablishment of leafy spurge following satisfactory control for at least 3 years with picloram. Continuous sheep grazing gave satisfactory long-term control of leafy spurge because the vegetative portion and the number of viable seeds in the soil were greatly reduced. For equivalent weed control with picloram, it is necessary that repeat applications of picloram prevent seed set for at least 8 years.

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Sprouting and Carbohydrate Reserves of Two Wildland Shrubs Following Partial Defoliation

E. EARL WILLARD AND CYRUS M. McKELL

Highlight: Two wildland shrubs, little rabbitbrush and snowberry, were subjected to three intensities of defoliation at each of four distinct stages in the carbohydrate reserve cycle. These treatments, comparable to browsing and other forms of natural defoliation, were designed to determine the effects on sprouting and associated carbohydrate reserve levels the following spring. Little rabbitbrush plants had reduced carbohydrate reserves, shorter sprouts, and more sprouts following most defoliation tretments. In contrast, carbohydrate reserves increased in snowberry plants with all intensities of defoliation, but there were no significant variations in their sprouting characteristics. Most dormant buds on the root crowns of little rabbitbrush and snowberry plants that were protected from defoliation were prevented from developing as basal sprouts because of apical dominance. Removal of twig tips, however, stimulated more of these buds to produce sprouts. Once a sprout began to grow, a direct relationship seemed to exist between its elongation and the amount of carbohydrate reserves available to it.

Basal sprouting of woody plants, as influenced by mortality of all aboveground plant material, has been the subject of numerous experiments. Many of these studies have related the carbohydrate reserve levels in the roots and root crowns to sprouting responses of plants with killed tops (Aldous 1929; Wenger 1953; Sterrett et al. 1968). Severe defoliation releases dormant buds on the root crown from competition with aboveground plant tissues for stored carbohydrates. Unfortunately, it also eliminates the photosynthetic material that produces these reserves. The removal of all topgrowth provides little insight into natural processes induced by insects, native and exotic herbivores, fire, and prolonged drought that effect sprouting in shrub communities.

We previously used simulated grazing systems to define the effects that large herbivores might have on sprouting of wildland shrubs (Willard and McKell 1973). In the present study, we examined the effects of partial defoliation at different controlled intensities during various stages of the carbohydrate reserve cycle. Our aim was to define resultant influences on sprouting and associated carbohydrate reserve levels the following spring. Two wildland shrubs, little rabbitbrush (*Chrysothamnus viscidiflorus*) and snowberry (*Symphoricarpos vaccinioides*), were selected as representative of the many sprouting shrub species.

McKell (1956) observed sprouting of little rabbitbrush plants that were no more than 3 months of age after their tops had been damaged by an extreme drought. Sprouts 10 to 15 cm long were also observed as regrowth when tops were removed to clear research plots for other purposes. Stoddart and Smith (1955) reported that root sprouting is common in little rabbitbrush following a fire. Top removal of snowberry by mowing induces basal sprouting (Aldous 1929). These reports indicate the potential of these species to produce sprouts following disturbance of topgrowth.

Studies to determine the influence of defoliation by insects show a significant decrease in flower and seed production (Simmonds 1951; Cameron 1935; Jameson 1963); however, the life of the plant may be prolonged through inducing the formation of sprouts (Cameron 1935). A review of the influence of insect defoliation on trees (Kulman 1971) indicates that complete defoliation results in partial mortality of buds and new shoots.

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Site Description

Plants used in the investigation were taken from exclosures that had excluded livestock grazing for more than 10 years prior to our study. The fenced areas were at approximately 2,080 meters elevation in the Cache National Forest in the Wasatch Mountains of northern Utah. In all cases, the exclosures were on the mountain-brushland type on slopes with south or southwest exposures.

Precipitation in the study area averages 75 cm, with the major portion falling in winter as snow or sleet. Snowmelt in the spring brings soil moisture close to field capacity. Rainfall is normally high from March through June, but is low in July, August, and early September. Many plants on the site complete their annual growth cycle by the onset of the dry summer period or else their growth rates are reduced. Certain species, mostly shrubs, renew growth in the fall as rainfall increases.

Soils on the brushy slopes average 75 cm in depth and consist of A, B, and B_2 horizons. Textures range from a silt loam at the surface to a clay at 75 cm, which blends into rocky subsoil.

Methods

Clipping dates were set at monthly intervals to coincide with early (June 1), mid (July 1 and August 1), and late (September 1) phases of the growing season. These phases corresponded with definite changes in the carbohydrate depletion and storage cycles of little rabbitbrush and snowberry as described by Baker (1967). Carbohydrate reserves on June 1 were at or near the low point in the depletion which occurs with the initiation of new growth. By July 1, the reserves were still low, but had begun to increase after the earlier depletion. The August 1 treatment occurred when the reserves were at the annual high for snowberry and near the annual high for little rabbitbrush. Flowering and seed production reduced or slowed the storage of carbohydrates after August 1. By September 1 the storage for the growing season was completed and plant growth had essentially ceased. Twenty-four plants of each species were assigned to each of the four defoliation dates. On each date, eight of the 24 plants were clipped at each degree of defoliation: light (30%), moderate (60%), and intense (90%). Another group of 24 plants of each species was left unclipped as a control unit. Each individual plant was identified with a numbered stake.

Preliminary practice on nontest plants before each clipping date insured a high degree of accuracy in removing the desired percentages of leaf and twig tissues. The percentage of clipped foliage was determined by ocular estimates.

Plants were clipped during the summer of 1969, and then allowed the remainder of that year to respond to the treatments applied. All clipped and control plants were carefully excavated on June 1, 1970 to obtain as much of the root system as possible. This date was assumed to equate with maximum carbohydrate depletion. The roots were carefully washed to remove all foreign matter, and then divided into two groups: 6 mm or less and greater than 6 mm in diameter. Root crowns formed a third category, and were defined as the tissue between the first root and the first branch. Samples were stored in 95% ethanol for later drying with steam-heated ovens and grinding in a micromill.

Roots and root crowns were also collected periodically from unclipped control plants of both species throughout the 1969 growing season and analyzed for total available carbohydrates (TAC) to correlate points in the carbohydrate reserve cycle with clipping treatments.

Several plants of both species were excavated during the dormant period to determine if buds were present on root crowns as a potential source of sprouts the next spring.

Sprouting responses were determined on clipped and control plants when the plants were excavated in 1970. Quantification involved counting the number of sprouts emanating from the root crown of each plant and measuring the length of each sprout.

Root and crown samples were analyzed for total available carbohydrates using laboratory techniques described by Coyne (1969). Total available carbohydrates were defined as reducing and nonreducing sugars, starches, dextrins, and fructosans by Weinmann (1946) and Smith et al. (1964). Results are reported as milligrams of available carbohydrates per gram of oven-dry material (mg/g).

Our clipping dates corresponded to four definite periods in the TAC cycle of little rabbitbrush (Fig. 1). The June and July defoliation dates occurred when reserves were at or near low points in the depletion phases of the cycle. The two latest dates occurred when reserves had been replenished.

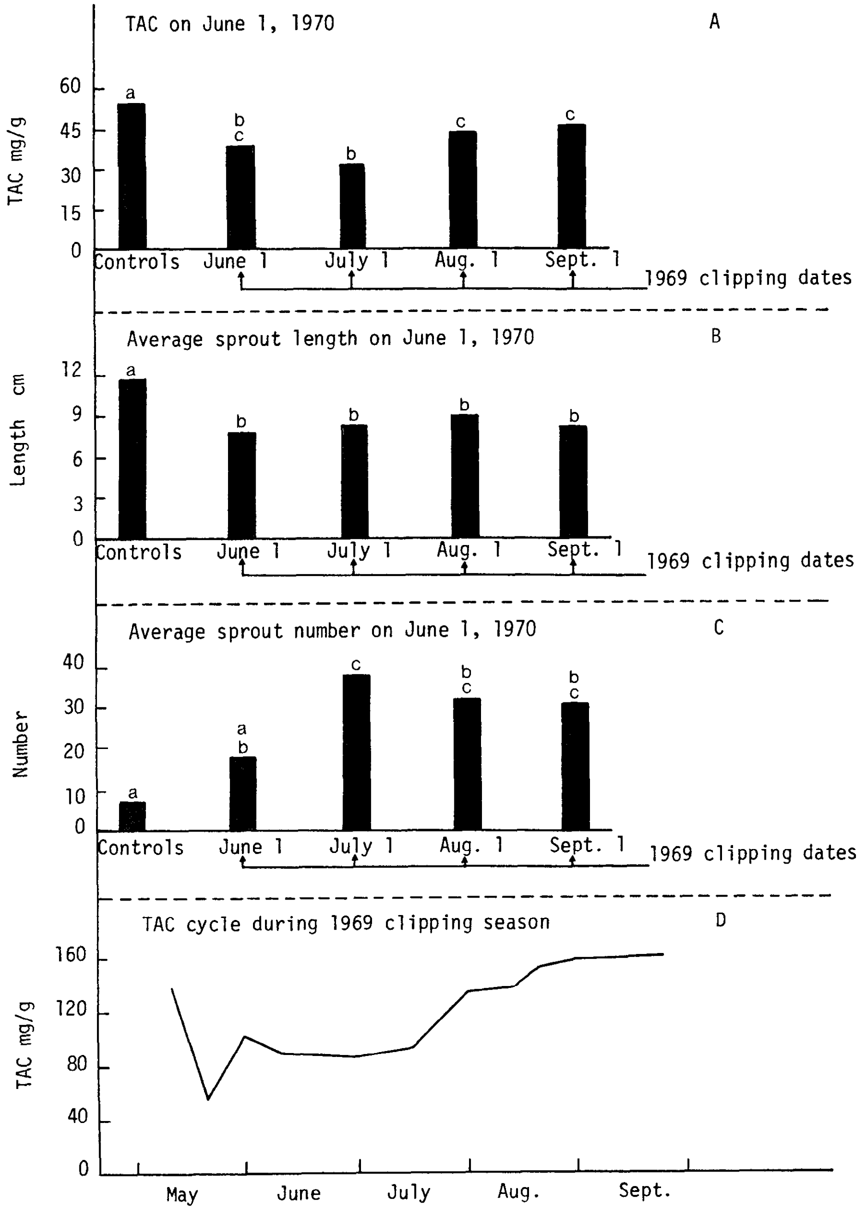

Fig. 1. *Total available carbohydrates (A) and sprouting responses (B, C) of little rabbitbrush on June 1, 1970, after partial defoliation at different dates in 1969 as related to carbohydrate reserves of unclipped plants (D) at the time of defoliation. Bars labeled with the same letter are not significantly different at the .05 level.*

The clipping dates also correspond to distinct periods in the carbohydrate reserve cycle of snowberry (Fig. 2). June 1 and July 1 defoliation treatments were applied when reserves were just beginning to recover from periods of rapid depletion. The August 1 defoliation coincided with the peak of the storage cycle, while the September 1 treatment occurred when seed production was complete and reserves were being restored. The effect of twig and leaf removal (whether by man, browsers, or defoliators) at these distinct points in the carbohydrate reserve cycle of little rabbitbrush and snowberry can thus be determined.

