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The Trail Boss

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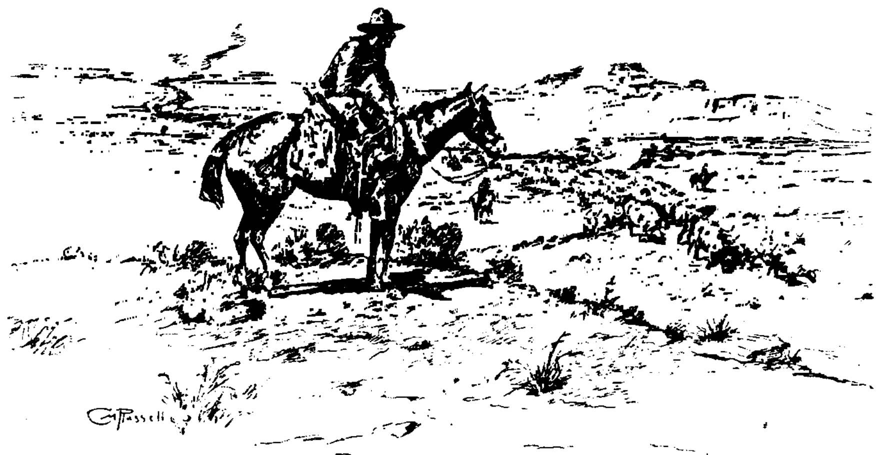

THE TRAIL BOSS

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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;

—to promote professional development of its members.

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

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Writing for the reader

RICHARD H. HART

"Yeah. Streetstyle is happening. It's raw. Aggressive. Fluid. And the key word is STREET—so if there ever are street contests they should be held on the natural environment—the street. Let's keep it OUTSIDE. Rip it up.—A.J." (Jenkins 1986).

Now THAT is writing for the reader. That's my son-in-law A.J., writing for the typical reader of *Freestylin'* magazine, who is a 14-year-old who has gone over the handlebars once too often without a helmet.

This paper is about "Writing for the Reader," from Bernard DeVoto's advice to his students: **"Write for the reader, never for yourself"** (Stegner 1974). And I might add, not for *JRM* or *Rangelands* but for the **reader** of *JRM* or *Rangelands.*

The next question: What is the appropriate style for readers of *JRM* or *Rangelands?* The easy answer is "the way we've always written." When Don Quixote told Sancho Panza to get on with the story without so many diversions, Panza replied, "The way I'm telling it is the way all stories are told in my country. It isn't fair for your worship to ask me to get new habits" (quoted in Zimmerman & Clark 1987).

The way "stories are told in *our* country" was established in the 17th century (Wallsgrove 1987). Scientists had to distinguish themselves from politicians, poets, philosophers, and theologians; they had to prove they were telling the truth about the material world, long before they had any impact on it. They wrote in the first person, what "I" did, to indicate they were reporting personal experience, not what Aristotle or some other ancient had said. They reported what happened when they performed an experiment; convinced readers that it had happened; and convinced readers they should care what happened. Those are still the essentials; everything else is style.

Everything Else Is Style

And style changes. Look at Charles Darwin's description of what happens when grazing is excluded:

> ...the land having been enclosed, so that cattle could not enter ...self-sown firs are now springing up in multitudes...In one square yard...I counted thirty-two little trees; and one of them, with twenty-six rings of growth, had during many years tried to raise its head above the stems of the heath, and had failed. No wonder that, as soon as the land was enclosed, it became thickly clothed with vigorously growing young firs. (Darwin 1958).

Now look at a modern example:

> The relict site (RM) had significantly more herbaceous vegetation than all the other sites (Table 1), which were not significantly different from one another. The reduced cover of Indian ricegrass [*Oryzopsis hymenoides* (R. & S.) Ricker], a very palatable grass, was the primary reason for this difference. The cover of galleta grass [*Hilaria jamesii* (Torr.) Benth.], a grass tolerant to grazing, was not significantly different between sites, but as the total herbaceous vegetation cover decreased, the relative percent cover of this species increased. (Jeffries & Klopatek 1987)

The scientist has disappeared (no more "I counted"). Scientific names, complete with authority, reassure the reader that the writer really knows his plants, and data have been relegated to a table and subjected to statistical analysis. All this interferes with narrative flow; we think we need it to reassure the reader that we know what we're talking about, but it might better be in appendices.

Day (1979) denies the existence of style; he says "...the preparation of a scientific paper has almost nothing to do with writing....A scientific paper is not 'literature.'...if the ingredients are properly organized, the paper will virtually write itself." That last statement alone casts considerable doubt on Day as an authority.

In contrast, Knoll (1988) in his review of the book *The Young Earth* applauds the author's style, and reminisces of an era when the term "scientific literature" was not a contradiction in terms—like "quiet Texan."

So style exists, else why the proliferation of "Style Manuals"? And why the proliferation of styles? For example, the pontifical:

> Being a new approach altogether to the range deterioration problem it should not be surprising that SGM is totally different from any of the approaches that were in use. The differences are too many to list here but two which have caused the greatest unrest in the range profession are the facts that:
>
> 1. No matter how bad the range deterioration there is never a need to reduce stock numbers to start the reclamation process. As a general rule, the conventional or government-prescribed stocking rates can safely be doubled in the first year of operation as long as adequate time control is brought into the grazing handling. Furthermore this doubling of government or conventional rates can be done regardless of how poor the range condition is at the time. (Savory 1983)

The author is absolutely certain of his position ("altogether", "totally", "no matter", "regardless") and cites no data or references.

The conventional:

> The stocking rate recommended by the Soil Conservation Service (SCS 1986) is 36.0 steer-days/ha. Net profit at 1986 prices and the SCS-recommended rate = \$20.90 per ha (Fig. 5). Increasing to the optimum stocking rate of 57.6 steer-days/ha (a 60% increase) produced a 16% increase in net profit. Thus stocking rates recommended by SCS might be increased profitably, at least in the short term; but this is possible with all systems, not just with short-duration rotation systems. Potential short-term increases in livestock gain must be weighed against potential long-term decreases in range condition and productivity (Hart et al. 1988).

Note the flat style and the absence of "absolute" words; data, calculations, and references are expected to speak for themselves.

The popular:

> Claims for range improvement in southern Africa through intensive SDG at double conventional stocking rates are not founded in fact. To the contrary, evidence in literature from Zimbabwe and elsewhere in southern Africa indicates that it is impossible to have both heavy stocking and improvement in range condition. In fact, studies of SDG involving 12–16 units at only medium rates of stocking have shown no greater range improvement than conventional systems. Moreover, there are numerous cases where double stocking (with cartwheel systems) on a long-term basis has led to severe degradation. (Skovlin 1987).

Supporting evidence and data are cited, but not explicitly; language is less formal; and transition words move the narrative along.

And finally, the barn-burner:

> A modern equivalent of Wovoka has appeared to show besieged ranchers the way. His name is Allan Savory, a man who teaches the rancher that he can bring back the grass by doubling his cattle numbers....More than any other reason, Savory owes his success thus far to the utter failure of today's range management establishment....The allegiance of the range management professionals to the cow and to the maintenance of the rancher in his traditional position of dominance on the public lands now threatens to make the entire archaic structure collapse. (Carr 1986)

Lots of fun to write, and to read if you already agree with it, but not likely to convince anyone; the writer is writing for herself, not the reader. No data are given, the language is inflammatory, and the author is completely and utterly convinced that she is right, just as in the pontifical style.

The author is range scientist, US Dept. of Agriculture, Agricultural Research Service, Cheyenne, Wyoming. This paper was presented at the symposium "You and SRM Publications" at the Annual Meeting of the Society for Range Management, Corpus Christi, Texas, 10 February 1988.

What, Then, Is The Appropriate Style?

What, then, is the appropriate style? Irmscher (1976) says style should be based on the four writer-reader relationships: the specialist talking to the specialist, the specialist to the generalist, the generalist to the specialist, and the generalist to the generalist. He omits the most common of all: the specialist talking to himself.

A more useful classification, also by Irmscher, identifies six styles:

1. Legal & technical
2. Popular reporting
3. Learned discourse
4. Popular discourse
5. Public address
6. Private discourse

Range writers are most likely to be concerned with 1, legal & technical writing; 3, learned discourse; and 4, popular discourse. Here is an example (Zimmerman and Clark 1987) of the same material in these three styles:

> *Technical report* (legal & technical writing): Standard measurements of length of six newborn swift foxes *(Vulpes velox)* taken in the study area were 15.5 cm, 14.7 cm, 16.5 cm, 14.9 cm, 15.0 cm and 16.2 cm (Smith 1965).
>
> *Script for wildlife biologists* (learned discourse): Newborn swift fox in the study area averaged 15 and a half centimeters in length.
>
> *Script for television audience* (popular discourse): Newborn swift fox pups would fit in the palm of your hand.

Legal and technical writing for *JRM* and other journals uses a specialized vocabulary, which permits a highly compressed style. The writer is a specialist writing for specialists and can assume that explanations of terms are unnecessary because the reader knows what he's talking about. On the other hand the writer is expected to give detailed accounts of materials, methods, and measurements; as in the 17th century, the writer must convince the reader that he writes from evidence, not hearsay.

Learned discourse for *Rangelands* and similar publications uses a more general vocabulary and a less compressed style. The specialist is writing for specialists in other fields as well as his own. There is less concern for detailed descriptions of methods and more concern for helping the reader to follow a train of thought. Transitional words and phrases like "on the other hand" and "therefore" are used; examples are given; sentence structure and length are varied.

Popular discourse for farm and other magazines lets the writer's presence show through. First person, personal experiences, narrative style, uncomplicated sentences, figures of speech and other rhetorical devices are used. Some of us are uncomfortable with figures of speech; ask us "What's a metaphor?" and we're likely to answer "To keep cows in."

Points of Interest

I'm not going to discuss many specifics of style; that's what style manuals are for. But I'm not going to miss an opportunity to bring up a few style points that interest or irritate me (note the personal touch; that is popular discourse).

His, Hers, Its

Consider gender bias, sexist language, et al. I like the approach of van Leunen (1979):

> My expository style relies heavily on the exemplary singular, and the construction 'everybody...his' therefore comes up frequently. This 'his' is generic, not gendered. 'His or her' becomes clumsy with repetition and suggests that 'his' alone elsewhere is masculine, which it isn't. 'Her' alone draws attention to itself and distracts from the topic at hand. 'Their' solves the problem neatly but substitutes another. 'Ter' is bolder than I am ready for. 'One's' defeats the purpose of the construction, which is meant to be vivid and particular. 'Its' is too harsh a joke. Rather than play hob with the language, we feminists might adopt the position of pitying men for being forced to share their pronouns around.

This may be too cavalier an approach, but you can perhaps move too far in the other direction; Zimmerman and Clark (1987) present a 2-page table of rules for avoiding gender bias. But they offer some good suggestions:

1. If you know the gender of the person, use the appropriate pronoun.
2. Use titles instead of pronouns. Use gender-neutral titles when good ones are available; avoid awkward ones such as "cowperson."
3. Replace possessives with articles or use plurals: not "Every branch chief should submit his report" but "Every branch chief should submit a report" or "Branch chiefs should submit their reports", but not "Every branch chief should submit their report."

"I did it!"

It is not, repeat **not** "unscientific" to use first person and active voice. Both were used for centuries in scientific writing, but lately all research has been done by disembodied spirits: "Plots were clipped," "It was concluded," etc. "We clipped plots," "I concluded" are far superior.

Can't Stand Alone

Do not make statements unsupported by data or references. A recent article in *JRM* (Ethridge et al. 1987) stated, without either, "The rotation system was assumed to increase stocking capacity...by 30%," proceeded to build a complex economic analysis on this assumption, and concluded that "Several range improvement practices were shown to be generally profitable...These include a rotation grazing system...".

On the other hand, do not hang unnecessary references on statements that are common knowledge. A reviewer recently asked me for a reference to support the statement that "milk provided most of (nursing calves') nutritional needs"; the editor of the journal suggested I refer the reviewer to "Dial-a-Cow."

Play It Again

This suggests that reviewers' comments should not be swallowed whole, at least not without a grain of salt. But revision is a necessary part of writing; few of us can rip out perfect manuscripts on the first try. Hemingway said: "Easy writing makes hard reading"; and DeVoto often advised his students: "Just run it through the typewriter again" (Stegner 1974).

Style manuals can help you write better: Day (1979), van Leunen (1979), and the ever- reliable Strunk & White (1979). But the best way to learn good writing is to read good writing, designed for the same readers you're trying to reach. "You'll never be Leo Tolstoy!" Lucy jeered at Snoopy. And we shouldn't try to be. But we might try to be Charles Darwin, Carl Sagan, or Alan Moorhead.

And finally, learn by doing: write, write, write. I'll close with another quote from son-in-law A.J. (Jenkins 1986). A hot-dog wrote to the magazine that he was going to be the raddest, most aggro free-styler around; he had bought "the hottest scoot in town" and now what should he do? And A.J. replied, "Ride."

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Writing for your audience

JAMES A. YOUNG

It would appear that for a portion of the membership of the Society for Range Management there is a considerable crisis in communication. This is illustrated by the proposal that not all members be required to subscribe to the *Journal of Range Management* because the contents of the society's journal do not apply or are too difficult for a portion of the membership to understand. At the same time, I have been told rather haughtily by scientists that they do not read *Rangelands* because it contains nothing of interest. This would seem to be a society that is tearing itself apart for lack of communication.

The Measure of Success

I propose that a measure of the success of a society dedicated to the art and science of range management is which portion of its membership contributes to the publications of the society. The publications can only be as good as the sum of the contributors. Who should contribute to society publications? Only those who have something to say is the only logical answer to this question. Stop and think about the alternative of having *nothing* to say. Where does this answer leave you professionally, and as a member of society in general? Members of any organization always seem to have complaints about the organization that can be heard in the halls and bars at meetings, but seem never to make it into print. At the same time a great number of practitioners of the science and art of range management that truly make outstanding contributions never seem to get a word of praise in print. Many of the issues that face range managers are highly controversial. Management of free-roaming horses, revegetation of mine spoils, design of grazing experiments, pseudo-replications are only the start of list of topics that must raise some desire to communicate.

How?

How do you communicate in writing in the Society for Range Management? This is the easy part. The society has everything you want to know about writing for society publications and were afraid to ask, written down in instructions to the authors for each society publication. These exhaustive, ironclad instructions are seldom followed or interpreted twice in the same manner, but it is like herding chickens—if you get most of them going in the same direction do not fight it. The society only has one editor because editors belong to an expensive guild that dates from medieval times. The secret methods of editing are passed during the dark of the night from one generation to the next. The editor delegates authority for approving material for publication to editorial boards who are composed of society members. The purpose of these boards should be to foster communications within the society, and among other individuals interested in the environment we define as rangelands. Any time these editorial boards lose sight of this goal, they are defeating their purpose.

Everyone can write so the story can be understood. Admittedly, writing comes easier for some than others, and certainly some have more experience than others, but everyone is able to communicate in writing. There was the extreme case of the brilliant Nevada soils scientist who made a detailed study of range sites, ecological sites, and habitat types and probably understood these concepts in environmental classification better than anyone else in the society. When asked why he did not submit this material for publication, he maintained that he tried once, but the editor took out all his swear words and he had nothing left to communicate with.

Wonder at the Masters

This brings us to the point of this discourse—writing for the audience. There is one thing in communication that is more important than just writing the material down: it is getting someone to read your creation. Highly stylized scientific writing is seldom interesting. The more it is edited, the less interesting the articles often become. The reason for this is the need to communicate very precisely in scientific writing. If you go through the collection of a major library and skim through scientific journal articles, you will soon realize that there are a few, really good scientific writers that have the gift of communicating, no matter how basic the subject. Try articles by G. Ledyard Stebbins, Daniel Axelrod, or Israel Cook Russell and wonder at the masters at work. Stebbins has a biting, but brilliant, sense of humor. Axlerod is always positive and direct, while ignoring the maybe and might have been. Russell wrote in the 19th century with a pen that could capture the deserts of the American West and educate the American public to the wonders of glaciers, rivers, and landforms.

We've Got Color

The transfer of technical information allows the writer greater freedom to exercise individuality. The Society for Range Management is alive with color and steeped in history. There are endless opportunities to use the color and pageantry of rangeland environments and the culture of the herdsman to enhance interest in our communications. Range management enhances the color in individuals. There is something about clipping willows for browse estimates on the Copper River Delta of Alaska, or feeding hay to hungry cows on the North Fork of the Humboldt River, or working for the BLM in Battle Mountain that tends to separate one from the yuppie clones of the metropolis. It does not matter that you are currently a bureaucrat filling out forms on the banks of the Potomac—you once saw the sunset on the Red Desert. At the next society annual meeting, sit in the hotel lobby or bar and watch the delegates. If you do not see at least one person that could pass for Porter Wagoner's brother the wagon train ran over, I would be very surprised. Of course, some of the rancher members dress like Harvard lawyers because they got the habit while attending Harvard graduate school for their MBA.

If you think the society lacks color, stand back and observe the participants in the various student contests at an annual meeting. From the haunt of the cadets to the pride of the teams from

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Mexico, you can draw upon a wealth of emotions. Many range managers have the opportunity to benefit from association with herdsmen whose fathers' fathers have observed the cycles of new grass, calving, and drought on prairie, veld, pampas, or steppe. This is the real stuff. The point is that you can use the color, history, and pageantry of range managers and range environments to help sell your communication by making it attractive and interesting to read.

Look at some of the highly successful slide shows that have been prepared on rangelands. Package the same approach in your writing. Borrow from journalists and hook your readers with a good lead sentence. Borrow from popular writers and have the hero treed by a bear and then rescue him with good range management. Hide your point in the story and keep referring to it subtly. Get your readers to believe they thought of it themselves. Many issues in range management have audiences highly polarized. If you jump in with a title or lead sentence that strongly supports or opposes one point of view, you automatically lose half your audience. Stop and think about the consequences of such an approach. Did you really want to communicate with the audience that already agrees with you or did you want to influence the non-believers?

Remember our friend, the soil scientist, who could argue the concepts of vegetation classification in bars from Vya to Wild Horse but suffered from an edited vocabulary? Would you like to try to communicate these concepts in classification to the general membershp of the society? You could introduce the subject with, "habit types are abstractions that only occur in the minds of ecologists and are represented by concrete examples that only reflect a portion of the normal distribution of variability." An alternative approach might be, "Graduates in natural resources from Utah State University date events from the morning when Dr. West got the shock from the overhead project while lecturing on concepts in vegetation classification——".

Everyone can communicate through writing. A few can communicate exceedingly well and the rest of us can become experienced writers. The only thing that can stop you from communicating and becoming experienced is yourself.

Reader expectations: How important to meet?

DAVID A. FISCHBACH

As an International professional society, we have two predominant modes of communicating with others in our society and our profession: our annual convention and our two regular publications. With as diverse a membership as our organization has in experience, education, interest, and occupation, is it realistic to think that two publications can meet the expectations of everyone we intend to reach, or is it even important? The answer to both of these questions must be a unqualified YES! That is not to say that we only read what we agree with or already know about. We learn by reading or hearing things with which we either DISAGREE OR ARE UNAWARE OF—something unexpected!

The Mission

If the mission of our publication is to inform and educate we must first get the attention of the prospective reader. Boy, did that color photo of branding calves on the cover of the February 1987 issue of *Rangelands* get my attention, as well as the color photos in two articles in the December issue. These were totally unexpected, and they were effective and added to the readability and enthusiasm of the article. Colored photos are now expected. Enthusiasm has been described as when, on your wedding night, you turn off the lightswitch on the wall and get into bed before the room is dark! It is neither impressive nor effective to make statements like, "We procured a geotome with which to architect an aperture into the B_2", when you could simply say, "We used a spade to check the soil profile."

The subject of reader expectations goes much deeper than just, "What do the publications have to offer?" What our publications offer is the culmination of years of experience, education, expertise, and derived opinions on the many-faced subject of range. Our success in expanding upon and spreading this knowledge can not be achieved by sitting back and asking, "What do the society or the publications have to offer me?", but rather by asking ourselves as individuals and as a society, "What do we have to offer the world?" Minding our own business and remaining anonymous achieves little and contributes nothing.

Everybody's Job

The offering of our efforts and knowledge includes not only having articles or research papers published, but also taking an active part in the society and in what is going on in range research and management on a world-wide scale. It is good to see that after many years of being afraid to become involved in any political aspects of range we have, in the past few years, finally begun making some public statements: not so much taking sides on issues, but rather as being an "expert witness" in instances where such witness is appropriate and essential. While being an expert witness on political issues may seem to diverge from the topic of Reader Expectations, it would be impossible for the Society to be a credible witness without having the material in *JRM* and *Rangelands* to back our claim to being professionals and experts in this highly scientific and technical field.

Prospective authors must constantly ask themselves, "To whom will the proposed article appeal and how can I get it to appeal to more people?" A basic fundamental of this can be learned from the example set by the late C.M. Russell in his career as a western artist. His paintings seem to come to life before your eyes, and this is caused in part by the fact that he lived the life of a Montana cowboy for eleven years before he painted commercially. The point here is that sooner or later, what is learned from research and articles must be able to be **understood and evaluated** by those of us educated in "the school of all outdoors." That is not to say the user will agree with or can use the information, but he must be able to understand it well enough to determine what might apply to his needs. The success or failure of the endeavors of the society and its publications is determined in the end by the user and his understanding and application of information.

A good article, like a good talk, is not measured by its length but by its content. A priest friend once said, "I've never heard a *bad* five-minute sermon".

A story is told of an elderly organist in a European cathedral. He

The author is a rancher in Faith, S. Dak. This paper was presented in the symposium "You and SRM Publications" at the annual meeting of the Society for Range Management in Corpus Christi, Texas, February 1988.

had reached the age of retirement and was to be replaced by a much younger man. One day the younger man approached the elderly man while he was practicing his beloved organ for the last time. The elderly man turned off the organ, slid the key into his pocket and began to leave the church. The younger man stopped him and said, "Sir, the key, please." The elderly man put his hand into his pocket, pulled out the key and placed it in the hand of the younger man. The younger man then began playing music such as the world had never heard, for that young man was Johann Sebastian Bach. The older man said later, "Just suppose I had not given the master the key".

We have that key. Whether we use it or how we use it is up to each of us. By trying something new, by breaking the mold of what we are used to, we meet the expectations of our readers; namely that we publish the *most reliable articles* written by the *most qualified authors* in the *highest respected journals published* which deal with the topics surrounding the renewable natural resource we know as range.

Peer review of technical manuscripts

GARY W. FRASIER

"Peer Review," the downfall of many papers and the heartbreak of authors, is the most difficult component of publishing for researchers to accept. What is peer review? Peer review is the analysis of a paper by someone with sufficient knowledge of the subject to be able to make a judgement as to the merit of the paper.

Why Review?

Why do we need to review papers? In the early history of scientific investigations, the researcher kept detailed notes and logs of the observations, procedures, and results. Many early studies were conducted to satisfy the researcher's personal curiosity. The notebooks were a method of keeping track of information. These notebooks provided the written record of the investigations but were relatively inaccessible. There are several instances where duplicate research was conducted at several locations because the information was not available in common media. This problem led to the establishment of technical journals for the publication of scientific research results.

The early journal articles were frequently quite long and detailed with extensive tables and figures of the actual data. From these detailed reports, a reader could make a judgement decision as to the validity of the study. With time, the articles become shorter with condensed summaries of the actual data. These shorter articles created problems for readers. An author is very familiar with the procedures and actual data. A statement that is very clear to the author may lack an important component to make it understandable to others. Peer reviews insure that a knowledgeable reader can understand how the information is collected and make a judgement decision as to the validity of the results.

Kinds of Review

Peer reviews may be relatively informal or a highly structured process. There are several degrees of peer review. While they are not completely unbiased, co-authors are the first level of peer review. The author's co-workers are another level of peer review. Many institutions, agencies, and organizations have a formal review process as part of their publication policy. Most technical journals employ a peer review process, with refereed journals usually utilizing some form of anonymous review.

Peer reviews by co-authors and co-workers can be of great benefit in the early stages of manuscript preparation by giving the author guidance in maintaining a coherent logic. These peer reviews however, can also be misleading. Co-workers may have some knowledge of the studies which they inadvertently use to interpret the results, although that information is not clearly stated in the paper. These reviews also are usually done at the author's request and there is a tendency to be forgiving of errors. Some reviewers do not like to be overly critical of a co-worker's material for fear of appearing to be jealous or petty. In some instances co-workers will be lenient, using the justification that someone else in the peer review process will point out the problems that need to be corrected.

Some agencies and groups employ technical editors to work with the authors. These editors provide a valuable service by offering assistance in the writing structure. Unfortunately, these technical editors do not have the technical training to provide the necessary evaluation of the scientific merit of a paper that is required for a good peer review.

In most instances, the best peer review is obtained when the identity of the reviewer remains anonymous. Reviewers tend to be more critical when they are assured that the author does not know the source of the comments. Then too, even in science there are instances, fortunately rare, where an author has deliberately made misleading or erroneous statements or conclusions. Anonymous peer review is one mechanism for detecting this practice.

Critical Comments

The most important contributions from anonymous peer review are the comments to clarify the paper. These comments are frequently needed to better understand the procedures used, such as the experimental design and data analysis. A good scientific paper must be written so that someone else can duplicate the study and end up with the same results.

Authors are frequently quite upset with peer reviewer's comments. In many instances they state "...the reviewer did not understand what was being said." What the author failed to understand was that the reviewers were reading and interpreting in their own minds what was written. Their interpretation was different from what the author had in mind during the writing. The author had failed to clearly state what was being done. The author had not prepared a good paper.

Most people take the peer review of a paper as a serious task. If the reviewer can understand the paper, the author will receive a "good" review. If the paper is poorly written and not clearly stated, the reviewer must then try to interpret what the author was trying to say. This is when the reviews become more and more "unsatisfactory." There will be a point where the reviewer feels that time is being wasted and the author will receive a "reject" recommendation.

Author is Editor of *Rangelands* and a past Associate Editor of the *Journal of Range Management.*

Journals usually have subjects and standards which the author must meet. A well-written paper on the wrong subject or in the wrong format may be rejected by the peer reviewers of one journal and accepted by the peer reviewers of another. Journal editors use the peer reviewers to maintain the quality of papers that are published.

There are very few writers who are capable of preparing a scientific paper that does not require some modification and editing. The peer review process gives the author the guidance to present the information in a forum that can be used by others. A peer review that does not make suggestions for improvement probably means that the reviewer did not read the paper or did not understand what was being said, and did not have the courtesy to admit it. A good peer review can be worth its weight in gold. Don't look a gift horse in the mouth.

What do researchers like to read?

HENRY A. WRIGHT

I like to read papers that answer **why** questions, not the **what happened** questions: science proceeds most rapidly when **explanation** is coupled with **description**. The sooner we know when and why a plant will be susceptible to a chemical, the sooner research on type of chemical and rate of application will be informative. Similarly, resistance or susceptibility to fire of a plant varies with season. Once we know our objective (kill or keep a plant), we can prescribe a burn to achieve our objective. A paper should expand our knowledge base and add to management information. Remember, this is the *Journal of Range Management*.

Moreover, I like to read papers that determine thresholds. When will firebrands give us problems and when will they not? Why? When will logs burn up and when will they not. Why? When are plants susceptible to rootkill and when are they not? Why? When will fires burn safely and when will they not? What are the upper and lower limits of weather conditions for permissible burns?

Papers that resolve field problems through basic and applied research are preferred reading. Laboratory work, special field testing, and, ultimately, application are usually involved. Also, this research might incorporate basic information from other disciplines.

As a scientist, I do not like to get papers rejected for the wrong reasons. Associate editors should set the standard for our journal and should take their job seriously to serve the members of the society. They should have the fortitude to make final decisions on acceptance or rejection of papers. I do not like to hear an editor say, "I rejected your paper because my reviewers rejected it, and I need to honor their judgement. Otherwise, they may not review papers for me in the future."

There are harsh reviewers and there are lax reviewers. I can get negative comments on any paper by sending it to certain people for review. Similarly, I can guarantee acceptance from other reviewers. Thus, the editor needs to be rational and fair, and must exercise good judgment if we are to have a quality journal, regardless of reviewer comments. This is necessary if we want good research papers to continue to come to the *Journal of Range Management*.

I am not impressed with editors who say, "We reject 50% of our manuscripts." That is like telling a class of students that "50% of you will flunk this course, regardless of your level of performance." *Ecology* used to send me papers to review. They prefaced their cover letter by saying that "We reject 50% of all manuscripts." I returned their requests for review and said, "I review papers for content, not to make sure that 50% get rejected." In my judgment, editors should accept papers because there is something good in this paper. It should be a contribution that will enable us to better understand ecosystems or manage our lands.

A paper should be scientifically sound. Some of our editors and reviewers are pseudo-statisticians who often reject papers "because of improper design." I had a paper in which we studied the relationship between forage yield and percent cover of brush on a grazed and ungrazed area. The paper was rejected because of "used pseudo-replications." What is wrong with comparing regression lines between two areas?

Some of our editors have made bad decisions based on poor reviews, and they are accepting straightforward **what** studies in place of good **why** research. This is dangerous and embarrassing to our profession. Editors are encouraging scientists to do nothing. If you do not do anything, you cannot be accused of doing anything wrong.

Statistics should be a tool for researchers to evaluate their research. Randomization and replication should be incorporated in all studies to the greatest degree possible. After researchers have analyzed their data, they should set statistical analyses aside and "tell their story."

When associate editors are chosen, there should be some minimum criteria. They should have a good publication record in several journals. Some people have been scientists for 20 to 30 years and only published 2 or 3 papers. These people do not make good editors because they are too critical of themselves. Nevertheless, they generally are some of our best reviewers if their review comments are handled by a rational editor. Lastly, associate editors should preferably be senior scientists, but not necessarily.

All of us need to remember that our goal is to serve our profession so that ultimately we can do a superior job of managing our natural resources. If we use the **why** approach in our research and get reasonable and fair treatment from associate editors, we will be doing what is best for our profession.

Author is Horn Professor and Chairman, Department of Range and Wildlife Management, Texas Tech University. The paper was presented as part of the "SRM Publications and You" Symposium at the SRM Annual Meeting, Corpus Christi, Texas, February 1988.

Obligations and expectations of your peers: manuscript review at the *Journal of Range Management*

N.T. HOBBS

It has been said that the principal virtue of the peer review system is that it assures your paper will be read by at least 2 people. However, we have all occasionally wished that 1 particular reader had been otherwise engaged. Let me paraphrase a review I once received. The referee told me, in essence, that my paper showed a unique capability for turning a sow's ear into a sow's nose. If that wasn't enough, he went on to say that never before had he seen a young man who could transform a valuable commodity like paper into something thoroughly worthless merely by adding ink. It would seem that scientific publishing is not for the faint of heart.

Why do we put ourselves through this painful, time consuming business? We do it because we want to be believed. Credibility ultimately determines the effectiveness of a scientist, particularly the effectiveness of an applied scientiest who must answer to practitioners as well as to other researchers. To the extent that we value our trustworthiness, we will invest in enhancing and protecting the credibility of our profession. Peer review is one such investment. What we gain from it collectively is worth some individual inconvenience.

An effective system of peer review should avoid 2 classes of errors. Errors of commission are the ones that come to mind first: we wish to avoid publishing unsound information. The consequence of that mistake, if it is made frequently enough, is the erosion of the credibility of range scientists. On the other hand, we don't want to mistakenly exclude worthwhile papers. The consequences of errors of omission include a loss of innovation in research and its application, as well as a general unraveling of the peer review process, a process that fundamentally requires a perception of fair treatment by its participants. So, we need a equitable system that assures a high level of quality.

Author is wildlife researcher, Colorado Division of Wildlife, 317 W. Prospect Rd., Fort Collins, Colo. 80526. The paper was presented as part of the "SRM Publications and You" Symposium at the SRM Annual Meeting, Corpus Christi, Texas, February 1988.

The Current System

Our current system includes editor-in-chief Pat Smith, 12 associate editors, and many referees (usually 200+ each year). Associate editors are nominated by the membership of the Society for Range Management, are elected to the editorial board by a vote of the board's current members, are recommended by the editor-in-chief, and are appointed by the president of the Society. They are chosen to represent several subject areas including plant and animal physiology, grazing systems, plant and animal ecology, soils, hydrology, economics, wildlife management, and range improvements. Once selected, associate editors serve a 2-year term with a possible renewal for 2 additional years.

The function of the system is illustrated in the following example (Fig. 1). A manuscript is submitted to the editor-in-chief, who

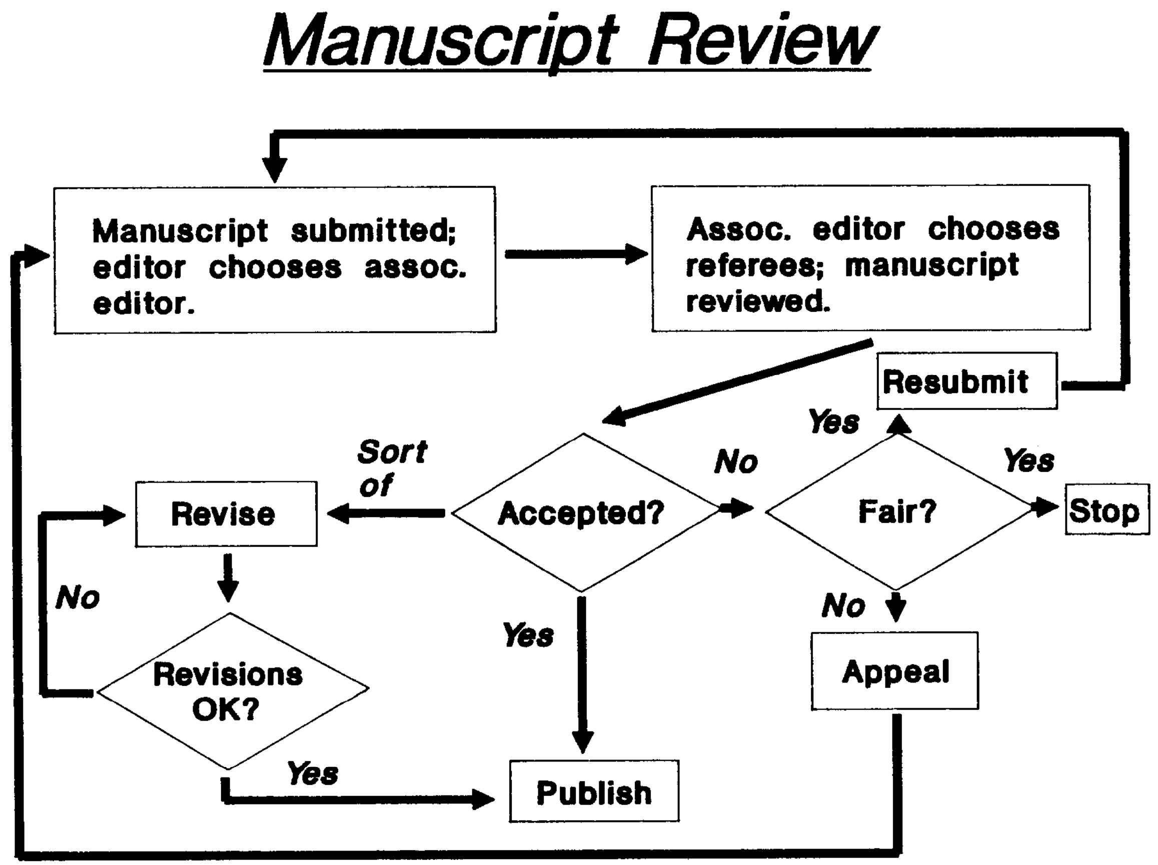

Fig. 1. *Flow diagram of peer review at the* Journal of Range Management.

chooses an associate editor with expertise appropriate for its topic. Upon receiving the paper, the associate editor selects 2 or 3 referees to review it, usually allowing them 2 weeks to a month to get the job done. Most referees are persons whose work the associate editor knows, although citations in the paper, suggestions of colleagues, or recommendations of the author may also point out appropriate reviewers.

When the reviews are returned, the associate editor decides the fate of the manuscript based on the comments of the referees and his or her own evaluation. If the referees are thorough, then most associate editors will simply pass their recommendations on to the author, adding only minor comments as needed. However, if 1 or both of the reviews are weak, then the opinions of the associate editor take on greater weight. If the reviews are inadequate, the associate editor may seek others.

When the paper is returned to the author, he or she has several choices. If the paper is accepted without revision, then it is simply a matter of choosing the correct champagne. (Given the salaries of scientists, it is perhaps fortunate that this occurs rarely.) If revisions are required, then the author can choose to make the changes as asked, or can provide a detailed rebuttal explaining why they should not be made. The associate editor will evaluate the revisions and rebuttal, and at that point may proceed with publication, may ask for additional changes, or, in some cases, may require further review. Finally, if the paper is rejected, the author can decide to submit it elsewhere, can revise and resubmit it to *JRM*, or can appeal the decision of the associate editor. In the case of resubmissions, the process starts over. In the case of appeals, the paper will be reviewed by a different associate editor and different referees. On appeal, the second editor considers all reviews, rebuttals, and correspondence, and arrives at a final decision on publishing the paper. About half of appealed decisions are decided in favor of the author. On average, the review process requires 7.5 months from submission to acceptance; accepted papers are usually published within 5 months.

What Can You Expect?

As an author, what can you expect from the process of peer review at the *Journal of Range Management*? You can anticipate a rigorous evaluation of the quality of your product. Your manuscript must treat a topic that is appropriate and interesting, and in so doing, must offer original, reliable information, clearly presented. Roughly half of the papers submitted meet these criteria. Papers are rejected most frequently because referees and the associate editor believe they fail to meet standards for reliability, particularly in experimental design and execution. These problems frequently include inadequate replication of experimental material, confounding of treatments, and inappropriate procedures for measuring responses. Topics are judged uninteresting if they merely echo a well-established literature, if they are excessively parochial, or if they are largely irrelevant to important issues in range management.

Opaque writing rarely causes outright rejection, but often leads to major revisions. Although some editors and referees are willing to polish dull prose, authors are ultimately responsible for the clarity of their work. If good writing demands inordinate effort, get professional help—I am often surprised that scientists who actively seek statistical guidance in designing and analyzing their experiments wouldn't think of obtaining help in reporting them. If you believe working to improve your writing isn't a worthwhile investment, consider that most referees are far more forgiving of flaws in a clear paper than in a murky one.

In addition to rigor, you can expect fairness. You are entitled to a review that is unbiased, that evaluates your work solely on its merit. You are due a review that responds to your perception of the message implicit in your paper. For example, if you think the editor and referees have asked for a revision that is uncalled for or misleading, then you have every right to tell them so. I know of no editors who will persist in requiring a change that an author can refute in a well-documented rebuttal. After all, the editors and reviewers are, by definition, your peers, not your superiors. In the end it is *your* paper, and within reason, should reflect your values and interpretations. Finally, you can expect a review that is as expedient as is consistent with thoroughness and reliability.

Everyone's Share

As a professional, what are you obliged to contribute to peer review? If you want to publish in refereed journals, you then are obliged to actively participate in the peer review process by providing a reasonable number of critiques of manuscripts. Your obligations are not limited to triage; you should strive to improve the quality of manuscripts, not merely sort them according to their quality. To that end, your comments need to be thorough, scholarly, and constructive. Even when rejecting a paper, you must clearly explain your objections, and suggest approaches that might remedy them. If nothing else, rejected authors should learn something from the reviewers. Finally, I emphasize that you must be prompt. If you are unduly burdened with requests for reviews, or have occasional scheduling conflicts, there is nothing wrong with begging-off and returning a manuscript to the associate editor. However, there is no excuse for a tardy failure to review. If you commit to reviewing by not promptly returning the paper, then get with it. As one of my colleagues said, it won't take any less time next week than this one.

The process of peer review belongs to all of us, and as such, should respond to individuals who believe that it isn't working properly. Evaluation of manuscripts at the *JRM* has drawn fire for several reasons, but the complaint I hear most frequently is that the process is inconsistent; that standards for acceptance vary among editors, and this variation leads to widely varying rates of acceptance. All of this is true. However, I think it comes with the territory of a diverse endeavor like range science and a subjective, pluralistic process like peer review. Any system that relies on many opinions to achieve judgments will be somewhat inconsistent in its outcomes. The only way to assure homogeneity of standards is to reduce the number of people making decisions, thereby distilling the variety of opinion they represent. Alternatively, rules for acceptance or rejection can be imposed from above. In the end, I think such efforts will lead to elitism, inflexibility, and the loss of a sense of collective responsibility for peer review. It is true that consistency is not far removed from fairness, but the appeal system should assure equitable treatment of authors who believe their work has been held up to unfairly inconsistent standards.

Honors for Review

This is not to say the system is perfect. However, I believe that the quality of the review system, as measured by its fairness, as measured by the quality of products that appear in the *Journal of Range Management*, is more or less directly proportional to the time and imagination that referees are willing to invest in their reviews. If we wish to improve the peer review system, if we wish to improve our *Journal*, if we wish to enhance the credibility of our profession, then we can do so by rewarding high quality participation in peer review. I think these objectives are sufficiently valuable to require that evidence of high quality reviewing become one of the criteria for promotion of range scientists. Such evidence should not be limited to a list of the journals one has reviewed for, but should include an evaluation of the thoroughness and scholarship of the reviews themselves. Promotion folders should contain reprints. They should also contain contributions to peer review.

Peer review at the *Journal of Range Management* is a system for enhancing the credibility of our profession by assuring that our products meet standards for quality. In this process, we should be able to expect fair and thorough treatment. We are professionally obliged to provide it.

Viewpoint: Who are those Smiths?

ALAN A. BEETLE

Ever since "Smith 1959" appeared in Vol. 33 page 457 of *Journal of Range Management* (without further designation), I have felt the need to distinguish between the Smiths—to give those devils their due, so to speak. Now the appearance of *Index to Volumes 1-35, 1949 to 1982* brings need to a boil. The *Index* lists 30 Smiths, more or less, depending on whether Smith D.R.; Smith Dixie; Smith, Dixie R. are three persons or one.

The *Journal of Range Management* has made references to more than 200 Smiths. Twenty of these have been referred to 20 times or more. The other 180 have been mentioned fewer than 20 times. Now that is a lot of Smiths. From page to page, issue to issue, and volume to volume, ambiguity can only increase unless, in all good conscience, the writers contributing to the *Journal* respect each Smith for what he or she is worth.

Among the Smiths I count many good friends: Mike, Pat, Art, and Dixie, but what I know about the Smiths comes from the *Journal*. Jedediah was the first, a western explorer in 1828. Jared was publishing range management articles around 1900.

The most important Smith, based on references in the *Journal*, is Arther D., with 584 references last count. The *Index* lists Smith, A.D. 3 times as follows: 18:136—a Canadian; 32:275—from Utah State; 32:433—a Canadian. These references are separated by 4 other Smiths from Smith, Arthur D., where all 12 references go to the gentleman from Utah. However, the *Index*, which misplaced 32:275, has also ignored 5:304, "What should the goal of range education be?" apparently because it is an editorial and has overlooked 30:119 for no apparent reason.

Here is an annotated checklist of the 20 Smiths most mentioned in the *Journal*:

(1) Arther D. (ranking 15th among all range managers, with 595 references); Utah wildlife and range manager as well as co-author of a classic McGraw-Hill text called *Range Management*
(2) Dale W. (ranking 143, with 198 references); agronomist from Wisconsin specializing on the survival of winter hardened legumes and on carbohydrates
(3) Dixie Ray (ranking 215, with 140 references); career range manager with USDA; US Forest Service
(4) Edgar F. (ranking 280 with 114 references); Kansas specialist on the Flint Hills
(5) Justin G. (ranking 283 with 113 references); specialist on forage quality and quantity for wildlife (Utah and Oregon); also cheatgrass and point frames
(6) Patricia G. (ranking 326 with 102 references); editor of the *Journal of Range Management*
(7) Henry H. (ranking 495 with 72 references); with the Soil Conservation Service in Texas
(8) David A. (ranking 515 with 70 references); with the Soil Conservation Service in Arizona
(9) Michael A. (ranking 538 with 67 references); professor of range management at the University of Wyoming
(10) Dwight R. (ranking 680 with 52 references); in Colorado with the United States Forest Service
(11) A.D. (ranking 753 with 48 references); agronomist from Alberta, Canada
(12) N.S. (ranking 829 with 44 references); specialist on deer diets
(13) H. (ranking 1,030 with 35 references); co-author with Draper, N. of a book on applied regression
(14) Richard C.G. (ranking 1,288 with 28 references); Australian specialist on grazing systems
(15) Jared G. (ranking 1,395 with 26 references); pioneer range manager, around 1900
(16) Clayton Carl (ranking 1,525 with 24 references); in Oklahoma on overgrazing and Texas on brush control
(17) Burton M. (ranking 1,582 with 23 references); in Utah with the United States Forest Service
(18) S.J. (ranking 1,656 with 22 references); on Oklahoma soils
(19) D.D. (ranking 1,731 with 21 references); on erosion
(20) R.P. (ranking 1,732 with 21 references); on infiltration rates in New Mexico

Twenty-eight of our 50 states have contributed Smiths—some more than others, e.g. Texas 19, Utah and California 9 each.

Foreign Smiths have come from:

(1) Africa: D.W.W.
(2) Australia: D.F.; L.W.; M.D.; N.G.; R. and R.C.G.
(3) Canada: Arthur D.; D.A.; D.W.; E.R.; J.H.G.; P.J. and R.L.
(4) Great Britain: A.; Charles; J.H. and R.
(5) New Zealand: A.J. and K.P.

Government Smiths have been found in:

(1) ARS: Paul F.
(2) SCS: Byron T.; Bud; Guy D.; Henry N. and Ralph
(3) USFS: Alexander E.; Benton M.; John B.; John C.; and L.S.
(4) BLM: Eastburn and Robert J.
(5) BIA: V.D.
(6) US Fish and Wildlife Service: Allen G.

Are some of them ranchers? Yes, some of them, for example:

(1) Allen (South Dakota)
(2) Arthur H. (Arizona)
(3) Byron A. (Montana)
(4) C.C. (Texas)
(5) John B. (Oklahoma)

There are some doctors, e.g., Dixie Ray and Michael A., but there are many more with the M.S. or M.S., e.g. Charles Ray, Clayton Carl, Michael Allen, Lynne Lorayne Bixler, D.G., David A. and D.R.

In Colorado Mrs. Page is a librarian and Patricia G. is an editor. Otherwise J. Allen edited the *Proc. of the XIV Grassland Congress.* Books were written by Edward H. *(Land Uses and Wildlife Resources)*; Guy-Harold (*Conservation of Natural Resources* with N. Draper), a book on applied regression; H.P. *(Farm Machinery and Equipment)*; Lamont W. *(Agriculture Food and Man)*; R.L. *(Ecology and Field Biology)*; and S.E. *(Mycorrhizal Symbiosis)*.

From the allied field of Animal Sciences come:

(1) C.K. (on cobalt)
(2) G.E. (on sheep diets)
(3) Harry H. (beef and livestock)
(4) J.C. (on sheep)
(5) J.S. (growth in beef cattle)
(6) L.W. (dairy cattle)
(7) M.E. (on beef)
(8) N.E. (on dairy cattle)
(9) Paul F. (taking the long view for Swift and Co.)
(10) R.H. (on cows)
(11) R.L. (wintering beef in South Dakota)
(12) S.E. (phosphorus and vitamins for cattle and sheep)
(13) T.M. (cattle grazing in Nevada)
(14) V.F. (digestive capacity of sheep)
(15) Walter H. (progress with angus)
(16) W.W. (potassium in the winter supplement of range beef cows)

and some roughly related subjects as dung (A.), mulch (R.) silage (R.E.), earthworms (R.M.). To continue the allied fields:

chemistry:

(1) F.B.
(2) F.E.
(3) F.W.
(4) Paul E.
(5) H.M.

economics:

(1) Stephen C.

entomology:

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(1) C.F.
(2) D.R.
(3) L.L.B.
(4) W.

forestry
(1) D.A.
(2) Herbert B.
(3) Howard B.
(4) J.G.
(5) Lloyd F.

botany:
(1) Alan L. *(Scholochloa festuca)*
(2) C.A. (*Hyparrhenia* in Rhodesia)
(3) D.R. (*Cercocarpus* in Utah)
(4) E.V. *(Cyperus rotundus)*
(5) G. David *(Tetradymia glaubrata)*
(6) W.K. *(Bouteloua gracilis)*
(7) G.S. (*Bouteloua gracilis* in New Mexico)
(8) H.P. (pricklypear eradication in Texas)
(9) P.J. (*Salvia columbariae* in California)
(10) W.T. *(Nicotiana)*

soils:
(1) H.L. (infiltration along the Pecos River)
(2) H.W. (on the Kelley Soil Sampler)
(3) Henry W. (soil morphologist)
(4) I.L. (sampler for gravelly plastic soils)
(5) J.L. (on a soil erosion gauge)
(6) K.J. (on a soil erosion gauge)
(7) L. (on soils with W. DeYoung)
(8) M./I. (on selenium)
(9) M.S. (on soil denitrigication)
(10) R. (on soils in Australia)
(11) R.L. (soil nitrogen losses in Utah)
(12) R.M. (soil erosion in Texas)

range management:
(1) A.C. (brush control in Texas)
(2) C.C. (overgrazing in Oklahoma)
(3) D.W. (fire in Canadian pine)
(4) Harold E. (from sagebrush to grass)
(5) H.H. (aqueous spray of 2-4D)
(6) J.S. (reseeding)
(7) R.D. (seed dormancy and germination)
(8) R.P. (oak control in Texas)
(9) T.A. (seed germination)
(10) D.D. (handbook on conservation planning)
(11) Dale W. (survival of winter hardened legumes)
(12) L.H. (foliar regrowth of alfalfa)
(13) Mark A. (on *Medicago*)
(14) N.G. (on legumes)
(15) R.M. (forage grasses)

taxonomy:
(1) J.P., Jr. (on vascular plant families)

watershed:
(1) J.P. (on hydrology)
(2) M. (on watershed)
(3) R.E. (on rainfall and surface water hydrology)
(4) R.L., Jr. (on water evaporation)
(5) R.P. (infiltration rates in New Mexico)
(6) S.J. soil loss and sediment discharge
(7) V.E. (physical and hydrometeorological characteristics)

weeds:
(1) J.D.

wildlife:
(1) H. Clay (in deer browse)
(2) J.C. (on deer food habits in Texas)
(3) J.D. (Bureau of Sport Fisheries and Wildlife)
(4) L. (Virginia Polytex. Inst.)
(5) N.S. (deer diets)
(6) P.J. (Fish and Wildlife Service)
(7) R.H. (waterfowl)
(8) R.J. (State Game and Fish Commission)
(9) R.S., Jr. (frost injury to bitterbrush)
(10) S. (deer food in Texas)
(11) V.G. (animal communities of deciduous forest succession)

and related subjects: Courtney B. (rabbits in Utah), R.H. (rabbits in Arizona), R.E. (the natural history of prairie dogs), G.D. (hawks) and J.N.M. (finches).

In a recent letter to Abigail Van Buren (Dear Abby) the problem was given national attention:

> Dear Abby, I work in the public relations office of the Hughston Sports Medicine Hospital in Columbus, GA., and one of my duties is to forward mail to patients after they are discharged. Sometimes this is next to impossible. For example: Mrs. John Smith. We have hundreds of discharged Smiths on file, but I don't know which one is married to John, so I have to go through every Smith in our files to find the most recent patient. If there are three or four, I must return this card to the sender.

The moral is: Smiths come in many forms (maybe they outperform the Johnsons). Somewhere between non-Smiths Ralph Aaker and E. Zyznar they lie in troublesome wait. Indexers beware. May all editors avoid incomplete or inconsistent citations of all names.

Editor's Note: And may all authors tell us who they are—consistently!

Call for Associate Editor Nominees

We are seeking nominees to replace associate editors who will be leaving the editorial board of the *Journal of Range Management* in February 1989. Scientists in range wildlife, animal nutrition, and forage selection and quality are especially needed. Associate editors serve a 2-year term with an additional 2 years possible. Attendance at the editorial board meeting at the Society's annual meeting is strongly encouraged. Candidates should be experienced in research and show sound judgment in dealing with others. They may be asked for a list of representative publications as well as references for their work as reviewers of articles. Nominators should determine first that the nominee is willing to serve as an associate editor.

The office of Associate Editor is critically important for both the Society and the profession and ultimately for rangelands. We need the best.

To nominate: Send the name, address, and telephone number of the nominee, along with brief comments on the nominee's qualifications to Pat Smith, Editor, Journal of Range Management, 1839 York St., Denver, CO 80206 by September 30, 1988. For additional information, contact Dr. Smith at (303)355-7070.

Plant community development on petroleum drill sites in northwestern Wyoming

P.W. SMITH, E.J. DEPUIT, AND B.Z. RICHARDSON

Abstract

Plant community and soil development were investigated on oil/gas drilling sites occupying both sagebrush and coniferous forest vegetation types in northwestern Wyoming. Sites ranged from 3 to 33 years in age since abandonment. Some sites were seeded at abandonment, while others revegetated naturally. Vegetation and soils were sampled and compared on disturbed and adjacent undisturbed sites. Both soils and vegetation were altered by drilling activities. Disturbed soils generally had higher bulk density and pH and lower organic matter content than undisturbed soils. All disturbed sites were vegetationally dissimilar to adjacent native sites. However, sagebrush disturbances were progressing toward undisturbed conditions more rapidly than coniferous forest disturbances. Seeding accelerated vegetation development, although at different rates between sagebrush and coniferous forest disturbances. Seeding and establishment of introduced grass species on disturbed sites did not prevent natural recolonization of native species.

Key Words: oil/gas drilling, reclamation, succession, soil development

Oil and gas exploration and production can have major impacts on rangelands and forest lands in the western United States. Reclamation of drill sites and ancillary disturbances is not only essential for alleviating such impacts, but is required by law.

Studies have been conducted within various ecosystems to determine the time required for natural revegetation after disturbance. Estimates of recovery have ranged from as little as 40 years for sagebrush communities (Tisdale and Hironaka 1981) up to 200 to 300 years for climax spruce-fir forests (Ronco 1976). This and other research (Judd 1940, Antos and Shearer 1981, Brown et al. 1976) suggest that reclamation techniques are necessary to accelerate plant community succession on disturbed lands, if recovery within a reasonable time frame is desired.

Much research has been conducted to characterize plant succession on disturbed lands and to identify factors controlling this process (e.g., Skilbred 1979, Doerr et al. 1984, Sindelar 1978, Jaynes and Harper 1978). Unfortunately, lands impacted by oil and gas exploration have received little emphasis in such research. These lands differ from many other disturbances because of the small-sized, often scattered and environmentally disparate nature of individual drill sites, and the necessity of extensive access road systems.

This project was conducted to evaluate succession on abandoned petroleum drill sites as influenced by time and a range of physical and biological factors. Specific objectives were to: (1) Evaluate the influence of surrounding vegetation, (2) Determine the effects of seeding vs. natural revegetation, and (3) Evaluate the influence of disturbance-induced edaphic changes, on plant community development.

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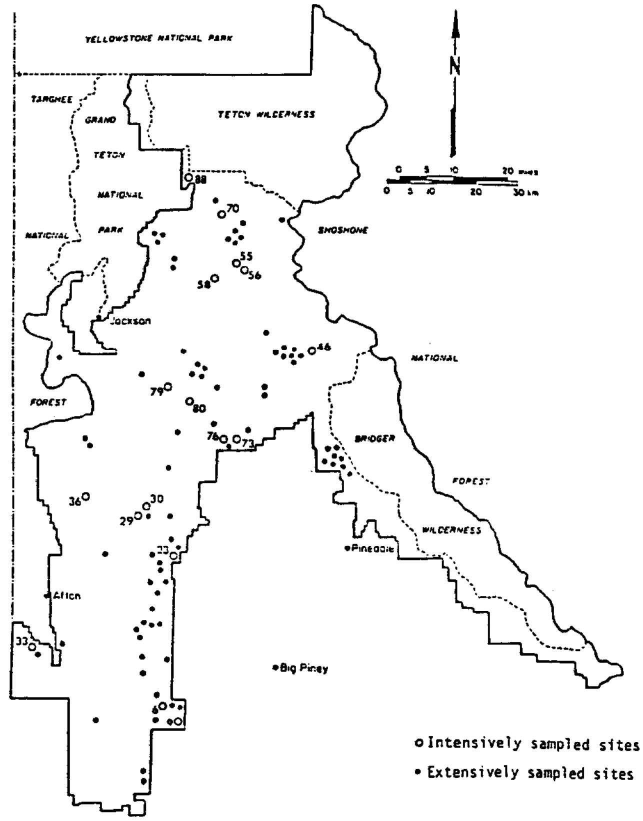

Fig. 1. *Locations of intensively and extensively sampled drill sites within the Bridger-Teton National Forest, northwestern Wyoming. Identification numbers are adjacent to intensively sampled sites.*

Study Area

All sampling was conducted on abandoned oil and gas drilling sites within the Bridger-Teton National Forest of northwestern Wyoming (Fig. 1). Plant communities within this Forest include grasslands, xerophytic shrublands, aspen and coniferous forests, and alpine plant communities (Beetle 1961, Bramble-Brodahl 1978, Youngblood and Mueggler 1981, Steele et al. 1983).

The Bridger-Teton National Forest occurs within a petroleum rich geologic formation known as the Overthrust Belt (Anschutes 1980). As a result, the Forest has been the focus of oil and gas exploratory operations for over 50 years. By 1981, at least 91 drill sites had been abandoned within the Forest.

Methods

Study Design

A field survey was conducted in 1981 to locate and qualitatively characterize most of the 91 abandoned drill sites. Results of this survey were presented by Waldvogel (1984).

It was impractical to intensively sample all sites for vegetation and soil characteristics. Therefore, a sub-array of 17 sites (Fig. 1)

Table 1. Comparison of mean disturbed and native area soil characteristics among sites within the sagebrush and coniferous vegetation types.

		Sagebrush Sites			Coniferous Sites		
Soil attribute[1]	Soil depth[2]	Disturbed areas	Native areas	Significance of difference(α)	Disturbed areas	Native areas	Significance of difference(α)
Bulk density	1	1.54	1.21	.01	1.52	1.23	.01
(g/cm^3)	2	1.54	1.28	.10	1.72	1.33	.01
	3	1.65	1.35	.10	1.81	1.40	.01
	4	1.74	1.58	none	1.79	1.48	.05
	5	1.75	1.53	.01	1.85	1.66	.01
ph	1	6.9	6.5	.10	7.0	5.8	.01
	2	7.1	6.6	.05	7.0	5.6	.01
	3	7.3	6.7	.05	6.9	5.6	.01
	4	7.4	6.6	.01	6.9	5.7	.01
	5	7.4	6.7	.05	7.0	5.8	.01
% Organic matter	1	4.7	9.2	.05	3.5	7.4	.05
	2	4.6	5.8	none	2.8	6.3	.05
	3	3.5	3.9	none	3.0	3.0	none
	4	2.8	3.0	none	1.7	2.1	none
	5	2.1	2.5	none	1.8	1.7	none
Available phosphorus	1	27.0	32.2	none	22.0	20.1	none
(ppm)	2	24.4	29.4	none	16.9	21.6	none
	3	23.0	32.1	none	16.2	28.8	.10
	4	27.0	27.8	none	16.2	25.0	none
	5	19.2	19.5	none	14.4	23.1	.10
Exchangeable potassium	1	.86	1.07	none	.64	.72	none
(meq/100g)	2	.71	.96	.10	.56	.61	none
	3	.50	.83	.10	.44	.48	none
	4	.44	.72	.10	.38	.39	none
	5	.43	.57	none	.40	.37	none
Effective rooting depth (cm)		38	48	.05	42	51	.10

[1]Data for CEC, EC, exchangeable cations and SAR are not presented due to lack of significant (α = .01–.10) differences between disturbed and native areas.
[2]1 = 0–5 cm; 2 = 6–10 cm; 3 = 11–20 cm; 4 = 21–30 cm; 5 = 31–50 cm.

was selected for intensive sampling which best represented the range of site variables to be investigated. These variables included.

1. *Nature of Surrounding Vegetation:* sagebrush/grassland vs. coniferous forest.
2. *Age of Site Since Abandonment*
3. *Presence vs. Absence of seeding.*

Nine of the 17 sites occupied sagebrush/grassland areas and ranged from 3 to 33 years in age since abandonment; 6 of these sites had been seeded. Eight sites were located within coniferous forest vegetation, also ranging from 3 to 33 years in age; 5 of the coniferous forest sites had been seeded. Waldvogel (1984) provided a complete description of biophysical conditions for each of the 17 sites.

A static approach (Austin 1977) was used to evaluate the successional status of abandoned drill sites. This method involves the derivation of trends from data collected at one point in time on a series of sites with varying ages or varying characteristics. Differences attributable to drilling disturbance were evaluated by comparing disturbed site data with concurrently collected undisturbed site data.

All 17 sites were sampled for soil attributes. Two sites selected initially were later judged inappropriate for vegetation sampling due to alteration of surrounding native vegetation. Consequently, vegetation sampling was confined to 15 sites.

Sampling Procedures

Vegetation and soil sampling were conducted once at each site during 1982. Results of tree overstory sampling on native coniferous forest sites were presented by Waldvogel (1984); this report will present results of herb, shrub, and tree seedling (<140 cm in height) sampling only. Forty (40) was determined (Cook and Bonham 1977) to be an adequate sample size for all vegetation measurements. Therefore, 40 sample points were randomly located in each sampling zone (disturbed and native) at each drill site. The quadrat method of Daubenmire (1959) was used to estimate canopy cover at each sampling point. A 0.25-m^2 quadrat was used to estimate total vegetation cover, individual species cover, and ground cover. Vegetation descriptors generated from canopy cover included plant frequency, species composition, floristic richness and diversity (using the Shannon-Wiener Index [Shannon and Weaver 1973]).

Soils were characterized by sampling excavated pits within disturbed and native soils at each site. Soil depths sampled were 0–5, 6–10, 11–20, 21–30, and 31–50 cm. Effective rooting depth was visually identified at each pit. Each soil sample was analyzed for texture, organic matter content (Walkley-Black), pH (saturated paste), cation exchange capacity (CEC), electrical conductivity (EC, saturated paste), sodium adsorption ratio (SAR), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P) and bulk density. All soil tests were conducted using procedures described by Black (1965), with the exception of organic matter (Greweling and Peech 1965).

Data Analysis

Plant and soil data were compared between disturbed and undisturbed areas, both at individual drill sites and among groups of sites with similar characteristics (i.e., age, surrounding vegetation and/or seeding treatment). Results of soils analysis were averaged across disturbed and native sites within each vegetation type, and analyzed at varying levels of probability (α = 0.01 to 0.10) using a paired *T*-test to identify any differences between disturbed and

Table 2. Mean plant class[1] canopy cover (%) for disturbed and native portions of each drill site sampled[2].

	Site I.D. number	Years Since abandonment	Seeded (S)/Non-Seeded (NS)	Total vegetation		Perennial grasses and grasslikes		Perennial forbs		Annual forbs		Shrubs and tree seedlings	
				Dist.	Nat.	Dist.	Nat.	Dist.	Nat.	Dist.	Nat.	Dist.	Nat.
A. Sagebrush Sites	58	3	S	18.2^{b}	49.0^{a}	15.2^{a}	13.2^{a}	1.2^{b}	27.4^{a}	$.5^{b}$	2.4^{a}	$.2^{b}$	8.5^{a}
	30	3	S	43.2^{b}	64.4^{a}	35.6^{a}	20.2^{b}	3.6^{b}	27.3^{a}	4.1	0	$.1^{b}$	27.9^{a}
	29	12	S	34.8^{b}	63.1^{a}	30.2^{a}	23.4^{b}	3.9^{b}	32.1^{a}	1.9^{a}	$.3^{b}$	0	21.4
	46	17	S	55.1^{b}	66.0^{a}	15.3^{b}	23.7^{a}	32.8^{a}	32.4^{a}	1.3^{a}	$.1^{b}$	6.9^{b}	15.9^{a}
	73	18	S	29.4^{b}	47.8^{a}	3.7^{b}	9.9^{a}	4.6^{b}	7.2^{a}	1.0^{b}	2.6^{a}	16.7^{b}	28.4^{a}
	76	19	NS	23.1^{b}	50.5^{a}	5.0^{b}	19.8^{a}	16.3^{a}	9.1^{b}	1.5^{a}	1.5^{a}	$.7^{b}$	20.7^{a}
	88	24	NS	48.4^{b}	61.8^{a}	34.8^{a}	20.4^{b}	6.2^{b}	15.4^{a}	0	.6	6.5^{b}	41.8^{a}
	33	33	NS	20.5^{b}	66.0^{a}	5.6^{b}	14.8^{a}	7.7^{b}	31.3^{a}	$.5^{b}$	4.8^{a}	9.1^{b}	23.0^{a}
	Mean			34.1	58.6	18.2	18.2	9.5	22.8	1.4	1.5	5.0	23.4
B. Coniferous Sites	9	3	S	19.0^{a}	25.7^{a}	16.5^{a}	3.1^{b}	$.5^{b}$	13.6^{a}	2.1^{a}	$.2^{b}$	$.1^{b}$	7.0^{a}
	36	4	S	43.4^{a}	44.5^{a}	37.4^{a}	4.0^{b}	2.2^{b}	28.8^{a}	3.0^{a}	$.2^{b}$	$.3^{b}$	13.2^{a}
	6	9	S	15.0^{b}	26.3^{a}	11.8^{a}	3.8^{b}	2.5^{b}	9.8^{a}	1.3^{a}	$<.1^{b}$	0	8.6
	80	12	S	30.4^{b}	51.7^{a}	15.8^{a}	5.3^{b}	4.4^{b}	33.5^{a}	6.8^{a}	2.9^{b}	0	5.2
	23	21	S	36.0^{a}	23.1^{b}	13.2	0	18.4^{a}	9.9^{b}	.1	0	3.4^{b}	16.1^{a}
	56	22	NS	31.6^{b}	81.1^{a}	8.2^{a}	$.1^{b}$	11.8^{b}	22.8^{a}	.4	0	1.4^{b}	40.1^{a}
	55	28	NS	46.5^{a}	50.1^{a}	11.4^{a}	$.3^{b}$	18.5^{a}	19.8^{a}	.3	0	2.5^{b}	28.5^{a}
	Mean			31.7	43.2	16.3	2.4	8.3	20.0	2.0	.5	1.1	17.0

[1]Independently estimated; i.e. not sumed parameters.
[2]Values between disturbed-native site pairs followed by the same letter are not significantly different at $\alpha = .05$ (t-test).

native soils. A 2-sample independent *T*-test was utilized to detect significant ($\alpha = 0.05$) differences in vegetation attributes between disturbed and native areas at each drill site. A similarity index designed by Spatz (Mueller-Dombois and Ellenburg 1974) was used to evaluate vegetation similarity for each pair of disturbed and native sites.

Simple and multiple linear regression was used to detect any relationships between edaphic or vegetation attributes and time. Ratios of disturbed to native site data (i.e., disturbed ÷ native data at each site for each attribute) were used in most regressions because of the wide disparity in absolute data values among sites.

Results

Soils

Data indicated that exploratory drilling altered several physical and chemical soil properties (Table 1). Effective rooting depth was shallower in disturbed than in native soils within both vegetation types. Bulk densities were significantly higher in disturbed than in native soils at all depths within the coniferous vegetation type, and at most depths within the sagebrush type. It might be expected that differences in bulk density between disturbed and native sites would lessen over time. However, regression analyses indicated no such trend.

Soil pH was higher on disturbed soils within both vegetation types at all depths. The degree of difference varied among soil depths for sagebrush sites. A wider disparity in pH existed between disturbed and native soils within the coniferous type, and differences were always highly significant ($\alpha = 0.01$). Regression analysis did not indicate disturbed soil pH to become more similar to that of native soils over time.

Near-surface soil organic matter content was greater on native than on disturbed areas in both the sagebrush (at 0–5 cm depth) and the coniferous (at 0–5 and 6–10 cm depths) vegetation types. These differences in organic matter did not diminish with time in the coniferous type. However, regression analysis of sagebrush site data did suggest a decline in organic matter differences between disturbed and native soils over time, although the significance of this trend was low ($\alpha = 0.20$).

Several soil attributes were either minimally or variably changed as a result of drilling disturbance. CEC, EC, SAR, and exchangeable cations were not altered by disturbance. No differences were detected in available P between disturbed and native soils in the sagebrush type. Concentrations of P in disturbed and native coniferous type soils were statistically different only at the 11–20 and 31–50 cm depths, where P was greater in native soils. Within the sagebrush type, mean concentrations of K were higher in native than in disturbed soils at all depths. However, no significant differences in K concentrations were detected at any soil depth within the coniferous type.

Vegetation

Total vegetation cover was significantly greater on native than on disturbed areas at nearly every drill site sampled (Table 2). No consistent pattern of increasing similarity in total cover between disturbed and native areas was apparent over time.

Perennial grass and grasslike species were usually dominant on seeded disturbed sites, and differences in cover between disturbed and native areas were generally significant. Grass cover on seeded sagebrush and coniferous disturbances was initially greater than that on native areas. However, regression analysis (Fig 2A) indicated that such differences declined over time, suggesting an eventual equilibration of grass cover between seeded disturbances and surrounding areas. On older, non-seeded sites, grass cover was consistently higher on disturbed than on native areas in the coniferous type, but relationships were inconsistent in the sagebrush type.

Perennial forb cover was generally lower on disturbed than on native areas. This relationship was strongest on more recently abandoned, seeded sites in both vegetation types. Linear regression analysis (Fig 2B) indicated that forb cover on disturbed areas increased relative to that on native areas over time. Analysis of seeded sites suggested a more rapid rate of forb increase for coniferous than for sagebrush disturbances. Regression analysis of all sites (seeded and non-seeded) did not yield a significant correlation in the sagebrush type, but did result in a positive correlation in the coniferous type. It is noteworthy that the rate of forb increase in the latter analysis was slower than when seeded sites only were analyzed. This suggests that seeding enhanced the rate of forb establishment on coniferous disturbances. Benefits of seeded grasses in

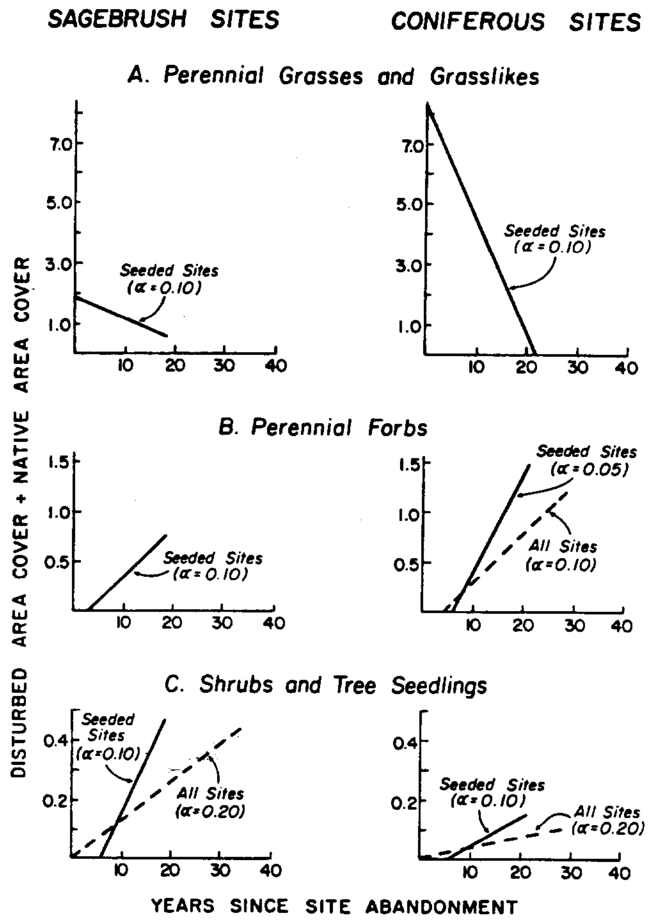

Fig. 2. *Ratios of disturbed ÷ native area plant class cover values over time, as derived from linear regression analyses of seeded and all sites.*

site modification in this case may have outweighed effects of increased competition stress to forbs, resulting in enhanced forb establishment.

Shrub and tree seedling cover was always significantly lower on disturbed than on native areas. Shrubs and tree seedlings were either absent or very limited in cover on recently abandoned sites (i.e., <12 years in age) in both vegetation types. Tree seedlings were observed only on the 3 oldest coniferous forest disturbances. Despite their slow establishment, regression analysis (Fig. 2C) did indicate a trend of increasing shrub/tree seedling cover on disturbed relative to native areas over time. The rate of increase was far more rapid for sagebrush than for coniferous disturbances. In both vegetation types, regression analysis of seeded sites only indicated that shrub cover increased at a greater rate than when all sites (seeded plus non-seeded) were grouped and analyzed. As with forbs, shrub establishment was apparently favored by the seeding of disturbances.

Species richness and Shannon-Wiener diversity index (H′) relationships between disturbed and native areas varied for sagebrush and coniferous forest sites (Table 3). In the sagebrush type, both richness and H′ values of disturbed and native areas generally converged over time among both seeded and non-seeded sagebrush sites.

Different patterns of richness and H′ over time were apparent on coniferous sites. Seeded disturbances initially declined in richness and H′ relative to adjacent native areas. However, this trend eventually reversed; on seeded and non-seeded sites older than 12 years both richness and H′ on disturbed areas exceeded values on native areas.

A characteristic of most sites sampled was the relatively low number of plant species common to both disturbed and adjacent native communities (Table 3). This and the disproportionality of cover contributed by common species were reflected in low disturbed:native area similarity indices among sites (Table 3), ranging from 0.6 to 10.7%.

Within the sagebrush type, disturbances tended to become more similar to surrounding native plant communities over time. Linear regression analyses of similarity indices vs. site age for both seeded and all (seeded and non-seeded) sites yielded weakly positive correlations ($\alpha = 0.20$). The rate of increase in similarity was more rapid for seeded sites, suggesting that seeding accelerated progression of sagebrush disturbances toward native conditions.

Similarity indices were generally lower in the coniferous than in the sagebrush vegetation type (Table 3). Furthermore, regression analysis of seeded coniferous sites resulted in a weakly negative

Table 3. Shannon-Wiener diversity indices (H′), floristic richness, number of common species and Spatz similarity indices (Isp) for disturbed and native areas at each drill site.

Site I.D. #	Years since abandonment	Seeded (S) or Non-seeded (NS)	H′ Disturbed	H′ Native	Richness Disturbed	Richness Native	No. common species[1]	Isp[2]
A. Sagebrush Sites:								
58	3	S	0.84	1.44	33	62	13	1.7
30	3	S	0.95	0.94	21	26	11	3.5
29	12	S	0.96	1.20	24	54	14	1.6
46	17	S	1.18	1.30	48	43	22	9.1
73	18	S	0.82	0.85	28	30	14	10.7
76	19	NS	0.74	1.18	17	45	10	4.2
88	24	NS	0.77	0.93	20	33	9	3.9
33	33	NS	1.30	1.40	44	57	27	9.9
B. Coniferous Sites:								
9	3	S	1.08	1.25	35	34	12	3.2
36	4	S	0.78	1.00	31	49	15	2.4
6	9	S	0.60	1.26	21	37	7	0.7
80	12	S	0.89	1.62	25	80	13	1.7
23	21	S	1.08	0.61	31	11	3	0.6
56	22	NS	1.04	0.61	36	17	6	0.8
55	28	NS	0.99	0.51	41	18	8	1.9

[1]Species jointly occupying disturbed and native sites.
[2]Between disturbed and native plant communities.

correlation ($\alpha = 0.20$) between index values and time. This suggests that the type of seeding practiced retarded the progression of disturbances toward native forest conditions.

Discussion

Although cover of plant classes became more similar between disturbed and native areas over time, plant species composition remained very different between disturbed and native communities over the 33-year time span represented by sites studied. This suggests that more time may be necessary for floristic (i.e., plant species) than for plant class recovery on disturbances sampled.