The small roots of little rabbitbrush and the root crowns of snowberry are the most important and active sites of carbohydrate reserves (Willard 1972). These tissues contain the greatest amounts of total available carbohydrates, and in the 1972 work were more responsive to clipping treatments and seasonal fluctuations than were the other tissues analyzed. These are the storage sites implied, therefore, when carbohydrate reserves are mentioned in the following discussion and figures.

Results

Little Rabbitbrush

The carbohydrate reserve cycle of little rabbitbrush during the 1969 growing season is shown in Figure 1 D. Reserves were rapidly depleted during the latter part of May as leaf buds began to swell and open. Replenishment was rapid after leaf development until early June, followed by an extended period when reserves were again depleted for flower production in late June and early July. Reserves then increased rapidly again until the first of August, after which the rate of replenishment was much reduced.

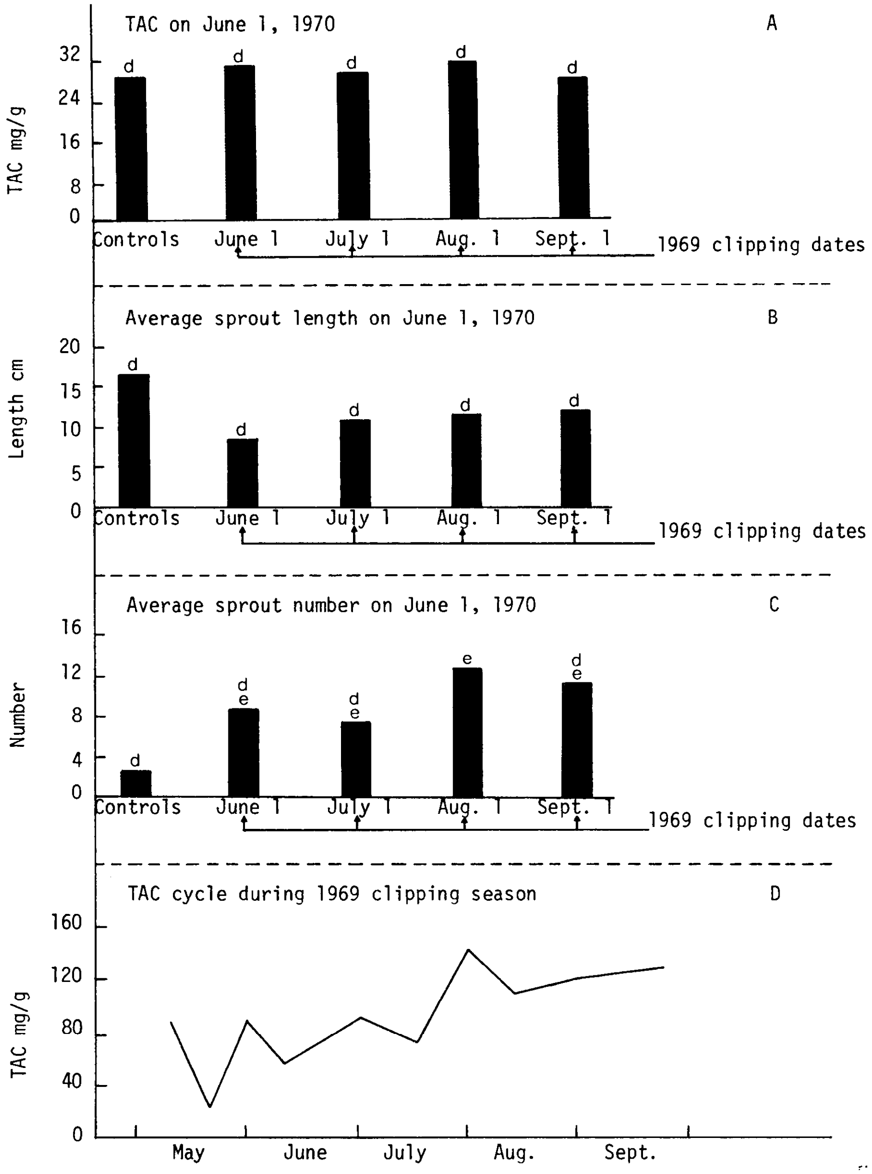

Fig. 2. *Total available carbohydrates (A) and sprouting responses (B, C) of snowberry on June 1, 1970, after partial defoliation at different dates in 1969 as related to carbohydrate reserves of unclipped plants (D) at time of defoliation. Bars labeled with the same letter are not significantly different at the .05 level.*

Partial defoliation of little rabbitbrush at any of the four points in the TAC cycle reduced reserves the following spring (Fig. 1 A). Reserves were reduced more by clipping on July 1 during flower formation than by clipping later in the summer. However, carbohydrate reserves in plants clipped during the initial spring depletion (June 1) period did not sgnificantly differ from those in plants clipped during flowering depletion (July 1) (Fig. 1 A).

All clipping intensities imposed during 1969 reduced stored carbohydrates in little rabbitbrush the following spring (Fig. 3 A). The light intensity treatment reduced TAC reserves more than did the moderate intensity. No other differences in reserves were detected among clipping intensities (Fig. 3).

The number of subsequent new sprouts was significantly increased by clipping during flower formation (July 1) or later in the summer (Fig. 1 C). Sprouts were shorter on clipped plats regardless of defoliation dates, however, than on unclipped plants. All clipped plants had sprouts of essentially the same length (Fig. 1 B).

All intensities of clipping similarly increased the numbers of new sprouts (Fig. 3 A) and in all cases, these sprouts were shorter than ones of unclipped plants (Fig. 4 A).

Snowberry

The carbohydrate reserve cycle of snowberry during the 1969 growing season is shown in Figure 2 D. Trends in reserves were similar to those of little rabbitbrush. The most obvious difference was that the reserves in snowberry were depleted to a much lower level than those of little rabbitbrush during initiation of spring growth. TAC reserves were rapidly replenished in late May and early June when plants were in full foliage, with another reduction during flowering from mid-June to mid-July. A gradual increase then occurred until early August, when reserves were utilized for seed production. Net storage was slight after mid-August.

Total available carbohydrate reserves and sprout lengths of plants partially defoliated at any of the four points in the TAC reserve cycle did not vary significantly from those of unclipped plants the following year (Fig. 2). Clipping on August 1, however, when reserves were at their high point for the growing season, increased the number of new sprouts produced the following spring (Fig. 2). These data suggest that snowberry is not as much influenced by the timing of partial defoliation as is little rabbitbrush.

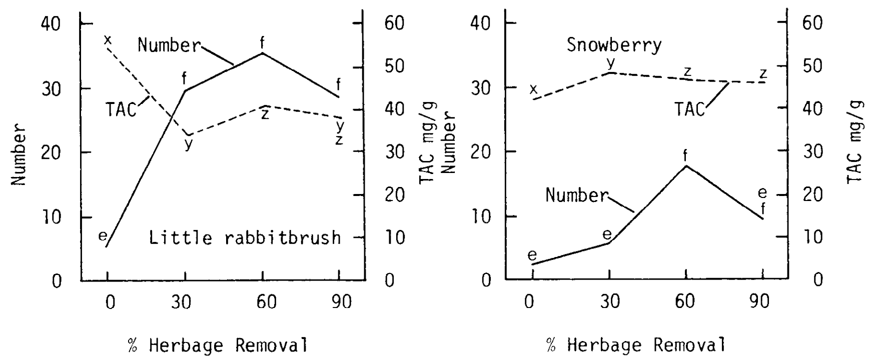

Fig. 3. *Numbers of new sprouts and TAC reserves of little rabbitbrush (A) and snowberry plants (B) in the spring following partial defoliation at different intensities the previous year. Points on curves labeled with the same letter are not significantly different at the .05 level.*

By contrast, the degree of defoliation appears relatively influential on the TAC reserves and sprouting of snowberry. All intensities of defoliation produced an increase in carbohydrate reserves the following spring. Plants clipped lightly had greater reserves than did those more severely defoliated (Fig. 3 B).

The intensity of defoliation did not influence the length of new sprouts the following spring (Fig. 4 B). However, the moderate clipping treatment significantly increased the number of new sprouts over those of unclipped or lightly clipped plants (Fig. 3 B).

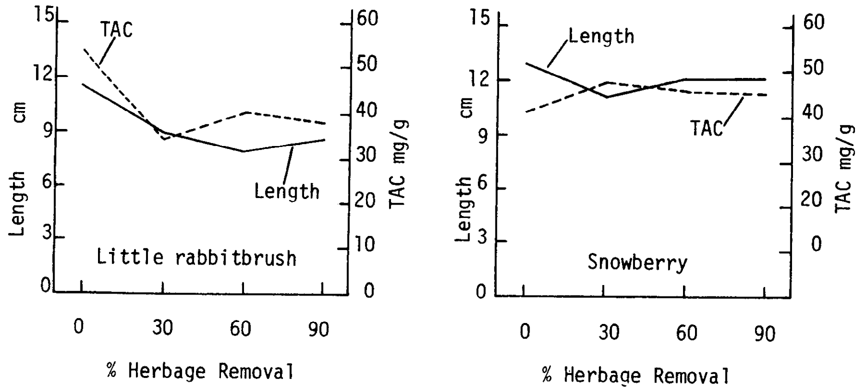

Fig. 4. *Lengths of new sprouts and TAC reserves of little rabbitbrush (A) and snowberry plants (B) in the spring following partial defoliation at different intensities the previous year. Points on curves labeled with the same letter are not significantly different at the .05 level.*

Discussion

Unclipped plants of snowberry and little rabbitbrush that were excavated during the winter had numerous buds on their root crowns. These were apparently the source of new root crown sprouts the following spring. The number of new sprouts varied on clipped plants depending upon the clipping treatment of the previous year. We were unable to detect if adventitious buds developed following the clipping treatments. It is apparent, however, that both plant species have a sprouting potential that does not require defoliation as an activator. Also, varying numbers of buds were observed on the root crowns of both clipped and unclipped plants at the same time that sprouts were well developed. Why some of the buds remained dormant is unknown.

Investigations into causes of bud dormancy have been numerous and it was not our purpose to investigate this subject. Thimann (1937, 1948) and Romberger (1963) have reviewed the subject extensively, and they reported that lateral buds commonly begin growth following decapitation of the stem apex, which releases apical dominance. Apical dominance may contribute to the dormancy of buds on the root crowns of snowberry and little rabbitbrush, although the sprouts on unclipped plants illustrated that this dominance is not complete.

Partial apical dominance, rather than an "all-or-nothing," mechanism, seems to be regulating the number of sprouts appearing on snowberry and little rabbitbrush following partial defoliation. Plants clipped lightly had intact shoot apices left on several twigs, while those clipped moderately had fewer and heavily-clipped plants had no intact twig apices. This might explain why moderately clipped plants had greater absolute numbers of sprouts than plants under other clipping intensities or control plants. (Although not statistically significant in all instances, our data indicate a similar trend in both species.) Plants clipped moderately had fewer twig apices left to exert apical dominance than those clipped lightly or left unclipped. Thus, lowered apical dominance allowed more sprouts to grow. Those plants clipped intensely, although having no twig apices remaining, had lower TAC reserve levels than those clipped moderately. This probably explains the greater number of sprouts on moderately defoliated plants. It appears, then, that partial defoliation lessens apical dominance and mobilizes available carbohydrate reserves, which regulate the number of sprouts produced.

Once sprouts begin to grow, their vigor is related to carbohydrate reserves. Yocum (1945) reported that bud growth depends upon food reserves. Tew (1970) also reported that root sections of *Populus tremuloides* maintained in the greenhouse initially produced rapid sprout growth that ceased rather abruptly, indicating a depletion of carbohydrate reserves. Our data illustrate that in addition to affecting carbohydrate reserves, clipping also increases the number of sprouts that draw upon these reserves. Each sprout on a clipped plant has a smaller amount of carbohydrates available to it for growth than does a sprout on unclipped plants. Conversely, unclipped plants generally have longer sprouts since few sprouts are drawing upon stored carbohydrate reserves.

Differences betwen snowberry and little rabbitbrush in their depletions of TAC reserves following an initial defoliation treatment are probably related to differences in vigor between the two species when they are protected from defoliation. Snowberry has a markedly low level of vigor; it tends to produce fewer young shoots and has a shorter period of growth. Clipping stimulated growth of numerous new shoots and more leaves remained on the plant for several weeks longer in the fall. Seed production, a physiological drain on carbohydrate reserves, was quite noticeably greater in nonclipped than on clipped plants. The combination of these factors probably provides for greater net production of photosynthate for storage in the sinks of previously defoliated snowberry plants.

Little rabbitbrush plants protected from defoliation produce vigorous shoots annually on older stems. Clipping of this species simply stimulates a larger number of new sprouts, which draw upon carbohydrate reserves for initial growth. Thus, these new sprouts as a group apparently require more carbohydrates than they can replace during the year of defoliation, resulting in a net reduction in the various stoage sites.

Various degrees of defoliation of wildland shrubs by insects, drought, wild herbivores, livestock, wildfires, or other factors commonly occur in most plant communities. Our data suggest that changes in carbohydrate reserve levels and in sprouting following a partial defoliation may change the competitive ability of certain shrub species in the community. Partial defoliation may enhance the vigor and perhaps the competitive ability of shrubs such as snowberry by affecting an increase in carbohydrate reserves, sprouting, and overall plant vigor.

Other species may react differently. The significantly lower carbohydrate reserve levels and reduced sprout growth of clipped plants of little rabbitbrush suggest that the vigor of certain species may be reduced following partial defoliation.

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Elemental Concentrations in Native Range Grasses from the Northern Great Plains of Montana

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Highlight: A study of elemental concentrations in five range grasses from the Northern Great Plains of Montana indicated levels of calcium, magnesium, iron, and manganese adequate for optimum performance of range cattle. Concentrations of copper and zinc were below established nutrient requirement levels. Concentrations of these two elements were usually highest in spring samples and decreased throughout the summer and fall. Year-to-year variation was small in spring grass collections for both elements, but summer and fall collections revealed wide fluctuations in elemental levels. For maximum performance of range cattle in the study area, copper and zinc supplements appear to be necessary during summer, fall, and winter grazing seasons.

The trace element requirements for cattle have been established, particularly for animals in feedlots (National Research Council 1976). However, range cattle encounter different environmental conditions than do feedlot cattle and these affect nutrient requirements as well as the intake of range plants. There are numerous reports of trace element toxicity and deficiency diseases in pasture cattle (Fontenot 1972; Miller 1970; Hartmans 1974) and trace element additives are commonly incorporated into food supplements for range animals. The extensive use of trace mineral supplements in the livestock industry points out the need for establishing the pattern of potential mineral intake based on forage plant concentrations.

The availability and consumption of trace elements by livestock on native range is influenced by a number of factors. A variety of life forms and individual plant species constitute the range resource and represent varying elemental compositions. Within single species, investigators have even shown that mineral levels are related to the stage of maturity of the plant (Smoliak and Bezeau 1967; Hamilton and Gilbert 1972). Selective grazing behavior of cattle and over- or under-grazing at different seasons, as well as soil intake, influence elemental balances on native range (Healy 1974). The availability of an element may also be influenced by concentrations of other elements in the forage. The relationships between copper, molybdenum, and sulfur illustrate this point (Lessard et al. 1970).

Miltmore et al. (1970) noted copper and zinc deficiencies in some cattle forages in British Columbia, and Hamilton and Gilbert (1972) found adequate levels of copper but marginal concentrations of zinc in Wyoming grasses. Elemental levels in pasture grasses from the Northern Great Plains of Montana have not been examined.

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The purpose of this study was twofold: to establish the levels of calcium, magnesium, iron, manganese, copper, and zinc in range forage grasses, and to determine if these elemental concentrations were high enough to meet nutrient requirements of range cattle as established by the National Research Council (NRC 1976).

Methods and Procedures

The grasses analyzed in this study were collected from sites located in Rosebud County, Mont., approximately 180 km west of North Dakota and 70 km north of Wyoming. The area constitutes a mixture of mid-grass prairie and open ponderosa pine stands. Permanent collection sites were established in vegetation representative of the local plant communities. Three perennial grasses, western wheatgrass (*Agropyron smithii*), bluebunch wheatgrass (*A. spicatum*), and needleandthread grass (*Stipa comata*), were selected for analysis, as well as a sample of mixed perennial grasses and the annual cheatgrass (*Bromus tectorum*). These plants represented the dominant range grasses within the study area. Soils were quite variable. Needleandthread and bluebunch wheatgrass were common on sandy-skeletal, mixed Borollic Camborthids, and Typic Torriorthents on flat uplands, while western wheatgrass was found primarily on the coarse and fine loamy Aridic Haploborolls and Borollic Camborthids on toeslopes and gently sloping alluvial terraces. Mixed perennial grasses and *Bromus* species were found on all soils in the study area. Chemical analyses of surficial materials from these sites indicated that the soils represented a spectrum of nutrient regimes.

Grasses were clipped approximately 5 cm above ground level during March, May, July, and October of 1973. Samples from 1974 were collected during February, May, August, and October. Cuttings were dried to a constant weight in a forced-draft oven at 70°C. Tissues were digested in a 3:2 mixture of hot nitric-perchloric acids and elemental concentrations determined by atomic absorption spectroscopy. Accuracy of analyses was assured by simultaneous analyses of National Bureau of Standards (NBS) Standard Orchard Leaves and comparison of these values to certified levels. Precision and accuracy were also determined using the NBS standard (Table 1).

Table 1. Summary of accuracy and precision studies using NBS reference material, orchard leaves (all values in mg/kg unless otherwise indicated).

Element	NBS certified value	Mean and SD of 6 analyses	Relative SD (%)*	Relative error (%)**
Ca	20100 ± 300	20700 ± 500	2.4	1.0
Cu	12 ± 1	12.3 ± 0.4	3.2	2.5
Fe	300 ± 20	291 ± 27	9.3	3.0
Mg	6200 ± 200	6000 ± 300	5.0	3.2
Mn	91 ± 4	87.9 ± 0.7	0.8	3.4
Zn	25 ± 3	25.6 ± 1.2	4.7	2.4

* SD/$\bar{x}$ × 100.
** Absolute value of (certified value − $\bar{x}$)/certified value × 100.

Results

The elemental concentrations of the native grasses and the established nutrient requirements are summarized in Table 2. The averages, standard deviations, and numbers for all plants analyzed during the 2-year collection period are shown in this table.

Calcium

The National Research Council report (1976) indicated a calcium concentration in the dry diet from 1,800 to 4,400 mg/kg as sufficient for most range cattle. All of the grasses studied in each of the eight seasons exhibited calcium levels within this range (Table 2). Minimum calcium values were recorded in western wheatgrass in spring samples (3,000 mg/kg). Summer and fall concentrations were higher than those in winter and spring in all samples except needleandthread grass.

Table 2. Summary of elemental concentrations in cattle feeds calculated on dry weight basis (all values in mg/kg).

Element	Dietary requirement*	Dietary requirement**	This study	
Ca	1800 to 4400		3500 ± 700	(N=261)
Mg	400 to 1000		1200 ± 200	(N=252)
Fe	10	30	167 ± 99	(N=274)
Mn	1.0 to 10.0	40	39 ± 14	(N=969)
Cu	4	10	3.6 ± 0.8	(N=1181)
Zn	20 to 30	50	17 ± 4	(N=1181)

* National Research Council (NRC), 1976.
** Agricultural Research Council (ARC), 1963.

Magnesium

The average magnesium level for all grasses from all seasons (Table 2) was above the nutrient requirement range of 400 to 1,000 mg/kg. The mixed perennial grasses collected in the fall of 1974 showed the highest concentration of magnesium—1,700 mg/kg. The lowest concentration was found in cheatgrass samples from the summer of 1974 with an average magnesium level of 800 mg/kg. These values indicated that cattle grazing on these five grasses were consuming sufficient quantities of magnesium.

Iron

Although a minimum requirement for iron has not been established, a level of 10 mg/kg in the dry diet was indicated by the NRC (1976) as sufficient for most cattle. The grasses in this study exhibited a large range in iron content. The maximum and minimum averages were 499 and 70 mg/kg in cheatgrass, fall 1973, and western wheatgrass, spring 1974, respectively. The samples collected in the spring contained lower levels (< 100 mg/kg) of iron, while those collected in the fall exhibited much higher concentrations (> 200 mg/kg). Compared to the NRC (1976) recommended level, these data indicated adequate levels of dietary iron in the grasses of the study area.

Manganese

The manganese requirement of beef cattle is usually 1 to 10 mg/kg in the dry diet (NRC 1976). The requirement for reproduction appears to be higher, with an intake of 20 mg/kg adequate for normal pregnancy. All of the grasses in this study exceeded these manganese levels. Bluebunch wheatgrass exhibited the lowest level (21 mg/kg) in the summer of 1973. Manganese did not appear to pose a dietary problem in the study area.

Zinc

Dietary requirements for zinc in cattle forage are reported to be 20 to 30 mg/kg (NRC 1976). Determination of levels of this element in cattle forages consistently showed marginal or below minimum dietary concentrations in the rangeland grasses of the study area. Figure 1 shows the zinc concentration for each of the five grasses throughout the 2-year study.