Vegetation data also indicated a slower rate and different pattern of recovery toward native conditions on coniferous forest disturbances than on sagebrush disturbances. In actuality, the rate of recovery of coniferous disturbances was probably slower than data indicated because the tree overstory of native sites was not represented in site comparisons. These differences between vegetation types may be attributable to several factors. As reviewed by Grime (1979) and others, in grass- or shrubland succession many species and life forms may be common to both early seral and climax stages. The higher and temporally increasing similarity of disturbed and native sites in the sagebrush vegetation type may reflect this relationship. Conversely, forest succession may be characterized by a more complete turnover in species and/or life form composition. This relationship may have partially contributed to the slower apparent recovery rates on coniferous disturbances.

Drilling activities in forested areas create openings in the tree canopy, thereby eliminating the shaded environment necessary for re-establishment of shade tolerant, climax species. Shade tolerant understory and tree species common to undisturbed forest communities were rarely encountered on disturbances. Instead, disturbances were colonized by shade intolerant species. Lodgepole pine *(Pinus contorta),* a shade intolerant mid-seral species (Ronco 1976), was the primary tree species establishing on older disturbances. The time required for establishment and growth of this species delayed availability of shaded habitats conducive to late-seral species. This may be a major factor contributing to slower rates of recovery for coniferous forest disturbances.

Sagebrush disturbances generally became more similar to native sites over time in terms of diversity. In contrast, diversity of coniferous forest disturbances initially declined relative to that of native areas but ultimately increased to exceed that of native areas. An eventual expression of higher diversity on mid-seral disturbances is not unexpected in view of the fact that mature coniferous forests often support only a small number of shade tolerant understory species (Antos and Shearer 1981).

Direct consequences of seeding on plant community development were not easily identifiable because only the more recently abandoned sites (<21 years) were seeded. Furthermore, the specific methods and rates of seeding applied varied among sites, as did species composition of seed mixes. However, all reclaimed sites were sown primarily with vigorous, competitive perennial grasses not native to the area, as well as introduced legume species on certain sites. Exclusive use of such introduced species has sometimes been reported to inhibit the reestablishment of native species (Laycock 1980, Schuman et al. 1982, Sindelar 1978). However, while seeded disturbances were dominated by introduced grasses, non-seeded native shrubs and forbs were also present. The younger, seeded sites generally possessed as many (or more) species in common with native communities as did older, non-seeded sites. Therefore, an extensive cover of seeded perennial grasses did not completely prevent native species establishment.

Similarity index data suggested that seeding introduced species accelerated successional progression toward native conditions on sagebrush disturbances. Site modification benefits from established introduced species may have enhanced the establishment of native species. However, absolute similarity of disturbed to native sagebrush plant communities was still low on even the oldest seeded sites. It is possible that changes in seeding practices, such as sowing primarily native rather than introduced species, may further accelerate succession and thereby shorten recovery time.

In contrast to the sagebrush type, the seeding of introduced grasses on coniferous forest disturbances negatively influenced their similarity to native communities over time. However, seeding did accelerate the establishment of non-seeded shrub and forb species. These seemingly contradictory relationships may be explained by the fact that the shrubs and forbs naturally colonizing disturbances were predominantly shade intolerant species not found in adjacent forest communities.

Changes in revegetation strategies for coniferous forest disturbances may increase the rate of recovery toward predisturbance condition. For example, seeding or planting practices may strive to establish not only early seral grasses but also mid-seral shrubs and trees (Ronco 1976) to hasten development of an environment conducive to later seral, shade tolerant species.

Changes in soil characteristics may have been major factors affecting vegetation development on sampled disturbances. The number, magnitude and statistical significance of disturbed:native soil differences were usually higher for coniferous than for sagebrush sites. This suggests that forest soils were more highly modified by drilling disturbance than shrubland soils, which may be another reason for slower rates of vegetation recovery on forest disturbances.

The increased bulk density of disturbed soils was probably attributable to soil compaction from the heavy equipment used on sites before and after drilling operations. Increased bulk density on non-topsoiled sites may also have been caused by the removal of less dense upper soil horizons during site preparation. Overly compacted soils can detrimentally affect plant establishment through negative effects on water availability (Hill and Sumner 1967) and may also directly reduce root growth. Bulk densities of 1.6 to 1.8 g cm^{-1}, which were exhibited by many of the disturbed soils sampled, have been shown to reduce root penetration (Foil and Ralston 1967, Zimmerman and Kardos 1961), and may have been one cause of the shallower effective rooting depth noted in disturbed soils.

Soil pH was usually higher in disturbed than in native soils. Within the sagebrush type, however, drilling disturbance did not increase pH sufficiently to warrant a change in acid or alkaline classification. In contrast, pH was strongly altered on coniferous forest disturbances. Most native soils varied in pH from 5.2 to 6.6, which is a normal, strongly to slightly acid range for forest soils (Spurr and Barnes 1973). Soil pH was generally within the neutral to slightly alkaline range of 7.0 to 7.6 for coniferous disturbances. This decrease in acidity in disturbed soils may have encouraged establishment of species normally not found on native soils because of non-adaptation to acidic conditions.

Percent organic matter in the upper 5 cm of disturbed soils was generally lower than that in native soils in both vegetation types. Topsoil loss or modification resulting from drilling activities may have removed or diluted organic matter at this uppermost soil depth. Organic matter is of critical importance to the function of plant:soil systems, and such reductions of soil organic matter content by disturbance can be detrimental to successional and pedogenic recovery (Schafer and Nielsen 1978). A trend of increasing organic matter content over time was apparent in disturbed sagebrush soils. However, no such trend was evident for disturbed coniferous forest soils, suggesting that equilibration of soil organic matter content may take far longer in that vegetation type.

Conclusions

The findings of this research must, in a proper sense, be considered tentative in light of the non-replicated, survey nature of the study, and of course specifically apply to the sampled drill sites only. Despite these limitations, we can conclude that drilling disturbance altered a number of soil attributes of sites sampled, and that certain of these alterations persisted for considerable periods of time. None of the drill sites sampled supported plant communities which closely resembled those of adjacent native areas. However, trends in vegetation recovery over time were apparent, and were interactively influenced by the nature of surrounding vegetation and seeding.

These conclusions allow a number of relationships to be hypothesized for drill site reclamation in the study area. First, they suggest that amelioration of detrimental changes in soils may be necessary in reclamation programs. Second, they suggest that rates and patterns of recovery can be expected to vary for drilling disturbances in disparate environments. Lastly, results suggest that while a given type of reclamation practice (i.e., grass seeding) may prove beneficial to environmentally different drilling disturbances, the nature of benefits will vary.

The dynamic nature of vegetation and soils on disturbances was demonstrated on sites sampled, and must be considered in reclamation planning. This implies that immediate or rapid achievement of pre-disturbance conditions should not be expected on drill sites in northwestern Wyoming. Instead, acceptable trends toward desired conditions should be sought through revegetation practices properly based on ecological principles.

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Root excision and dehydration effects on water uptake in four range species

M. BASSIRI, A.M. WILSON, AND B. GRAMI

Abstract

Germinating seeds of crested wheatgrass *(Agropyron desertorum)*, Russian wildrye *(Elymus junceus)*, alfalfa *(Medicago sativa)*, and cicer milkvetch *(Astragalus cicer)* were dehydrated for 4 days at −22 MPa, and/or their roots were excised, and used as treated materials. In an experiment in root growth boxes, where the seedlings depended for 60 days on the initial soil water supply, seminal primary and seminal lateral roots of grasses penetrated to the same depth. Both types of roots were similarly effective in taking up water, mainly from the upper 50 cm of the soil profile. In a sealed pot experiment under favorable moisture conditions, water uptake increased with seedling age up to 34 and 41 days for crested wheatgrass and Russian wildrye, respectively, and up to the end of the experiment (53 days) for the legume species. Leaf area of grasses was not affected by root excision alone, but it decreased due to the combined effects of root excision and temporary dehydration. Leaf area was generally proportional to water uptake within each species. In all 4 species, root excision and temporary dehydration did not affect transportation rates, while transportation rate decreased as a function of age. Transportation rates were higher in legumes than grasses and were higher in Russian wildrye than crested wheatgrass.

Key Words: crested wheatgrass, Russian wildrye, alfalfa, cicer milkvetch, seedling development

Drought is the most important single factor limiting plant growth in the arid and semiarid regions of the world. Grassland species differ considerably in their abilities to tolerate drought conditions. In trials from 1930 to 1950, Hull (1974) examined 90 species of grasses and reported that crested wheatgrass *(Agropyron desertorum)* and fairway wheatgrass *(A. cristatum)* were the most successful species on the drier sites. Harris and Wilson (1970) found that crested wheatgrass was a better competitor for moisture than bluebunch wheatgrass *(A. spicatum)* because of faster root penetration. Drawe et al. (1975) observed that seedlings of Russian wildrye *(Elymus junceus)* were not vigorous and grew slowly, and thus were susceptible to moisture stress during emergence and establishment. Bleak and Keller (1974) indicated that germinating seeds of Russian wildrye were less tolerant to dehydration than those of crested wheatgrass.

Among legumes, alfalfa *(Medicago sativa)* is considered to be drought tolerant. Rumbaugh and Pedersen (1979) showed that alfalfa could survive and remain productive after 23 years of grazing in a region with an average annual precipitation of 200 mm. Peterson (1972) indicated that active roots of alfalfa commonly penetrate to depths of 2.4 to 3.6 meters. On the other hand, cicer milkvetch *(Astragalus cicer)* is relatively slow in establishment and seems to be adapted to areas of the central Great Plains which receive more than 400 mm annual precipitation. Information on root development in cicer milkvetch is very limited.

Working on crested wheatgrass and Russian wildrye, Hassanyar and Wilson (1978) observed that the lateral roots of these species remain quiescent up to a week and this enables the germinating seeds to recover from drought injury which might kill seminal primary roots. They related drought tolerance during germination to embryo morphology and presence of seminal lateral root primordia. Bassiri et al. (1988) showed that temporary dehydration and root excision had pronounced effects on the growth and development of seedlings of crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch. The seedlings of grasses and legumes developed seminal lateral roots and replacement tap roots, respectively. These roots supported seedlings for as long as 20 days while soil moisture was limited to the initial irrigation.

The objective of this study was to examine the capability of a single lateral root of the grasses and of replacement tap roots of the legumes to extend in a drying soil profile and to use soil moisture in the deep layers for nearly 2 months after germination. The effects of temporary dehydration during seed germination on subsequent water uptake capacity of these roots was also determined.

Materials and Methods

Seed source and scarification treatments, methods of temporary dehydration and root excision, and seed germination were the same as described by Bassiri et al. (1988). Germinating seeds of the 4 species were selected and given 1 of the following treatments: (1) Planted directly in moist soil (control treatment), (2) Planted in moist soil after the roots were excised, and (3) Planted in moist soil after being excised and dehydrated at −22 MPa for 4 days. Such treated materials were used in the following 2 experiments to determine their effects on root extension and on water uptake.

Root Extension Experiment

Wooden root growth boxes (9×16×120 cm inside dimensions) were assembled with screws so that sides could be removed. Polyethylene liners, with holes at the bottom for drainage, were placed inside the boxes to avoid loss of water by evaporation from sides of the soil columns. Boxes were filled with known amounts of autoclaved, air-dry sandy loam soil and a total of 3.7 to 4.0 liters of water was added in 6 or 7 increments during a 3-day period. This amount of water was sufficient to moisten the soil to a water potential of approximately −0.03 MPa (field capacity).

Twelve of the treated and untreated germinating seeds were planted in each box and covered with 1 cm of dry soil. After emergence, grass seedlings were thinned to 3 seedlings per box, 1.5 cm of soil was removed from around the seedling crown, and seedlings were restricted to either the seminal primary root or 1 seminal lateral root by excision of all other roots. About 2 cm of air-dry soil was then placed around the root and crown of seedlings to support the plants and prevent the development of adventitious roots. The legumes were thinned to 2 seedlings per box, and the soil surface was worked so that it was similar to the air-dry surface of boxes in which the grasses had been planted.

Seedlings were grown for 55 to 60 days in a greenhouse where temperatures fluctuated between 25 and 30° C, maximum midday photosynthetically active radiation from 300 to 400 μ $EM^{-2}sec^{-1}$, relative humidity from 25 to 50%, and daylength was about 14 hours.

At the end of the experiment, 1 side of the box was removed and it was observed that soil columns were not moistened uniformly in

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some of the boxes. Apparently water had channeled down along the side of the soil column and had left pockets of dry soil. Therefore, soil could not be sampled for determination of moisture content. Consequently, the whole experiment was exactly repeated except that the method of moistening the soil columns was improved. Only data from the repeated experiment are reported. In the new procedure, before planting, boxes filled with soil were placed horizontally in large pans of water and soaked for a few hours. Boxes were removed from the water and placed successively at angles of 15, 45, and 90° C (about 5 days in each position) to allow drainage of excess water from the soil columns. Because the soil surface had dried somewhat during drainage, an additional 250 ml of water was added to the soil column just before planting seeds. To ensure the successful emergence of legumes, increments of 50 ml water were added to all treatments whenever the soil surface appeared dry prior to emergence. This additional water for legumes totaled about 500 ml.

Finally, 1 side of the box was removed and soil samples were taken from depths of 10, 30, 50, 70, 90, and 110 cm. Water content of the soil samples was determined gravemetrically (105° C for 24 hours) for all treatments as well as for the control boxes in which no seedlings had been planted. Roots were washed on 1 mm screen with a fine spray of water. The length of the longest root in each box was recorded, and roots and shoots were oven-dried (70° C for 24 hours) and weighed.

Water Uptake Experiment

Petri dishes with 3 holes for aeration (1 cm diameter) and 1 hole for seedling growth (2.5 cm diameter) were painted dark grey to eliminate light penetration and the growth of algae and mosses beneath the dish. Pots (15 cm diameter by 15 cm depth) were filled to the rim with autoclaved and air-dried soil and irrigated before the petri dishes were sealed into the rims of the pots with butyl rubber sealing compound (Fig. 1). Two centimeters of soil was added over the petri dish and was irrigated to a water potential of about −0.03 MPa. Seeds were planted (2 to 3 mm deep) in the center of each pot so that their roots could extend through the hole in the center of the petri dish. Pots were placed in 2 growth chambers where the conditions for the grasses and legumes were, respectively, 25 and 30° C temperature, 40 to 50 and 38 to 42% relative humidity, and 450–500 and 800 $\mu EM^{-2} sec^{-1}$ photosynthetically active radiation. Daylength was 15 hours in both growth chambers. Pots were adequately watered from the top until seedlings in all treatments had emerged. Pots were placed in the growth chamber, and soon after emergence they were subirrigated to maintain a dry soil surface and to prevent adventitious root development in grasses. The amount of water to be added at each irrigation (to increase soil water content to field capacity) was determined by weighing each pot.

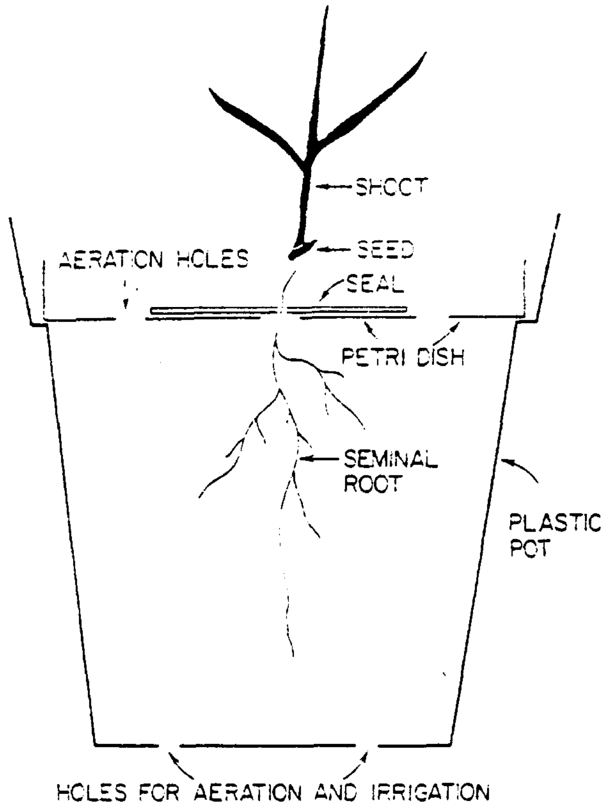

Fig. 1. *Drawing of a plastic pot with a grass seedling prepared for water uptake measurement.*

When seedlings were between 21 and 30 days old, soil around the crown and the upper 1.8 cm of the root was removed by washing and seedlings were thinned to 1 per pot. Grass seedlings were restricted to either the seminal primary root or to 1 seminal lateral root. Legume seedlings were supported by the original tap root or by 1 or more replacement tap roots. A seal of aluminum foil was

Table 1. Effects of root excision and temporary dehydration treatments (MPa) on subsequent root depth (cm), root and shoot weight per box (mg) of the 4 species, in a 60-day growth performance test in the greenhouse with seedlings limited to the initial soil water supply.

Treatments		Species			
Excision[1]	Dehydration[2]	*Agropyron desertorum*	*Elymus junceus*	*Medicago sativa*	*Astragalus cicer*
		Root depth (cm)			
–	0	84 a[3]	84 a	117 a	112 a
+	0	90 a	89 a	113 a	98 b
+	−22	82 a	63 a	112 a	90 b
		Root weight (mg)			
–	0	219 a	234 a	4565 a	3047 a
+	0	209 a	202 a	4635 a	2156 a
+	−22	169 a	173 a	4034 a	1747 a
		Shoot weight (mg)			
–	0	2152 a	2225 a	4424 a	3849 a
+	0	1773 a	1701 a	3194 a	3240 a
+	−22	1518 a	1751 a	3924 a	2702 a

[1]In the excision treatments, the entire seminal primary roots of grasses and 2 mm of the root tips of legumes were removed.
[2]Germinating seeds were dehydrated for 4 days in constant humidity trays at −22 MPa.
[3]Means within each column followed by a similar letter are not significantly different (P=0.05).

placed around the remaining root and fastened to the upper surface of the petri dish (Fig. 1). A wire support held seedlings in a vertical position.

Measurements for the grasses had to be initiated at an earlier seedling stage than the legumes. Water uptake by roots was determined on each observation date by sealing the aeration holes and weighing the pot and seedling before and after a 24-hr period. Seals were then removed from aeration holes. On each observation date, green leaf blade length was determined for the grasses and number of leaflets was counted for the legumes. After the last water uptake measurement, 10 green leaf blades from each grass seedling and 50 leaflets from each legume seedling were collected for determining area:length ratios and area per leaflet. Area per leaflet was determined with the use of an optical leaf area meter. The resolution of the meter, however, was not adequate for measuring area of narrow grass leaves. Therefore, areas were estimated by placing a transparent 1-mm grid over the flattened leaves and counting the number of grid intersections within the perimeter of the leaf. Leaf area:leaf length ratio for grasses and area per leaflet for legumes were used for estimating seedling leaf area on each of the observation dates. Pots were arranged in a randomized complete block design with 4 replications in the root extension experiment, and 3 and 8 replications in the water uptake experiment for the grasses and legumes, respectively.

Results

Root Extension Experiment

Differences in root depth between crested wheatgrass and Russian wildrye and among treatments were not significant (Table 1). Alfalfa roots penetrated to greater depths than cicer milkvetch roots, and original tap roots of cicer milkvetch penetrated to greater (P=0.01) depths than its replacement tap roots.

The inhibitory effect of temporary dehydration on secondary growth of replacement tap roots was not permanent. Under favorable soil moisture conditions, alfalfa replacement tap roots were generally as great as the original tap roots. The combined effects of excision and temporary dehydration on diameter of replacement tap roots varied greatly among seedlings in cicer milkvetch. The formation of 2 or more replacement tap roots was more common in cicer milkvetch than in alfalfa.

Excision and dehydration treatments tended to reduce crested wheatgrass and Russian wildrye root weight (Table 1). Under uniformly favorable moisture conditions in the soil column, seminal lateral roots grew almost as well as seminal primary roots. Alfalfa had greater (P=0.01) root weight per box than cicer milkvetch.

There were no significant differences caused by treatments in shoot weight per box of any of the 4 species, indicating that seminal lateral roots of grasses and replacement tap roots of legumes were, respectively, similar to seminal primary roots and to original tap roots in their ability to support shoot growth under favorable soil moisture conditions. Shoot weight of cicer milkvetch, however, was significantly more affected by the excision and dehydration treatment than alfalfa.

In boxes planted with grass species, soil water percentages increased (P=0.01) with increasing soil depth (Table 2). In grasses, species and treatment, did not have any significant effect on soil water percentages at the end of the experiment. Soil water percentages were greater in control boxes than in boxes planted with grasses in the upper 3 sampling depths (10, 30 and 50 cm). The results suggest that roots of grasses used water mainly from the upper 50 cm of the soil profile and that seminal lateral roots were about as effective in taking up water as were seminal primary roots.

In boxes with alfalfa and cicer milkvetch, differences caused by species, treatments, soil depths, and all two-way interactions were significant (P=0.05) (Table 2). Legume species extracted much more water from the soil profile than grass species. Replacement tap roots that originated from dehydrated germinating seeds of legumes tended to use less water from the 110 cm depth than did the original tap roots.

Water Uptake Experiment

In grasses, there were significant differences (P=0.01) in water uptake caused by seedling age, species, and treatment. Water uptake increased with seedling age during the 27- to 34- day interval for crested wheatgrass and 27- to 41-day interval for Russian wildrye and then reached a plateau with little further change (Fig. 2). Seminal primary roots of crested wheatgrass and Russian wildrye were similar in water uptake in this experiment. Seminal lateral roots originated from germinating seeds that had been exposed to temporary dehydration were less effective in water uptake than seminal primary roots in both grass species.

Water uptake in alfalfa and cicer milkvetch significantly increased with increasing seedling age (Fig. 3). Original tap roots of cicer milkvetch had a higher capacity for water uptake than replacement tap roots, especially when replacement tap roots had developed from germinating seeds that had been temporarily dehydrated. In

Table 2. Effects of root excision and temporary dehydration treatments on the soil water content (%) in various depths of the soil profile (cm) in root growth boxes of 4 species at the end of the 60-day experiment in the greenhouse with seedlings limited to the initial soil water supply.

	Soil water content					
Soil depth	Not excised & not dehyd.	Excised[1] & not dehyd.	Excised & dehyd.[2]	Not excised & not dehyd.	Excised & not dehyd.	Excised & dehyd.
	Agropyron desertorum			*Elymus junceus*		
10	3.1 a[3]	4.1 a	4.1 a	3.0 a	3.9 a	3.7 a
30	7.6 b	8.3 ab	6.8 ab	6.5 ab	7.4 b	7.4 ab
50	7.8 b	8.2 ab	10.7 b	9.8 b	10.3 bc	10.4 b
70	12.2 c	11.8 bc	11.1 b	12.5 c	12.3 cd	9.8 b
90	11.1 bc	13.3 c	15.4 c	14.5 c	15.2 de	15.2 c
110	15.3 c	14.7 c	17.3 c	16.0 c	17.0 e	15.5 c
	Medicago sativa			*Astragalus cicer*		
10	2.7 a	2.9 a	2.6 a	2.9 a	3.0 a	3.3 a
30	3.4 ab	3.5 ab	3.5 ab	3.8 a	4.0 a	4.4 a
50	3.5 ab	3.5 ab	3.5 ab	3.8 a	4.2 a	4.4 a
70	3.5 ab	3.5 ab	3.5 ab	4.1 a	5.5 ab	4.8 a
90	4.0 ab	3.9 ab	3.5 ab	5.1 ab	8.7 c	10.5 b
110	5.9 b	6.7 b	6.3 b	8.3 b	7.5 bc	10.1 b

[1]In the excision treatment, the entire seminal primary roots of grasses and 2 mm of the root tipes of legumes were removed.
[2]Germinating seeds were dehydrated for 4 days in constant humidity trays at −22 MPa.
[3]Means within each column followed by a similar letter are not significantly different (P=0.05).

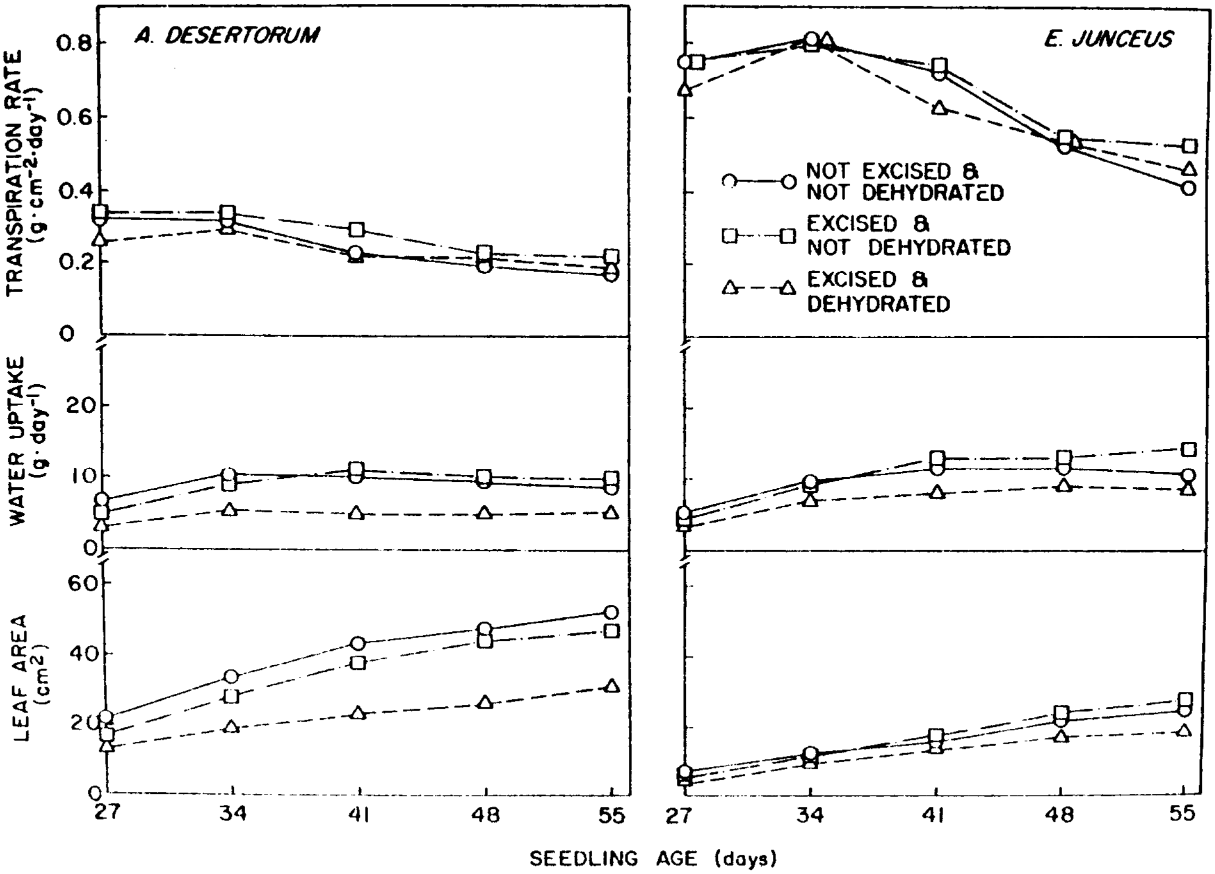

Fig. 2. *Effects of root excision and dehydration treatment (-22 MPa) on subsequent leaf area, water uptake, and transpiration rate of wheatgrass* (A. desertorum) *and Russian wildrye* (E. junceus) *seedlings.*

alfalfa, however, there was little difference in water uptake capacity of original tap roots and replacement tap roots.

Legume seedlings generally had substantially higher rates of water uptake than grass seedlings. Water uptake rates in legumes increased sharply with increasing age of seedlings; whereas in grasses, after about 40 days of age, water uptake reached a maximum and then remained more or less constant until the end of the experiment.

Crested wheatgrass and Russian wildrye generally increased leaf area slowly with increasing seedling age. When seedlings of both grasses were restricted to seminal lateral roots originating from seeds that had not been exposed to temporary dehydration, leaf areas were as great as in seedlings restricted to the seminal primary root. When grass seedlings were restricted to seminal lateral roots originating from temporarily dehydrated seeds, leaf areas were lower than in seedlings restricted to the seminal primary root. Within a species, leaf area generally was proportional to the magnitude of water uptake.

Alfalfa and cicer milkvetch sharply increased their leaf area with increasing seedling age. Treatments did not affect leaf area of alfalfa; but replacement tap roots of cicer milkvetch, especially those originating from seeds that had been temporarily dehydrated, did not support as much leaf area as original tap roots of this species.

Transpiration rates in grasses also decreased with seedling age because of the increase in green leaf-blade area during the period when water uptake was nearly constant. Crested wheatgrass had significantly lower transpiration rates than Russian wildrye. Treatments had little or no effect on transpiration rates. Transpiration rates were higher in legumes than in grasses.

Transpiration rates in the legume species decreased with time, and the decrease was more pronounced in cicer milkvetch than in alfalfa. Species and treatments did not have significant effects on transpiration rates.

Table 3. Effects of seedling growth on the soil water content (%) at various depths of the soil profile (cm) the end of the 60-day experiment in the greenhouse with seedlings limited to the initial soil water supply.

	Soil water content		
Soil depth	Legumes	Grasses	No seedling (Control treatment)
	[1,2]		
10	2.9 a	3.6 a	7.6 b
30	3.9 a	7.7 b	9.8 b
50	3.8 a	10.3 b	11.3 b
70	4.1 a	12.4 b	12.6 b
90	6.0 a	14.5 b	15.6 b
110	7.5 a	16.0 b	16.8 b

[1]Average of the 2 species and all treatments.
[2]Means within each soil depth followed by a similar letter are not significantly different from the control treatment (P=0.05 in a t-test).

Discussion

The seminal lateral roots of grasses were almost as effective as their seminal primary roots (even when germinated seeds had been temporarily dehydrated) in penetrating to and extracting water from the soil profile. In semiarid zones where soil moisture conditions at planting depth rarely are adequate for development of adventitious roots, crested wheatgrass and Russian wildrye may survive for 60 days, or more, when restricted to only the seminal root system. Thus, if the seminal primary root of germinating seed

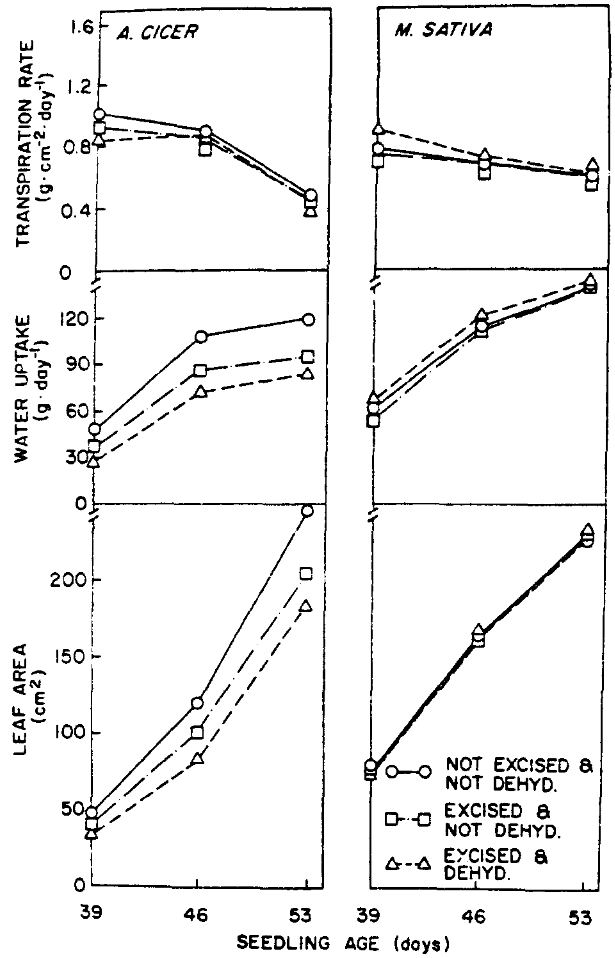

Fig. 3. *Effects of root excision and dehydration treatment (-22 MPa) on subsequent leaf area, water uptake, and transpiration rate of alfalfa* (M. sativa) *and cicer milkvetch* (A. cicer) *seedlings.*

is killed by temporary dehydration, the subsequent development of seminal lateral root(s) would often provide for water and nutrient uptake until weather conditions eventually allow for development of adventitious roots.

Similarly, replacement tap roots of alfalfa and cicer milkvetch were vigorous enough to penetrate to and extract water from deep layers of the soil profile. The legumes, unlike the grasses, do not depend on favorable soil moisture at planting depth for establishment of seedlings; rather, they depend on secondary growth of vascular tissues. Dehydration treatments temporarily delayed secondary growth of roots in many seedlings.

Differences between legumes and grasses in trends of water uptake with increasing age are explained by fundamental differences in the morphology of root growth. Legumes have a vascular cambium which, under favorable growth conditions, continuously produces new xylem and phloem. The new xylem and phloem give an increased water and food transporting capacity, respectively, to the shoot and root. The increased food transporting capacity supports increased growth and total extension of the root. Increased water absorbing and water transporting capacity resulted in a several-fold increase in the water uptake in legumes during a 2-week interval. Erie et al. (1968) reported that mature stands of alfalfa obtained about 46, 26, 18, and 10% of their required moisture from the top 60 cm of the root zone and from each successive 60 cm increment, respectively. In cicer milkvetch, the effects of temporary dehydration on subsequent water uptake by replacement tap roots were probably caused by a reduction and delay in total extension and secondary growth of roots. This requires a moist soil profile but does not require moist soil at planting depth. In grasses, the limited amounts of phloem and zylem tissues probably places upper limits on the root extension and on water transportation to the shoot, respectively. The grass species apparently reached their upper limits at about 40 days after planting. Thereafter, rates of water uptake by individual roots were nearly constant, even though leaf area continued to increase. The effects of temporary dehydration on water uptake by seminal lateral roots probably resulted from inhibition of total extension of roots and reduction in number and size of xylem vessels. In grasses, the inhibitory effects of dehydration may be overcome by production of additional seminal lateral roots (in young seedlings) or of adventitious roots (in older seedlings). Development of new roots requires favorable soil moisture conditions at planting depth as well as in the soil profile.

In the species investigated, transpiration rates decreased with increasing age of seedlings. The decreases in the legumes probably resulted from the limited size of the pot (i.e., limited amount of water available for uptake) as well as mutual shading. Alfalfa also produces smaller leaves under dry conditions as compared to optimum moisture situations. In grasses, leaf area indices were estimated to be much less than 1.0. Therefore, decreases in transpiration rate in grasses probably resulted from the increased growth of leaf area during the interval when water uptake by a single seminal root had reached an upper limit. Grasses had lower transpiration rates than legumes, probably due to differences in leaf diffusion resistance. Frank and Barker (1976) founder higher leaf diffusion resistances in crested wheatgrass than in Russian wildrye, which is consistent with our results.

Kneebone (1972) suggested that in a breeding program for seedling vigor and establishment in grasses, the tolerance of dehydration at seedling stage is an important criterion. Also, Nason et al. (1987) showed the effectiveness of recurrent selection for seedling water uptake and shoot weight in blue grama. Great variations in rate of water uptake among seedlings of both legume and grass species in the present study indicate the potential for selection and development of drought tolerant varieties of these plants. Environmental conditions in the field, especially the amount of water in the root zone, need to be carefully studied to determine if low or high rates of water uptake are advantageous in relation to plant productivity.

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Dehydration effects on seedling development of four range species

M. BASSIRI, A.M. WILSON, AND B. GRAMI

Abstract

The effects of temporary drought periods of semiarid regions were simulated by dehydration of germinating seeds of crested wheatgrass *(Agropyron desertorum),* Russian wildrye *(Elymus junceus),* alfalfa *(Medicago sativa),* and cicer milkvetch *(Astragalus cicer)* in 8 constant humidity environments, ranging from -10 to -220 MPa for 4 days. Combined effects of root excision and temporary dehydration at -22 to -160 MPa were also studied. Subsequent growth of seedlings was evaluated in growth performance tests under favorable soil moisture conditions. When the initial roots were killed by dehydration, survival of grasses depended on the development of seminal lateral root(s) from the scutellar nodes, and survival of legumes depended on development of a new meristem at the distal end or along the side of hypocotyl-root axis. The effect of dehydration was more drastic on the legumes than on the grasses, particularly at more severe conditions. While temporary dehydration of -59 MPa had little effect on grasses, it reduced the percent emergence of the legumes by about 70%. In the -220 MPa treatment, emergence percentages of crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch were 59, 35, 6, and 1, respectively, and percentages of rooted seedlings were 58, 12, 3, and 1, respectively. Under combined effects of excision and dehydration at -160 MPa, emergence percentages of the 4 species were 50, 34, 14, and 0, respectively, and their root lengths decreased by 37, 42, 44, and 100%, respectively. Within species variation in tolerance of dehydration suggested opportunities to select and breed for this characteristic.

Key Words: crested wheatgrass, Russian wildrye, alfalfa, cicer milkvetch, drought tolerance, plant selection

In arid and semiarid zones with low and unreliable rainfall, germinating seeds are often exposed to periods of drought, the severity and duration of which may vary. Germinating seeds of various plant species may respond differently to dry conditions. Levitt (1972) and Brown (1977) used the term "drought tolerance" as equivalent to "dehydration tolerance." The latter was defined by Kramer (1978) as the ability of plant protoplasm to survive drought without irreversible injury.

Crested wheatgrass *(Agropyron desertorum)* is a perennial bunchgrass which is widely used for rangeland rehabilitation on light-textured soils of both shrublands and grasslands where the rainfall is between 230 to 380 mm (Hafenrichter et al. 1949). Wilson (1971) indicated that seeds of this species were able to resume their physiological processes after being exposed to wet and dry periods. On the other hand, Russian wildrye *(Elymus junceus)* is a perennial bunchgrass which grows slowly in the seedling stage and is somewhat more susceptible to moisture stress during emergence and establishment (Bleak and Keller 1974).

Townsend et al. (1975) found that alfalfa *(Medicago sativa)* was the most promising legume species under dryland conditions and also the legume which could compete favorably with crested wheatgrass by the fourth year after establishment. In contrast, cicer milkvetch *(Astragalus cicer)* has poor seedling vigor and relatively slow germination and establishment, although it may tolerate moderate drought conditions (Townsend and McGinnies 1972).

Because these grasses and legumes are often seeded in mixtures on semiarid lands, it is important to understand their comparative drought tolerance during germination and establishment.