Of the grasses, cheatgrass (Fig. 1) exhibited the highest consistent zinc content throughout the seasons. This grass probably does not form a significant food source on these ranges during summer, fall, or winter, however, because it matures very early and is less palatable thereafter than perennial grasses (Cook and Harris 1952). Needleandthread grass yielded low zinc levels, with all seasons below the nutrient requirement range. The zinc content of the other grasses showed levels below or in the lower part of the dietary range.

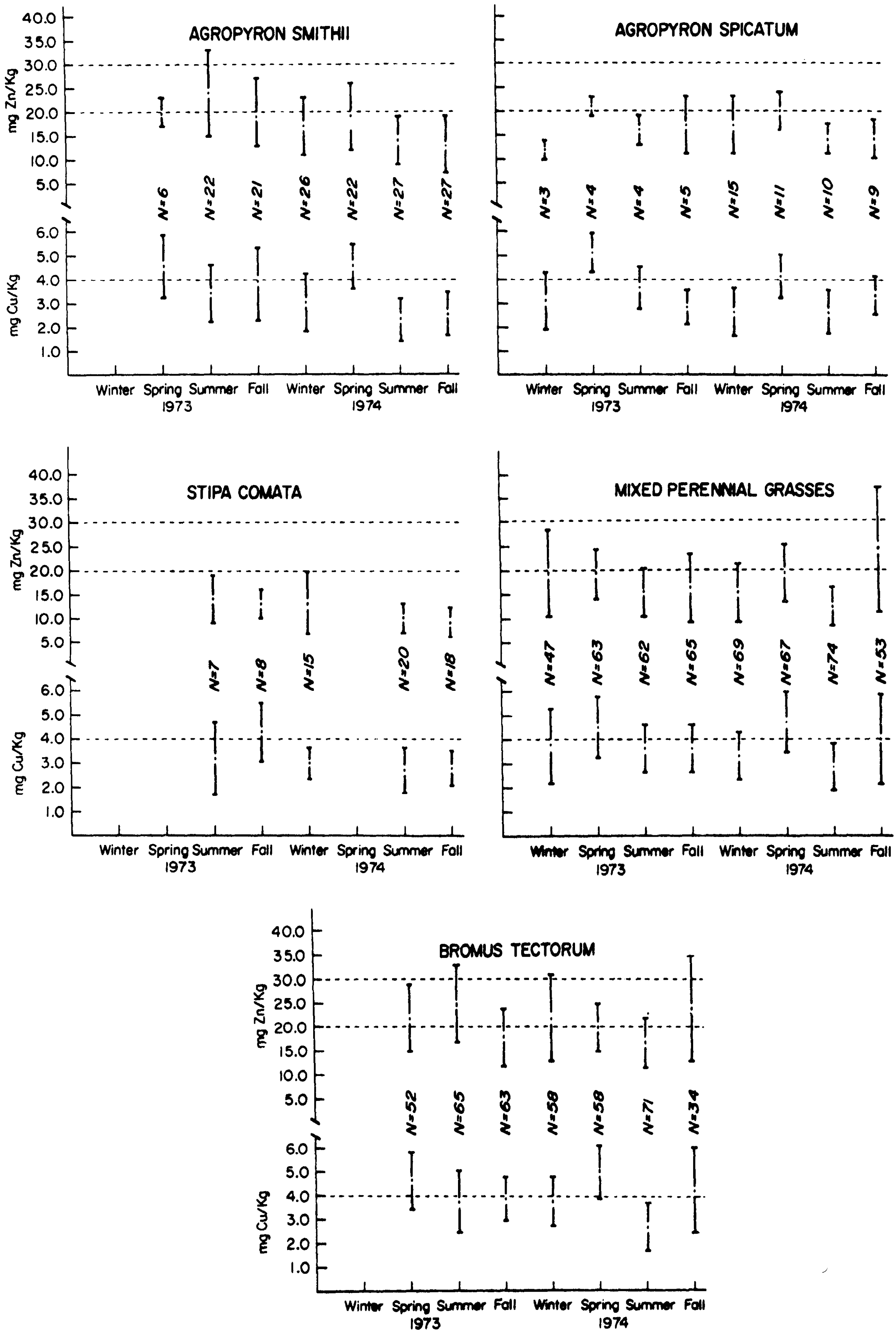

Fig. 1. *Zinc and copper concentration of five range grasses. Dashed lines represent minimum dietary level on range. Vertical lines represent* ± 1 S.D., means indicated by mid point.

When seasons were combined, that is both spring zinc levels versus all summer and all fall zinc levels, elemental concentrations in spring collections of bluebunch wheatgrass were significantly higher (P=0.01) than summer, fall, and winter levels. The zinc content of the mixed perennial grasses showed highest levels in both spring and fall samples while the other grasses showed no significant seasonal changes.

When these data were viewed on the basis of individual seasons for each species, there is a marked consistency in spring-to-spring zinc levels. Summer, fall, and winter averages, on the other hand, exhibited wide fluctuations. For example, western wheatgrass showed spring zinc concentrations of 20 and 19 mg/kg but summer concentrations of 24 and 14 mg/kg and fall levels of 20 and 13 mg/kg.

Copper

The National Research Council has established a nutrient requirement of 4 mg/kg of copper in the dry diet for beef cattle. The average copper value for all grasses in this study (Table 2) was 3.6 ± 0.8 mg/kg. Average, seasonal copper concentrations in the grasses analyzed in this study were below the NRC minimum level in 24 out of 35 collections. Needleandthread grass (Fig. 1) yielded the lowest copper concentrations with only samples collected in the fall of 1973 having an average above the minimum dietary requirement. When seasons were combined, spring grasses exhibited maximum copper values with a general trend of decreasing content as the plants matured. This is clearly shown in bluebunch wheatgrass and the mixed perennial grasses. Both grasses have significantly higher (P=0.01) copper levels in spring samples.

When the data were analyzed by species on a seasonal basis, copper concentrations were most consistent in spring samples. Elemental levels in summer and fall showed wide variations, similar to those found in zinc concentrations. Copper levels in spring collections of western wheatgrass were 4.5 mg/kg for both years of the study. Summer levels in this species were 3.5 and 2.3 while fall samples showed concentrations of 3.9 and 2.5 mg/kg.

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TECHNICAL NOTES

Frequency of Endomycorrhizal Infection in Grazed and Ungrazed Blue Grama Plants

PATRICK E. REECE AND CHARLES D. BONHAM

Highlight: The frequency of mycorrhizal infection in blue grama roots was determined from two criteria: (1) occurrence of any mycorrhizal element, and (2) occurrence of fungal vesicles. No significant differences were observed with respect to grazing using the first frequency criteria. However, roots of previously grazed plants had significantly higher frequencies of vesicles than those collected from exclosures. Frequency of vesicles was found to increase linearly with increase in rooting depth of blue grama. Significant grazing effects on the frequency of vesicles were observed primarily in the first sample depth, 0–10 cm.

A region of intense microbial activity exists in soil surrounding plant roots. The majority of plant species growing under natural conditions are dual organisms in that the organs through which they absorb water and nutrients consist of root and fungus tissue, mycorrhiza. The entire root system of an individual plant may be mycorrhizal or only a portion of the roots may be infected. However, relatively few species are completely nonmycorrhizal (Gerdemann 1968; Khan 1974).

Fungi which infect root systems of grasses are predominantly vesicular-arbuscular (V-A) endotrophs which are most commonly placed in the genus *Endogone* (Mosse 1973). V-A mycorrhiza have a loose network of hyphae in soil surrounding the root and extensive hyphal growth within the root cortex (Fig. 1). The external hyphae network may extend into the soil as much as 7 cm (Rhodes and Gerdemann 1975).

Recent interest has increased in examining the influence of mycorrhiza on tolerance of plants to various soil nutrient and water stresses (Williams et al. 1974). While the presence of mycorrhiza in grasslands was documented as early as 1929 (Weaver and Clements 1929), we are not aware of any published reports dealing with the influence of mycorrhiza on the tolerance of plants to grazing stress.

A study was conducted at the Eastern Colorado Research Center to examine the occurrence and extent of endomycorrhiza infection in roots of blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) plants under grazed and ungrazed conditions on two soil types. The Center is located 26 km north of Akron, Colo., in the sandhills of northeastern Colorado at an elevation of 1,300 m. The climate is semiarid with cold, dry winters; moist, cool springs; hot, occasionally dry summers; and mild, usually dry autumns (Sims et al. 1973). Seventy percent of the long-term 38 cm average annual precipitation falls as rain from April 1 to August 31. The average frost-free period of 140 days usually begins in mid-May and ends in early October (Dahl 1963).

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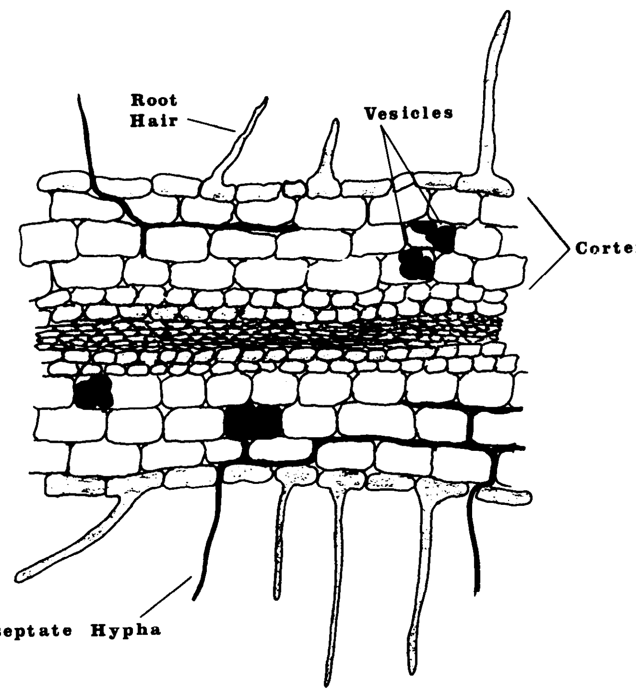

Fig. 1. *Enlarged view of blue grama root infected by endomycorrhizal fungi. Intercellularly located vesicles and intercellularly located aseptate hyphae are restricted to the root cortex.*

Five root cores (44.2 cm^2 × 100 cm) of blue grama were collected inside and outside exclosures, which were located on loamy sand and sandy loam sites. Cores were taken in early November with the aid of a pneumatic hammer and jack (Bartos and Sims 1974). Three 10-cm increments were taken from each core at 0–10, 20–30, and 40–50 cm soil depths. Samples were placed in ziplock plastic bags and stored at 5°C. Cores were rinsed with water over a 32-mesh screen, after which roots were bleached and stained according to procedures described by Trappe et al. (1973). Stained root segments (3 cm) were mounted in Howyer's solution and examined with a 100 × microscope. Frequencies of mycorrhiza were based upon occurrence of any mycorrhizal elements in 30 2-mm view segments of roots per slide. Because of the sampling procedure, the acropetal end of the root segments was not known and segments were randomly placed on the slides.

The 30 slides prepared from the loamy sand site were reexamined following the initial review. Frequency of mycorrhiza infection in the reexamination was determined by the occurrence of vesicles. The two

Table 1. Mean frequencies (%) and standard errors (S.E.) of mycorrhizal infection in blue grama roots basedupon the occurrence of fungal elements, e.g., hyphae or vesicles in the root cortex, for soil types and grazing.

	Soil types					
	Loamy sand		Sandy loam		Grazing	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Grazed	89	2.5	87	2.4	88	1.7
Ungrazed	89	2.8	84	6.4	86	3.5
Soil type	89	1.8	85	3.4		

sets of frequency data were analyzed separately using a factorial analysis of variance (Snedecor and Cochran 1973).

Results

Soil differences did not significantly influence the frequency of infection based upon occurrence of any mycorrhizal elements under grazed or ungrazed conditions (Table 1). Infection frequencies of previously grazed plants were not significantly different from previously ungrazed plants at either soil site (Table 1). Roots were equally infected at all three soil depths based upon occurrence of any mycorrhizal elements (Table 2).

Table 2. Mean frequencies (%) and standard errors (S.E.) of mycorrhizal infection in blue grama roots based upon the occurrence of fungal elements, e.g., hyphae or vesicles in the root cortex, for soil depths.

	Soil depth					
	0–10 cm		20–30 cm		40–50 cm	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Grazed	87	2.6	87	9.1	90	3.8
Ungrazed	92	2.4	81	2.7	86	4.6
Depth	90	1.8	84	4.7	88	2.9

The mean infection frequency (based upon the occurrence of vesicles) for previously ungrazed plants was 49%, while the mean infection for plants from the grazed pasture was higher at 67% frequency ($P = .025$). Significant differences ($P = .005$) among mean frequencies of vesicles for soil depths were also observed. Mean frequencies for the 0–10 and 20–30 cm soil depths were not significantly different from each other but both were significantly less than the mean frequency observed at the 40–50 cm soil depth. Overall, the frequency of vesicles increased linearly ($P = .001$) with increasing soil depth, 42, 52, and 80%, respectively. Grazing did not significantly modify the linearity of the increase in vesicle occurrence with increasing soil depth.

Discussion

Interpretation of mycorrhiza frequency data requires a review of factors influencing the occurrence of fungi in roots. Generally, as the length of root segments examined from a given sample increases, so will the frequency of mycorrhiza occurrence. Another point of concern is the influence of root growth upon this occurrence. Neill (1944) observed that vigorous, actively growing roots of citrus trees were rarely infected and that as the rate of growth declined the infection increased. Harley (1959) suggested that any external factor which causes a slow growth rate of roots or which reduces the proportion of actively growing tissue on a root system will appear to increase infection. Furthermore, plants growing in fertile soil tend to have more roots than comparable plants growing in less fertile soil. Thus, it is possible that the plant in fertile soil with a lower percent of mycorrhizal roots might have a greater total length of mycorrhiza (Gerdemann 1968). It is important, however, to note that increased absorbing tissue provided by greater abundance of mycorrhizal hyphae under stress conditions may be a significant compensation for reduced root development (Trappe et al. 1973; Williams et al. 1974).

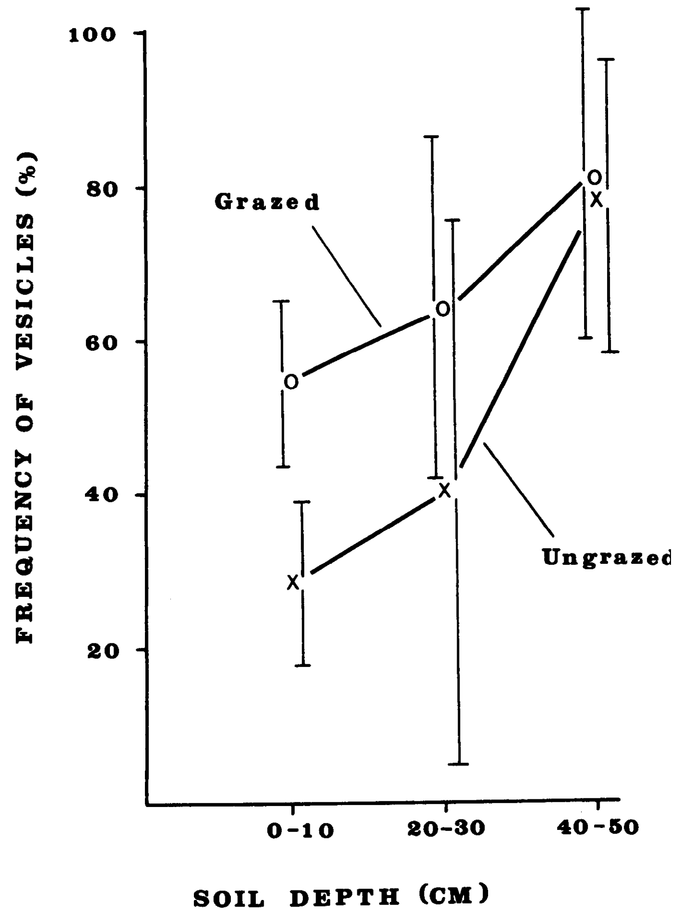

Fig. 2. *Mean frequencies (%) of mycorrhizal infection in blue grama roots from the loamy sand site based upon occurrence of vesicles in the root cortex. Vertical lines represent 95% confidence intervals for frequencies of vesicles with respect to grazing treatment.*

The literature does not provide adequate information for a thorough discussion of the differences observed between frequencies based upon the two criteria used in this study. While morphological characteristics of V-A fungal developmental stages have been described, there is still much to be learned about their ecological significance, especially with respect to vesicles (Cox and Sanders 1974; Old and Nicholson 1975). It has been suggested that vesicles may function as storage units for nutrients such as phosphorus and potassium (Gerdemann 1968). However, the availability of these nutrients to an infected plant is not known. It has also been stated that vesicles with thickened walls can function as resting spores (Carson 1974).

Treatment differences were observed but the present void in understanding the ecological significance of vesicles limits the extent of the discussion. The difference observed between grazing treatments appears to have been the result of reduced root growth. Further examination of mean occurrence of vesicles for each grazing treatment indicated that differences occurred primarily in the first soil sampling depth (Fig. 2). The root system of blue grama tends to be shallow and spreading with a major portion of root biomass production generally occurring above 30 cm (Weaver 1958; Bartos and Sims 1974). Grazing tends to reduce root growth (Crider 1955; Weaver 1958), which may be the reason for the higher occurrences of vesicles in grazed than ungrazed plants. Substantiation of this plant-fungi relationship will require examination of root length and biomass and mycorrhiza infection frequency of samples collected during several periods within a growing season. The influence of mycorrhizal fungi upon the resistance of blue grama to grazing stress might best be studied by conducting greenhouse experiments in which infected and uninfected plants are defoliated.

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Development and Evaluation of Anti-coyote Electric Fencing

N. L. GATES, J. E. RICH, D. D. GODTEL, AND C. V. HULET

Highlight: An electric fence with alternating ground and charged wires was tested for anti-coyote properties. Under the conditions tested, the fence was coyote proof. The fence may evolve as an effective, nonlethal method of preventing coyote depredation of domestic livestock.

Fencing as a means of excluding canid predators from domestic livestock has received continued interest for many years. Modern use of barrier fencing as a nonlethal method for controlling canid depredation on domestic livestock began in Australia about 1900. By 1908, 9,012 km of dingo (*Canis dingo*) fencing had been built in South Australia (McKnight 1969). In the United States, "coyote proof" fencing for protecting sheep was described in 1911 (Jardine). Although a "coyote proof" fence conceivably could have been designed, the fence configuration developed by Jardine (1911) certainly was not "coyote proof." Since that time, various researchers have tested a multitude of fence designs to deter coyotes (*Canis latrans*).

Because of the relatively low cost involved, electric fencing has been a concept of particular interest. Unfortunately, the results of research on electric fencing have been discouraging. Shelton (1973) concluded that poor grounding of the coyote and the insulating effect of vegetation and fur on the animal's body reduced the electric shock to the extent that the electric fences tested were ineffective in deterring coyotes. Thompson (1976) evaluated 18 electric fence configurations and observed that in 466 tests, coyotes responded to the electric shock only 13 times. Consequently, he concluded that electric fences were generally ineffective for controlling coyotes. Occasional undocumented reports of effective use of electric fencing for warding off coyotes and dogs (*Canis familiaris*) are heard of. These reports have kept alive interest concerning eventual development of practical, effective electric anti-predator fencing. The obvious attributes of such a fence would be (1) relatively low cost, (2) environmental acceptability, and (3) immediate availability.

The purpose of this study was to develop and evaluate practical electric fencing that would effectively protect sheep from coyotes.

At the time of the research, all authors were with the U.S. Sheep Experiment Station, U.S. Department of Agriculture, Agricultural Research Service, Dubois, Idaho 83423, in cooperation with the University of Idaho, Moscow. D. D. Godtel is now with the U.S. Forest Service, U.S. Dep. Agr., Eureka, Montana.

The authors wish to acknowledge the technical assistance of Robert L. Piesse, Melbourne, Australia, and Mark Armbruster, Moscow, Idaho.

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Materials and Methods

Trials were conducted within a 64-ha, coyote-proof test pasture. A pair of captive wild coyotes with radiotransmitter collars were contained in the pasture. Two sheep enclosures were constructed within the 64-ha pasture. Each sheep enclosure was about 8,000 m^2. One enclosure was constructed to approximate conventional sheep fence (81.3-cm woven wire with two strands of barbed wire spaced 15 cm apart above the woven wire). The other sheep enclosure was an electric fence consisting of 12 wires alternating ground to hot beginning with the bottom wire (Fig. 1). An additional hot wire (trip wire) was placed 20 cm from the fence around the outside perimeter and 15 cm from the ground (Fig. 1). All ground wires were connected to four 2.5 cm steel pipes driven about 1.5 m into the ground (Fig. 3). All energized wires were connected to a 12-volt charger [1,2] (Fig. 4). Fiber glass fence posts and battens were used between wooden corner and brace posts. Wire was 12.5 ga, 1,000 psi, and was strained to 181-kg tension. A nonenergized gate was constructed from 2.5×5 cm welded fabric and aluminum tubing. A wood sill was buried under the gate (Fig. 5). End post wire strainers were used (Fig. 6). Corner post detail is shown (Fig. 7).

Each trial lasted for 2 weeks. The trial was replicated twice. A different pair of coyotes was used in each trial. Eight lambs were placed within each of the two sheep enclosures at the beginning of each trial. Lambs were observed daily. All dead lambs were necropsied to determine cause of death.