The objective of this study was to evaluate and quantify the effects of various degrees of temporary dehydration during the germination stage on the emergence and development of 4 promising species of grasses and legumes for seeding in dry regions. The combined effects of temporary dehydration and root excision on the subsequent growth of seminal lateral roots in grasses and of replacement tap roots in legumes were also examined.

Materials and Methods

Experimental materials included 'Nordan' crested wheatgrass, 'Vinall' Russian wildrye, 'Ladak' alfalfa, and 'Lutana' cicer milkvetch.

Dehydration Experiment

Light weight seeds and inert material were removed in a seed blower. They were then treated with bis (dimethylthiocarbamoyl) disulfide. Legume seeds were scarified. This experiment included 3 sequential steps:

(1) Seed germination: Seeds were germinated at 20° C under favorable moisture conditions until the seminal root had extended to a length of 3 to 5 mm.

(2) Dehydration treatment: Germinating seeds were exposed to a dehydration treatment by placing them in constant humidity trays for 4 days. Saturated salt solutions of sodium sulfate, potassium chloride, sodium chloride, magnesium acetate, calcium nitrate, potassium carbonate, calcium chloride, and potassium acetate had maintained constant humidities equivalent to water potentials of -10, -22, -37, -59, -92, -120, -160, and -220 mega-

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pascals (MPa), respectively, at 25° C prior to insertion of germinating seeds. Seeds did not touch the salt solutions, but lost water vapor to the constant humidity air. Hassanyar and Wilson (1978) found that the water content of germinating seeds of crested wheatgrass and Russian wildrye reached equilibrium within 2 days under humidity.

(3) Growth performance test: To evaluate the effects of temporary dehydration treatments, 25 control or treated seeds were planted at a depth of 1 cm in plastic pots (15 cm diameter by 15 cm depth) filled with autoclaved sandy loam soil. Soil was maintained at approximately -0.03 MPa by surface irrigation with distilled water. Emergence and growth performance during the 10-day test were evaluated under both growth chamber and greenhouse conditions. Growth chambers were maintained at 20° C, 70% relative humidity, a 12-hour daylength, and photosynthetically active radiation of 400 μE m^{-2}sec^{-1}. Greenhouse conditions were maintained at 20° C to 25° C, a variable relative humidity, 12-hour daylength (supplemented with sodium vapor lamps), and maximum midday photosynthetically active radiation of 300 μE m^{-2}sec^{-1}.

At the end of the 10-day growth test, number of emerged seedlings per pot was recorded. It was found that not all seedlings that emerged had developed roots, nor did all seedlings with roots emerge. Therefore, the percentage of seedlings that developed at least one root during the growth test was determined. Roots were washed with a fine spray of water over a 1-mm screen. The length of the shoot and depth of the longest root were measured from the planting level. Shoots and roots from each pot were separated, oven-dried (70° C for 24 hours) and weighed. Shoot and root data were averaged over the number of seedlings emerged and number of rooted seedlings, respectively. Biomass change was calculated as root plus shoot weight minus seed weight at the end of the 10-day test.

Excision-Dehydration Experiment

The distal 2-mm portion of the root of legumes and the entire seminal primary root of grasses were excised before the germinating seeds were exposed to the 4-day dehydration treatments at -22, -92, and -160 MPa. Two additional treatments were included in which germinating seeds were not exposed to temporary dehydration: (1) roots were excised, and (2) roots were left intact.

Pots (20 cm diameter by 20 cm depth) were filled with autoclaved sandy loam soil and water was added to increase soil moisture content to 15% (approximately field capacity). Fifty germinated seeds were planted in each pot and covered first with about 2 mm of moist soil, then with a layer of 2 cm of air-dried soil to reduce soil surface evaporation rate. At the end of the 20-day growth test, percentage emergence, shoot and root length, and shoot and root weight were determined in the same manner as indicated earlier.

Randomized complete block designs were employed in both experiments and significant differences among means were determined by Tukey's test (Steel and Torrie 1980). A polynomial regression was used to determine the effect of water potential on root development.

Results and Discussion

Dehydration Experiment

Temporary dehydration treatments significantly (P=0.01) reduced the emergence of seedlings of the 4 species during the 10-day test under favorable soil moisture conditions (Table 1). The effect of dehydration was more drastic on the legumes than on the grasses, particularly at more severe conditions. While temporary dehydration of -59 MPa had little effect on grasses, it reduced the percent emergence of the legumes by about 70%. Very similar trends were obtained for the emergence percentages in the growth chamber and greenhouse tests. In a similar study with green needlegrass (*Stipa viridula* Trip.), Fulbright et al. (1984) demonstrated that percent emergence was zero at -22 MPa.

Trends in root development for all species were similar to those for percent emergence in response to dehydration treatments, although under higher stress conditions root development was somewhat more adversely affected than was percent emergence (Table 1). In both the growth chamber and the greenhouse tests, species were significantly different (*P*=0.01) in their ability to develop roots after they had been exposed to dehydration treatments. In grasses, presence of seminal lateral root primordia, and in legumes, ability of root tissues to produce meristematic tissue in the hypocotyl-root axis are important factors in drought tolerance and survival of the seedlings (Hassanyar and Wilson 1978). Temporary dehydration of -37 MPa had no effect on subsequent root development in the grass species in growth chamber test, whereas it reduced percent rooted seedlings by about 75% in both legume species. In a similar study (Fulbright et al. 1984), when the seminal primary root of germinating seeds of needlegrass (*Stipa viridula* Trin) was excised or injured by dehydration (-10 MPa), seedlings developed up to 3 (average of 1.3) seminal lateral roots per seedling. They observed that no additional seminal roots developed when seminal primary root was undamaged. In the present study, root development was consistently more affected in cicer milkvetch than in alfalfa under similar stress conditions. The response of both grass species to dehydration treatments, in terms of percentage of seedlings with a root, was found to be linear, in contrast to a quadratic response in both legume species.

The water potentials during temporary dehydration which resulted in subsequent development of at least 1 root in 50% of the seedlings were calculated from the regression equations for the growth chamber test. The water potentials for crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch were -247, -129, -32, and -22 MPa, respectively. For crested wheatgrass, the value was obtained by extrapolation of the regression equation because the lowest value for percent of seedlings with at least 1 root was 58%. Bleak and Keller (1974) also observed that germinating seeds of crested wheatgrass were more tolerant to dehydration than those of Russian wildrye.

Germinating seeds of legumes exposed to dehydration treatments below -59 MPa did not develop roots in most replications during the 10-day test. An analysis of variance for both grasses and legumes was, therefore, performed only on the root depth and root weight data of the first 5 treatments (control, -10, -22, -37, and -59 MPa). Differences in root depth as well as in root weight per seedling caused by species, treatments, and the species × treatment interaction were significant (*P*=0.01) in both growth chamber and greenhouse tests. Root depth of the 4 species were nearly the same in the control treatment (Table 1). The dehydration treatments, however, inhibited the extension of roots in legumes more than in grasses. While a water potential of -37 MPa reduced the root depth of grasses by 32%, the reduction for the legumes was 74% under similar conditions. The results clearly indicated that root extension of cicer milkvetch was more adversely affected than that of alfalfa.

Since the grasses did develop roots in almost all treatments and replications, 2 additional analyses of variance, including all treatments, were conducted on the root depth and root weight per seedling of the 2 grass species. Differences in root depth and in root weight caused by species, treatments, and the species × treatment interaction were significant (*P*=.01) in both analyses. It appeared that dehydration treatments inhibited root extension in Russian wildrye more than it did in crested wheatgrass.

Root weights per seedling of crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch in the -59 MPa dehydration treatment, expressed as the percentage of control treatment, were: 41.9, 36.6, 28.5, and 42.1, for the growth chamber test, respectively. Corresponding data for shoot weights per seedling were 46.1, 45.8, 36.2, and 66.1, respectively. Both average root weight and shoot weight per seedling of cicer milkvetch were elevated by the high weights of very few superior seedlings that survived the dehydration treatment.

In water potentials below -59 MPa, seedling survival of the

Table 1. Effects of temporary dehydration treatments (MPa) during seed germination on subsequent emergence, and root and shoot development of 4 species in growth chamber and greenhouse tests under favorable soil moisture conditions.

	Growth chamber test				Greenhouse test			
Water potential	*Agropyron desertorum*	*Elymus junceus*	*Medicago sativa*	*Astragalus cicer*	*Agropyron desertorum*	*Elymus junceus*	*Medicago sativa*	*Astragalus cicer*
				Emergence (%)				
0	90 ab[1]	91 a	95 a	84	93 a	99 a	89 a	84 a
-10	99 a	99 a	82 a	79 a	91 a	96 a	83 a	70 a
-22	92 a	95 a	84 a	61 b	91 a	92 a	85 a	50 b
-37	90 ab	93 a	36 b	16 c	94 a	85 a	25 b	33 bc
-59	86 abc	93 a	16 c	16 c	91 a	93 a	37 b	22 cd
-92	74 bcd	62 b	14 c	5 c	65 b	55 b	28 b	7 de
-120	74 bcd	62 b	15 c	6 c	71 b	57 b	22 bc	3 e
-160	69 d	46 bc	6 c	3 c	57 bc	46 bc	8 c	3 e
-220	59 d	35 c	6 c	1 c	43 c	30 c	7 c	1 e
				Seedlings with a root (%)				
0	92 a	94 a	94 a	83 a	96 a	99 a	91 a	86 a
-10	99 a	99 a	86 a	79 a	95 ab	97 a	82 a	76 ab
-22	93 a	97 a	84 a	55 b	94 ab	96 a	84 a	63 b
-37	91 a	94 a	28 b	15 c	94 ab	83 a	33 bc	39 c
-59	86 ab	90 a	17 bc	16 c	92 ab	94 a	50 b	36 c
-92	73 bc	54 b	10 c	2 de	86 c	46 bc	36 bc	12 d
-120	71 cd	55 b	12 c	4 cde	75 bc	52 b	25 c	6 d
-160	66 cd	36 c	5 c	3 cde	56 cd	32 c	19 c	6 d
-220	58 d	12 d	3 c	1 e	40 d	12 d	17 c	2 d
				Root depth (cm)				
0	9.4 a	9.0a	10.2 a	9.1 a	7.0 a	6.3 a	7.3 a	6.7 a
-10	7.6 b	8.2 a	6.9 b	5.1 b	4.8 b	4.7 b	5.0 b	3.2 b
-22	7.7 b	6.5 b	5.7 b	3.0 c	4.2 b	3.6 bc	2.8 c	1.1 c
-37	6.8 bc	5.7 bc	3.4 c	1.7 c	3.8 bc	2.9 cd	2.2 c	1.0 c
-59	6.1 cd	5.2 cd	3.7 c	1.9 c	3.7 bc	3.0 cd	1.8 c	1.2 c
-92	4.9 ef	3.9 e	—[2]	—	2.4 de	1.4 e	—	—
-120	5.5 de	3.4 e	—	—	2.9 cd	2.0 de	—	—
-160	4.2 f	2.9 f	—	—	2.0 de	1.0 e	—	—
-220	3.8 f	4.2 de	—	—	1.6 e	1.4 e	—	—
				Root weight per seedling (mg)				
0	0.80 a	0.66 a	1.24 a	1.02 a	0.40 a	0.45 a	0.52 a	0.62 a
-10	0.58 b	0.57 a	0.66 b	0.62 b	0.26 b	0.33 b	0.42 ab	0.40 b
-22	0.49 bc	0.34 b	0.52 bc	0.47 bc	0.21 bc	0.19 c	0.35 bc	0.28 b
-37	0.41 cd	0.29 bc	0.34 d	0.50 bc	0.18 bcd	0.15 cd	0.26 c	0.29 b
-59	0.33 de	0.24 bcd	0.35 cd	0.43 c	0.19 bcd	0.15 cde	0.22 c	0.35 b
-92	0.24 efg	0.19 cde	—	—	0.12 de	0.06 f	—	—
-120	0.31 def	0.16 de	—	—	0.14 cde	0.09 def	—	—
-160	0.22 fg	0.13 e	—	—	0.12 de	0.04 f	—	—
-220	0.19 g	0.16 de	—	—	0.09 e	0.07 ef	—	—
				Shoot weight per seedling (mg)				
0	2.55 a	2.18 a	3.34 a	2.22 a	1.35 a	1.32 a	1.23 a	1.30 a
-10	2.02 b	1.88 b	1.86 b	1.67 b	1.12 b	1.18 a	0.86 ab	1.01 a
-22	1.62 c	1.30 c	1.50 bc	1.19 b	0.90 c	0.85 b	0.79 b	1.28 a
-37	1.33 d	1.17 cd	1.08 c	1.24 b	0.73 d	0.70 c	0.71 b	1.01 a
-59	1.17 de	1.00 de	1.21 c	1.47 b	0.75 d	0.70 c	1.07 ab	1.40 a
-92	0.90 ef	0.83 e	—	—	0.57 ef	0.52 d	—	—
-120	0.98 ef	0.82 e	—	—	0.65 de	0.57 c	—	—
-160	0.82 f	0.75 ef	—	—	0.51 ef	0.41 d	—	—
-220	0.76 f	0.52 f	—	—	0.47 f	0.41 d	—	—

[1]Each value is the mean of eight replications. Differences caused by species, treatments, and species × treatment interactions were significant in all cases in both the growth chamber and the greenhouse tests. Means within each column followed by a similar letter are not significantly different (P=0.05).
[2]Because of the very low percentage survival of legumes in the last 4 treatments, root depth, and root and shoot weights per seedling were not calculated in these treatments.

legumes was too low to consider their root and shoot weights as representative of the species. Faster emergence and more vigorous growth resulted in more gain in biomass in alfalfa and crested wheatgrass during the 10-day growth performance test than in the other 2 species examined. Dehydration treatments caused a delay in emergence, and probably reduced the growth rate. This may be the explanation for lower gain or more loss of biomass in seedlings that were temporarily dehydrated during early germination stages than in the control seedlings.

Grass species developed 1 or 2 seminal lateral roots per seedling when the roots were excised or the dehydration treatments damaged or killed their seminal primary roots. Legume species developed replacement tap roots whenever their root apices were damaged, killed, or excised. Replacement tap roots in legume species were either formed as branches or as a continuation of the original tap root, with a distinct reduction in diameter. Alfalfa and cicer milkvetch had similar patterns of root development, although cicer

Table 2. Effects of root excision and temporary dehydration treatments (MPa) during seed germination on subsequent emergence, and root and shoot growth of 4 species in pots at the end of a 20-day growth performance test in the greenhouse with seedlings limited to the initial soil water supply.

Treatment		Species			
Excision[1]	Dehydration	*Agropyron desertorum*	*Elymus junceus*	*Medicago sativa*	*Astragalus cicer*
		Percent emergence (%)			
–	0	84 a[2]	90 a	93 a	86 a
+	0	85 a	88 a	90 a	70 a
+	–22	84 a	82 a	53 b	18 b
+	–92	64 ab	69 ab	20 c	8 b
+	–160	50 b	34 b	14 c	0 b
		Root weight (mg)			
–	0	3.6 a[2]	3.0 a	3.3 a	2.3 a
+	0	2.6 ab	2.0 b	2.0 b	1.4 ab
+	–22	2.3 bc	1.5 bc	1.2 bc	0.6 bc
+	–92	1.5 cd	1.1 bc	1.1 bc	0.8 bc
+	–160	1.0 d	0.7 c	0.9 c	0.0 c
		Shoot weight (mg)			
–	0	10.7 a	7.6 a	11.2 a	6.7 a
+	0	8.9 ab	6.2 ab	7.6 b	4.1 b
+	–22	7.7 b	4.9 bc	4.8 c	2.1 bc
+	–92	5.4 c	3.8 c	4.6 c	2.3 bc
+	–160	4.0 c	3.3 c	3.2 c	0.0 c
		Root length (mm)			
–	0	18 a	17 a	16 a	14 a
+	0	17 ab	16 a	14 ab	12 ab
+	–22	16 ab	14 a	12 abc	7 c
+	–92	13 bc	13 a	10 bc	9 bc
+	–160	11 c	9 b	9 c	0 d
		Shoot length (mm)			
–	0	22 a	18 a	11 a	7 a
+	0	21 a	18 a	9 ab	6 ab
+	–22	20 ab	16 ab	7 bc	4 b
+	–92	18 bc	15 b	7 bc	4 b
+	–160	16 c	13 b	6 c	0 c

[1]In the excision treatments (+), the entire seminal primary root in grasses and 2 mm of the root tip of legumes were removed from germinating seeds before transferring to the pots.
[2]Each vaue is the mean of 4 replications. Means within each column followed by a similar letter are not significantly different (P=0.05).

milkvetch roots generally formed more branches than did alfalfa roots.

Excision-Dehydration Experiment

Differences in various characteristics of seedling growth caused by species, treatments, and species × treatment interactions were all significant (P=0.01) except that the species did not respond differently to treatments in relation to shoot length. Emergence percentages of crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch, after an excision and temporary dehydration treatment at –16 MPa were 50, 34, 14, and 0, respectively (Table 2). Emergence of crested wheatgrass and Russian wildrye decreased linearly with a decrease in water potential in dehydration treatments. In alfalfa and cicer milkvetch, the decrease in emergence seemed to be curvilinear, indicating high tolerance to dehydration in a few seedlings.

The survival advantages of seminal lateral roots in crested wheatgrass and Russian wildrye, as well as replacement tap roots in alfalfa and cicer milkvetch, were confirmed in the dehydration-excision experiment, where seedlings were limited to the initial soil water supply (about –0.03 MPa) in the pots. The roots which developed after excision and dehydration treatment at –160 MPa were shorter and probably less effective than the seminal primary roots of grasses and original tap roots of legumes. The results of excision-dehydration experiment indicate that the effects of dehydration were more important than the effects of excision in impairment of root growth and development. Root lengths and root weights of all 4 species were affected more by the combination of excision and dehydration treatments than by only the excision treatment.

Shoot and root length of all 4 species as well as shoot and root dry weight of the grasses decreased linearly with decreasing water potentials in temporary dehydration treatments (Table 2). Shoot and root dry weight of the legume species, however, appeared to have decreased in a curvilinear manner with decreasing water potentials in temporary dehydration treatments.

The excision treatment simulated the theoretical situation in which the only effect of dehydration might be the killing of the entire seminal primary root in grasses and the root apex in legumes. The excision treatment alone did not cause significant reductions in shoot or root lengths of either grasses or legumes, nor did it reduce root or shoot weights of grasses, but caused moderate reduction in root and shoot weights of legumes. The combination of excision and dehydration treatment, however, caused moderate to severe reductions in growth parameters of grasses and legumes. This combination at –160 MPa, decreased root lengths of crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch by 39, 42, 44, 100%, respectively (Table 2). One could rank the 4 species investigated for most to least drought tolerant during germination stages as follows: crested wheatgrass, Russian wildrye, alfalfa, and cicer milkvetch.

Frequency distribution for rooting depths of the 4 species indicated great within-species variation among seedlings as affected by each dehydration treatment. Even in the more severe dehydration treatments, there were a number of seedlings in each species that had adequate rates of root elongation. In semiarid zones, such plants should be able to extend their roots into moist layers of the soil profile ahead of the drying soil front. Frequency distributions can be used to determine which dehydration treatments are suitable for screening in a selection program for a given species under given environmental conditions.

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Water and nitrogen effects on growth and allocation patterns of creosotebush in the northern Chihuahuan Desert

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Abstract

A field experiment using 2 patterns of irrigation and 1 level of nitrogen fertilizer (10 g-N m^{-2}) was conducted in order to discern water and nitrogen interactions that may control production of creosotebush, (*Larrea tridentata* (D.C.) Cov. The 2 patterns of irrigation simulated precipitation from small, frequent events (6 mm water added weekly) or large, infrequent events (25 mm water added monthly). Understanding the factors controlling the production of this rangeland shrub may aid in the development of strategies for its management.

Vegetative growth occurred mostly during March–May (spring) and August–October (summer–fall). Fruit production occurred mainly in the spring and root growth occurred mainly in the summer–fall. Irrigation increased vegetative growth and decreased fruit production. Responses to irrigation were greater during summer–fall than in the spring. Small, frequent water additions caused larger increases in vegetative plus fruit growth than did large, infrequent water additions. Nitrogen fertilization increased the growth of both vegetation and fruit in irrigated and unirrigated plots. Stem mortality and root growth were not significantly affected by irrigation or nitrogen fertilizer. These results suggest that creosotebush production is limited by both soil moisture and nitrogen availability and that temporal patterns of rainfall may be as important as total amounts.

Key Words: *Larrea tridentata*, apical stem growth, reproductive allocation, stem mortality, root growth, simulated rainfall, nitrogen fertilizer

The increasing dominance of creosotebush (*Larrea tridentata* [D.C.] Cov.) in desert rangelands of the southwestern U.S. is well documented (Buffington and Herbel 1965, York and Dick-Peddie 1969). The invasion of creosotebush into grasslands is accompanied by increased erosion and reduced production of perennial grasses, and efforts to restore grass production have met with little success (Cox et al. 1984). An improved understanding of the factors limiting the production of creosotebush may aid in the development of management strategies for desert rangelands.

Plant production in deserts is thought to be largely limited by water, with most growth occurring in pulses associated with infrequent and highly variable precipitation (Noy-Meir 1973). However, a direct relationship between precipitation and plant production is frequently not observed (Charley 1972, Webb et al. 1978, Ludwig and Flavill 1979). Charley (1972) and Ludwig and Flavill (1979) reported reduced productivity in the second of 2 consecutive wet years. Charley (1972) attributed this to depletion of available nutrients, particularly nitrogen (N). Other explanations for varying responses to precipitation are that the effects of moisture inputs may be modified by the timing, duration, and intensity of precipitation events, or that total plant production responses may be masked by changes in biomass allocation patterns.

Besides water, N is generally considered to be the factor most limiting to desert plant growth (Charley 1972, West and Skujins 1978). Floret et al. (1982) suggested that N is an important limiting factor in the northern portion of the Sahara and Penning de Vries and Djiteye (1982) found that primary production varied with N availability over a wide range of precipitation in the sub-Saharan Sahel. Charley (1972), Ettershank et al. (1978), and James and Jurinak (1978) reported significant responses of arid vegetation to N fertilizer without additional water.

The seasonal timing and pattern of moisture availability has been shown by the field experiments of Cunningham et al. (1979) to be an important factor influencing creosotebush growth. Ludwig and Flavill (1979) examined above-ground production of creosotebush in the northern Chihuahuan Desert over a 5-year period and suggested that small, frequent precipitation events were more effective than large, infrequent events delivering the same amount of moisture. This seems anomalous for a deep-rooted shrub, particularly since water from small events may be mostly lost through evaporation. However, if small, frequent events stimulate N mineralization thereby enhancing N availability, increased production could result (Fisher et al. 1987).

Despite the large body of data on factors affecting productivity of desert vegetation, we are aware of no studies assessing the interactions of these factors. Therefore, we designed a factorial study to examine the effects of small and large rain events and available soil N on growth and biomass allocation of creosotebush (*Larrea tridentata* [D.C.] Cov.). We hypothesized that small, frequent events would result in higher productivity than large, infrequent events. Further, based on forest studies (Waring and Schlesinger 1985), we hypothesized that increasing available N by fertilization would increase productivity of irrigated plants more than unirrigated plants. We also hypothesized that below-ground biomass allocation would decrease with irrigation and fertilization.

Reproduction may account for 50% or more of total above-ground production of creosotebush. Previous studies suggested that reproductive allocation was inversely related to moisture availability (Oechel et al. 1972, Cunningham et al. 1979). It is therefore necessary to measure reproductive allocation in order to understand the responses of creosotebush to various moisture and N additions.

Materials and Methods

Study Site

The study was conducted on the Jornada Long-Term Ecological Research (LTER) site located 40 km NNE of Las Cruces, New Mexico, at the New Mexico State University College Ranch. The LTER site, located on a northeast facing piedmont slope, traverses 7 vegetation types along a topographic gradient ranging from a rocky mountain side to an ephemeral lake bed. The creosotebush-dominated vegetation in which the study was conducted is located approximately mid-slope (3% gradient) in loamy sand soils with a calcium carbonate deposition layer (caliche) at a depth of about 40 cm. The soil is classified as a Typic Haplargid of the Dona Ana series. Additional soil characteristics are reported by Fisher et al. (1987). Annual precipitation averages 213 mm, 55% falling during July–September as convectional thundershowers. Average daily

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maximum temperature in June, the hottest month, is 36° C, and the average daily minimum temperature in January, the coldest month, is -3.3° C.

Experimental Procedures

Three irrigation treatments (control, 6.3 mm water added weekly, 25.4 mm water added monthly) were assigned in a completely random design to 9 experimental plots (5 × 10 m). Plots were fenced to prevent herbivory by rabbits and were irrigated from June, 1981, until March, 1985, except after precipitation events >25 mm. Fertilizer (NH_4NO_3) was applied (10 g-N m^{-2}) to the down-slope half of each plot (to prevent run-off of added N onto the unfertilized half) on 23 February 1983 and 19 June 1984. All plots were lightly watered to move the granular fertilizer into the soil.

Plots were irrigated with water from a stock tank located at the headquarters of the New Mexico State University College Ranch. Average total N content of the water from occasional analyses was 0.21 mg l^{-1}, which is within the range of natural precipitation. Sodium concentrations were negligible. Concentrations of calcium (Ca^{++}), magnesium (Mg^{++}), and sulfate SO4--) were somewhat higher than typical precipitation. Water was pumped from a tank trailer through sprinkler fittings raised to a height of 1.5 m. The irrigation spray descended upon the creosotebush shrubs from above, producing throughfall and stemflow patterns similar to those of an actual precipitation event. The irrigation volume was calibrated by placing containers inside of each of the study plots.

Ten apical stems were randomly selected on each of 5 shrubs per plot, tagged with yarn, and marked at 40 mm from the tip with enamel paint. Beginning April, 1983, the length of all marked stems and the numbers of buds, flowers, and fruits were recorded at approximately 3-week intervals until November, 1983. All marked stems were harvested on January 1984 and oven dried at 50° C for determination of dry mass.

In February, 1984, new apical stems were selected and tagged using the same procedures as before. Stem length was measured monthly from March, 1984, until March, 1985. Counts of buds, flowers, and fruits were made every 2 weeks until November, 1984, and monthly thereafter. In this series of measurements, we attempted to distinguish stems suffering natural mortality from those dying or disappearing from disturbance during research activities. Dying stems were recognizable by the loss of leaves and lack of growth occurring over several measurement intervals. Mature fruits were collected from tagged shrubs on each plot to estimate the dry mass of individual fruits in November, 1984.

Root growth was examined in root tubes comprised of a fiberglass mesh cylindrical bag supported by a slotted PVC plastic pipe 60-cm long, 6-cm internal diameter. Three 2.5 × 50-cm slots were cut in each tube. Soil for the root tubes was obtained adjacent to the study site from a depth of 0-60 cm, mixed, and sieved through a 2-mm mesh to remove larger roots. The mesh bags were filled with sieved soil and placed in the slotted pipes. Fifteen root tubes were installed at the edges of creosotebush canopies to a depth of 60 cm in 6 of the 18 plots (15 tubes in each of the treatment combinations) in March 1984. Five tubes per plot were removed and replaced with fresh tubes in June, 1984, and August, 1984, and all 15 tubes were removed in October, 1984. Larger roots were removed manually. Fine roots and other light materials were collected by floating on $CHCl_3$. Non-root light material was removed by hand from the floated fraction prior to ashing at 400° C for 24 h. Estimated root biomass <2 mm diameter initially present in the tubes was subtracted from the root biomass found in the retrieved tubes.

Calculations and Statistical Analyses

Initial statistical analyses were performed on the mean of stem lengths or of counts of fruits, buds, and flowers for each shrub. For the first year's data, missing or dead stems were excluded from calculations. For the second year, shrub means were calculated in the same way but stem mortality was calculated as lost stem length.

The stem length measurements were converted to stem + foliage (vegetative) mass estimates using regression equations. Significant differences between the biomass regression lines for different treatments were indicated by Analysis of Covariance (Freund and Littell 1981).

Fruit mass per apical stem was calculated as the number of fruits per branch times the mean fruit mass estimated from fruit harvests. Seasonal mass increments of fruits and vegetation were then calculated by dividing the year at July 1 to reflect the 2 periods of creosotebush growth in the Chihuahuan Desert (Cunningham et al. 1979). Total mass increment of the apical stems was calculated by adding the vegetative mass estimates from the regressions to the fruit mass estimates. Finally, reproductive allocation was calculated as the fruit mass increment divided by the sum of vegetative + fruit mass increments.

Initial analysis of variance (ANOVA) indicated that the error term associated with the irrigation treatments was similar in magnitude to that of the N fertilizer treatments (P>0.25), so the error terms were combined for subsequent analyses (G.M. Southward, personal communication). Stem lengths and fruit counts from each sampling date were analyzed separately to reduce problems with heterogenous variances. Orthogonal contrasts and Tukey's HSD test were used to indicate significant differences (P<0.05) between treatments (Steel and Torrie 1980).

A second stage of the analysis was conducted in order to simplify the interpretation of the water/N interactions. Since the error associated with the water and nitrogen plots had been pooled, it was possible to reanalyze the stem increment data and the reproductive allocation data using a one-way ANOVA. Significance tests used (Tukey's HSD, Dunnett's t) were appropriate for *a*

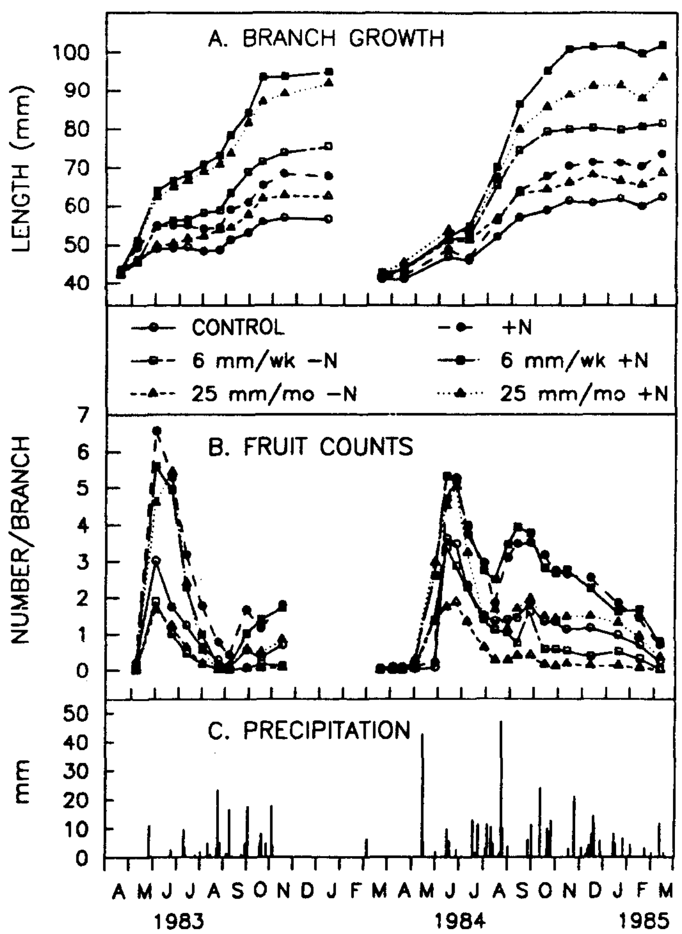

Fig. 1. *Effects of nitrogen fertilization and 2 patterns of irrigation on the length and number of fruits on tagged creosotebush branches. Values are means of 3 plots. Precipitation recorded at the study site is also shown.*

posteriori comparisons (Steel and Torrie 1980). Significant differences ($P<0.05$) between treatments were indicated by Tukey's HSD test and significant differences of all water and nitrogen treatments vs. the unwatered unirrigated controls were indicated by Dunnett's test.

Residuals from all analyses were plotted against predicted values and tested for normality using the Kolmogorov D statistic. Log transformations were used to homogenize the variance of fruit counts and the mass increment data.

Results

Stem growth occurred mostly during March–May (spring) and August–October (late summer–fall) with the latter period being more important (Fig. 1). Fruit production occurred mainly in the spring. Stem growth increased in response to both irrigation and N fertilizer ($P<0.05$). Numbers of fruits per branch were increased by N fertilizer ($P<0.05$), but were decreased by irrigation ($P<0.05$). Stem mortality did not differ between treatments during 1984 and amounted to 42% of the mean stem length of the unirrigated, unfertilized controls.

The relationship between the length and vegetative mass of the tagged stems was described by 2 equations, 1 for unfertilized plots and 1 for fertilized:

$$\text{Unfertilized vegetative mass(g)} = 2.30 \times 10^{-5} \times \text{length (mm)}^{2.32}$$
$$\text{Fertilized vegetative mass(g)} = 2.68 \times 10^{-5} \times \text{length(mm)}^{2.32}$$

The pooled R^2 from the analysis of covariance of the 2 equations was 0.76.

Total mass increment (vegetative + fruit) per branch during spring, 1983, increased in response to N fertilizer in irrigated and unirrigated plots (Fig. 2). Irrigated plots without N fertilizer were not significantly different from controls. Total mass increment per branch in spring, 1984, showed a similar pattern across treatments except that the N fertilized plots without water were not significantly different from the controls. In the fall of 1983, total mass increment per branch was increased by all water and nitrogen treatments except for 25 mm mo^{-1} water without N. A similar pattern of total mass increment responses occurred in the fall of 1984. The principal difference between the responses of total mass increment of fall, 1983, and fall, 1984, was that the responses were higher in 1984.

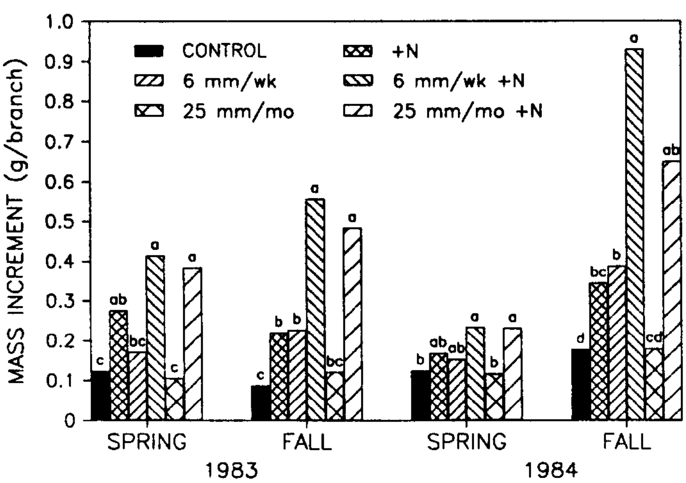

Fig. 2. *Effects of nitrogen fertilization and 2 patterns of irrigation on seasonal mass increments of vegetation + fruit of tagged creosotebush branches. The spring and fall seasons correspond to before and after 1 July, respectively. Values are means of 3 plots. Significant differences (Tukey's HSD,* $P<0.05$*) within a year and season are indicated by different letters.*

Reproductive allocation was consistently higher in spring than in fall across all treatments in both years (Fig. 3). In the spring of 1983, irrigation without N fertilizer reduced reproductive allocation relative to the controls. N fertilizer tended to return reproductive allocation to control levels in the water + N treatments. A similar pattern of reproductive allocation across treatments occurred in the spring of 1984 except that irrigation with 6 mm wk^{-1} without N fertilizer did not significantly reduce reproductive allocation below the level of the controls. In the fall of both 1983 and 1984, reproductive allocation was reduced below the controls in all irrigation treatments, even those with added N. As with total mass increment, the major difference between years for reproductive allocation was in overall response level with similar patterns occurring across treatments in both years.

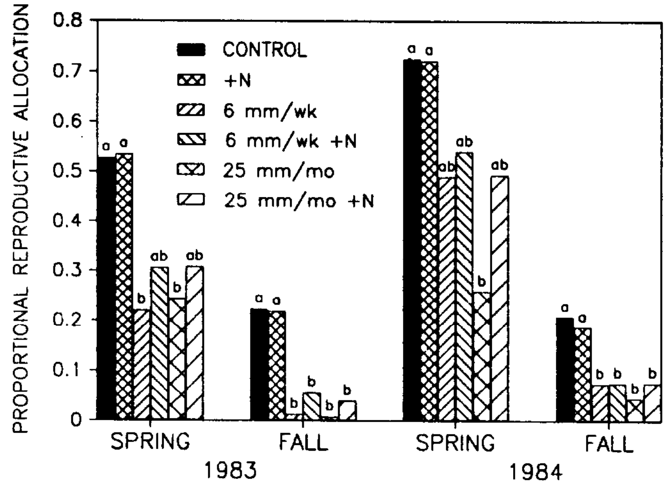

Fig. 3. *Effects of nitrogen fertilization and 2 patterns of irrigation on seasonal reproductive allocation (fruit mass increment divided by the sum of vegetative + fruit mass increments). The spring and fall seasons correspond to before and after 1 July, respectively. Values are means of 3 plots. Significant differences (Tukey's HSD,* $P<0.05$*) within a year and season are indicated by different letters.*

The similarity of response patterns in the 2 years led us to combine the years for further analysis. In this analysis, we used Dunnett's *t* statistic to test for significant differences between each treatment mean and the control mean (Steel and Torrie 1980). Total mass increment in the spring was greater in all N fertilizer treatments than for the controls (Fig. 4). Irrigation without additional N had no effect on spring total mass increment. A similar pattern of responses occurred in the fall except that total mass increment was increased by irrigation with 6 mm wk^{-1} without N fertilizer. Reproductive allocation in the spring decreased in response to irrigation without N (Fig. 4). N fertilizer maintained reproductive allocation at levels not significantly different from the controls. Fall reproductive allocation was also decreased by irrigation but N fertilization did not overcome the depressing effect of irrigation as it did in the spring.

Data from the root tubes indicated that a modest amount of root

Table 1. Growth of creosotebush roots into root tubes (60 cm depth). Values are means across all treatments corrected for residual root biomass initially present in the tubes. Effects of nitrogen fertilizer and irrigation were not statistically significant ($P<0.05$). Letters indicate significant differences between time intervals ($P<0.05$).