Results and Discussion

All lambs confined in conventional woven and barbed wire enclosures were killed by coyotes in all trials (Table 1). No lambs confined within the electric enclosures were killed by coyotes in any of the trials.

Results from this investigation clearly show that properly designed electric fencing can effectively protect sheep from coyotes and thus contradict conclusions from previous reports. Lack of adequate grounding was overcome by alternating ground and charged wires and by connecting all ground wires to grounding posts. Digging under the fence by the coyotes was prevented by the incorporation of the charged

[1] Model E12, Gallagher Electronics, Ltd., Frankton, Hamilton, New Zealand.

[2] Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Dep. Agr. and does not imply its approval to the exclusion of other products that may be suitable.

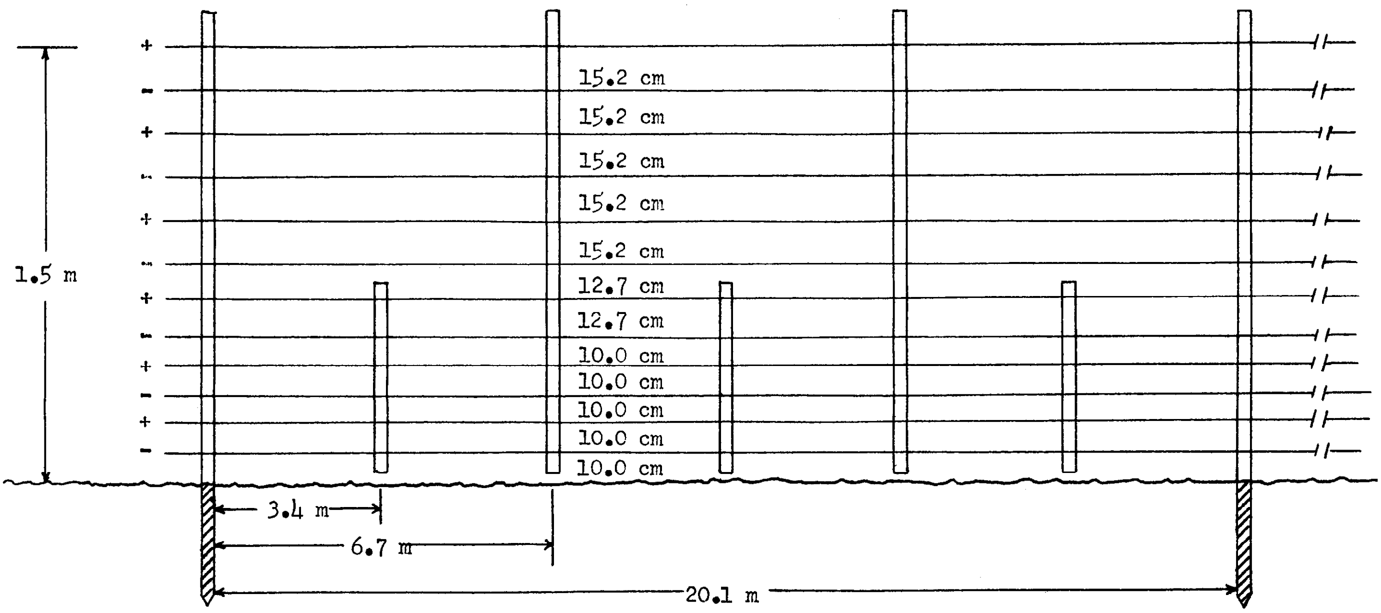

Fig. 1. *Electric fence configuration.*

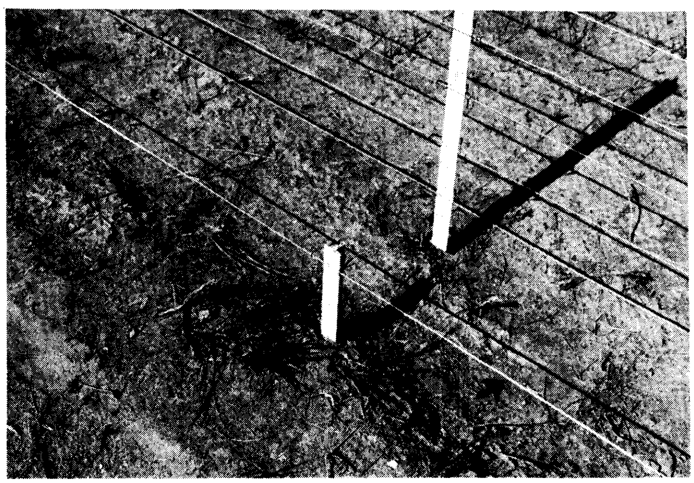

Fig. 2. *Charged trip wire around perimeter of fence.*

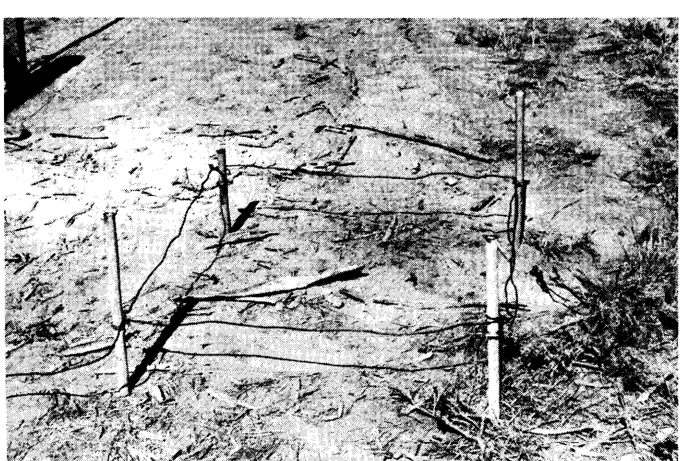

Fig. 3. *Grounding posts.*

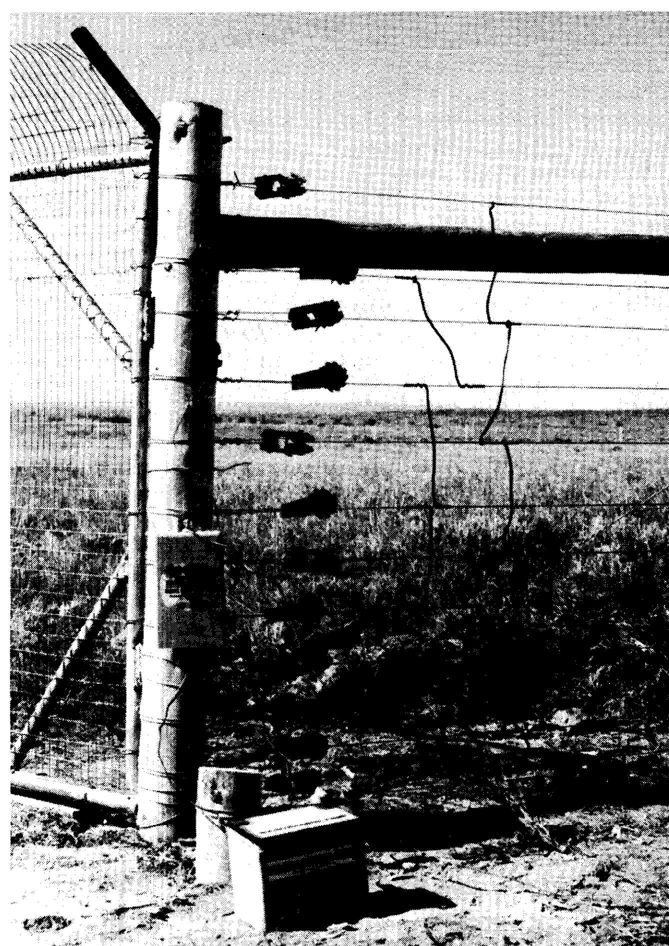

Fig. 4. *Battery charged energizer attached to gate post.*

Fig. 5. *Sill under gate to prevent dig under.*

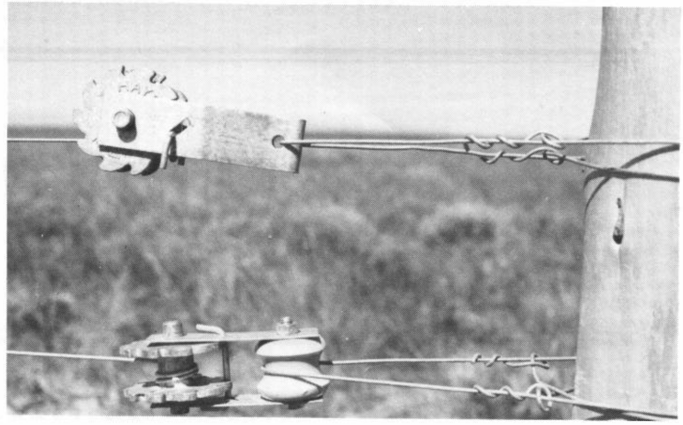

Fig. 6. *Insulated (bottom) and noninsulated post wire strainers for attaching charged and ground wires, respectively.*

Table 1. Kill frequency (number killed/day) of lambs confined within conventional sheep enclosure.

Trial No.	Day of trial 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	2	0	1	0	1	3	1	All lambs dead					
2	0	1	0	2	0	2	0	2	1	All lambs dead				
3	0	0	0	0	3	2	1	2	All lambs dead					

trip wire. Furthermore, the high pulse current capacity of the energizer used in this investigation resulted in a relatively high line voltage (3,000–5,000 V) and thus overcame voltage drainage factors such as fence contact with brush. The reader should not conclude that the configuration used in this study could not be modified, perhaps by use of fewer wires, different spacings between wires, or different sources of power. The post and stay spacings shown (Fig. 1) would probably be subject to modification, depending upon the slope of the terrain.

Additional advantages of the fence described in this report would be economic feasibility and environmental acceptability. The estimated cost of materials used in the fence tested is $1,000 per km; the cost of materials used in conventional woven and barbed wire fences is about $1,500 per km. With regard to environmental acceptability, the electric fence could not be used where it would interfere with antelope movement. Birds of prey (raptors) could be kept off the fence by metal cones attached to the tops of wooden posts. Adult deer should have

Fig. 7. *Detail of corner post.*

little difficulty in jumping the fence although fawns probably could not get through. Because of the foregoing considerations, obviously, the electric fence may evolve as an effective, nonlethal method for preventing coyote depredation on sheep and may have widespread, but not universal, application.

VIEWPOINT

The State Land Trust, Its Retention or Elimination

G. WESLEY BURNETT

Recommendation 106 of the Public Land Law Review Commission stated that:

> Limitations originally placed by the Federal Government on the use of grant lands, or funds derived from them, should be eliminated.[1]

There is evidence that heated public and political debate on the merits of this recommendation is forthcoming.[2] This paper reviews the nature of limitations placed on state land use, and the arguments of those favoring and opposing implementation of Recommendation 106.

Limited Use of State Grant Lands

Congress has generally required that each new state acknowledge federal sovereignty over unsettled land prior to admission to the Union. This acknowledgement has reduced the tax base of the new state and has forced the cost of public institution development on residents of the longest standing. To lessen this inequitable burden, Congress has traditionally granted land to the new states for the support of public institutions and vital improvements.

The grant process has involved the conveyance of specified lands in support of "common schools." In addition, statehood generally has empowered the state to select lands in lieu of school lands not actually available as well as additional land for the support of other institutions.

The salient aspects of this process are the lands' dedication to the support of particular institutions and that the dedication exists as a sacred trust between the state and Congress. Implicit is the understanding that the granted land should be managed to make money for the beneficiaries. Neither Congress nor the new state may alter the agreement established by statehood without the consent of the other. To Congress, this means that it may pass any law with respect to the grant lands, but that the law is meaningless unless the state concurs. To the state, without Congressional consent, no new land management innovation can be implemented unless it produces revenues. The state, of course, may pass laws necessary to manage the lands so long as the laws do not violate the trust concept either conceptually or specifically.

The specific terms of the trust were sparse in the initial land grant states. Abundant abuses could be expected, but without restrictions in the original trust there was little that Congress could do to assuage the often frightening waste of the grant lands. Since Congress could learn from its mistakes and provide assurances that the same abuses would not occur in subsequent land grants, land grants came to states in the West with more and more restrictions on their use. Most notably, Congress established stringent minimum sale prices and the procedures by which state grant land could be sold or leased.

Though the specific management rules have often been altered, the western states still retain substantial grant lands subject to both the general grant concept and the specific rules attached to it. Theoretically two dichotomous points of view may be taken concerning potential modification of this trust. At one extreme is that of the trustee. The trustee adheres to the concept of the trust as historically and presently good and worthy. It must be guarded against change. The other extreme is the point of view of the revisionist. To the revisionist the trust is a frontier anachronism which places unrealistic restraint on modern practices which benefit the entire public. The entire trust is a weight upon the shoulders of the land manager to be disposed of forthwith.

The positions of the trustee and the revisionist are theoretical extremes on a continuum of ideas, but future debate on Recommendation 106 is likely to center on these two theoretical positions as if no middle ground exists. The realist recognizes the existence of the extreme positions, but he also recognizes that the actual operation of the state lands has not, and probably will not, approach either theoretical extreme. Where the trustee and revisionist subscribe to their positions with religious and emotional fervor, the realist centers his concern about the trust's impact on actual and desired goals for state land management.

In the remainder of this paper, the rationale for and against the extreme positions is outlined, followed by an argument for a more realistic review of state land management goals. In essence, it is argued that too little is certainly known about the management of most state lands to substantiate the arguments of either the trustee or revisionist.

The Trustee

The trustee is conservative in his approach to the trust concept and understands it, regardless of its weaknesses, as an idea above reproach. Bert L. Cole, Commissioner of Public Lands in Washington, has recently given superb expression to this position. He writes:

> I strongly believe the intent and purpose of the original grant of trust lands to the State should be protected at all levels. We should not allow a deterioration of our management responsibilities. . . . To do otherwise, in my opinion, would dilute my effective management as a trust officer.[3]

Cole obviously views himself as the guardian of a trust and as such may be incapable of addressing the broader questions concerning the social worth of that trust. Nonetheless, there is merit in his uncompromising position. Historically, if no other lesson has been

The author is with the Parks Division, Montana Department of Fish and Game.
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[1] Public Land Law Review Commission. 1970. *One Third of the Nation's Land.* Recommendation 106.

[2] For example, in Montana, recent Legislative debate has centered around the opening of state trust land to recreational use as well as the reservation of selected lands as "natural" areas. Allowing noncompensatory recreational use of state lands has been considered in the 43rd and 44th Legislative Assembly and studied in the interim, but so far the debate has produced no successful legislation. The natural areas concept was approved by the 43rd Assembly and subsequently found by the Montana Attorney General to breach the trust as established in the Montana Constitution and Enabling Act.

[3] Letter, Bert L. Cole, Commissioner of Public Lands, Washington Department of Natural Resources, to Leo Berry, Jr., Acting Commissioner, Montana Department of State Lands, December 28, 1976.

learned, it is that state lands are easily abused either criminally or through failure to achieve intended management objectives. Further, there is the fear that opening the grant lands to a single non-compensatory use, no matter how reasonable, is to open them to every conceivable use no matter how unreasonable. Cole again summarizes the position:

> I think the designation of natural areas is commendable, but so are many other activities. Any exception made for uses which do not return the fair market value to the trust would soon lead to a wholesale raid of trust lands.[4]

As a group, educators whose pupils derive most of the economic benefit from state lands tend to agree with Cole. For example, Arizona educators have staunchly defended the Arizona grant lands from non-compensatory use by the Arizona Highway Department.[5] Their objections have been exactly those argued by Cole.

The principal user group of state lands, the ranchers, have regularly objected to trust alterations. State land grants in the West, many critics proclaim, have been manipulated solely for the benefit of the rancher; but attempts to demonstrate that this relationship has lessened the value of the trust have been less than successful.[6] Logically, however, it appears reasonable that ranchers are receiving unpaid-for-benefits from state lands, and to the extent that this is true, they can be expected to be conservative adherents to the status quo.

Even if the rancher were not deriving unpaid-for-benefits from state lands, his conservatism is well founded. Few state lands would be used at all were it not for the rancher. Indeed, many state lands have been leased to the same operator for such extended periods of time that the lands are now a *de facto* portion of the estate upon which the operator is dependent for his economic survival. Any alteration of the trust which would make uncertain the operator's leasehold is understandably to be resisted.

These three groups—state trust officers, educators, and ranchers—tend to be conservative in approach to the state land trust concept. Even if their position is suspect as selfish, their point that the trust protects the grant lands from abuse is credible.

The Revisionist

The reasoning of the revisionist is not so orderly as is that of those who subscribe to the trustee concept. Selfishness may be as prevalent among revisionists as among trustees. To many land management agencies, it is unreasonable to pay for interests in state "public" land while in pursuit of objectives established by state law. The misconception is in viewing state grant lands as "public lands." Furthermore, those agencies which view state lands in such a light are not themselves unified. The agency which desires free use of state lands for habitat on the theory that habitat ultimately provides indirect benefit to school children is not likely to support a similar argument brought forth on behalf of highways. Nonetheless, such arguments are based on the theory that state lands are not being best utilized in terms of the overall "needs of society," a situation correctable by riddance of the major impediment—the trust.

The professional land manager in a state land management agency often sympathizes with arguments in favor of trust revision. Having been schooled in multi-use concepts, he is eager to apply his knowledge and skills to a wide variety of land use practices. He understandably becomes frustrated when he discovers that state land management is largely limited to writing of leases. His arguments in favor of multi-use management are appealing but possess a fatal flaw—so far, the professional land manager has not convinced the trustee that professional judgment can be guarded from abuse.

Possibly the greatest argument in favor of revisionism is that the trust has never fulfilled its potential. To the revisionist, selection and administration of the lands has been to the exclusive benefit of limited segments of society. Specifically, state lands are a public subsidization of large ranch estates. This subsidization is so serious that lease revenues often do not equal the tax revenue had the land been disposed of rather than retained. The trust concept is appealed to today only when the land manager wishes to defend himself from innovation which would upset the inequitable and inadequate status quo. Overall, these revisionist arguments regard the trust as not only historically and presently inadequate but nearly an evil to be laid to rest once and for all.

There is abundant evidence in support of these revisionist arguments, but in fairness to the trustee, the evidence is inconclusive. Indeed, the hypothesis has been advanced that rancher-state companionability in administering state grant land reflects only the historical implementation of the most rational investment alternative for state lands.[7] Even if the management history of state lands has been dismal and even if full worth has not been achieved, a management program without the trust might simply exacerbate an unfortunate situation. Management history does not necessarily provide the model for future management, so either to abandon or sustain the trust on the grounds of its historical efficacy alone is a *non sequitur*.

Alternatives

The debate which has surrounded the trust concept has been emotional, and while this argumentation helps identify the advocacy position of interested groups, it does not provide sufficient information to assist the decision-maker. Implicit in the original trust are goals which Congress sought to achieve in making the land grants, and which the states agreed to in accepting. Any persuasive revisionist argument must attack the trust by attacking the goals implicit in the trust. It must be shown that the goals have either been achieved or cannot be achieved under the present system. Once this has been accomplished, the revisionist has the obligation of presenting a positive program for state land management consisting of new goals and the management mechanism which will achieve the goals. It would then be the trustee's task to accept the new program or defeat the revisionist argument on the basis of its logic or social acceptability.

So far revisionist arguments have lacked widespread support and appeal because they have been fragmented, indirect, and difficult if not impossible to implement. These weaknesses in revisionist arguments will be overcome only as a solid base of theoretical, applied, and managerial research concerning the state lands is accumulated. Those with academic and applied interests in our land resources have an obligation to accumulate that needed research base.

Research may identify new goals for the state trust lands but interestingly may reveal no need to alter the trust concept. The trust accomplishes necessary protection of the grant lands but has seldom been so blind as to thwart accomplishment of social goals when truly significant nonpecuniary values are at issue. If such an hypothesis can be sustained, it would suggest that most new goals for state lands could be met at a reasonable cost with only minor adjustments in existing management tools. Certainly, without such analysis the conclusion that the trust must be either eliminated or altered is premature.

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[4] Letter, Bert L. Cole, Commissioner of Public Lands, Washington Department of Natural Resources, to Leo Berry, Jr., Acting Commissioner, Montana Department of State Lands, December 28, 1976.

[5] Gladen, Frank H. 1970. "Public School Lands in Arizona: History and Management." *Journal of the West* 9, 110-124.

[6] See for example, Murray, Henry T. 1942. "State Land Management in Montana." Unpublished Master's Thesis. Montana State College (Bozeman).

Mosk, Sanford A. 1943. "Land Policy and Stock Raising in the Western United States." *Agricultural History* 17, 14-30.

Cole, Stanley M. 1968. "A Study of Leasing Practices of Public School Lands in Colorado: Final Report." Unpublished report, Colorado State University. Research in Education Report ED 022339.

Cole, Stanley M. 1966. "Relative Merits of the Sale or Retention Under Lease of Public School Lands in Colorado." Unpublished report, Colorado State University. Research in Education Report ED 010422.

[7] Burnett, George Wesley. 1976. "Montana Becomes a Landlord: A Study of State Land Selection." Unpublished PhD Thesis, University of Oklahoma.

BOOK REVIEWS

Wildflowers across the Prairie. By F. R. Vance, J. R. Jowsey, and J. S. McLean, Western Producer Prairie Books, Saskatoon, Saskatchewan, Canada. 1977. 214 p. Illus. Paperback, $8.95; hard cover, $14.95.