Time interval	Root biomass ($g\ m^{-2}$)	Root growth ($g\ m^{-2}\ d^{-1}$)
23 Mar. 1984 to 19 June 1984	122 a	1.4 a
21 June 1984 to 25 Sep. 1984	625 b	6.5 b
30 Aug. 1984 to 10 Oct. 1984	475 b	14.4 c

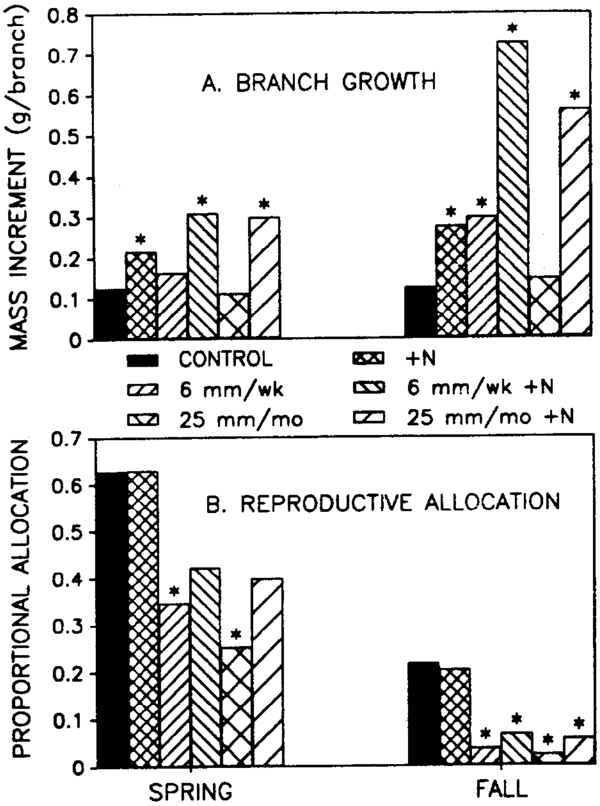

Fig. 4. *Effects of nitrogen fertilization and 2 patterns of irrigation for 1983 and 1984 combined. Reproductve allocation is calculated as fruit mass increment divided by the sum of vegetative + fruit mass increments. The spring and fall seasons correspond to before and after July 1, respectively. Values are means of 3 plots. Significant differences from the control (Dunnett's* t, P<0.05) *within a season are indicated by '*'.*

growth occurred during the entire period of above-ground vegetative growth in 1984. However, as with above-ground vegetative growth, most root growth occurred during the July through September period (Table 1). There were no statistically significant differences in root production among the treatments ($P<0.05$).

Discussion

As has been observed previously in creosotebush in the Chihuahuan Desert (Cunningham et al. 1979), flowering and fruit production occurred primarily in the spring and early summer and vegetative growth primarily in late summer and autumn. This pattern persisted despite 4 years of continuous irrigation and 2 years of N fertilization. Thus the phenological patterns of creosotebush appear to be controlled by photoperiod and/or temperature, not by water and nutrients.

In contrast to studies in other ecosystems (Waring and Schlesinger 1985), we found no evidence that water or N added individually or in combination affected the production of roots. Since additions of both water and N increased above-ground production, it can be concluded that both additions reduced the relative allocation of biomass to roots.

Relative allocation to reproductive effort was not affected by N additions alone. In contrast, water additions alone reduced reproductive allocation, confirming the results of Cunningham et al. (1979) and Oechel et al. (1972). Added N, although ineffective without added water, appears to compensate to some extent for the water-induced reduction in reproductive allocation.

Nitrogen availability limited creosotebush growth in the absence of added water, confirming a previous study in the Chihuahuan Desert (Ettershank et al. 1978). However, the response of creosotebush in our study to 10 g-N m^{-2} was much larger: adding N without water increased total above-ground mass increment by 97% vs. 24% in the previous study. The previous study was conducted in a transition zone from shrubland grassland with a significant cover of fluff grass, *Erioneuron pulchellum*. The response of fluff grass to added N, an increase of 100% over the controls, was similar to that of creosotebush in our study. Evidently, the shallow-rooted grass successfully competed with creosotebush for the surface-applied N.

Also confirmed was the hypothesis based on the observations of Ludwig and Flavill (1979) that small, frequent events were more effective than large, infrequent events. In fact, the large, infrequent water additions had virtually no effect on creosotebush growth in the absence of N fertilizer. Given the responses of creosotebush to added N reported in this study, and the responses of soil N to irrigation previously reported (Fisher et al. 1987), the simplest explanation is that the small, frequent water additions enhance N availability compared to large, infrequent water additions. Fisher et al. (1987) proposed that small, frequent events increase N mineralization by concentrating water in the surface soil layers containing most of the readily available organic N. Frequent wetting and drying episodes occurring in the surface soil appear to promote rapid turnover of soil organic N. Large, infrequent water additions, on contrast, allow more of the water to penetrate to deeper soil layers containing less available organic N.

Creosotebush growth appears to be limited by both water and N in an interactive or synergistic manner: the combined water and N additions increased creosotebush growth more than the sum of the responses to the 2 resources alone. This implies that both resources are limiting (Chapin et al. 1987). Added N did not appear to affect the relative responses to the 2 patterns of irrigation. This is consistent with our contention that N availability is higher in plots receiving small, frequent water additions.

Our results suggest some of the factors that may contribute to the success of creosotebush in the northern Chihuahuan Desert. First, creosotebush appears to be well adjusted to the relative availability of water and N in the environment since both resources appear to limit growth. Secondly, creosotebush, despite being a deep-rooted perennial plant, is able to respond to the small precipitation events which often occur in the region. Finally, creosotebush is most responsive to increased moisture availability during the seasons of the most reliable precipitation in the northern Chihuahuan Desert, the late summer and early fall.

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Variability within a native stand of blue grama

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Abstract

Considerable variability and patchiness have been observed within sites of native range dominated by blue grama [*Bouteloua gracilis* (H.B.K.) Griffiths] range at the Central Plains Experimental Range, Weld County, Colorado. Patches containing tall plants of blue grama with many seedstalks were interspersed with patches of short plants with few seedstalks. Differences in plant height were not entirely related to soil properties. Relative differences in plant height among plants collected in the field were maintained when these plants were grown in a greenhouse environment. "Dry spots" (usually 2 to 4 m in diameter) that contain dark-colored, wilted plants have also been observed during dry, hot weather. We found several differences in soil properties that could be responsible for the dry spots. All differences in soil properties were within the range for the soil series of the experimental site, an Ascalon fine sandy loam (Aridic Argiustoll). Sixty-two plants of blue grama were collected based on their variability from a single pasture, increased vegetatively in the greenhouse, and transplanted into a spaced-plant nursery. In the third growing season following transplanting, mean values for measurements on replicated clones ranged from 202 to 719 reproductive culms per ramet, 25 to 46 cm height of reproductive culms, 17 to 24 cm basal diameter, 39 to 93 grams dry matter per ramet, and from 11 June to 20 July for first anthesis. Somatic chromosome numbers were determined for 60 plants and 55 were tetraploids (4x = 40), 3 were pentaploids (5x = 50), and 2 were hexaploids (6x = 60). We concluded that the observed variability and patchiness apparently result from a combination of both genetic and edaphic factors.

Key Words: Colorado, *Bouteloua gracilis*, genetic, edaphic, Great Plains, shortgrass prairie

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McGinnies (1984) measured the effects of thinning blue grama [*Bouteloua gracilis* (H.B.K.) Griffiths] on forage production at the Central Plains Experimental Range (CPER) and observed considerable plot-to-plot variation and patchiness for which there was no ready explanation. Where patchiness was observed (Fig. 1) some patches had relatively tall seedstalks while on other patches seedstalks were much shorter or largely absent. There were also patches with a high proportion of bare ground. The various patches ranged from 2 to 10 m in diameter. The patchiness was intensified because these pastures were grazed only during the winter so that all of the current year's growth was present. If the pastures had been grazed during the growing season, the patchiness would have been less obvious.

On other occasions, numerous dry spots (1 to 4 m in diameter) were observed where the blue grama appeared wilted, brown and lifeless. However, the wilted appearance of the plants on these spots disappeared following a substantial rainstorm and reappeared when the soil again dried.

The present sequence of studies reported here was designed to determine the nature and causes of the observed variablity and to evaluate whether this variability resulted from genetic or edaphic causes.

Experimental Area

The studies were conducted at the Central Plains Experimental Range, Weld County, Colorado. Elevation is 1,630 m and average annual precipitation is 310 mm. Native vegetation is dominated by blue grama, but sun sedge (*Carex heliophila* Mack.), sand dropseed [*Sprorbolus cryptandrus* (Torr.) Gray], red threeawn (*Aristida longiseta* Steud.), and bottlebrush squirreltail (*Sitanion hystrix* J.G.Sm.) are also present. Field studies were conducted, and the blue grama genotypes for the spaced-plant nursery were collected on an Ascalon fine sandy loam (Aridic Argiustoll) in NW¼ Sec. 17, T10N, R65W. The spaced-plant nursery was estab-

Fig. 1. *Patchiness in a chemically thinned stand of blue grama at Central Plains Experimental Range, Colorado. Chemical thinning accentuates the patchy appearance.*

lished in SE¼, NE¼, Sec. 18, T10N, R65W where the soil is a Vona sandy loam (Ustollic Haplargid).

Tall and Short Blue Grama

Methods

In an area where patches of blue grama with taller seedstalks were intermingled with patches containing shorter seedstalks, 13 10-cm-diam. cores were taken from the "tall" seedstalk patches and 13 cores from adjacent (usually within 2 m) "short" seedstalk patches in September 1980. The cores were then placed in 15-cm diam. pots and the pots were filled with additional soil from the site. The plants were then grown in the greenhouse under a 15-hour day and 24° C temperatures regimen. Seedstalk heights were measured 14 Feb., 20 April, 11 June, and 7 Oct. 1981. Plants were clipped to a 5-cm stubble after each height measurement. A complete liquid fertilizer was added 5 Mar. and 20 Mar. Treatment means were evaluated by analysis of variance.

Results

The plants from the tall class in the field were consistently, but not always significantly, taller than plants from the short class when grown in the greenhouse (Table 1). Plants in the tall patches in the field grew in soil that was slightly less sandy and contained slightly more total N. In the greenhouse, all plants received sufficient fertilizer to overcome any differences in soil fertility that might have caused differences in height in the field. Consequently, at least part of the difference in height may be due to genetic differences. The relatively smaller difference in height observed on 7 Oct. 1981, in the greenhouse probably was a result of all plants becoming "pot-bound."

Table 1. Height of seedstalks from 13 cores with "short" and 13 cores with "tall" seedstalks when transplanted into a greenhouse in September 1980, and soil characteristics of the cores.

	"Short"	"Tall"	Significance
Maximum seedstalk height (cm)[1]			
24 February 1981	53.5	61.1	0.10
20 April 1981	56.0	63.8	0.05
11 June 1981	40.5	49.9	0.01
7 October 1981	55.7	56.5	N.S.
Soil characteristics[2]			
Sand (%)	80.4	75.7	
Silt (%)	11.8	14.7	
Clay (%)	7.8	9.6	
Total N (μg/g)	1305	1436	

[1]Plants cut to 5 cm stubble after each height measurement.
[2]Soil characteristics at location of core collection. In greenhouse, a uniform soil was added to fill the pots.

The difference in height between the tall and the short plants appeared to be relatively greater in the field than in the greenhouse. The patchiness in the field gives the appearance of soil variability, but the greenhouse tests showed that there apparently was also a genetic component to the variability.

First Dry Spot Study

Methods

In July, 1981, frequent round or oval "dry" spots 1 to 4 m in

Table 2. Soil characteristics of first dry spot study, 1983.

	"Dry" depth (cm)			"Wet" depth (cm)		
	0.0–7.5	7.5–15.0	15.0–22.5	0.0–7.5	7.5–15.0	15.0–22.5
Sand (%)	80	77	70	77	72	66
Silt (%)	11	11	14	13	12	13
Clay (%)	9	12	16	10	16	21
Total N ($\mu g/g$)	970	860	1050	1090	1030	1190
$NaHCO_3$ ($\mu g/g$)	19	9	6	16	9	7
Organic matter (%)	0.93	0.80	0.95	1.10	0.94	0.98
Soil moisture (%)						
July 26	8.3	8.8	8.2	11.1	11.5	9.0
28	4.7	6.3	6.5	6.5	8.7	8.6
Aug. 3	2.8	3.6	5.9	3.0	4.8	6.7
8	5.9	6.3	6.7	8.3	9.6	9.9
12	3.6	6.4	8.3	4.4	8.7	9.9
16	3.3	7.0	8.9	4.3	7.5	8.9
23	2.3	5.0	6.6	3.6	5.7	8.1
29	4.2	4.8	6.7	5.0	6.2	7.8
Sep. 2	3.3	4.4	6.5	3.1	5.0	7.1
Mean	4.3	5.8	7.1	5.5	7.5	8.4

diam. were observed in the pastures. Within the dry spots, the blue grama appeared wilted or brown, but again turned green after a rainstorm. The dry spots were separated by green areas of blue grama 1 to 5 m wide (referred to as "wet" areas in this paper). On 14 July 1981, 5 dry spots and adjacent wet areas were sampled. The wet areas contained less sand, but more clay, N, and soil water than the dry spots. From these preliminary data, it was hypothesized that the cause of the dry spots was an edaphic factor, and the dry spots were staked for future study. In 1983, soil water was measured gravimetrically on 10 days between 16 July and 2 Sept. at depths of 0.0 to 7.5, 7.5 to 15.0, and 15.0 to 22.5 cm. Soil samples from these depths were also analyzed for texture, total Kjeldahl N, $NaHCO_3$ P, and organic carbon.

Results

Soil from the dry spots contained slightly more sand and slightly less clay, N, and organic carbon in the surface 15 cm than did soil from the wet spots (Table 2). Soil moisture was consistently higher in the wet spots than in the dry spots during the period from 26 July to 2 Sept. There was no difference in the rate of drying during the summer in the surface 7.5 cm, but in the 7.5 to 15-cm zone the rate of drying was slower in the wet than in the dry areas. The differences in soil moisture between the wet and dry spots were presumed to be, at least in part, caused by higher amounts of clay and organic carbon in the wet spots. Although soil differences existed, it was not possible to determine if these differences alone could explain the presence of the dry spots. No difference in micro-relief between wet and dry spots could be discerned.

Second Dry Spot Study

Methods

Eleven pairs of wet and dry plots (30.5 by 30.5 cm) were selected and sampled in Aug. 1985. Aerial plant cover by species, litter, and bare ground were measured in these plots with a point frame (100 points). Total standing herbage was determined by clipping to ground level and drying.

A 10-cm diam. hydraulically driven probe was used to obtain soil cores in all plots. Horizons were described and soil was saved for subsequent laboratory analyses. Particle size (hydrometer method), total Kjeldahl nitrogen (N), total $NaHCO_3$ phosphorus (Pt), inorganic $NaHCO_3$ phosphorus (Pi), organic phosphorus (Po) by difference (Pt-Pi), and organic carbon (OC) were determined for each horizon. Very fine, fine, medium, coarse and very

Table 3. Second dry spot study. Soil characteristics, plant cover, species composition, and herbage production on wet and dry spots, 1985.

	Dry	Wet	P value
A horizon, N ($\mu g/g$)	1020	1310	0.022
A horizon, organic P_o ($\mu g/g$)	7.6	10.4	0.030
A horizon, organic OC (%)	0.6	0.9	0.030
Top 10 cm, N ($\mu g/g$)	930	1180	0.005
Top 10 cm, organic P_o ($\mu g/g$)	6.0	8.3	0.001
Top 10 cm, organic OC (%)	0.6	0.8	0.009
Top 10 cm, sand (%)	74.8	69.8	0.003
Top 10 cm, silt (%)	13.4	17.4	0.006
20-cm depth, clay (%)	20.6	25.3	0.055
Total cover (%)	65.1	77.1	<0.001
Cover, blue grama (%)	61.8	54.3	0.270
Cover, sedge (%)	2.2	10.1	0.025
Cover, buffalograss (%)	0.3	6.8	0.255
Bare soil (%)	15.0	2.1	<0.001
Dry weight (g/plot)	6.4	10.3	<0.001

Table 4. Number and height of seedstalks, basal diameter, weight per plant, and date of first anthesis for 60 clones of blue grama in a spaced-plant nursery at CPER.[1]

	1984				1985			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Number of reproductive culms	54	287	134	46	202	719	404	99
Maximum seedstalk height (cm)	26	48	37	4	25	46	36	4
Basal diameter (cm)	8	17	13	2	17	24	20	2
Plant weight (g)	9	54	21	7	39	93	57	10
Date of first anthesis	29 June	27 July	10 July	5	11 June	20 July	24 June	9

[1]Based on averages for all ramets of each clone alive at date of measurement.

coarse sand was determined by sieving for the first 2 horizons of the profile, typically the A and BA. Comparison of wet and dry areas was made on the basis of chemical and particle size data as well as thickness of the A horizon, depth to the top of the Bt horizon, depth to lime, solum depth, depth to lithologic discontinuity, and thickness of the Bt horizon. Laboratory analyses for the top 10 cm of soil, independent of horizons, were also compared, as was percent clay at 20 cm depth. Differences between wet and dry areas were evaluated by analysis of variance.

Results

Values for N, Po, and OC were all greater in the wet spots than in the dry spots (Table 3), and these higher values could explain the greater total cover and dry weight in the wet spots than in the dry spots. The wet spots also had less sand and more silt in the top 10 cm and more clay at 20 cm than did the dry spots; these differences would tend to increase the water-holding capacity of the wet spots. Most of the roots were concentrated in the top 20 to 30 cm of soil. The higher percentage of bare ground in the dry spots would increase the rate of evaporation and the higher sand content near the surface would result in lower soil water-holding capacity. Both of these conditions could contribute to the formation of the dry spots. There were no obvious problems within the solum, such as a hardpan or a gravel layer, that might account for the dry spots.

Species composition, based on cover, in the wet spots was 70% blue grama and 13% sun sedge. Species composition in the dry spots was 95% blue grama and only 3% sun sedge. The significantly higher amount of sun sedge in the wet spots was expected because most sedges tend to favor moist sites. The difference in species composition between wet and dry spots is probably more a reflection of the difference in available soil water than a cause of it.

Spaced Plant Nursery

Methods

A high degree of variability was observed among blue grama plants growing in a 7-ha pasture that had never been plowed at CPER. This variability did not appear to result from microsite differences. To evaluate the variabilty among plants, 62 plants were selected from this site. Plants were selected on 10 September 1981, based on phenotypic variability for such characters as seedstalk height, number of seedstalks, leaf length, leaf color, bunchiness, or general plant appearance. Selected plants were removed as 10-cm diam. soil-plant cores and immediately watered. Because there appeared to be an intermingling of genotypes within a core, each core was washed to remove the soil, and a single tillering sequence was selected to insure that only 1 genotype was being tested. The tillering sequence was then divided and planted in 10-cm pots and grown in the greenhouse. These ramets were subsequently divided vegetatively to produce enough ramets for 12 replications. The ramets were transplanted from the greenhouse into a spaced-plant nursery in a field at CPER on 28 July 1982. Ramets were planted in a grid with 76 cm between ramets using a randomized complete block design with 12 replicates. The ramets were allowed to grow undisturbed through 1983. In 1984 and 1985 data were collected on each ramet for number of seedstalks, height of seedstalks, basal diameter, date of first anthesis, and dry matter yield. Soil samples obtained at the time the original clones were collected were analyzed for total Kjeldahl N, $NaHCO_3$ P, organic C, and texture. Somatic chromosome numbers of 60 of the clones were obtained from mitotic root-tip cells from ramets grown in the greenhouse.

Results

Considerable variation was observed among the 60 surviving clones in the spaced-plant nursery. The range in means among the replicated clones for number of reproductive culms, maximum seedstalk height, basal diameter, dry matter yield and date of first anthesis is shown in Table 4. In 1984, jackrabbits grazed some individual ramets differentially early in the season, and this utilization probably had some effect on the measured characteristics. A rabbit-proof fence was constructed in July 1984 and eliminated this problem. Because essentially no interplant competition was present in this spaced-plant nursery, these results may not necessarily reflect results obtained in a solid sward on rangeland where there would be intensive competition among plants. For example, it is not uncommon in rangeland to see patches of blue grama 1 to 2 m in diameter where no seedheads are present. In the spaced-plant nursery all clones had seedheads, yet some of the clones came from patches without seedheads on rangeland.

Growth forms differed widely among the clones, but it is difficult to quantify these differences. Variation included tall, tightly bunched plants with few basal leaves, spreading plants with short seedstalks and many basal leaves, and all combinations between. No apparent relationship existed between growth form or size of plant and any of the measured soil factors (texture, level of N and P) associated with the soil at the spot where the clone was collected.

Somatic chromosome number was determined for the 60 surviving clones. Fifty-five were tetrapoids ($4x = 40$), 3 were pentaploids ($5x = 50$), and 2 were hexaploids ($6x = 60$). Fults (1942) reported that the basic chromosome number (x) for blue grama was 7, but our results show that the basic number was 10, which agrees with the results reported by Snyder and Harlan (1953). Pentaploids of blue grama have not been previously reported. In the spaced-plant nursery, the pentaploids and hexaploids did not differ in appearance or size from the tetraploids. A more detailed report on the cytogenetics of blue grama will be published elsewhere.

Conclusions

In many years of observation at CPER, few seedlings of blue grama have been observed, and even fewer are known to have become established (CPER personnel, unpublished). Even in drought-thinned stands, blue grama roots form a dense mat near the soil surface, and competition likely prevents seedlings from becoming established. Consequently, most of the clones collected in the field from which the plants for the nursery were taken likely had been growing there for a very long time. That such a wide variety of blue grama plants would be found in 1 pasture may seem unusual, but Harper (1977) points out that such variability within a stand dominated by a single species is expected. He states that, "The diversity of a plant community is inadequately described by the number and abundance of species within it. A major part of community diversity exists at the intraspecific level....It has indeed been suggested that where the number of species is low (loose species packing) the intraspecific diversity may be higher—a form of compensation." We believe that the blue grama pasture that we sampled was really a mosaic of microenvironments and soil properties significant to plant growth. We should expect, then, that there would be a mosaic of genotypes and polymorphs occupying these diverse ecological niches.

Once we became aware of patchiness, we were able to find it in most stands of blue grama. The patchiness is most easily observed in pastures that have been chemically thinned, and is more obvious in pastures that have not been grazed during the growing season. The dry spots have been observed in a number of locations and were most easily seen late in the summer during dry periods. Patchiness and dry spots appear to be mutually exclusive, and both frequently occur in the same field.

The patchiness observed in our study is attributable to both genetic and edaphic characteristics. Wet spots generally had a more favorable nutrient balance and a slightly higher water holding capacity than the dry spots, but these differences were subtle. Although we believe that the dry spots are caused primarily by edaphic factors, the exact factors involved have not been determined. Further information is needed to explain both the patchiness and dry spot phenomena. We hope that this paper will help to stimulate such research.

There is apparently much more genetic variability within a stand of blue grama than was previously supposed. Differences among the geographic sources of blue grama have been reported (Griffiths 1912, Riegel 1940, Snyder and Harlan 1953), but little information is available concerning the variation within a single stand (Samuel 1985).

Variability within a single stand of blue grama is of particular importance to persons doing research on this species. One must consider the effects of patchiness and dry spots on the sample size needed to characterize a stand. Stratification may be one way to approach this problem. When dealing with individual plants, an adequate number must be collected across the mosaic of microenvironments found at a particular range site so that a representative sample of the genetic variability present is acquired. The high level of genetic variability (polymorphs) should benefit the plant breeder interested in developing improved cultivars of blue grama for the Central Great Plains.

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Use of UV absorption for identifying subspecies of *Artemisia tridentata*

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Abstract

Use of UV absorption spectra for identifying subspecies of *Artemisia tridentata* Nutt. was investigated by analyzing the relative optical densities of alcohol extracts from herbarium and fresh plant material at 240 nm, 250 nm, and 265 nm. In all but 1 comparison, mean relative optical densities were significantly different (p=0.95) between subspecies, but intraplant and intrasubspecies variation and overlap was found to be too large to permit use of UV absorbance alone for identifying individual specimens. These results held whether dry or fresh leaves were extracted, or whether methanol or ethanol was used as the extracting solvent.

Key Words: big sagebrush, phenotypic expression, chemotaxonomy

Recognition of major evolutionary trends (formally established as taxonomic subspecies) within *Artemisia tridentata* Nutt. has led to a better understanding of the ecology of big sagebrush (Gifford et al. 1979, Winward 1980, Tisdale and Hironaka 1981, Hironaka et al. 1983), but subspecific identification based on morphological features is not always easy (Winward and Tisdale 1977, Tisdale and Hironaka 1981, Hironaka et al. 1983). Several workers have reported, however, that UV fluorescence or absorption characteristics of tissues or extracts may be valuable in identifying subspecies of *A. tridentata* (Tisdale and Hironaka 1981, Shumar et al. 1982, Hironaka et al. 1983). Subjective evaluations of UV properties is a major limitation in their use, but Shumar et al. (1982) recently published some quantified spectral descriptions of alcohol leaf extracts. Their results indicated that spectra between 220 nm and 270 nm are consistent and unique for each subspecies and might be used as the sole criterion for identification. Their results were the same for fresh or dried material, although their main findings were based upon extracts from fresh leaves.

Following this report, we attempted to use similar methods for identifying various specimens of big sagebrush, but in preliminary trials, we were not consistently able to obtain distinctive subspecific spectra. Subsequent investigations suggest that UV spectra may not always be suitable as the sole criterion for specimen identification. In these investigations we evaluated intraplant variation as well as interplant differences within subspecies. In contrast to Shumar et al.'s use of ethanol (EtOH) and fresh leaves, we primarily used methanol (MeOH) as an extracting solvent and dry material from herbarium specimens, but additional studies indicate that these differences in techniques do not account for the differences in the results.

Materials and Methods

Subspecific identifications were made using the morphological criteria presented in Winward (1980). Specimens from the University of Idaho Herbarium (ID) were used as the source of dried leaves (Table 1); 23 specimens of *Artemisia tridentata* Nutt. subsp. *tridentata*, 31 of *A.t.* subsp. *vaseyana* (Rydb.) Beetle, and 8 of *A.t.* subsp. *wyomingensis* Beetle & Young. Twelve duplicates of the above taxa plus 2 specimens of uncertain identity were used for investigating intraplant variation and for comparing the 2 methods of extraction (MeOH vs. EtOH). In the first case, 3 subsamples from each species were used, while in comparing solvents, material from 2 leaves was divided between the 2 solvent systems for each paired sample. In all cases a single leaf was found to provide sufficient material.

Limited studies were also done with fresh material of subsp. *tridentata* for intraplant and intrataxon comparisons. In this case, 6 single-leaf subsamples were obtained and extracted from 5 individuals from each of 2 populations near Lewiston, Idaho (Table 1).

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Table 1. Source of leaf material. All dried material from University of Idaho Herbarium (ID). Specimens are listed by location, collector and number. Numbers appearing in () are ID accession numbers in lieu of a collector's number.

Dried Material

A. tridentata subsp. *tridentata*

USA. **California:** Riverside Co., Hendrickson 4257. **Idaho:** Ada Co., Keithly 19; Bingham Co., Lyman s.n.(8028); Cassia Co., Biggers s.n.(8826), Wellner 3007; Gooding Co., Wellner 2911; Idaho Co., Johnson 77227; Lewis Co., Sattler 13; Oneida Co., Richardson 47; Owyhee Co., Henderson 5571, Tisdale s.n.(65312); Valley Co., Henderson 5239. **Montana:** Carbon Co., Booth 54574; Park Co., Suksdorf 993.

Nevada: Elko Co., Kinnaman s.n.(30846). **Oregon:** Deschutes Co., Steward 6849; Malheur Co., Tisdale s.n.(69162). **Wyoming:** Natrona Co., Dueholm 8500.

CANADA. **British Columbia:** Anonymous (63051).

A. tridentata subsp. *vaseyana*

USA. **Colorado:** Routt Co., Christ 1420. **Idaho:** Adams Co., Bingham 245, Wellner 1678, 2066; Bear Lake Co., Wellner 2407; Butte Co., Zink s.n.(34392); Caribou Co., Wellner 3329; Clark Co., Moseley 463, Wellner 2365, 2385; Custer Co., Henderson s.n.(74140), Wellner 1563, 1956; Franklin Co., Wellner 3336; Fremont Co., Rust 728; Idaho Co., Bingham 169; Lemhi Co., Baker 14666, Henderson 5038; Valley Co., Wellner 1447, 1890A, 2688; Teton Co., Brunsfeld 2341. **Montana:** Big Horn Co., Booth 55781; Gallatin Co., Booth s.n.(38945); Madison Co., Ellison 58Q; Powell Co., Booth 55677. **Nevada:** Humboldt Co., Rosentreter 3491. **Oregon:** Klamath Co., Coombs 157; Wallowa Co., Mohan 28. **Wyoming:** Teton Co., Lowrie s.n.(24865).

A. tridentata subsp. *wyomingensis*

USA. **Idaho:** Bingham Co., Baker 9985; Butte Co., Andersen 89, Stafford s.n.(84503); Cassia Co., Baker 8784; Lemhi Co., Wellner 2000; Twin Falls Co., Wellner 2900.

A. tridentata (subspecies uncertain)

USA. **Idaho:** Franklin Co., Wellner 3350. **New Mexico:** Hardesty 22.

Fresh Material

A. tridentata subsp. *tridentata*

USA. **Idaho: Nez Perce Co., top of Lewiston Grade along hwy US 95, ca. .5 km N of Lewiston, elev. ca. 820 m; bottom of Lewiston Grade, N edge of Lewiston along hwy US 95, elev. ca. 230 m.**

Whether herbarium or fresh tissue was used, no obviously damaged or discolored leaves were included.

Extraction were made by first crushing the tissues in the bottoms of centrifuge tubes. Five millilitres of solvent (80% v/v aqueous MeOH, except in the comparison of solvents where 70% v/v aqueous EtOH was also used) were then added, and the contents were shaken vigorously for about 15 s. After this material was centrifuged at top speed in a clinical type centrifuge for 5 min., the supernatent was decanted and stored at 4° C until spectral measurements were made. Preliminary studies showed that such storage for several days altered readings by less than 1%.

Optical densities (OD) in all cases were measured against a blank containing the respective solvent in a (doublebeam) Beckman Spectronic 2000. Optical density was measured at 220 nm, 250 nm, and 265 nm in each case. As in Shumar et al. (1982), relative OD was obtained for 250 nm and 265 nm by dividing the respective OD readings at these wavelengths by the OD at 220 nm for that sample. The spectral slope between 250 nm and 265 nm, where Shumar's group found the most significant differences in their spectra, were evaluated by dividing 15 nm into the differences between the 250 nm and 265 nm relative OD values.

Means and standard deviations were computed for the individual specimens that were subsampled. Means from the subsampled herbarium material were then combined with single sample specimen's values for given subspecies to compute the means, standard deviations, and 95% confidence intervals for that subspecies. All differences were tested for significance using a standard *t*-test for unpaired data. The correlation between MeOH and EtOH extractions was assessed using linear regression. A *T*-test (Guenther 1965) was then used to ascertain if the regression slopes were significantly different from 1.00.

Subsequent to the preceding, we became aware that 250 nm might not be an appropriate wavelength for separating subspp. *vaseyana* and *wyomingensis* based upon Shumar et al. (1982). Therefore 5 leaf samples each from 4 herbarium specimens of subspp. *vaseyana* and *tridentata,* and 3 of subsp. *wyomingensis* were extracted with McOH. Optical density was then measured at 220 nm and 240 nm, and analyzed as before.

Results

Spectra obtained in these studies were similar to those of Shumar et al. (1982) with the highest OD's at 220 nm and the lowest at 265 nm. Values at 250 nm were intermediate but closer to those for 265 nm than to 220 nm.

When intraplant samples were compared, considerable variation was observed. The average plant relative OD at 250 nm was 0.817 for the 12 herbarium specimens and the mean standard deviation (SD) was ± 0.081, while the relative OD mean and SD at 265 nm was 0.685 and ± 0.078. Thus the mean SD was 10% or more of sample plant means. The relative OD values at 250 nm differed by 0.001 to 0.321 in individual specimens, and by 0.003 to 0.299 at 265 nm. Similar intraplant variation was found with all three taxa. Fresh material of subsp. *tridentata* exhibited as much variation with a mean of 0.777 and 0.701 for 250 nm and 265 nm, respectively, and mean SD's of ±0.073 and ±0.092.

Intrataxon values were also found to vary widely (Fig. 1), but SD values were generally less in comparison to intraplant SD. There was considerable overlap in values among the subspecies, but mean relative OD values proved to be significantly different ($p = 0.95$) in all cases except for subspp. *tridentata* and *vaseyana* at 250 nm and all 3 subspp. at 240 nm (Table 2). Mean spectral slopes

Table 2. Comparisons of relative OD at 240 nm of extracts from 3 subspp. of *A. tridentata.*

subspp.	mean	range	± SD	±95% C.I.
tridentata	0.589	0.520-0.627	0.047	0.086
vaseyana	0.588	0.520-0.714	0.087	0.160
wyomingensis	0.610	0.523-0.664	0.231	0.231

between 250 nm and 265 nm were significantly different between all subspecies. As a whole, fresh tissue extracts of subsp. *tridentata* were not significantly different from herbarium tissue extracts (Fig. 2), but the mean relative ODs for the population at the top of the Snake River Canyon were significantly different ($p = 0.95$) from that of the population at the bottom.

Correlation between the MeOH and EtOH extractions of similar tissues were poor to moderate (Table 3), but this may reflect intraplant variation. More importantly, intraspecific variation was as large among the EtOH extracts as it was among the MeOH extracts, e.g., EtOH extracts from 4 subsp. *tridentata* specimens yielded a mean relative OD of 0.691 and a SD of ± 0.192 compared to the mean of 0.543 and a SD of ± 0.126 for MeOH extracts. In

Table 3. Linear regression equations of MeOH extracts on EtOH extract spectra values of 10 herbarium specimens.

Relative OD at 250 nm: MeOH = 0.39 EtOH + 0.29	($r^2 = 0.33$)
Relative OD at 265 nm: MeOH = 0.40 EtOH + 0.19	($r^2 = 0.66$)
Relative spectral slope from 250 nm to 265 nm: MeOH = 0.93 EtOH + 0.001	($r^2 = 0.0631$)

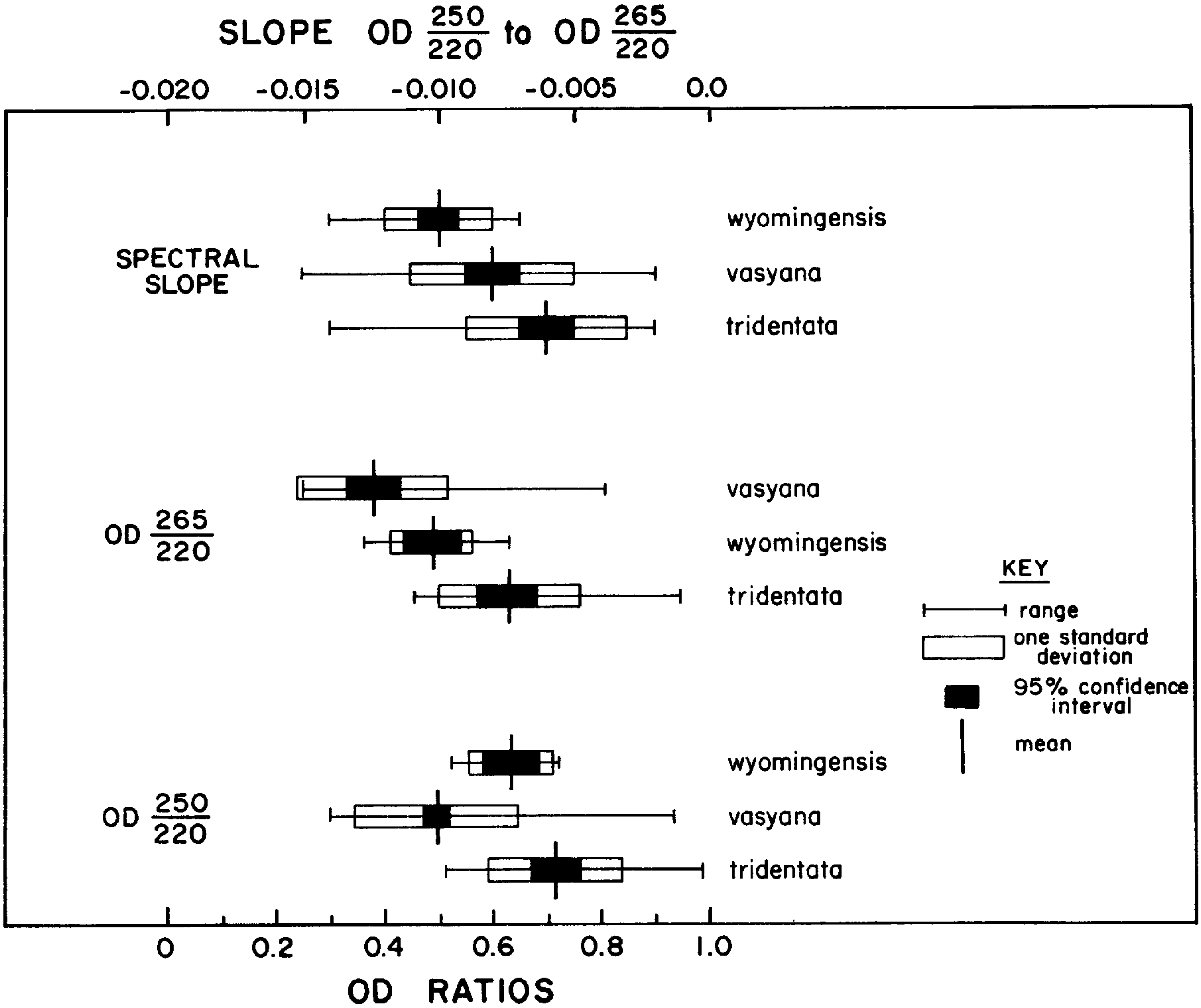

Fig. 1. *Comparisons of combined relative optical density measurements among the 3 subspecies of* Artemisia tridentata. *(N = 23, 31, and 8 for subsp.* tridentata, vaseyana *and* wyomingensis, *respectively.*

both cases SD was about 20% of the mean values. In general, EtOH had higher relative ODs than MeOH extracts (i.e., less difference between ODs at 220 nm and those at 250 nm and 265 nm), but the regression slopes of EtOH vs. MeOH OD's did not prove to be significantly different from 1.00 ($p = 0.95$).