This book is intended primarily as an identification guide, especially for nonprofessionals, on wildflowers of the prairies. It contains descriptions and illustrations of some 260 species of plants from the northern portion of the Great Plains. The area covered spreads from southern Alberta to western Ontario and extends south of the border to include North Dakota and parts of Montana, Wyoming, South Dakota, and Minnesota.

A notable feature of the book is the presence of several photographs of each species that depict the plant and its natural habitat. The main figure is a close-up at flowering and/or fruiting time. Colored reproductions of similar species are often included on the same page for comparative purposes. Users must rely on the colored reproductions for visual identification since taxonomic keys are not included as an aid in identification. However, a flower color index for the included species is provided to assist in that process.

Vance is the primary contributor of the more than 400 color photographs in this book. With a few exceptions, the quality is generally good. Color distortions of flowers were noted in the reproduction of a few photograhs. For example, the western red lily is too red (page 15, lower left) and the early blue violet is pinkish rather than blue (page 94, top). In certain illustrations, such as the cattail on page 9, the printing is out of register.

The photographs are supplemented by McLean's line drawings. They are intended to draw attention to characteristics important for plant identification, but some are not very enlightening. The shapes, positions, and fusions of petals and sepals are occasionally distorted and the numbers of stamens and pistils are not always clear.

Combined on a single page with color reproductions and often a line drawing are Jowsey's concise description of the species. The text includes information on flowers, fruit, leaves, growth habit, and habitat. Brief mention is also made of any similar species which are illustrated.

The glossary of terms is supplemented by seven figures, reproduced from *Wild Plants of the Canadian Prairies* by Budd and Best, showing leaf variations, types of inflorescence, flower parts, characteristics of composite flowers and fruits, types of flowers, shapes of simple leaves, and types of divided leaves.

There are a few technical flaws in what is generally a carefully edited book. Some glossary definitions are inaccurate. Plumose, for example, means feathery and does not usually mean "having fine hairs" as indicated. Some statements on plant distribution are wrong. As an example, red Indian paintbrush is not limited to the Cypress Hills but is widespread. The identifications of a few photographs, such as lady's thumb (page 33, lower right), seem questionable.

For those, from children to adults and from naturalists and ranchers to botanists, who are interested in the flowering plants of the northern Great Plains, this book is recommended. However, users should not assume that it fully covers the entire flora of the region. Range managers and others who require a more complete text will want to supplement it with the classic work of Budd and Best.—*George W. Scotter*, Edmonton, Alberta, Canada.

SOIL EROSION: Prediction and Control. The Proceedings of a National Conference on Soil Erosion May 24–26, 1976, Purdue Univ., West Lafayette, Indiana. Edited by George R. Foster. Soil Conserv. Soc. of Amer., 7515 N.E. Ankeny Rd., Ankeny, Iowa. 1977. 393 p. $10.00 cloth; $7.00 paper.

It was appropriate to hold the National Conference on Soil Erosion in honor of W. H. Wischmeier, who so successfully headed a team of researchers that developed the universal soil loss equation (USLE). USLE provided a uniform vehicle for the development of legislation on soil erosion control and made possible the evaluation of different crop systems in terms of erosion and sedimentation, thereby contributing to the development of superior crop management systems.

As is customary for proceedings of professional meetings, the editor did not attempt to "streamline" the individual papers (a total of 44), and repetitions, therefore, were unavoidable. But division of the book into six chapters helps the reader to concentrate on areas of interest. The chapters are: applications of the universal loss equation; erosion research; erosion and sediment yield modeling; use of the universal soil loss equation in planning; soil erosion control; and conservation needs.

There are two major themes in the book. One, is a profound gratitude for USLE; the other is a deep concern for the limitation of applicability of USLE. Although both themes seem to be in contradiction, this is by no means the case. At the end of the book, Wischmeier gives an excellent examination of use and abuse, applicability and limitation of USLE.

Satisfaction and dissatisfaction stem from the fact that USLE is an empirical equation whose coefficients were based on a multitude of data gathered from agricultural croplands. Formulation of the equation began in North Carolina in the early 1930's and later included 26 states east of the Rocky Mountains. Attempts to fit the equation to other regions and continents, for example Africa, as well as for other land types (forests, rangelands) are still in process. Evidence of the enormity of this task is the 10,000 plot-years of erosion research which went into formulating the present equation. Further, USLE is a statistical regression, yielding averages only; it can not give answers to a single event. Land managers find that conditions of forests and ranges differ drastically from those of croplands. For instance, slope angles may exceed the range in slope for which the equation was developed. Normally, plow soles do not exist in forests and on ranges. Frozen soils, gullies, missing overland flow in many forests, or rain-on-snow events are not considered in USLE.

Only one article is directed toward rangeland. It explains attempts to fit the equation to California conditions. This paper belongs to the first theme of the book, (i.e., optimism for generating applicable coefficients).

The time has come to deemphasize data gathering for the establishment of statistical relationships not necessarily based on sound physical law, and to concentrate on the study of the erosion processes. Despite the national concern about erosion in the last 50 years, far too little is known about the processes of erosion to allow the formulation of *universal* physical erosion and sedimentation models. Promising beginnings are reported by Li et al. in the chapter on modeling. Once a theoretically sound erosion equation is obtained, applicability in different physiographic regions and for different land uses will be possible. Possibly, the article by Robinson and Meyer on the Agricultural Research Service research program best sums up the urgency for future erosion research as well as our research shortcomings, mainly lack of staffing, during the last decade.—*Burchard H. Heede*, Tempe, Arizona.

A Manual of Ghana Grasses. By R. Rose Innes. Published by the Land Resources Division, Ministry of Overseas Development, Surbiton, England. 1977. 265 p + 1-xxiv. 3 diagrams (maps and charts), 19 plates (photographs) and 99 line drawings; paperbound £1.50.

This book is presented as "an illustrated working guide for Ghanaian students of agriculture and botany and for field officers of the Ghanaian Ministry of Agriculture."

The manual is organized in seven parts, under the headings: Introduction, Vegetation Zones and Major Grassland Communities, Grasses and Their Associates as Animal Feed, Management and Development of Ghanaian Grasslands, Key to the Grasses of Ghana, Checklist of Species, Descriptive and Ecological Notes, and References. A glossary of botanical and general terms is presented immediately before Part 1.

The relatively brief chapter on vegetation zones of West Africa and the Ghanaian vegetation is illustrated by diagrams of the vegetation zones of West Africa, the rainfall zones of West Africa, a comparison of Ghana. Various aspects of the Ghana vegetation as influenced by current farming and grazing practices are illustrated by 19 photographs.

In the systematic treatment of grass species, separate keys are presented for the 16 tribes, 95 genera, and 304 species. The keys are attractively presented and easily followed. The indented couplets allow rapid scanning of comparative characters and a positive "drift" towards the proper name. Brief species descriptions are presented in the chapter on descriptive and ecological notes. Species names are listed in alphabetical order without number or author citation. The presentation of species names without author citation is unfortunate as this can lead to inaccuracies in taxonomic designation. This usage is not to be recommended for publications by ecologists, taxonomists, and range management specialists.

"The Manual of Ghana Grasses" by Mr. Innes is a well-prepared, scholarly treatment which will find use as an important reference for all concerned with the vegetation of West Africa. Unfortunately, the binding of this book is poor (2 pages fell out during the course of this review) and with any amount of use of the book, the binding will have to be redone.—*Frank W. Gould*, Texas A&M University, College Station.

NEW PUBLICATIONS

Atlas of the Great Plains Flora, by Great Plains Flora Association. Iowa State University Press, Ames, Iowa 50010. 1977. 500 p. $25.00. This atlas provides dot-distribution maps for the vascular plants known to occur in an area bounded on the west by the base of the Rocky Mountain uplift and on the east by the advent of continuous wooded area; the southern boundary crosses the Texas panhandle and bisects Oklahoma on a south-west-northwest diagonal; the Canadian border is the northern limit. Four maps are on each page and complete indexing is provided for both Latin and colloquial names. The atlas contains some 3,000 entities. The atlas is based upon recent collections and the herbarium resources of the nine institutional members of the GPFA, plus the cooperation of the New York Botanical Garden. This cooperative effort enabled fuller coverage. Plans are for a series of three more volumes of the flora of the Great Plains to follow the present atlas.

Approved Practices in Feeds and Feeding, Fifth Edition, by W. R. Patton, D. W. Cassard, and E. M. Juergenson. Interstate Publishing Co., Danville, Illinois 61832. 1977. 445 p. $10.00. This edition of the handbook gives in ready reference form "how-to-do-it" information on the best method and procedures to follow, also gives advice on "what not to do." The treatment is practical, and specific, easy to read and easy to understand. One of the chief purposes has been to tell how each activity should be done in order to accomplish the approved practice involved. Whenever possible, specific information has been given. There are many activities and approved practices that are common in livestock feeding which, with minor local adaptations, can be used in many areas of the United States. Therefore, much of the information can be readily adapted and used throughout the country.

THESIS: MONTANA STATE UNIVERSITY

The Effect of Spring Burning on Big Sagebrush-Grassland (*Artemisia tridentata* Nutt.-Grassland) on Soil and Vegetation, by Mutasim Bashir Nimir, MS, Range Management. 1974.

The study was planned to find the effect of spring burning of big sagebrush-grassland (*Artemisia tridentata* Nutt.-grassland) on the soils and vegetation of a part of Taylor Fork cattle and horse allotment, Gallatin National Forest, Montana.

The study area was burned on May 30, 1973. The burn was not thorough because of unfavorable weather conditions and considerable green growth.

Procedures used to obtain information on the effect of burning on the soil physical properties were: measurements of soil temperature during the burn, weekly measurements of the soil temperature following the burn, biweekly measurements of the soil penetration indices, measurements of the infiltration rates, and measurements of the soil moisture contents.

Samples of soil were collected before and after burning for chemical analyses.

Procedures used to obtain information on the effect of burning on vegetation were: weekly measurements of the basal cover, weekly measurements of the vegetational development, measurement of the production, and estimation of the big sagebrush killed by the burn.

This study produced the following results: The soil physical properties did not show major changes induced by the burn. The slight changes of the soil physical properties reported are not expected to trigger immediate changes in the vegetation. The soil chemical analyses reflected that the changes due to biological reasons were greater than the changes due to burning effect and that the change in soil nutrients was not very important. Burning resulted in a considerable temporary reduction of the basal cover of most of the vegetation as a result of direct damage caused by the fire. The damage did not last for more than 3 or 4 weeks for most of the species. Differences in vegetation and soil characteristics were more related to the time of measurement than to burning.

Festuca idahoensis was more susceptible to damage by the burn while *Agropyron trachycaulum* was favored by the burn.

Range Management Theses 1968–1975

Compiled and Edited by
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continuation

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