Discussion and Conclusions

The results above indicate that, similar to many taxonomic features, UV absorbance is probably too variable to be used alone for positive subspecific identification of individual specimens in *Artemisia tridentata.* The variation may be due to phenotypic expression in the extracted materials (terpenes) in response to current local conditions. Thus the wide geographic and seasonal diversity represented in herbarium specimens could also represent a wide variety of growing conditions and phenotypic responses. Phenotypic variability could also explain the differences found between 2 Snake River Canyon populations, which, at any one time, usually experience rather different habitat conditions.

On the other hand, there were definite trends in values as seen in the significantly different subspecific means. Consequently, UV absorbance could be a valuable taxonomic tool when used in conjunction with other features for comparing populations in adjacent habitats, or perhaps for identifying and separating whole populations. In individual cases, however, it may be best to use a combination of morphological features coupled with UV spectra for reliable identification, as suggested by Goodrich et al. (1985) and Winward (pers. comm.). It may also be possible to obtain more definitive UV absorption spectra by refining and separating the extracts before examining the spectra. Certainly more work in this area seems warranted.

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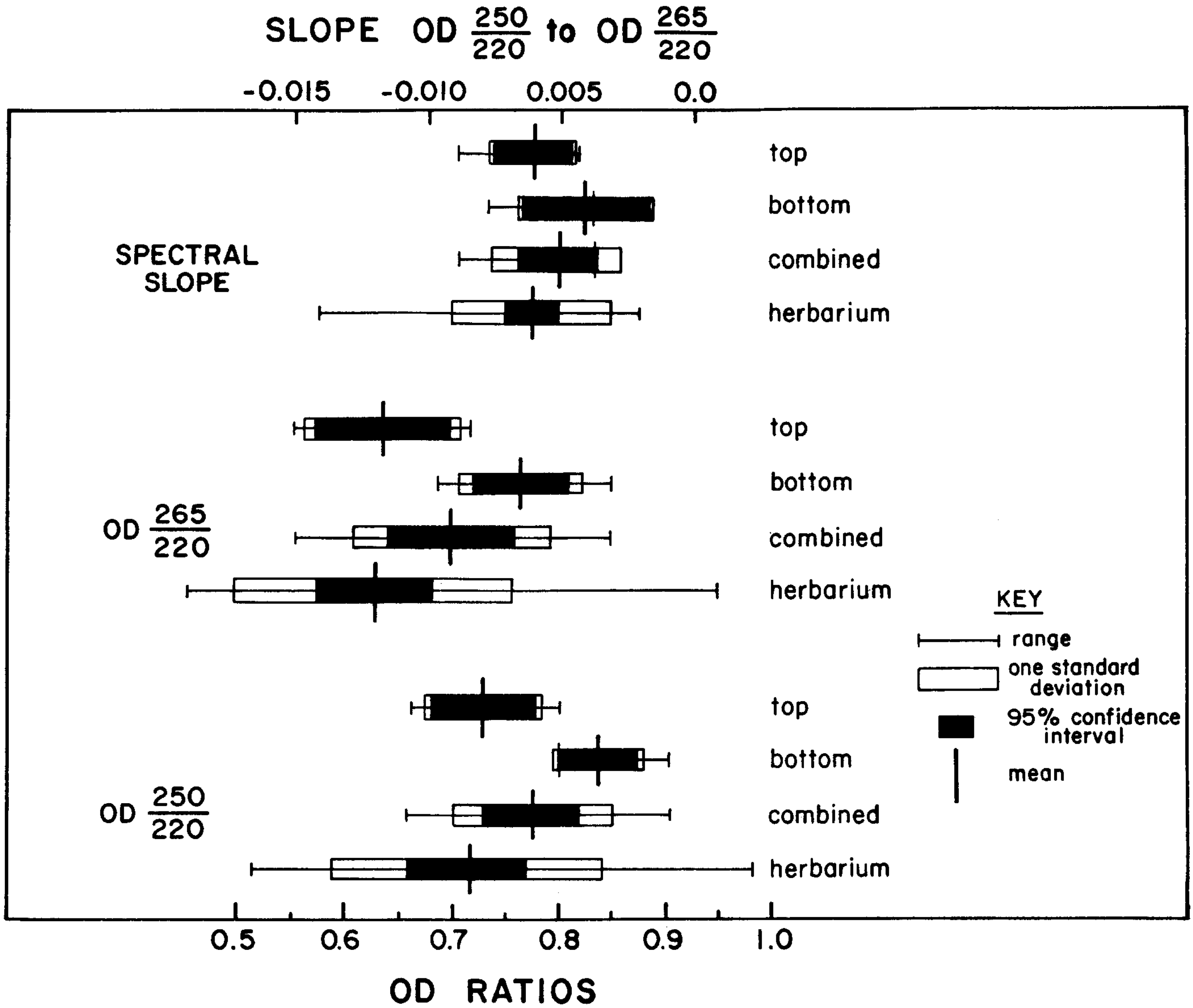

Fig. 2. *Comparisons of relative optical density measurements from fresh tissues and (dry) herbarium material of* A. tridentata *subsp.* tridentata. *Fresh material represents 2 populations (N = 5 each), one each at the top and bottom of the Snake River canyon near Lewiston, Id. Results are presented for the populations individually and combined for comparison with herbarium samples (N = 23).*

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Toxicological investigations on Ruby Valley pointvetch

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Abstract

Ruby Valley pointvetch (*Oxytropis riparia* Litv.), a native of the central Soviet Union, was inadvertently introduced into the United States during the early part of the 20th century. Ruby Valley pointvetch has long been established in southwestern Montana, is spreading into Wyoming and Idaho, and is being investigated for its potential as a forage plant. The plant was analyzed for aliphatic nitro compounds, soluble oxalates, nitrates, cyanide, and swainsonine. Swainsonine is found in 2 native *Oxytropis* species and causes the loco syndrome and congestive heart failure. The plant was tested for toxicity to 1-week-old chicks.

Ruby Valley milkvetch tested negative for aliphatic nitro compounds, soluble oxalates, cyanide, and swainsonine. Nitrates were present at nontoxic levels. Leaves, stems, seeds, and pods were nontoxic when fed to chicks for 5 days at 1% of body weight as dried plant. Extracts of these plant parts fed in one dose at 10% of body weight (as dried plant) were likewise nontoxic.

Key Words: introduced plant, legume, chemical analysis, swainsonine, forage

Ruby Valley pointvetch (*Oxytropis riparia* Litv.) is native to the central Soviet Union east of the Caspian Sea and south and southeast of the Aral Sea (Komarov 1948). Ruby Valley pointvetch is a perennial, subglabrous plant with nearly prostrate branches 70 to 100 cm long. The corolla of the bluish-purple flowers is 6 to 7-mm long and the standard is about 4.5 mm wide. Pods are 10 to 12-mm long, 5-mm wide, and hang on 2-mm stipes. The plant flowers from June to August.

Ruby Valley pointvetch was inadvertently introduced into North America and it is the only introduced species of *Oxytropis* found in the United States. The plant was earlier known as Ruby Valley milkvetch (*Astragalus rubyi* Green and Morris) (Green and Morris 1935) and thought to be an indigenous species until the taxonomy was clarified and its Russian origin noted by Barneby (1964). The plant is adapted to river valleys, moist meadows, waterways, and other areas where ample water is available. Ruby Valley pointvetch was well established in the Ruby (hence its common name) and Jefferson River Valleys of southwestern Montana by the early 1930's. The plant is now found along the Green River northwest of Green River, Wyo., and along the Snake River on the Fort Hall Indian Reservation north of Pocatello, Idaho. Ruby Valley pointvetch is prolific and is considered excellent pasture forage in southwestern Montana. No livestock losses have been reported from the plant. The forage is reported similar to alfalfa for protein, N-free extract, crude fiber, ether extract, and ash content, and 50 to 70% higher in P content than alfalfa when grown on P-deficient soils (Green and Morris 1935). The effects of temperature, water stress, and scarification on seed germination and establishment have been studied (Delaney et al. 1986, Hicks et al. 1987, Townsend and McGinnies 1972).

Two species of *Oxytropis* native to the western United States, Lambert crazyweed (*O. lambertii* Pursh) and silky crazyweed (*O. sericea* Nutt. ex T. & G.), have long been known to cause the loco syndrome in livestock (Ralphs et al. 1986). The toxic compound responsible for locoism is swainsonine, a potent inhibitor of α-mannosidase. Swainsonine was first isolated from the genus *Swainsona* in Australia (Colegate et al. 1979), then later from *Astragalus lentiginosus* Dougl. ex Hook. in the United States (Molyneux and James 1982). Swainsonine has been identified in both Lambert and silky crazyweeds (Molyneux et al. 1985). Swainsone has also been isolated from several other species of *Astragalus* in North America, 6 species of *Swainsona* in Australia, and from the fungus *Rhizoctonia leguminicola* (Schneider et al. 1983).

Silky crazyweed has also been shown to cause congestive heart failure in cattle that graze the plant at high elevations (James et al. 1985). This plant also causes abortions and death. Consumption of plants that contain at least 0.02 to 0.03% swainsonine (dry weight) and above may cause toxicosis in livestock.

Because Ruby Valley pointvetch is spreading in the western United States and is being examined for its potential as a crop plant, its examination for toxic compounds, particularly swainsonine, is important to insure that it will not endanger livestock. The presence of toxic levels of swainsonine would make the plant objectionable and necessitate efforts to control it and prevent its spread.

In this study, Ruby Valley pointvetch was analyzed for several toxic compounds and fed as dried plant and extract to chicks as an assay for poisonous properties.

Materials and Methods

Ruby Valley pointvetch was collected from a hay meadow 4 miles north and 4 miles west of the headquarters at the Fort Hall Indian Reservation north of Pocatello, Idaho. Collections were made 9 July 1987, when the plant was in bloom, and 12 August 1987, when the plants had both green and black (mature) pods. The plant was separated into leaves, stems, and flowers, green pods with seeds, empty black pods, and seeds. Plants were analyzed for presence of cyanide (Anonymous 1980), nitro compounds (Williams and Norris (1969), and soluble oxalates (Dye 1956). Nitrate analyses were performed at the Utah State University Soil Testing Laboratory.

Analysis for swainsonine was carried out by extraction of the ground plant material (0.5 g) with methanol. The extract was evaporated to dryness, the residue dissolved in 1N HC1, filtered and applied to short (4 cm $\times$ 0.5 cm) Dowex 50W-X8[1], 20–50 mesh ion-exchange column (NH_4 form). The column was washed with an equal volume of distilled water and the retained basic compounds eluted with 0.5% aqueous ammonium hydroxide. The eluate was evaporated to dryness, redissolved in distilled water and made up to 10 ml in a volumetric flask.

A 100 μl portion of the solution was transferred to a reaction vial and evaporated to dryness at 50° C under a stream of argon. The residue was dissolved in dry pyridine (100 μl) and treated with BSTFA [N,0-bis(Trimethylsilyl)trifluoroacetamide] (100 μl) at room temperature for 30 min to form the TMS derivative. Gas chromatography was carried out on a 0.32 mm $\times$ 30 m SE-30 capillary column with on-column injection. The column was temperature programmed from 120° C to 300° C at 5 C/min. An authentic sample of swainsonine, treated under the same condi-

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[1]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by U.S. Department of Agriculture and does not imply approval to the exclusion of other products that may also be suitable.

tions, eluted from the column at 14.37 min. None of the plant samples showed a peak at this elution time.

One-week-old Leghorn cockerels (50 g ± 3 g) were fed ground leaves, stems, seeds, and pods of Ruby Valley pointvetch at 1% body weight daily for 5 days. Four chicks were used per plant part. The chicks were deprived of food and water each preceding night, then given the material in No. 4 gelatin capsules the next morning of each day. They were then given chick mash and water free choice and observed for toxic signs from the first feeding through 8 days. Thirty grams each of leaves, stems, pods, and seeds were ground and extracted with ethanol for 24 hr on a Soxhlet extractor. The extract was evaporated to dryness, redissolved in water, and evaporated to 30 ml so that each ml was equivalent to 1 g of plant. Two chicks each were given a dose of extract with a syringe and polyethylene catheter. The dose was equivalent to feeding whole plant material at amounts equivalent to 10% of body weight. The chicks were then given chick mash and water free choice and observed 3 days for toxic signs. Weights of treated and control chicks were recorded daily during the tests.

Results and Discussion

No toxic signs were observed in chicks fed leaves, stems, pods, or seeds of Ruby Valley pointvetch for 5 days at amounts equivalent to 1% of body weight. The aqueous extract administered at 10% of body weight likewise produced no toxic signs. Treated chicks gained weight during the tests at the same rate as the controls.

The plant tested negative for cyanide, soluble oxalates, and nitro compounds. Nitrates were detected at 0.05%, expressed as KNO_3. Sublethal poisoning has been observed in livestock that ingested feed containing 0.5 to 1.5% nitrate; concentrations above 1.5% are potentially lethal (Kingsbury (1964). Leaves, stems, flowers, seeds, and pods tested negative for swainsonine.

Ruby Valley pointvetch contained none of the toxic compounds commonly associated with livestock poisoning. Of particular significance was the absence of swainsonine, the toxic compound found in 2 native species of *Oxytropis* responsible for the loco syndrome and congestive right-heart failure in livestock. The only objectionable characteristic of the plant seems to be in hay fields where its somewhat woody stems may foul cutter bars during mowing; and because it dries more slowly than grass, it often retains enough moisture to cause molding in baled hay (personnal communication, Delbert Farmer, Pesticide Control Officer, Fort Hall Indian Reservation, Fort Hall, Ida.).

Because Ruby Valley pointvetch is apparently nontoxic, and compares favorably with alfalfa in nutritional value, it has promise as a pasture forage plant. However, care should be taken to prevent its introduction and spread where it might infest crops or meadows where grass is harvested for hay.

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Comparative chemical composition of armed saltbush and fourwing saltbush

ANDRES GARZA, JR., AND TIMOTHY E. FULBRIGHT

Abstract

Armed saltbush [*Atriplex acanthocarpa* (Torr.) Wats.] and fourwing saltbush [*A. canescens* (Pursh) Nutt.] are browsed by livestock and white-tailed deer (*Odocoileus virginianus* Raf.). The objective of this study was to compare the chemical composition of these 2 shrubs growing together in south Texas. Leaves and stems from the outer 5 cm of current year's growth of each species were randomly collected from each of 5 stands in November 1985 and February, May, and August 1986. Samples were analyzed for crude protein (CP), calcium, potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), and in vitro organic matter digestibility (IVOMD). Height and standing crop were also determined. Crude protein of armed saltbush leaves ranged from 32% in February to 19% in August. Fourwing saltbush leaf CP ranged from 24% in February to 12% in August. Armed saltbush leaves and stems generally had greater P concentrations than fourwing saltbush. Calcium, K, and Mg concentrations and leaf IVOMD of the 2 species were similar. Fourwing saltbush had lower Na concentrations and greater leaf standing crop than armed saltbush. Laboratory-determined values suggest that both species may provide nutritious browse for cattle and deer on saline rangeland.

Key Words: *Atriplex acanthocarpa, Atriplex canescens,* browse, crude protein, in vitro digestibility

Saltbushes (*Atriplex* sp.) are found in semiarid environments in the western United States, the Middle East, Australia, Africa, and Siberia (Davis 1981), and many species are valued as forage for domestic and wild herbivores. Two saltbushes native to North America are armed saltbush [*A. acanthocarpa* (Torr.) Wats.] and fourwing saltbush [*A. canescens* (Pursh) Nutt.].

Armed saltbush grows on saline soils from south Texas west to Arizona (Vines 1960, Jones 1982). The half-shrub is palatable to cattle (*Bos.* sp.) and white-tailed deer (*Odocoileus virginianus* Raf.) (Vines 1960, J.H. Everitt, USDA-ARS, Weslaco, Texas, pers. commun.) and has potential for use in revegetation of saline rangeland (T. Gonzalez, SCS, Laredo, Texas, pers. commun.). Fourwing saltbush occurs from Canada south to Mexico and west to southern California (Vines 1960). The shrub is considered valuable browse for cattle, sheep, and deer (Stubbendieck et al. 1982) and is widely used in revegetation.

The chemical composition of fourwing and numerous other saltbushes is well documented (Beadle et al. 1957, Pieper et al. 1959, Chatterton et al. 1971, Cordova and Wallace 1975, Khalil et al. 1986, Petersen et al. 1987). However, the chemical composition of armed saltbush has not been documented. The objective of this study was to compare the chemical composition of armed saltbush with that of fourwing saltbush.

Materials and Methods

The study was conducted on the Hinnant-Fulbright Ranch in northeastern Zapata County, Texas. Study sites were on a rolling hardland range site. Soils are Maverick clay (fine, montmorillonitic, hyperthermic Ustollic Camborthid). Electrical conductivity of these soils exceeds 4 dS m^{-1} in the surface 25 cm and 12 dS m^{-1} in the 25 to 50 cm depth (Fanning et al. 1965). Topography is gently rolling with less than 3% slope. Hot summers and short, mild winters characterize the climate. Mean annual precipitation is about 38 cm, with peaks in May and September (Fulbright 1985). Associated woody vegetation includes honey mesquite (*Prosopis glandulosa* Torr.), creosotebush (*Larrea divaricata* Cav.), blackbrush (*Acacia rigidula* Benth.), guajillo (*Acacia berlandieri* Benth.), guayacan [*Porliera angustifolia* (Engelm.) Gray], leatherstem (*Jatropha dioica* Sesse ex Cerv.), allthorn (*Koeberlinia spinosa* Zucc.), vine ephedra (*Ephedra antisyphlitica* Berl. ex C.A. Meyer), allthorn goatbush [*Castela texana* (T. & G.) Rose], trecul yucca (*Yucca treculeana* Carriere), lotebush [*Condalia obtusifolia* (Hook.) Weberb.], and knifeleaf condalia (*Condalia spathulata* Gray). Associated herbaceous vegetation includes berlandier nettlespurge (*Jatropha cathartica* Teran & Berl.), Texas varilla (*Varillis texana* Gray), threeawns (*Aristida* sp.), and multiflowered false-rhodesgrass [*Chloris pluriflora* (Fourn.) Clayton].

Five stands supporting both saltbush species were sampled. Each stand was a replication (block) in statistical analyses since samples were collected, dried, and chemically analyzed separately for each stand. Samples of the outer 5 cm of current year's growth from at least 4 randomly selected individuals of each species were collected within each stand in November 1985, and February, May, and August 1986. Samples were dried at 40° C to a constant weight, separated into stems and leaves, and ground in a Wiley mill to pass a 1-mm screen. Dry and organic matter contents were determined following AOAC (1980) procedures. Crude protein (CP) (% N × 6.25) was determined by the micro-Kjeldahl procedure (AOAC 1980) and is reported on an organic-matter basis. Mineral analyses were done by the Soil Testing Laboratory, Texas Agricultural Extension Service, Texas A&M University, College Station. Atomic absorption spectrophotometry was used to determine calcium (Ca) and magnesium (Mg) concentrations. Sodium (Na) and potassium (K) levels were determined with flame photometry, and phosphorus (P) content was determined colorimetrically (Parkinson and Allen 1975). All assays were done in duplicate and values are reported on a dry matter basis.

In vitro organic matter digestibility (IVOMD) was determined by the procedure of Tilley and Terry (1963). Rumen inocula were obtained from a Jersey cow fed a high quality roughage diet. Forages with known in vivo digestibilities were included in each digestion batch to standardize results.

Height and standing crop of armed and fourwing saltbush were determined in August 1986. Height of 20 randomly selected, mature plants of each species was measured in each of 4 stands. Plants were then cut at ground level and dried at 55° C to a constant weight, separated into leaves and non-leaf material (stems, branches, trunks) and weighed. Density of armed and fourwing saltbush was estimated in April, 1988 by counting the number of individuals rooted in 6 randomly placed 2.44 by 15.25-m plots in each of 4 stands.

Bimonthly rainfall data from the Hinnant-Fulbright Ranch for 1985 and 1986 were obtained from C.W. Hanselka, Texas A&M University, Corpus Christi, Texas.

Chemical composition and digestibility data were analyzed by

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Table 1. Temporal trends in mean percent crude protein (CP), calcium (Ca), phosphorus (P), sodium (Na), potassium (K), magnesium (Mg), and in vitro organic matter digestibility (IVOMD) of armed and fourwing saltbush leaves and stems, Zapata County, Texas, 1985–1986.

	Sampling date and species							
	November 1985		February 1986		May 1968		August 1986	
Variable and plant part	Armed	Fourwing	Armed	Fourwing	Armed	Fourwing	Armed	Fourwing
CP								
Leaves	20.1a[1]	18.9a	32.4a	23.7b	24.6a	18.5b	18.8a	11.6b
Stems	9.1b	8.4b	20.1b	14.7c	14.3c	10.1d	10.9b	4.6c
Ca								
Leaves	1.8a	1.6a	1.3a	1.8a	1.3ab	1.5a	1.4a	1.3ab
Stems	1.0b	0.7c	1.3a	1.2a	1.4ab	1.1b	1.3ab	1.0b
K								
Leaves	1.6ab	2.3a	2.7a	2.8a	2.6a	2.7a	2.3ab	2.5a
Stems	1.3b	1.4b	2.1a	2.2a	2.6a	2.4a	2.1ab	1.9b
Mg								
Leaves	1.3a	1.0ab	0.9ab	1.1a	0.8a	0.8a	0.8a	0.7a
Stems	0.7b	0.3c	0.6b	0.5b	0.4b	0.4b	0.4b	0.3b
Na								
Leaves	7.7a	2.7b	9.4a	2.6c	9.8a	2.2c	10.5a	2.7c
Stems	3.3b	1.1c	4.4b	1.4d	5.4b	1.3c	5.4b	1.1d
P								
Leaves	0.23a	0.19a	0.29a	0.23ab	0.29a	0.21b	0.23a	0.18b
Stems	0.17a	0.09b	0.28a	0.16b	0.24ab	0.10c	0.20ab	0.07c
IVOMD								
Leaves	68.0a	66.2a	62.6ab	71.0a	66.6a	62.5a	58.2b	61.7a
Stems	34.2b	32.0b	59.1b	45.4c	47.7b	36.9c	41.5c	31.3d

[1]Means for a variable within a sampling date followed by the same letter are not significantly different at the 0.05 level according to Tukey's test. Leaves were compared to stems within a sampling date.

analysis of variance using a randomized complete-block experimental design with stands as blocks and sampling dates as a split in time. The sampling date × species and plant part interaction was significant ($P<0.05$) for all variables except P and K, thus a separate analysis of variance was done for each sampling date to compare species and plant part means. Tukey's test was used to separate means, where appropriate (Snedecor and Cochran 1967). Height and standing crop data were analyzed using *t*-tests. Inferences based on the results of this study are restricted to the study area.

Results and Discussion

Rainfall during August 1985 to August 1986 was 29.2 cm (Fig. 1). Rainfall was above average in June–July 1985 and 1986, but was below average during the remainder of the study.

Crude protein concentration of armed saltbush leaves and stems exceeded that of fourwing saltbush on all sampling dates except November 1985 (Table 1). Crude protein of armed saltbush leaves ranged from 32% in February to 19% in August while that of fourwing saltbush leaves ranged from 24% in February to 12% in August. Crude protein values for fourwing saltbush were similar to those reported for 4 fourwing ecotypes from west Texas (Petersen et al. 1987).

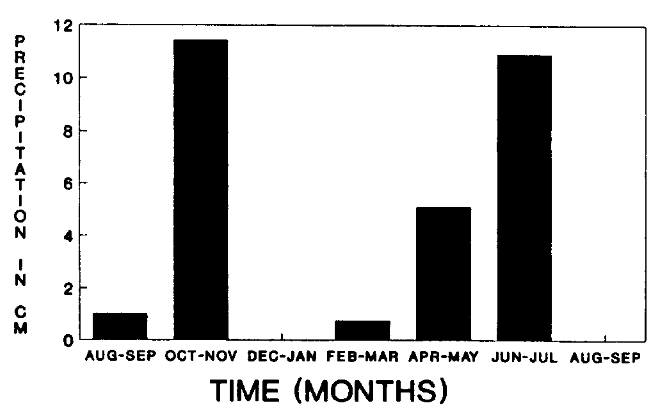

Fig. 1. *Bimonthly precipitation (cm) from August, 1985 through September, 1986 on the Hinnant-Fulbright Ranch, Zapata County, Texas.*

Calcium, K, and Mg levels were similar in armed and fourwing saltbush leaves and stems on all sampling dates except November (Table 1). In November, levels of Ca and Mg were higher in armed than in fourwing saltbush stems.

Sodium levels in armed saltbush leaves ranged from 7.7 to 10.5%, compared to 2.2 to 2.7% for fourwing saltbush leaves (Table 1). Armed saltbush stems were also higher in Na than fourwing saltbush stems on all sampling dates. Other researchers have reported lower Na concentrations in fourwing saltbush in comparison to other *Atriplex* species (Wallace et al. 1973, Smit and Jacobs 1978, Khalil et al. 1986).

Levels of Na in fourwing saltbush were higher than the 0.21% in leaves reported by Khalil et al. (1986), whereas K levels were much lower than the 6.06% they reported. Differences between our results and those of Khalil et al. (1986) possibly resulted because distinct biotypes of fourwing saltbush exist with regard to Na and K accumulation (Richardson 1982). Certain biotypes tend to exclude Na and absorb large amounts of K, while others accumulate Na and absorb less K. Also, differences in soil Na content probably caused results to differ between studies.

Phosphorus levels were similar in armed and fourwing saltbush leaves in November and February and were higher in armed than in fourwing leaves in May and August (Table 1). Armed saltbush

Table 2. Mean height (cm), standing crop/plant (g) of leaves and woody material, and total standing crop/plant (g) of armed and fourwing saltbush in August 1986, Zapata County, Texas.

	Saltbush species	
Characteristic	Armed	Fourwing
Height	65	95**
Leaf standing crop/plant	40	114*
Woody material standing crop/plant	146	920**
Total standing crop/plant	186	1,034**

*,**Significant difference between species at the 0.05 or 0.01 level, respectively.

leaves had P levels ranging from 0.23 to 0.29%, compared to 0.18 to 0.23% for fourwing saltbush leaves. Armed saltbush stems had higher P concentrations than fourwing saltbush stems on all sampling dates.

The IVOMD of fourwing saltbush leaves exceeded that of armed saltbush in August, but digestibility of leaves of the 2 species was similar on other sampling dates (Table 1). Armed saltbush stems were more digestible than fourwing saltbush stems on all sampling dates except November, when digestibility was similar. Lower digestibility of fourwing stems was expected because they are woodier than stems of armed saltbush.

Fourwing saltbush plants were 46% taller than armed saltbush (Table 2). Although leaf standing crop of fourwing saltbush was almost triple that of armed saltbush, the leaf:stem ratio was higher for armed saltbush than for fourwing (1:3.7 and 1:8.1, respectively). Total standing crop/plant of fourwing was 5.6 times higher than armed saltbush. Estimated mean density of armed saltbush was 1,648 ± 921 plants ha^{-1} ($\bar{x} \pm SE$, n = 4) compared to 2,836 ± 1,194 plants ha^{-1} for fourwing saltbush.

These data suggest that fourwing and armed saltbush on saline rangeland may provide nutritious browse for cattle and deer. Research on animal performance while consuming these plants is needed to fully understand their importance to herbivores on saline rangeland in southern Texas. Results of laboratory analyses may be misleading because many shrubs contain secondary plant metabolites that may interfere with protein digestibility (Robbins et al. 1987). Further research is needed to determine if armed saltbush and fourwing saltbush contain secondary plant metabolites.

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Effects of burning on germinability of Lehmann lovegrass

G.B. RUYLE, B.A. ROUNDY, AND J.R. COX

Abstract

Lehmann lovegrass (*Eragostis lehmanniana* Nees) may be viewed as either an undesirable exotic invader or an important ground cover and forage plant on southwestern rangelands, depending on management goals. Successional responses to management practices intended to control or enhance this grass are highly dependent on the processes of natural revegetation. The effect of seasonal burning on germinability of Lehmann lovegrass in the seedbank was investigated on the Santa Rita Experimental Range in southern Arizona. Samples of surface soil were taken for bioassay immediately after burning in February, June, July, and November for 2 years. Nearly 40% more seedlings emerged from bioassay samples taken from burned than unburned plots. The increase in germinability of Lehmann lovegrass seeds associated with fire may be one of several factors important in its observed ability to re-establish after mature plants are killed by burning.

Key Words: seedling emergence, fire, heat-treatment of seeds, *Eragrostis lehmanniana* Nees

Lehmann lovegrass (*Eragrostis lehmanniana* Nees) is a drought-tolerant, warm-season, perennial bunchgrass native to southern Africa. The grass was introduced into Arizona over 50 years ago and has been seeded extensively for erosion control and forage production (Cable 1971). The species is well adapted to southeastern Arizona and has increased in abundance, now covering approximately 200,000 ha (Cox and Ruyle 1986). Land managers have mixed emotions regarding the grass because it is an invader species and not considered palatable to grazing animals, yet it establishes easily on disturbed sites and provides excellent soil cover. Ranchers are faced with incorporating the new grass into grazing management schedules. On the other hand, preserve managers are concerned with Lehmann lovegrass invasion into native grasslands (Bock et al. 1986). In both cases prescribed burning is often recommended as a management tool. Observations suggest that while hot fires can kill Lehmann lovegrass plants (Cable 1965), new stands quickly re-establish from seed (Cable 1965, Cable 1971, Cox and Ruyle 1986), and cooler fires have little effect (Pase 1971, Martin 1983). Additionally, where native perennial grasses are killed by fire, Lehmann lovegrass seedlings quickly establish and persist on the site (Cable 1965, 1971).

Artificially induced heat treatments may increase both the percentage and rate of Lehmann lovegrass germination (Haferkamp and Jordan 1977, Weaver and Jordan 1985). Heat treatments scarify the seedcoat and increase the rate of imbibition of Lehmann lovegrass seeds (Haferkamp et al. 1977). Jordan (1981) suggested that a rapid germination rate would favor Lehmann lovegrass establishment in Arizona, given the erratic nature of summer precipitation and short periods of available soil moisture. Observations are that fire enhances emergence of Lehmann lovegrass seedlings. An important factor in this response may be the enhancement of germination directly by a natural heat treatment from fire. The purpose of this research was to experimentally determine the effects of seasonal burning on germinability of Lehmann lovegrass seed in the seedbank. We also documented field differences in seedling emergence associated with burning and seedling survival when burning resulted in the death of established plants.

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Materials and Methods

The study was conducted on the Santa Rita Experimental Range 60-km south of Tucson, Ariz. The 3-ha study site was on an alluvial fan at 1,200 m elevation and supported a nearly pure stand of Lehmann lovegrass. Annual precipitation averages 398 mm with 60% falling between June and September. The soil is a coarse-loamy, mixed (calcareous) thermic Typic Torrifluvent of the Comoro series. The site was fenced in January 1984 and subdivided into 48, 15 by 15-m plots, each separated by 2-m fire lines.

Treatments were assigned in a randomized block design and included winter (February), early summer (June), mid-summer (July), and fall (November) burned and unburned plots. All treatments were replicated 3 times and were performed on separate plots in 1984 and 1985. Burn treatments were applied as head fires following initial back firing. Temperatures at the soil surface were constantly monitored during the 1985 burns with 5 thermocouples per burned plot.

Within each treated plot, 5 soil samples, approximately 8 by 15 cm in area by 2-cm deep, were collected immediately following the burn. Unburned plots also were sampled on each burn date. Samples were collected in separate plastic bags for immediate transport to the greenhouse for processing and bioassay. The bioassay technique followed was modified from Young et al. (1981). Soil samples were placed in styrofoam cups over 250 ml of 60-mesh sterile sand. The cups had perforated bottoms and were kept moist by sub-irrigation with tap water. Emergent Lehmann lovegrass seedlings were counted daily for 42 days. New seedlings were removed after emergence.

To document differences in seedling emergence associated with burning in the field, seedling density was sampled on unburned plots and plots burned in 1984. Seedlings were counted in fifty 5 by 30-cm quadrats in each plot in August and December 1984 and May 1985. To document the stand renewal ability of Lehmann lovegrass, seedling density on the November 1984 burned plots, where 80% of the mature plants were killed, was tracked from July to November of 1985. Seedlings were counted in 30 permanently marked 0.25-m^2 quadrats in each burned plot. The larger permanently marked quadrats were necessary to assess emergence and mortality over time. To determine if changes in density in these quadrats were associated with recruitment or mortality, all seedlings in 3, 3 by 50-cm transects per burned plot were permanently marked with toothpicks color-coded to the sampling date when first observed. All bioassay and field seedling density data were scaled to number of seedlings per m^2 area. Analysis of variance was used to determine significance of burning treatments in time.

Results and Discussion

Bioassay

There was a significant treatment ($p = 0.06$) and seasonal ($p = 0.01$) response in the numbers of Lehmann lovegrass seedlings that emerged in bioassay samples (Table 1). Season, treatment and year interactions were not significant ($p \geq 0.05$). Overall, bioassay samples from burned plots averaged 342 emerged seedlings / m^2 or 40% more emerged seedlings than samples from unburned plots. Significantly ($p = 0.01$) more seedlings emerged from the samples collected in June before the summer rainy season than from the other

Table 1. Analysis of variance of Lehmann lovegrass emergence (seedlings/m²) in bioassay samples in relation to burning treatment and date of sample collection.

Source of variation	DF	F	P
Treatment (T)	1	3.76	.06
Month (M)	3	20.72	.01
Year (Y)	1	0.59	.41
T × M	3	0.45	.72
T × Y	1	0.01	.92
M × Y	3	1.12	.36
T × M × Y	3	2.17	.11

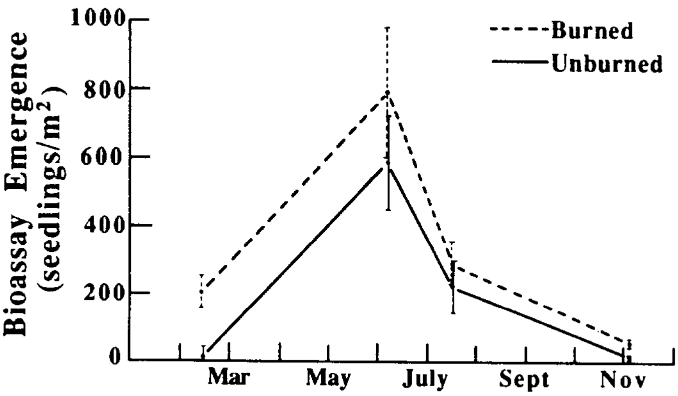

Fig. 1. *Lehmann lovegrass seedling emergence from bioassay samples taken from unburned and burned plots averaged from 1984 and 1985. Vertical lines are twice the standard error of the mean.*

3 collection periods (Fig. 1). Seedling emergence from soil collected in June was more than twice that from any other collection period, averaging 700/m².

Seedling Density

Seedlings were not found in December 1984 or May 1985 but emerged after summer rains and were counted in plots sampled in August 1984 (Table 2). Seedling emergence was much higher on burned than unburned plots and was similar among plots burned in February and June 1984. Contrary to results of Martin (1983), 80% of the mature Lehmann lovegrass plants died after the November 1984 burn. On these plots, numerous seedlings emerged after successive rains in July 1985 (Fig. 2). Observations of individually marked seedlings indicated that there was little recruitment after initial emergence and that subsequent changes in seedling density were due to mortality of emerged seedlings. Maximum seedling density on these November 1984 burned plots was 320 seedlings/m² compared to 0.8 seedlings/m² on the unburned plots on 30 July 1985. Seedling density on the burned plots decreased rapidly in August and September with decreased precipitation but leveled off in October and November. Lehmann lovegrass densities on the November burned plots also increased by rooting of nodes

Table 2. Lehmann lovegrass seedling density (x ± standard error) in August 1984 on seasonal burn and unburned plots.

Treatment	Seedlings/m²
Unburned	20 ± 0.8
February burn	120 ± 4.8
June burn	113 ± 5.2
July burn	80 ± 0.8

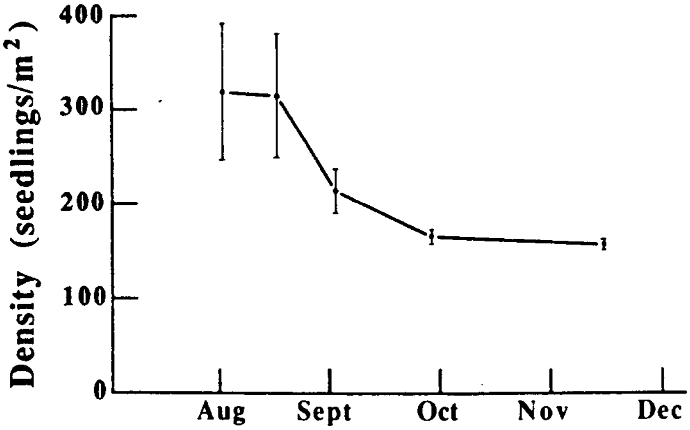

Fig. 2. *Lehmann lovegrass seedling density in 1985 on plots burned November 1984. Vertical lines are twice the standard error of mean.*

from decumbent tillers of mature lovegrass plants that survived the fire. An average of 3.2 new plants/m² were produced from rooted nodes on the burned plots while no rooted nodes were found on the unburned plots.

The bulk of Lehmann lovegrass seed in the Southwest is produced in August after summer rains and the seed shatters in October and November. Some seed may also be produced during the fall, winter, and spring. Spring temperatures and early-summer moisture conditions are not favorable for seed germination and seedling emergence until summer rains begin, usually in July. Dormancy of Lehmann lovegrass seed decreases with time after harvest (Wright 1973). A large seed reserve and afterripening of seed produced the previous summer may explain why emergence from bioassay samples taken in June was greater than from those taken in February. Lower emergence from bioassay samples collected in July probably resulted from loss of viable seeds from the seedbank through germination and decay associated with the summer rainy season. Low emergence from the November bioassay may reflect the initial dormancy of the current year's seed crop.

Burning apparently increases germination of Lehmann lovegrass seed reserves. Burning may raise soil surface temperatures to 450° C for a fraction of a second (Fig. 3). These natural heat treatments could reduce dormancy in a way similar to artificial heat treatments (Haferkamp et al. 1977) by breaking down the seed coat and increasing imbibition. Lehmann lovegrass only emerges from very shallow depths (Cox and Martin 1984) and may be exposed to high temperatures during burning (Fig. 3). The greater

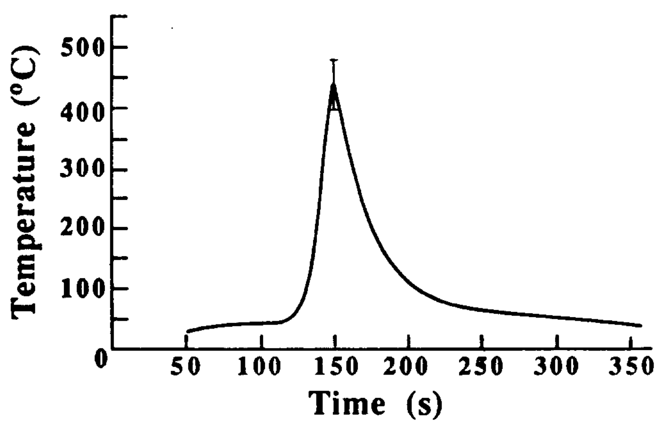

Fig. 3. *Soil surface temperatures during burning of a pure stand of Lehmann lovegrass. Data were similar and therefore averaged for burns conducted in February, June, July, and November for 2 years. Vertical bar at peak is twice the standard deviation of the mean.*

difference in seedling emergence between burned and unburned bioassay samples taken in February than November suggests that burning may increase germinability of seeds that have been in the seed bank a few months more than it does the germinability of newly fallen seed (Fig. 1). Yet the higher germinability of seed in June compared to February bioassays from both burn and control plots indicates that the majority of seeds require an afterripening period to germinate as has been reported by Haferkamp and Jordan (1977). Artificial heat treatments increase the germination of old seeds more than new seeds (Haferkamp and Jordan 1977). Natural heat treatments by fire may be more effective in reducing seedcoat dormancy of older seeds with weaker seedcoats than new seeds with hard seedcoats.

Although seed germinability as indicated by seedling emergence in bioassay samples was much lower after the February burn than after the June burn (Fig. 1), actual seedling densities in August 1984 were similar (Table 2). Seedbank germinability on both burned and unburned plots was low in November 1984 but a high number of seedlings emerged on the burned plots during the next summer rainy season in 1985 (Fig. 2). High seedling densities in August 1984 and 1985 on burned plots that had few seedlings emerge in the bioassay samples immediately after burning reflects the increase in Lehmann lovegrass seed germinability with afterripening.

The increase in seed reserve germinability associated with burning probably does not fully account for the much greater seedling emergence on burned than unburned plots in the field. Burning reduces the mature plant canopy and may result in increased incident radiation and soil temperatures, as well as reduced mature-plant transpiration and longer periods of available soil water for germination and seedling growth. Specific effects of fire on the seedbed environment that result in higher seedling emergence in the field requires future research. Meanwhile, the demonstrated ability of Lehmann lovegrass to renew itself by high seedling emergence after high mortality associated with burning indicates that fire may be used to increase, not reduce, dominance of this grass.

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Fire effects on tobosagrass and weeping lovegrass

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Abstract

Fireline intensity (kW/m) was measured on 61 plots of weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees.] and tobosagrass [*Hilaria mutica* (Buckl.) Benth.] burned as headfires and backfires during late winters of 1982 and 1983 in western Texas. Relative humidity, air temperature, wind speed, soil moisture, soil temperature, and fuel moisture were measured at time of burning. Vegetation response was based on plant yield, plant height, and number of seed stalks. Plant responses were not correlated with fireline intensity or any of the environmental parameters measured. Although fireline intensity is an important fire behavior measurement, high fireline intensities did not cause a negative impact on either weeping lovegrass or tobosagrass. Therefore, range managers can conduct high intensity fires to damage or burn down shrubs and not damage these grasses.

Key Words: prescribed fire, fireline intensity, yield, basal area, plant height, seed stalks, *Hilaria mutica, Eragrostis curvula*

Fire intensity is a commonly used term in prescribed fire literature. Virtually every vegetative response associated with prescribed fire or wildfire has been attributed to fire intensity (Wright and Bailey 1982). The hypothesis that a hot, intense, fast-moving fire results in more damage to grasses compared to a less intense, slow-moving fire has not been adequately tested in grassland communities.

Byram (1959) defined fireline intensity as heat released per unit time per unit length of fire front. Numerically, fireline intensity (kW/m) is the product of available fuel (kg/m^2), heat yield of the fuel (kJ/kg), and the forward rate of spread of the fire front (m/s). Therefore, fireline intensity integrates several important characteristics and is useful in predicting fire behavior.

Previous conclusions about the effect of fire intensity on herbaceous vegetation in grasslands have been based on artificial ratings of fire intensity. Blaisdell (1953) and Conrad and Poulton (1966) rated fire intensity based on the quantity of stems remaining or to the general level of fine fuel consumption after burning. These observed fire intensities were positively correlated to plant damage. However, Wright and Klemmedson (1965) observed that certain leafy bunchgrasses died following fire regardless of apparent intensity of the passing fire. The objective of this study was to measure a range of fireline intensities and determine the subsequent effect on yield, plant height, and number of seed stalks for 2 grasses in west Texas.

Materials and Methods

Weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees.] plots burned in 1982 and 1983 were 5 km north of Brownfield, Texas, at 1,000 m elevation. Climate of the area is warm, temperate, subhumid, continental with mean annual precipitation of 47 cm. Soil is an Amarillo loamy fine sand (Aridic Paleustalf) with caliche at 1.2 to 1.8 m (Miller et al. 1959). Study plots were located in a relatively homogeneous, ungrazed, decadent stand established in 1976.

Tobosagrass [*Hilaria mutica* (Buckl.) Benth.] plots were 11 km southeast of Gail, Texas, at 800 m elevation and were protected from grazing throughout the study by an electric fence. Average annual precipitation is 44 cm and the soil is classified as a Stamford clay (Typic Chromustert) (Dixon 1975).

Sixty-one plots were burned from 2 February to 15 April 1982 and from 14 March to 28 April 1983. Seventeen plots were burned as headfires and 10 plots as backfires in weeping lovegrass. Twenty-two plots were burned as headfires and 12 as backfires in tobosagrass. The minimum plot size was 20 by 20 m. Fires were ignited under a variety of weather conditions to produce a wide range of fireline intensities (Clark 1983).

Standing crops of fine fuel were estimated by clipping ten, 0.25-m^2 quadrats in weeping lovegrass and fifteen, 0.0625-m^2 quadrats in tobosagrass adjacent to the fire run in each plot. Samples were oven dried at 60° C to a constant weight, then weighed to the nearest 0.1 g. Heat yield of fine fuel was determined from duplicate subsamples in an oxygen bomb calorimeter. A final reduction correction of 23.9 kJ/kg/%MC (MC = weighted moisture content) was made to account for the difference between heat content determined in the laboratory with oven-dry samples and the additional moisture contained in each fuel component during test fires (Van Wagner 1973). Rate of fire spread was determined by photographing the spreading fire with infrared film using metal stakes to mark distances (Britton et al. 1977). Byram's fireline intensity was calculated as the product of fine fuel, heat yield, and rate of fire spread.

Soil samples were taken from the surface 5 cm at 5 random locations per plot and placed in airtight cans prior to each burn. The samples were weighed, then dried at 105° C for 48 hr and reweighed. Soil water contents were determined gravimetrically. Soil and grass crown temperatures were measured with soil thermometers 1 cm below grass crowns in 5 randomly located plants prior to burning. Readings were taken after a 10-minute equilibration period. Fuel moisture samples were taken prior to each burn and weighed in the field. Samples were then oven dried at 60° C for 48 hr and reweighed. Fuel moisture was expressed as a percent of the dry weight. Air temperature and relative humidity were determined within 3 min of ignition with a sling psychrometer (Anon. 1959). Wind speed at 2 m was measured with a totalizing anemometer (Clark et al. 1981).

Grass responses were estimated after 1 growing season. Fifteen 0.0625-m^2 quadrats were randomly located in each tobosagrass plot. The height of the tallest leaf was measured and number of seedstalks was counted in each quadrat. Vegetation was then clipped 1 cm above the soil surface. Ten, 0.25-m^2 quadrats were similarly located and sampled in the weeping lovegrass plots. Samples were dried at 60° C until weight was constant then weighed to the nearest 0.1 g.

Percentage change in basal area was measured on weeping lovegrass plots that were burned in 1982. Ten quadrat locations were permanently marked in each plot. Initial basal area was measured after each burn to minimize fuel continuity disturbance. Residual crown stubble was sufficient to obtain preburn basal area. Black-and-white, overhead photographs were made of each quadrat. Photographs were retaken after clipping at the end of the growing season. Five randomly placed lines were drawn through each print and basal area was measured by line intercept method. Percentage change in basal area was calculated from the difference in the initial and final measurements. Basal area measurements were not made

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Table 1. Fireline intensity and plant responses to spring burns of tobosagrass conducted in west Texas.[1]

Burn date	Yield (kg/ha)	Intensity (kW/m)	Seedstalk number (No./m²)	Height (cm)
		Headfires		
3/13/82	2089 (227)	2699	40 (7)	39 (2)
3/13	2360 (194)	5223	84 (8)	40 (1)
3/19	3888 (267)	4752	44 (5)	47 (2)
3/19	2176 (245)	1649	24 (3)	36 (2)
3/19	2418 (211)	2908	40 (5)	36 (2)
3/19	3156 (314)	3576	84 (10)	34 (2)
3/20	2386 (163)	85	24 (4)	40 (1)
3/20	2185 (248)	1083	32 (4)	38 (2)
3/20	3735 (480)	1424	52 (13)	43 (2)
3/27	2737 (194)	392	76 (6)	42 (2)
3/27	2850 (255)	591	84 (8)	43 (2)
3/27	3127 (281)	1273	92 (12)	41 (2)
3/27	1821 (84)	992	92 (9)	40 (1)
3/15/83	1406 (145)	1597	12 (4)	16 (1)
3/15	1563 (116)	302	32 (5)	22 (2)
3/15	2037 (337)	558	40 (13)	18 (2)
3/18	1399 (145)	646	40 (8)	19 (1)
3/18	2273 (242)	438	48 (7)	22 (1)
3/18	1298 (127)	170	52 (9)	21 (1)
3/31	1413 (175)	4453	40 (10)	20 (1)
3/31	1296 (151)	8036	40 (7)	21 (1)
4/19	549 (53)	1893	4 (2)	17 (1)
		Backfires		
3/13/82	2997 (234)	108	36 (6)	42 (2)
3/13	2971 (349)	101	56 (8)	44 (1)
3/19	2591 (166)	61	16 (3)	40 (1)
3/19	2291 (141)	103	64 (5)	31 (2)
3/19	3223 (354)	130	68 (9)	38 (2)
3/20	3199 (226)	51	44 (6)	37 (1)
3/27	2601 (169)	41	53 (5)	45 (2)
3/15/83	1111 (165)	63	20 (9)	37 (2)
3/15	1033 (92)	60	8 (3)	15 (1)
3/18	595 (98)	53	28 (7)	23 (3)
3/31	1673 (199)	125	40 (9)	21 (1)
4/19	756 (92)	97	0 (0)	17 (1)

[1]Standard errors are included in parentheses.

Table 2. Fireline intensity and plant responses to spring burns of weeping lovegrass conducted in west Texas.[1]

Burn date	Yield (kg/ha)	Intensity (kW/m)	Seedstalk number (No./m²)	Height (cm)
		Headfires		
2/10/82	1644 (290)	5569	128 (71)	84 (10)
2/10	1667 (295)	5824	80 (13)	17 (4)
2/10	1894 (240)	3406	116 (24)	81 (2)
3/15	1544 (164)	2823	52 (10)	77 (3)
3/17	1297 (95)	2046	8 (2)	70 (2)
3/17	1191 (203)	1278	48 (15)	72 (3)
3/18	2060 (205)	67	56 (10)	75 (4)
3/18	1395 (187)	191	40 (9)	68 (2)
3/18	1597 (198)	527	16 (6)	71 (3)
4/2	811 (138)	1889	48 (19)	74 (4)
4/15	772 (125)	1159	72 (14)	71 (3)
4/15	918 (120)	2194	28 (5)	75 (3)
3/14/83	1419 (88)	371	56 (11)	60 (2)
3/20	1094 (65)	1331	80 (16)	64 (2)
4/25	766 (103)	12603	112 (20)	53 (2)
4/28	1456 (135)	804	84 (19)	59 (2)
4/28	1138 (131)	3146	60 (19)	56 (1)
		Backfires		
3/17/82	1623 (137)	121	20 (8)	71 (2)
3/18	1016 (105)	112	16 (3)	72 (3)
4/2	518 (65)	202	4 (2)	61 (2)
4/15	801 (127)	474	48 (8)	79 (3)
4/15	640 (64)	366	20 (6)	70 (2)
3/14	1482 (108)	117	72 (14)	66 (2)
3/20	704 (78)	159	36 (12)	49 (5)
4/25	773 (226)	292	96 (29)	55 (6)
4/28	980 (100)	223	32 (7)	61 (2)
4/28	1131 (205)	199	60 (20)	63 (3)

[1]Standard errors are shown in parentheses.

Table 3. Basic statistics of headfires and backfires in tobosagrass and weeping lovegrass for burns conducted in west Texas in 1982 and 1983.

	Tobosagrass							
	Headfires (n=22)				Backfires (n=12)			
Parameter	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
Soil moisture (%)	15	5	9	26	14	5	9	25
Soil temperature (C)	15	4	9	21	17	4	9	21
Relative humidity (%)	42	25	11	97	34	19	11	70
Air temperature (C)	18	8	7	33	20	7	5	33
Wind speed (km/hr)	19	11	8	53	21	11	11	50
Fuel moisture (%)	26	8	15	42	23	6	16	37
Intensity (kW/m)	2034	2047	85	8036	83	31	41	130
Rate of spread (m/min)	13	13	1	55	1	0	0	1

	Weeping Lovegrass							
	Headfires (n=17)				Backfires (n=10)			
Parameter	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
Soil moisture (%)	8	3	3	14	7	3	3	12
Soil temperature (C)	16	5	7	23	17	5	6	23
Relative humidity (%)	37	27	12	93	29	19	12	63
Air temperature (C)	21	10	−3	30	23	9	1	30
Wind speed (km/hr)	19	8	6	39	20	6	16	36
Fuel moisture (%)	19	9	7	35	19	9	7	35
Intensity (kW/m)	2660	3075	67	12603	226	119	112	474
Rate of spread (m/min)	16	15	1	51	1	1	1	3

on tobosagrass due to its rhizomatous growth form.

Correlation analysis was used to determine if significant relationships existed between plant response and fireline intensity or environmental variables. Since burns were conducted in 2 years and at several different dates each year on plots with varying initial fuel loads, multiple regression was used to account for effects of years, dates, and initial yield in models relating plant response to fireline intensity and environmental variables. The importance of fireline intensity and environmental variables in these models was evaluated with partial correlation coefficients.

Results and Discussion

Data on fire intensities and grass yields, seedstalk numbers, and plant heights of tobosagrass and weeping lovegrass one season after burning are presented in Tables 1 and 2. Although over both years fireline intensities varied from 85 to 8,036 kW/m for tobosagrass headfires and from 67 to 12,603 kW/m for weeping lovegrass headfires (Table 3), no significant correlation was found between fireline intensity and yield of either grass (Table 4). The range of fireline intensity was smaller for backfires for grasses (Table 3) and no significant correlations were detected (Table 5). None of the measured independent variables were significantly correlated with yield, plant heights, or seedstalk number of either grass for the 2 fire types.

Table 4. Correlation of plant response variables to various independent variables for headfires conducted in tobosagrass (TG) and weeping lovegrass (WLG) during 1982 to 1983 in West Texas.

	Dependent variables					
	Yield (kg/ha)		Plant height (cm)		Seed stalks (No./m²)	
Independent variables	TG	WLG	TG	WLG	TG	WLG
Fireline intensity (kW/m)	0.00	0.00	0.00	0.00	0.01	0.14
Relative humidity (%)	0.05	0.09	0.00	0.00	0.12	0.02
Air temperature (°C)	0.02	–0.07	0.00	–0.03	–0.01	–0.06
Wind speed (km/hr)	0.00	–0.01	0.00	0.00	0.00	0.00
Soil moisture (%)	0.01	0.00	0.00	0.03	0.05	0.00
Soil temperature (°C)	–0.05	–0.06	–0.01	–0.02	0.02	–0.10
Fuel moisture (%)	0.04	0.09	0.00	0.00	0.12	0.03

Table 5. Correlation of plant response variables to various independent variables for backfires conducted in tobosagrass (TG) and weeping lovegrass (WLG) during 1982 to 1983 in West Texas.

	Dependent variables					
	Yield (kg/ha)		Plant height (cm)		Seed stalks (No./m²)	
Independent variables	TG	WLG	TG	WLG	TG	WLG
Fireline intensity (kW/m)	0.01	0.00	0.00	0.12	0.11	0.10
Relative humidity (%)	0.01	–0.48	0.02	–0.04	0.00	–0.03
Air temperature (°C)	0.01	0.41	0.00	0.08	0.03	0.28
Wind speed (km/hr)	0.00	–0.04	0.00	–0.08	–0.01	–0.18
Soil moisture (%)	0.00	0.08	0.02	–0.03	0.11	0.00
Soil temperature (°C)	0.01	0.28	0.00	0.13	0.01	0.23
Fuel moisture (%)	0.00	–0.37	0.00	–0.02	–0.01	–0.02

Percentage change in basal area of weeping lovegrass varied from +3.5% to –5.3% on headfired plots, compared to a range from +3.7% to –1.2% on backfired plots. Change in basal area of weeping lovegrass was not correlated with fireline intensity ($r = 0.45$; N.S.)

Fireline intensity is useful in forest communities for predicting maximum height of lethal scorch of conifer needles (Van Wagner 1973) and describing the general nature of wildfire for aid in suppression activities (Albini 1976). Although rarely used in rangeland situations, fireline intensity is equally important for predicting scorch height of shrubs. Rate-of-spread is the primary factor influencing intensity for a given fuel type, therefore, wind speed is an important parameter. Wind speed was the dominant factor influencing burndown of mesquite stems (Britton and Wright 1971) and consumption of mesquite debris on the soil surface in mesquite-tobosagrass communities (McPherson and Wright 1986). Although wind speed is easily measured and an important parameter, fireline intensity should have more biological sensitivity since it reflects the heat yield per unit time per unit length of fire front and integrates the effects of wind speed, temperature, humidity, fuel moisture, and fuel characteristics through rate-of-speed.

Tobosagrass and weeping lovegrass yields were not adversely affected by high levels of fireline intensity. Griffin and Friedel (1984) measured fireline intensity on 7 burns in central Australia. Fireline intensity varied from 35 to 1,902 kW/m, but fireline intensity did not affect herbaceous vegetation (primarily the genera *Aristida*, *Enneapogon*, and *Digitaria*). Fireline intensity had no effect on the herbaceous layer under a ponderosa pine overstory (Armour et al. 1984). The limited literature available on fireline intensity supports our results that intensity does not strongly affect herbaceous vegetation. This is important because a fast-moving fire with long flame lengths will not damage herbaceous vegetation any more than a slow moving fire with short flame lengths. Thus, a prescribed burn can be conducted under ambient conditions favorable for burning down woody stems, consuming debris, and scorching the aerial portions of shrubs. Concerns about damaging grasses with high intensity fires were not validated in this study. Therefore, managers can apply intense fires to meet a variety of objectives without fear of reduced grass yields or vigor.

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Effects of prescribed fire on *Chamaespartium tridentatum* ((L.)P. Gibbs) in *Pinus pinaster* (Aiton) forests

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Abstract

Prescribed burning in *Pinus pinaster* forests was evaluated in terms of the effects on *Chamaespartium tridentatum*. Postfire forage quantity and quality were studied. Total biomass production, current year's shoot production, and nutritive value were studied in relation to time since fire. *Chamaespartium*, a vigorous resprouter, achieved 50% of its preburn biomass level in 2 years. Current year's shoot production reached a maximum 3 to 4 years after fire. Nutritive value of *Chamaespartium* was briefly enhanced by burning but returned to preburn levels. Seasonal variations of forage quality were very important with lower values in summer or fall. Short-lived increases in protein, cellulose, and hemi-cellulose contents after fire in *Chamaespartium* shoots returned to preburn levels in 4 years. This supported the traditional fire frequency in the shrublands of 3 to 7 in order to maintain forage quality and productivity.

Key Words: biomass production, forage production, nutrition, Portugal

The practice of prescribed burning was a traditional land management practice on Portuguese shrublands as in the whole Mediterranean Basin for over 3,000 years (Le Houerou 1973, Naveh 1974). However, during the current century the practice has become less common. Reforestation of shrublands with *Pinus pinaster* (Aiton) has resulted in decreased use of fire in order to protect the young plantations. Prescribed burning has been reintroduced into older pine forests recently as an experimental practice to evaluate the effects on wildfire control. Since these forests are also important forage producing areas, the effects of fire on production, nutritive value, and biomass accumulation of the understory vegetation was considered important to evaluate. Shrubs produce over 80% of the annual biomass on these sites with *Chamaespartium tridentatum* ((L.) P. Gibbs) present as the dominant shrub on many areas.

Aboveground biomass (referred to as biomass in this paper) of shrubs accumulates after fire at a rate depending upon the amount of sprouting species present at the time of the fire (Morgan and Neuenschwander 1988), the age of the burned stand, the conditions during and after fire, and various habitat factors. However, where regeneration is largely vegetative and is rapid and uniform, there are 3 main growth phases: (1) the building phase, corresponding with a continuing, approximately linear, increase of biomass; (2) the mature phase, in which total biomass accumulation begins to decline; and (3) the degenerate phase, represented by a levelling out and possibly decrease in total biomass (Gimingham 1972).

Estimates of total production in perennial, evergreen, woody vegetation are not easily obtained. Aboveground production consists of current year's shoot production and input to stem diameter. Several grazing studies have concentrated on the production of current year's shoots since these provide an index of the production of edible material (browse) and often comprise most of the biomass removed by browsing, as shown for *Calluna vulgaris* ((L.) Hull) (Gimingham 1972, Milne 1974).

For *Calluna vulgaris,* Miller and Watson (1974) suggested a peak of shoot production in the building phase followed by progressive decline. Other studies in a variety of vegetation types have also documented increased annual shrub production for 3 to 5 years followed by declines in productivity (Lay 1965, Dills 1970). The ratio of annual shoot production to total above-ground biomass declines rapidly following a fire. Robertson and Davies (1965) showed that the proportion of young *Calluna vulgaris* shoots (the current and previous year's growth) drops from about 81% during the second year to about 21 and 14% by 15 and 35 years following a fire, respectively.

Published results on nutritional quality of postfire shrub forage are quite variable but, generally, indicate increases in nutrient content of shrubs are short lived. Increased nutrient level may last from only 1 year to as long as 20 years (Bendell 1974, Lyon et al. 1978). Miller and Watson (1974) found increase in nitrogen, phosphorus, magnesium, and potassium in *Calluna vulgaris* shoots after fire. Calcium initially decreases but then increases in concentration with a peak 5 years after fire. In spite of the reported variability most investigations agree that changes in nutrient concentrations occur within 5 years. Since increases in nitrogen and phosphorus are particularly significant for animal nutrition, burning will often improve quality of post-fire forage. Comparable twig segments obtained from recently burned sites are significantly more digestible than those from unburned sites. This is primarily due to increases in lignin and other cell wall components (Short et al. 1972). However, Milne (1974) found no significant differences in the digestibility of *Calluna vulgaris* twigs in stands of different ages.

Methods

This study was conducted in the mountain ranges separating Minho and Tras-os-Montes provinces in northern Portugal. Natural climax vegetation prior to human influence would have been dominated by deciduous oaks such as *Quercus robur* L. and *Q. pyrennaica* Willd. (Braun-Blanquet et al. 1956). However, most original natural forest vegetation has been removed through wood cutting and wildfires. The vegetation of the region is now dominated by shrublands or forest plantations of *Pinus pinaster*. Sites were selected among mature stands of *P. pinaster* with dominant *Chamaespartium tridentatum* in the understory. Other common shrubs include: *Calluna vulgaris, Erica arborea* (L.), *E. cinerea* (L.) *E. unbellata* (L.) and *Ulex minor* (Roth). Grasses were a minor component of the community but *Agrostis curtisii* (Kerguelen) and *Pseudarrhenatherum longifolium* (Rouy) were commonly present on the sites. The age of the *P. pinaster* stands varied from 26 to 62 years old and tree dbh varied from 20 to 31 cm. Total annual precipitation and mean annual temperature are approximately 1,000 mm and 13° C respectively, but show a close relation with elevation that varied from 280 to 880 m. Soils are shallow and stony, and derived from schists and granites. Slope varied from 12 to 20%. Areas subject to intensive grazing or other disturbances were avoided.

Five study sites were selected for prescribed burning at the beginning of the study. Each site was divided into 3 plots which are

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Table 1. Date of fire and fire characteristics of prescribed fires conducted in *Pinus pinaster* forests in northern Portugal. Windspeed for all prescribed fires was less than 3 km/hr.

Fire location	Fire date	Air temp. (C)	Rel. humidity (%)	Flame height (m)
Pedras Salgadas	Dec. 3, 1982	5.8	71	31.0
	June 4, 1983	14.0	76	5.0
Vieira do Minho	Dec. 28, 1982	11.1	67	6.0
	May 24, 1983	18.5	69	1.0
Amarante 1	Nov. 22, 1982	14.0	72	1.5
	Apr. 14, 1983	17.0	25	2.0
Amarante 2	Nov. 30, 1982	10.5	57	0.8
	May 5, 1983	13.0	80	1.5
Marao	Apr. 18, 1983	14.0	60	2.0

0.25 to 0.5 ha in size. Two of each of these plots were prescribed burned with backfires between November 1982 and May 1983 (Table 1). On each of the 5 sites, 1 plot was burned in spring 1983. However, only 4 sites had burns in winter of 1982. Vegetation data were collected prior to the fire. Data were collected for 4 consecutive years following the fires. In order to have as long-term information as possible on the ecological effects of burning, data were collected on sites that were prescribed burned prior to study initiation. These additional data were collected on 3 sites burned in 1979 and 2 sites burned in spring 1982.

Biomass determinations were made indirectly through previously developed relationships between biomass dry-weight for *Chamaespartium tridentatum* with cover and height. These relationships were established in 2×5 m plots, where shrubs were measured for height and cover and then clipped and weighed. Cover was determined by the line intercept method (Canfield 1941) by placing 2 lines through the diagonals of the plot. Cover and height were measured to the nearest cm. Dry weight biomass was determined by oven drying a subsample of the clipped sample at 65° C for 48 hours. A variety of *Pinus pinaster-Chamaespartium tridentatum* communities were sampled to develop an equation to predict *Chamaespartium* biomass values. These communities included the variation included in soils, slope, and elevation of the burned sites. These data resulted in the following regression equation:

$$Y = 154.40 \times - 1.850 X^2, \quad R^2 = 0.877 \quad n = 22$$

where Y is the dry weight biomass (Kg/ha) and X is the product of percent cover and height (m) for *Chamaespartium*.

Browse can be defined as the sum total of the plant material on woody species that is potentially edible to a specified set of animals. But commonly browse is viewed as current annual growth of leaves and twigs. In *Calluna vulgaris*, for example, the current annual growth generally comprises the bulk of the biomass utilized by herbivores (Gimingham 1972). Browse production can be estimated by determining the average weight per stem and estimating the average stems per plant (Wetzel et al. 1975). However, the always difficult task of defining the individual (plant or stem) becomes more difficult when working with species that propagate vegetatively (Mueller-Dombois and Ellenberg 1974) as *Chamaespartium tridentatum*. Therefore, we selected a procedure where the current year's shoots were hand-separated, and the proportion in whole shoots cut at ground level was computed. Since variability in this proportion is known to be low in even-aged stands (10–20% of the mean, Gimingham and Miller 1968) this proportion was determined in small subsamples, and the weight of the current year's growth per unit area calculated from the total biomass of the samples (Gimingham 1972).

For determinations of forage quality, current year's shoots of *Chamaespartium tridentatum* were collected during the 4 seasons in 1983, the first growing season following the fire. Three samples were collected at each prescribed burn site.

The dried forage was analyzed sequentially for the various cell wall components (CWC) as proposed by Goering and Van Soest (1970). Neutral-detergent fiber (NDF), acid-detergent fiber (ADF), and acid-detergent lignin (ADL) were measured. Cellulose was calculated by comparison of ADF and ADL, and hemi-cellulose by difference between NDF and ADF (Dietz 1972). Crude protein (Kjeldahl 6.25xN), ash, and dry matter of forage samples were determined by procedures described by A.O.A.C. (1975). In vitro organic matter digestibility (IVOMD) followed the method of Martens and Barnes (1980).

Biomass estimates were analyzed as a general linear model. Included in the model were sites and years after fire. Adjusted means (least square means) were used to build the model of biomass accumulation after fire.

Differences in forage chemical constituents were analyzed by an ANOVA using years after fire and season as sources of variation. Differences among means were determined with Duncan's multiple range test ($P = 0.05$), except when means of burned treatments were compared with the control. In that case the least significant difference ($P = 0.05$) was used (Steel and Torrie 1980).

Results and Discussion

Chamaespartium is a vigorous sprouter and well adapted to fire. Although biomass was reduced to nearly 0 during the fire, significant regrowth occurred every year during the first 4 years ($P<0.05$). However, no significant differences were observed between the fall versus the spring burned plots. This is possibly a result of its adaptation to frequent fires and defoliation which have been prevalent in the Iberian Penninsula for a millenia (Le Houerou 1973). Variation in regrowth between sites was significant. Using the means, adjusted for differences between sites, a model was built relating *Chamaespartium* biomass (Kg/ha) to age after fire:

$$\textit{Chamaespartium}\ \text{biomass} = 5800 - 4885\, t^{-0.6128} \quad R^2 = 0.977 \quad n = 7$$

Where t equals years after fire.

The *Chamaespartium* current year's shoot biomass as a percentage of total biomass was related to age after fire in the following regression equation:

$$\text{Current year's shoot percentage} = (0.457\, t^{-0.385})100 \quad R^2 = 0.762 \quad n = 37$$

Where $t>1$. Current year's shoots equal 100% total biomass during the first year.

The equation relating percentage of current year's shoots to total *Chamaespartium* biomass was established using individual plot data, since variation between sites was not significant. As occurred in most reviewed literature, *Chamaespartium* current year's shoots increased rapidly, nearly doubling every year for the first 3 to 4 years after fire. The annual productivity rapidly declines following this period. Annual production may exceed 1,000 kg/ha for the second to fourth year. It is estimated that annual production may decline to less than 500 kg/ha by 20 years after the fire. Nearly all production of *Chamaespartium* is from resprouting plants so post-fire biomass production is highly dependent upon preburn density.

Increased forage quantity may not be meaningful unless the quality is sufficiently high to sustain herbivores. Forage quality varies seasonally, between locations, and with age since fire. *Chamaespartium* quality on burned plots differed significantly from unburned sites (Table 2). We concluded that cellulose and hemicellulose increased significantly 6 months after fire, but their levels were not significantly different from the preburn level 2 years after burning. There was a delay between responses of cellulose and protein. Protein values were significantly higher between 6 months and 2 years after burning. Samples taken 4 years after fire were not significantly different from unburned plants for any component

Table 2. Effects of prescribed fire on the nutritive value of *Chamaespartium tridentatum* twigs in *Pinus pinaster* forests of northern Portugal.

	Treatment means				
		Times since fire			
Cell wall component (%)	Un-burned	3 months	6 months	2 years	4 years
Cellulose	19.17	23.64*	24.84*	19.76*	19.78
Hemi-cellulose	9.55	9.99	11.68*	8.48	8.90
Lignin	25.86	24.97	23.83	24.57	25.86
Protein	8.96	9.67	10.51*	10.60	9.30
Total organic matter	91.83	92.18	91.70	91.66	92.10
Organic matter digestibility (in vitro)	41.75	41.49	42.29	46.05	44.11

Means followed by an asterisk are significantly different from unburned ($P<0.05$) as determined by the least significant difference (LSD).

analyzed. While not significant, lignin values seem to vary in opposition to those of cellulose and hemi-cellulose. The increase in protein following fire is important since 9% is near the deficiency level for some ruminants (National Research Council 1975).

Chamaespartium is the most important forage species in the community with respect to both quantity and quality. Nutrient quality of current year's shoots varies directly with growth stage (Short et al. 1972). Cellulose and hemi-cellulose were lower during the winter than during the other seasons (Table 3). Protein content

Table 3. Seasonal variation in the nutritional value of *Chamaespartium tridentatum* twigs in *Pinus pinaster* forests of northern Portugal.

	Treatment means			
Cell wall component (%)	Spring	Summer	Fall	Winter
Cellulose	22.18b	22.15b	21.75b	18.73a
Hemi-cellulose	11.10b	9.96b	10.34b	8.45a
Lignin	20.98a	26.29b	26.03b	25.99b
Protein	9.62ab	9.33ab	9.16a	10.11b
Total organic matter	90.68a	92.46c	91.95b	92.01b
Organic matter digestibility (in vitro)	44.47b	41.80ab	39.89a	44.41b

Means followed by a similar letter within the same row are not significantly different at the 0.05 level of probability, as determined by the Duncan's new multiple range test.

was greatest during the winter and least during the fall. Protein content during the other seasons was intermediate. Forage digestibility appeared to more closely related to low lignin and high protein content than to cellulose and hemi-cellulose content.

Conclusions

Chamaespartium tridentatum is a dominant species in post-fire succession of the understory vegetation in the pine forests of the study area. A vigorous sprouter, it produced 50% of the preburn biomass in 2 years and it is estimated that biomass will return to preburn levels in 7 to 10 years after fire.

The effect of fire on the nutritional quality of *Chamaespartium* twigs is in agreement with what has been found in other studies (Grant and Milne 1973, Milne 1974). Short-lived increases in cellulose and hemi-cellulose (6 months) with a related decrease in lignin. An increase of 1.5% in the protein content from 6 months to 2 years, approaching the preburn level after 4 years. While not dramatic, this increase allows the protein content of the twigs to be adequate to supply the gestation requirements of ewes (National Research Council 1975). A similar trend is apparent for forage digestibility.

Fire increased production of *Chamaespartium* browse and benefited browse quality for at least 2 years after prescribed fire. Shepherds traditionally have used fire in these shrub communities at intervals of 3 to 7 years. The results of this study provide evidence of the rationality of this fire-free-interval when the primary objective is to provide the greatest amount of high quality forage. This information enables forest managers to use prescribed burning as a management tool in this region to enhance livestock grazing in *Pinus pinaster* forests.

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Economic comparison of aerial and ground ignition for rangeland prescribed fires

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Abstract

Average ignition costs per ha for aerial and ground ignited prescribed burns in redberry juniper *(Juniperus pinchotii)*-mixed grass communities were compared to determine the feasibility of using aerial ignition on rangelands. Aerial ignition techniques had greater total costs than ground ignition because of higher fixed costs. However, if greater than 4,000 ha could be burned, as a single or multiple unit, aerial ignition costs are $1.36/ha less than estimated ground ignition costs.

Key Words: fireline costs, average costs, redberry juniper-mixed grass, *Juniperus pinchotii*

Increased use of prescribed fire for natural resource management has resulted in a variety of ignition techniques for the implementation of prescribed fire. Ignition techniques can be classified into 2 categories, aerial and ground ignition. Aerial ignition technology has advanced so that the gellied-gasoline helitorch (dispenses gellied-gasoline through a pump assembly carried by a helicopter) and the aerial ignition device (which uses plastic spheres filled with potassium permanganate and ethylene glycol) are common ignition sources (Jukkala 1984). Both are being continually refined as they are tested on the many fuel types and conditions found in natural resource management. The most extensive work has been conducted in forests on prescribed fires and wildfires. Ground ignition is any type of ignition technique which is performed from the ground. Techniques range in sophistication from the fire rake to the vehicle-mounted terra torch (dispenses gellied gasoline through a high pressure pump placed in a truck). Most common, however, is the drip torch which uses a gasoline and diesel mixture as an ignition source.

Comparisons of aerial and ground ignition have been restricted to mechanical and functional aspects. For example, aerial ignition offers greater ignition speed and increased safety to ground personnel compared to ground ignition in specific cases (Mathews 1984). Economic considerations have received little attention.

The objective of this study was to compare aerial and ground ignition in redberry juniper (*Juniperus pinchotii* Sudw.)-mixed grass communities in western Texas. This study was conducted concurrently with another study to determine if the helitorch could meet prescribed fire objectives in this fuel type.

Materials and Methods

The dominant vegetation type on all units was redberry juniper-mixed grass. Herbaceous vegetation was dominated by little bluestem (*Schizachyrium scoparium* [Michx.] Nash.), buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.), tobosagrass (*Hilaria mutica* [Buckl.] Benth.), and sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.). All units had been chained or individually tree dozed to reduce redberry juniper competition and allow herbaceous production to increase. Mechanical treatments occurred from 3 to 15 yr before burning. This vegetation type is considered volatile, so most units were burned using a two-stage technique. Firelines were 125 m wide and were burned out using ground ignition techniques for safety considerations. The two-stage ignition technique used to burn this community type has been described previously (Wright and Bailey 1982, McPherson et al. 1986, Rasmussen et al. 1986). One aerial and one ground ignition unit were burned in one stage.

Costs associated with prescribed burning can vary greatly, depending on fuel type and how costs are determined (Lionberger 1984). Other variables within a fuel type which cause costs to vary include weather, fuel loads and continuity, existing fuel breaks, and topography. To reduce cost variability, economic comparisons were restricted to prescribed fires in redberry juniper-mixed grass habitat conducted between 1983 and 1986 by the Texas Tech University Department of Range and Wildlife Management for research and training purposes. Burns were classified by their source of ignition of the main unit (aerial or ground; firelines for all units were ground-ignited).

A survey by the authors indicated the helitorch is the most commonly available and widely used aerial ignition system in the United States, so it was selected for use in this study, though no aerial ignition system is available in western Texas. Aerial ignition with a helitorch was used on 6 units ranging from 659 to 4,014 ha. Organizational procedures for aerially ignited units followed Masters et al. (1986). Ground ignition was conducted on 5 units ranging from 142 to 964 ha. Preburned firelines were not used on the 142 ha unit. Drip torches were used for ground ignition because they are the most commonly used and available to prescribd fire practitioners. The ignition pattern for both techniques varied depending on the burn objectives, topography, and fine fuel loads.

Data obtained from each burn included number of personnel and assignments, distance traveled from Lubbock, Texas, hours of tracklaying tractor work needed to prepare the mineral soil lines, and drip torch and helitorch fuel needed. Costs are expressed in 1986 dollars. Only actual direct burning costs were included in this analysis. Pasture deferment and overhead costs were not included.

In the redberry juniper fuel type, preparation procedures are identical for both aerial and ground ignition techniques. Therefore, costs were separated into average preparation costs (APC) for all burns, and average ignition costs (AIC) for aerial and ground ignited units. Preparatory costs included reconnaissance, construction of mineral soil lines, and fireline burning costs. Ignition costs included only the labor, fuel, maintenance, and transportation costs that occurred during ignition of the main unit. For aerial ignition the costs of the helitorch and its required fuel was also included.

Since all burns were conducted for teaching and research, personnel costs were estimated by paying the fire boss $500.00/day, and other personnel $50.00/day. Vehicle costs were obtained by charging $0.31/km for four-wheel drive vehicles and $0.28/km for two-wheel drive vehicles. Drip torch fuel (70:30 ratio of diesel and gasoline) cost was $0.26/l. The tracklaying tractor (0.104 MW) equipped with a bulldozer blade was rented for $55.00/hr, which included the rental of the tractor and operator wages. Maintenance cost on equipment other than vehicles was estimated at $25.00/burn-

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Table 1. Costs incurred during preparation of 125-m wide firelines for prescribed burning redberry juniper-mixed grass rangeland.

Unit size (ha)	Total fireline length (km)	Time to burn (days)	Cost ($) Labor[1]	Trans.[2]	Tractor[3]	Fuel[4]	Eq.[5]	Total cost ($)	cost ($/km)
223	2.08	2	1800	560	292	50	50	2752	1323.08
311	4.31	2	1800	896	369	40	50	3155	732.02
364	5.27	2	1800	550	120	75	50	2595	492.41
648	2.40	1	800	285	369	25	25	1504	626.87
659	5.11	1	950	342	292	131	25	1740	340.51
769	7.19	2	1600	570	369	62	50	2651	368.71
964	7.19	2	1900	896	440	50	50	3336	463.98
1250	8.15	4	3550	896	369	50	100	4965	609.20
1417	8.62	2	1600	660	880	65	50	3255	377.61
1417	8.62	2	1800	660	589	115	50	3214	372.85
3715	9.74	3	2700	1146	732	192	75	4845	497.43
4014	19.80	5	5000	2156	2932	233	125	10446	527.58

[1]Fire boss paid $500.00/day for each day burned; other personnel paid $50.00/day.
[2]Transportation—4×4 at $0.31/km, 2×2 at $0.28/km.
[3]Track laying tractor (0.104 MW) with operator at $55.00/hr.
[4]Drip torch fuel at $0.26/1.
[5]Maintenance for miscellaneous equipment at $25.00/day.

ing day. This estimate was obtained by summing maintenance costs from 1983 through 1986, and dividing by the number of burn-days.

One reconnaissance trip was included in the preparation costs on all burns. The reconnaissance trip ensured correct placement of mineral soil lines and provided details for the fire plan. The cost of this trip was $500.00/day for the fire boss and $50.00/day for other personnel (1 to 4 depending on unit size) plus transportation. Trips taken to the burn unit but canceled due to inappropriate weather were included as part of the cost of preparation or ignition depending on when they occurred.

Use of the helitorch required additional support personnel including an aerial ignition boss, helipad boss, and suppression crew boss all at $150.00/day. In addition, a 3-person helipad crew (3) was needed at $50.00/day per person. Suppression crews were divided into 2 crews ranging in size from 2 to 6 people. These crews moved in conjunction with the helitorch depending on the ignition pattern.

The helitorch contractor estimated the cost of using the helitorch on individual units at $9.88/ha for 1,000 ha, $4.94/ha for 2,000 ha, and $2.47/ha for 4,000 ha. No further decrease in helitorch costs occurred if more than 4,000 ha were to be burned. Contracted cost included the helicopter, pilot, helicopter fuel, helitorch, and thickening agent for the helitorch fuel. Gasoline for the helitorch was purchased at an average cost of $0.26/liter.

Ground ignited headfires were ignited with ignition crews of 2 to 8 personnel depending on ignition pattern. One unit, burned to improve wildlife habitat, consisted of several segments ranging in size from 3 to 24 ha. A single mineral soil fire line was placed around each segment, which was then burned using a strip-headfire technique in a single stage. All other units consisted of a single segment and were ignited using a single headfire technique, with preburned firelines.

Summary statistics (means and standard errors) were determined for fireline preparation and headfire costs. Regression analysis was used to determine the effect of unit size on APC and AIC per ha for aerial and ground ignition. Total average costs were determined by summing APC and AIC regression equations.

Results and Discussion

Units can be burned without preburned firelines under specific conditions. However, firelines were used on most burns in this study to reduce the risk associated with prescribed burning. Average cost of installing these firelines and other preparatory operations (reconnaissance, constructions of mineral soil lines) was expressed as a logarithmic function (Fig. 1). Decreasing slope indicated an economy of size between the cost of preparing a unit to be burned and its size. The major source of variation in preparatory costs was attributed to burning firelines. When preparation costs are divided into individual categories, labor accounted for 56 $\pm$9.17% of the costs to burn out the fireline (Table 1). Unit shape as well as size influenced the length of fireline needed to prepare a unit to be burned. Time required to burn out firelines depended on

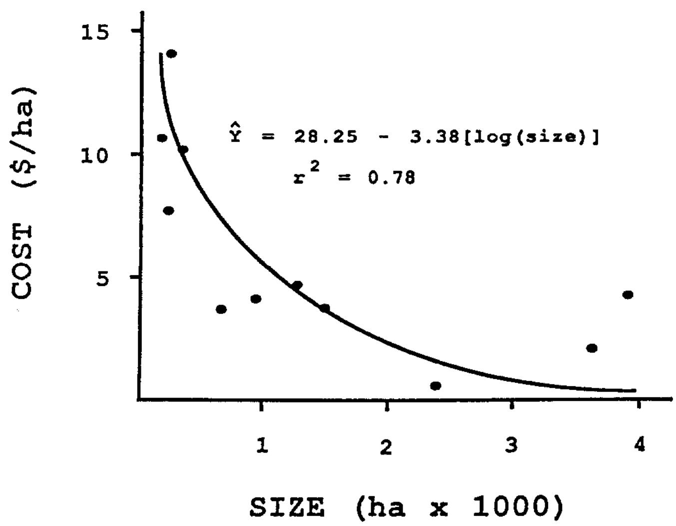

Fig. 1. *Relationship between unit size and average preparation costs for prescribed burns conducted between 1983 and 1986 in a volatile fuel type (redberry juniper-mixed grass) near Lubbock, Texas. These costs include reconnaissance, mineral soil line preparation, and burning firelines.*

weather, fine fuel characteristics, topography, availability of existing fuel breaks and unit size.

The relationship between unit size and AIC/ha for aerial ignition was logarithmic (Fig. 2). No significant ($P\leq0.05$) relationship was found between unit size and average ignition costs using ground ignition.

The sum of APC and AIC for ground and aerial ignited prescribed fires indicated similar trends for total average costs curves (Fig. 3). Factors affecting total average cost were the same as those previously discussed for burning firelines. Units larger than 1,000 ha are rarely burned using ground ignition because these problems

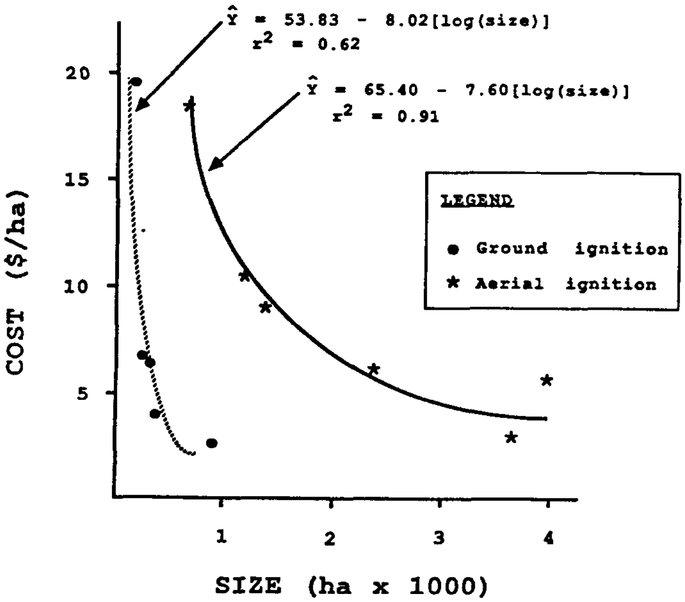

Fig. 2. *Relationship between unit size and average ignition cost for aerial and ground ignited prescribed burns conducted between 1983 and 1986 on a volatile fuel type (redberry juniper-mixed grass) near Lubbock, Texas.*

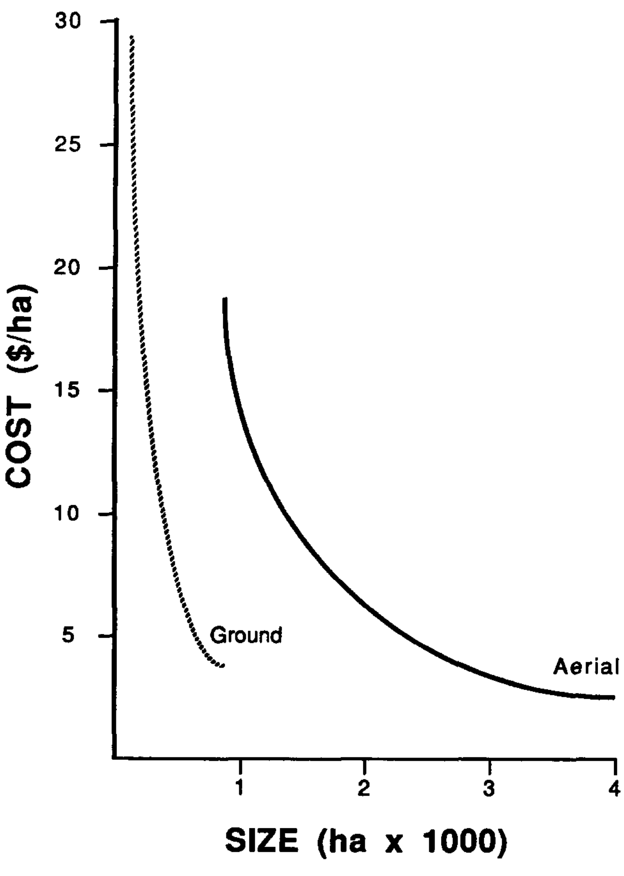

Fig. 3. *Relationship between unit size and total average ignition cost (sum of APC + AIC regression lines) for aerial and ground ignited prescribed burns.*

increase time required for ignition and decrease the probability that burn objectives can be met.

Before the helitorch became available, the largest unit attempted by the Texas Tech University research burning program was 964 ha. Larger units were not attempted because of labor and time requirements needed to complete these burns in the redberry juniper-mixed grass fuel type. For example, the largest unit ignited with the helitorch required 70 man-hours. It was estimated that 600 man-hours would be required to burn the same unit using ground ignition because of the inordinate number of fuel breaks (roads, trails, and ridges) (Masters et al. 1986). A 10-person ignition crew would be the largest which could safely ignite the unit with available equipment. Thus ground ignition would require approximately 12 days and the estimated budgeted cost would be $1.36/ha more than aerial ignition. This also assumes 12 burning days would occur during a single season. In western Texas, 12 days which are appropriate for headfire ignition rarely occur during 1 spring burning season.

Preparation costs accounted for an average of 22 ± 3.4% of the total average costs on aerially ignited units and 61 ± 1.3% on ground ignited units. Lower values for aerially ignited units were attributed to (1) increased cost of using the helitorch on the headfire phase of ignition, and (2) decreased distance of fireline per unit area on large units. Aerially ignited units in this study required an average of 0.0048 km of fireline per ha burned; ground-ignited units required an average of 0.0087 km/ha.

The helicopter and helitorch accounted for an average of 66 ± 5.5% of the average total cost on aerially ignited units. A helitorch contractor is not available in western Texas. The contractor used in this study required $10,000 to bring his helitorch to this area. If at least 4,000 ha could be burned as a single unit or in multiple units, the helitorch could be contracted for $2.47/ha. Helitorch costs probably can be reduced in areas closer to a helitorch contractor. The smaller aerially ignited units in this study burned as multiple units (contracted for the minimum cost of $2.47/ha) had total average costs of $5.96 ± 0.70/ha. If small units are to be burned, the full economic advantage of aerial ignition can be realized only if burned in association with other units.

These data indicate aerial ignition is an economically feasible alternative for burning large units or groups of smaller units. These data do not indicate precisely at what size aerial ignition becomes less expensive than ground ignition. Aerial ignition offers a practical alternative on units larger than 1,000 ha since it allows these units to be burned with increased efficiency. The increased efficiency allows a greater number of hectares to be burned for the same average cost as ground ignition. However, aerial ignition loses its advantage in the presence of area or capital constraints. Cost curves for aerial ignition found in this study were strongly influenced by the contractor's price structure. A different price structure for using the helitorch could alter these conclusions.

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Atrazine dissipation and off-plot movement in a Nebraska sandhills subirrigated meadow

J.J. BREJDA, P.J. SHEA, L.E. MOSER, AND S.S. WALLER

Abstract

Atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] can be used to modify species composition of naturally subirrigated Sandhills meadows. The potential for ground water contamination exists as the water table depth ranges from 0 to 3 m. Atrazine was applied at 2.2 and 3.4 kg ha^{-1} in May 1984, August 1984, or May 1985 to a Gannett fine sandy loam (Typic Haplaquoll, coarse-loamy, mixed, mesic) in a Nebraska Sandhills subirrigated meadow. Residues of atrazine applied in 1984 and 1985 carried over into 1985 and 1986, respectively. Herbicide dissipation and off-plot movement were monitored in 1985 by sampling soil at 0 to 5 cm and 5 to 15 cm depths within and outside the experimental areas. Atrazine dissipation initially approached zero-order kinetics after May 1985 application, but generally followed first-order kinetics during the entire 320-day sampling period. Atrazine half-life in the entire 0 to 15 cm sampling zone was 46 ± 7 days. Herbicide concentrations at the 5 to 15 cm sampling depth did not exceed levels measured at 5 days after application. Low and highly variable atrazine concentrations detected in some of the untreated plots and in some off-plot soil samples indicated minimal lateral movement of the herbicide.

Key Words: triazine, ground water, runoff, leaching, contamination

Atrazine can be used in Nebraska Sandhills subirrigated meadows to manipulate the vegetation for haying and grazing (Brejda 1986). The Nebraska Sandhills overlay a major portion of the Ogallala aquifer and water levels are at or near the soil surface in naturally subirrigated meadows. In many meadows the water table rises above the soil surface in the spring, then recedes to a maximum depth of approximately 2 m during the summer. Soils are coarse-textured, composed primarily of fine sand, and the surface horizon is high in organic matter. Subirrigated meadows are primarily used for hay production and most have never been cultivated.

Atrazine has been identified as a contaminant in rivers, lakes, estuaries, and ground water (Richards et al. 1975, Junk et al. 1980, Spalding et al. 1980, Frank et al. 1982). Lateral movement of atrazine dissolved in surface runoff water and adsorbed on eroded sediment has been documented (White et al. 1967, Hall et al. 1972, Ritter et al. 1974, Wauchope 1978), and leaching through soil has been reported (Burnside et al. 1963, Rodgers 1968, Wehtje et al. 1984). Atrazine can be adsorbed on soil clay and organic colloids (McGlamery and Slife 1966, Weber et al. 1969, Weber 1970), but may leach in coarse-textured soils low in organic matter (Burnside et al. 1965, Rodgers 1968, Roeth et al. 1969). Atrazine persistence can increase with soil pH and depth (Roeth et al. 1969, Lavy et al. 1973) and degradation may be very slow under aquifer conditions (Goswami and Green 1971, Wehtje et al. 1983). The potential for ground water contamination is greatest where atrazine is applied to soils overlaying shallow water tables (Spalding et al. 1979).

Information is needed on the fate of atrazine in subirrigated meadows before widespread use occurs. The objective of this research was to quantify herbicide residues in soil and determine off-plot movement following atrazine application to a naturally subirrigated meadow of the Nebraska Sandhills.

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Materials and Methods

Research was conducted in 1984 and 1985 at the University of Nebraska Gudmundsen Sandhills Laboratory (GSL) located in Grant County, 12 km northeast of Whitman, Neb. (Brejda 1986). The GSL lies in a precipitation zone of 500 to 560 mm per year, of which 75 to 80% occurs between April and September. Precipitation during this period was average in 1984 and below average in 1985. The soil was a Gannett fine sandy loam (Typic Haplaquoll, coarse-loamy, mixed, mesic) (Table 1). The meadow had a slope of <3% and surface drainage was from south to north. Subsurface water flow was from west to east.

Table 1. Soil properties of a Gannett fine sandy loam at two depths in a Sandhills subirrigated meadow at the Gudmundsen Sandhills Laboratory, Grant County, Nebraska.

Soil property	Depth 0–5 cm	Depth 5–15 cm
Organic carbon (g kg^{-1})	170[1]	42
Total nitrogen (g kg^{-1})	12	5
Phosphorus (mg kg^{-1})	20	7
CEC (cmol p$^+$ kg^{-1})	51	32
pH (1:1 soil:water)	7.6	7.7
Sand, 0.05 to 2.0 mm (%)	57	65
Silt, 0.002 to 5.0 mm (%)	33	21
Clay, ≤0.002 mm (%)	10	14

[1]Partially decomposed thatch was not removed.

The plant community of the experimental meadow prior to treatment consisted of predominantly cool-season grasses [Kentucky bluegrass (*Poa pratensis* L.), timothy (*Phleum pratense* L.), quackgrass (*Agropyron repens* L.), and redtop bentgrass (*Agrostis stolonifera* L.), and red clover (*Trifolium pratense* L.). Small populations of native warm-season big bluestem (*Andropogon gerardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], and switchgrass (*Panicum virgatum* L.) were also present.

Atrazine was applied to suppress the cool-season grasses and restore dominance of the more productive native warm-season grasses. Two separate experiments were conducted in which 0, 2.2, and 3.4 kg a.i. ha^{-1} atrazine was applied in 200 L ha^{-1} water to 6 × 12 m plots on 14 May or 23 August 1984, and on 15 May 1985 (Fig. 1). Wind speed was variable, but less than 16 km h^{-1} at herbicide application. A tractor-mounted sprayer with shielded, flat fan nozzles was used to minimize herbicide drift during application. Water table depth ranged from 0.3 to 1.0 m at herbicide application. The 1984 field plot design was a split plot with season of application as whole plots and atrazine rate as sub-plots arranged in a randomized, complete block. A randomized, complete block design was used in 1985. The 1985 experimental site was approximately 185 m east of the 1984 site.

Soil was sampled from the center 3 × 9 m of each plot with a 10-cm diameter hand-held auger 5 days after atrazine application in May 1985, and at monthly intervals through 1 September 1985.

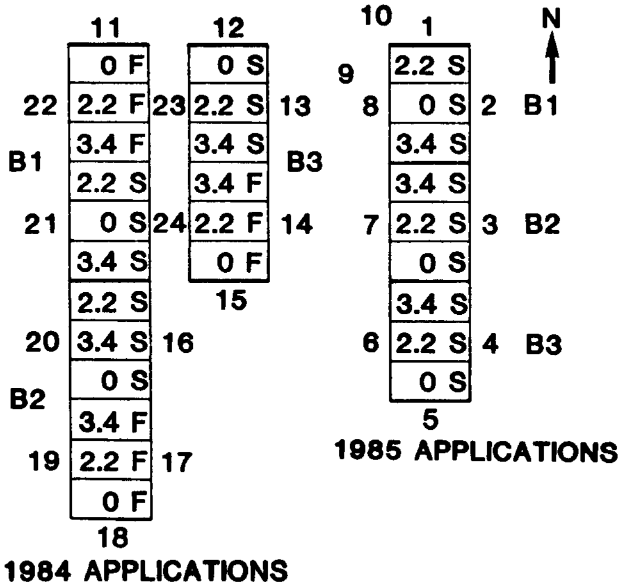

Fig. 1. *Field treatment plan for experiments initiated in 1984 and 1985 at the Gundmundsen Sandhills Laboratory in Grant County, Nebraska. Atrazine was applied in May (S) or August (F) at 0, 2.2, or 3.4 kg a.i. ha^{-1} in 3 blocks (B1, B2 and B3). The 1985 experimental site was approximately 185 m east of the 1984 site. Numbers outside treatment areas indicate locations of off-plot soil sampling.*

Soil samples were also collected on 1 April 1986 to determine carry over of atrazine residues. Samples were similarly collected at monthly intervals between 1 June and 1 September 1985 from all 1984 experimental plots. Soil samples were concurrently collected 3 m north, south, east, and west of 1984 and 1985 experimental sites, and from 2 depressions northwest of the 1985 site (Fig. 1). At each sampling date 3 soil cores were removed from random locations within each plot and off-plot locations at 0 to 5 and 5 to 15 cm depths, composited, and frozen at −20° C until atrazine analysis.

Samples were thawed; thatch and plant material were removed and discarded. Soil was screened through a 1-mm sieve and air-dried at 25° C prior to atrazine analysis. Atrazine was soxhlet-extracted from 30 to 40 g of soil with 125 ml methanol for 1.75 hours. The extract was reduced to 5 ml by rotary evaporation, transferred to a test tube, and taken to near dryness under a stream of nitrogen gas in a water bath at 45° C. Three ml of toluene were added to the tube and thoroughly mixed using a vortex stirrer. Atrazine concentration was determined with a Perkin-Elmer Sigma 2000 gas chromatograph equipped with a thermionic nitrogen-phosphorus specific detector. A spiral glass column (91 cm long, 2 mm i.d.) packed with 1.5% OV-17 + 1.95% OV-202 on 100/120 mesh Chromosorb W HP was used for the separation. Carrier gas was nitrogen at 30 ml min^{-1}, and detector gases were hydrogen at 3 ml min^{-1} and air at 160 ml min^{-1}. Peak area for each sample was integrated by a dedicated microprocessor. Minimum atrazine detection was 1 μg kg^{-1} and the limit of quantitative determination was 10 μ kg^{-1}. Extraction efficiency was greater than 90% and atrazine recovery following field application was calculated using a soil bulk density of 1.33 g cm^{-3}.

Data from the 1984 and 1985 experimental sites were analzyed using analysis of variance for split-plot and randomized, complete block designs, respectively (Steele and Torrie 1980, SAS Institute 1982). Soil depths and sampling dates were treated as repeated measures in both experiments. Treatment means were compared using preplanned orthogonal contrasts. Exponential regression equations for atrazine dissipation over time were computed using the least squares method (James et al. 1985) with best fit based on lowest root mean square error (RMSE) values (Willmott 1982).

Results and Discussion

Dissipation

Atrazine recovery from the 0 to 5 cm soil depth at 5 days after the May 1985 application was 27 ± 2% of that applied and only 2 ± 1% was detected at the 5 to 15 cm depth (Table 2). No rainfall was received during this period. Atrazine detection in some untreated plots indicated low level contamination during application, after application, or during soil sampling. The vapor pressure of atrazine is relatively low, 0.04 kPa at 20° C (Weed Science Society of America 1983), and air temperatures did not exceed 25° C during the 5-day period after application. However, some vapor drift may have occurred, as surface temperatures may be significantly higher than air temperatures under high light intensity (Parr and Papendick 1978). Some atrazine photolysis may also have occurred through secondary sensitization and catalysis from exposure to ultraviolet light (Jordan 1970). Thatch was not analyzed for atrazine, but previous research indicated significant atrazine interception and retention by crop residues (Ghadiri et al. 1984a).

Atrazine dissipation in soil initially approached zero-order kinetics following the May 1985 application, but generally followed first-order kinetics over the entire 320-day sampling period (Fig. 2). The initial deviation from first-order may be partially due to atrazine wash-off from the sod and thatch onto soil during rainfall, as previously observed (Ghadiri et al. 1984b). The 45 μg kg^{-1} atrazine detected at the 5 to 15 cm depth at 5 days after application may be due to contamination during sampling, as no rainfall was received during this period. Atrazine concentration did not exceed this level at any of the later sampling dates. The lack

Table 2. Atrazine concentrations[1] in soil at 0–5 cm and 5–15 cm depths in 1985 and April 1986 following applications at 0, 2.2 and 3.4 kg ha^{-1} in May 1985. Atrazine treatment and soil depth comparisons were made using orthogonal contrasts and preplanned tests of hypotheses.

Sampling date	Time after application	Cumulative rainfall	Untreated		2.2 kg ha^{-1}		3.4 kg ha^{-1}	
			0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
	(days)	(mm)	(μg kg^{-1} ± S.D.)					
20 May 1985	5	0	11 ± 11	T	749 ± 34	33 ± 7	1432 ± 215	45 ± 19
1 June	17	12	T	ND	795 ± 151	11 ± 5	1394 ± 34	T
1 July	47	29	10 ± 10	T	283 ± 110	22 ± 11	623 ± 21	15 ± 5
1 Aug.	78	65	11 ± 11	T	405 ± 5	14 ± 13	589 ± 109	T
1 Sept.	109	116	ND	T	241 ± 62	12 ± 6	159 ± 37	ND
1 Apr. 1986	320	289	T	ND	21 ± 11	T	47 ± 28	T
Comparison			PR > F					
Untreated vs. Treated			<0.001					
2.2 kg ha^{-1} vs. 3.4 kg ha^{-1}			0.002					
0–5 cm vs. 5–15 cm Soil Depth			<0.001					

[1]'T' indicates atrazine detected was below the 10 μg kg^{-1} limit of quantification.
'ND' indicates no atrazine was detected.

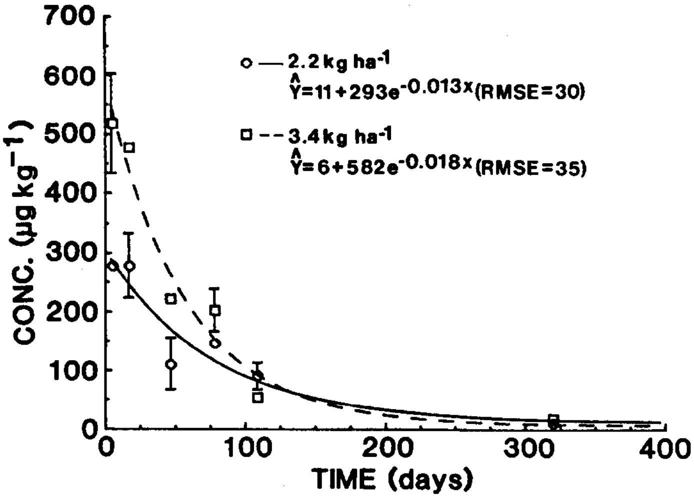

Fig. 2. *Best-fit exponential regression for atrazine dissipation over time at the 0 to 15 cm soil depth following application at 2.2 kg ha^{-1} or 3.4 kg a.i. ha^{-1} on 15 May 1985 to a subirrigated meadow at the Gudmundsen Sandhills Laboratory in Grant County, Nebraska. Vertical bars indicate standard deviations of the means. No bar indicates a standard deviation ≤13 μ kg^{-1}.*

of change may be due to herbicide retention in thatch, degradation, and the minimal precipitation received during spring and summer 1985. Atrazine half-life in the entire 0 to 15-cm sampling zone was estimated to be 46 ± 7 days.

Atrazine applied in August 1984 carried over and residues were detected in the 0 to 15-cm sampling zone within the treated area in June 1985 (Table 3). Atrazine concentrations at the 5 to 15 cm depth appeared to be higher in plots that had received the higher herbicide application rate, but variability was also greater in those samples. Less than 2% of the atrazine applied in August was recovered from the 0 to 15-cm sampling zone at 375 days after application.

Low concentrations of residual atrazine from May 1984 and May 1985 applications were detected at the 0 to 5 cm depth in June 1985 and April 1986, respectively, and trace concentrations were detected at the 5 to 15 cm depth (Tables 2 and 3). Residual atrazine concentrations in plots treated in May 1984 were not significantly different from that detected in untreated plots (Table 3). Soil was not sampled at depths greater than 15 cm, but data from the 0 to 15 cm depths did not substantiate atrazine leaching.

Atrazine mobility increases as soils become more coarse in texture (Helling 1970, 1971), but organic matter can adsorb the herbicide and reduce leaching (Rodgers 1968, Weber et al. 1969). Although the meadow soil was high in sand and low in clay content, the soil was covered by dense thatch and organic matter content was very high near the surface. Experimental data did not indicate mass displacement of atrazine, as concentrations at the 5 to 15 cm depth did not exceed initial levels at any later sampling date. Less residual atrazine was detected at both sampling depths at 320 days after the May 1985 application than after a similar interval following August 1984 application. However, no differences in atrazine residues after comparable intervals following August or May 1984 applications were apparent in 1985. Although experimental data were inconclusive, slower, degradation during the winter months (Talbert and Fletchall 1964, Burnside et al. 1965, Roeth et al. 1969) could increase the contamination risk from late-season atrazine application.

Off-Plot Movement

Low and variable atrazine concentrations detected in some untreated plots (Tables 2 and 3) and soil samples collected outside the experimental area (Tables 4 and 5) did not support lateral herbicide movement, with the possible exception of off-plot depressions where water accumulated. Elevated atrazine concentrations in the depressions on 1 June were not likely caused by runoff, as only 12 mm of precipitation was received (4 mm was the largest event) between herbicide application and soil sampling. The higher atrazine application found in 1 depression (site 10) on 1 July could have resulted from runoff, as 15 mm of precipitation was received in 1 event. Atrazine concentration did not increase in the other depression (site 9), and differences between the depressions may be due to variations in topography.

Atrazine concentrations were significantly higher in soil sampled

Table 3. Atrazine concentrations[1] in soil at 0–5 cm and 5–15 cm depths in 1985 following application at 0, 2.2 or 3.4 kg ha^{-1} in May and August 1984. Atrazine treatment and soil depth comparisons were made using orthogonal contrasts and preplanned tests of hypotheses.

Sampling date	Time after application	Cumulative rainfall	Untreated		2.2 kg ha^{-1}		3.4 kg ha^{-1}	
			0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
	(days)	(mm)	(μg kg^{-1} ± S.D.)					
			May 1984 Application					
1 June 1985	384	468	T	T	44 ± 17	ND	43 ± 10	ND
1 July	414	485	19 ± 17	T	T	T	33 ± 4	T
1 Aug.	445	521	31 ± 14	T	10 ± 4	ND	34 ± 12	T
1 Sept.	476	572	T	T	T	T	19 ± 17	ND
Comparison		PR > F						
Untreated vs. Treated		0.721						
2.2 kg ha^{-1} vs. 3.4 kg ha^{-1}		0.293						
0–5 cm vs. 5–15 cm Soil Depth		0.002						
			August 1984 Application					
1 June 1985	283	163	T	ND	274 ± 39	41 ± 17	1091 ± 722	342 ± 294
1 July	313	180	T	T	175 ± 21	44 ± 22	403 ± 91	39 ± 17
1 Aug.	344	216	18 ± 12	T	82 ± 47	37 ± 29	312 ± 146	23 ± 7
1 Sept.	375	267	T	T	19 ± 5	14 ± 7	47 ± 19	T
Comparison		PR > F						
Untreated vs. Treated		0.047						
2.2 kg ha^{-1} vs. 3.4 kg ha^{-1}		0.062						
0.5 vs. 5–15 cm Soil Depth		0.034						

[1]'T' indicates atrazine detected was below the 10 μg kg^{-1} limit of quantification.
'ND' indicates no atrazine detected.

Table 4. Atrazine concentrations[1] measured in 1985 and April 1986 in soil at 0–5 cm and 5–15 cm depths at sampling sites 3 m north (N), south (S), east (E), west (W) of the experimental area treated with the herbicide on 15 May 1985. Depressions (sites 9 and 10) were located northwest (NW) of the experimental area. Sampling date, depth and east-west comparisons were made using preplanned tests of hypothesis.

		1 June 1985		1 July		1 Aug.		1 Sept.		1 April 1986	
Site number	Direction	0–5 cm	5–15 cm	0–5cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
		($\mu g\ kg^{-1}$)									
1	N	T	T	T	T	T	ND	ND	ND	T	ND
2	E	ND	T	T	ND	T	T	ND	ND	T	ND
3	E	106	11	10	T	11	37	ND	T	T	ND
4	E	T	ND	T	T	—	T	10	T	ND	ND
5	S	T	ND	T	T	ND	T	ND	T	16	26
6	W	ND	ND	T	T	T	T	45	ND	T	18
7	W	T	40	152	ND	54	ND	T	T	T	ND
8	W	T	T	11	T	T	T	20	T	16	T
9	NW	581	315	97	34	121	T	12	T	—	—
10	NW	293	20	944	454	55	65	98	418	—	—

Comparison	PR > F
Sampling Date	0.761
Sampling Depth	0.111
East vs. West	0.021

[1]'T' indicates atrazine detected was below the 10 $\mu g\ kg^{-1}$ limit of quantification.
'ND' indicates no atrazine detected.

Table 5. Atrazine concentrations[1] measured in 1985 in soil at 0–5 cm and 5–15 cm depths at sampling sites 3 m north (N), south (S), east (E), west (W) and between (B) blocks at the experimental area treated with the herbicide on 14 May or 23 August 1984. Sampling date, depth and east-west comparisons were made using preplanned tests of hypotheses.

		1 June 1985		1 July		1 Aug.		1 Sept.	
Site number	Direction	0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
		($\mu g\ kg^{-1}$)							
11	N	ND	T	T	28	14	T	16	ND
12	N	ND	12	T	44	T	24	ND	ND
13	E	ND	ND	12	T	10	T	11	ND
14	E	15	T	T	T	29	T	25	12
15	S-E	ND	T	14	T	ND	ND	10	ND
16	E	T	T	T	T	10	—	T	ND
17	E	98	ND	16	ND	ND	ND	ND	ND
18	S	ND	13	T	T	10	32	ND	ND
19	W	ND	ND	33	T	18	T	ND	ND
20	W	T	ND	T	T	22	T	T	ND
21	W	ND \	ND	10	T	11	T	ND	10
22	W	10	ND	41	54	13	T	15	T
23	B	11	ND	33	ND	20	ND	113	ND
24	B	43	ND	12	ND	T	ND	70	ND

Comparison	PR>F
Sampling Date	0.319
Sampling Depth	0.002
East vs. West	0.533

[1]'T' indicates atrazine detected was below the 10 $\mu g\ kg^{-1}$ limit of quantification.
'ND' indicates no atrazine detected.

west than east of the experimental area in May 1985. As the direction was opposite ground water flow, these data did not support significant subsurface movement of atrazine in 1985. Atrazine concentrations were not consistently higher in any particular direction outside of the experimental area at the later sampling dates. Atrazine runoff has been observed to be greater when rainfall occurs shortly after herbicide application (Ritter et al. 1974), and little rainfall was received during the first several weeks after herbicide application in 1985 (Table 2).

A dense grass sod was present in the meadow and a 1.5 to 2.5 cm thick layer of roots, rhizomes and thatch had accumulated on the soil surface. As thatch accumulation would prevent sediment movement off treated areas, atrazine displacement would be limited to transport in water. Variable and irregular distribution of atrazine residues in off-plot soil samples did not indicate significant runoff or subsurface movement of atrazine at the Sandhills meadow during the experimental period.

Conclusions

The hydrology of subirrigated meadows, in which the water table periodically rises to the soil surface, may increase the potential for ground water contamination. Herbicide movement from treated areas could contaminate streams and ponds that drain the meadows. Observations following atrazine application to a subirrigated Nebraska Sandhills meadow did not indicate significant herbicide movement. However, late-season atrazine applications may have greater potential for contamination than spring applications due to slower degradation in cooler soils, and the fact that the water table rises to the soil surface in the fall and winter. Additional studies are needed to adequately characterize atrazine dissipation in naturally subirrigated meadows.

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Estimation of phytomass for ungrazed crested wheatgrass plants using allometric equations

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Abstract

The allometric relationship between plant volume and phytomass of crested wheatgrass was studied for the 1981, 1983, and 1984 growing seasons in west-central Utah. Basal diameters, canopy diameters, and standing plant heights were measured for individual plants. Three models of volume (basal elliptical cylinder, canopy elliptical cylinder, and elliptical cone section) were tested as predictors of plant phytomass using nonlinear regression. Elliptical cone section produced the highest R^2 and lowest SEE, but requires measurement of canopy diameters which may be subject to excessive measurement error. Basal elliptical cylinder produced R^2 and SEE values nearly comparable to those of the elliptical cone section; moreover, this model does not require measurement of canopy diameters, making it the practical choice. Nonlinear regressions for plants by size class (small, medium and large) were produced using 1983 data. Predictive ability of size class-specific equations was compared to that of the equation for all size classes combined. When phytomass of only small or medium size class plants was predicted, the SEE of size class-specific equations was slightly lower than the SEE of the equation for all size classes combined. When phytomass of plants from all size classes was predicted, however, the equation for all size classes combined produced the lowest combined SEE for new data (i.e., data not used to generate the equation). There were substantial year-to-year differences between equations, which indicates the necessity of producing new equations each year.

Key Words: *Agropyron desertorum*, volume-weight relationships, nonlinear regression, biomass prediction

There is considerable interest in using nonlinear models to predict plant biomass (phytomass) because these models generally fit biological data as well as, if not better than, linear models (Payandeh 1983). Allometric equations, which are nonlinear models of the form $y = aX^b$ (Causton and Venus 1981), have been used very successfully to describe relationships between various plant measurements and phytomass. There is an enormous literature reporting the use of allometric equations to relate the phytomass (total, foliage, wood, etc.) of many tree and shrub species to such variables as stem or bole diameter, crown area, and plant height (e.g., Ohmann et al. 1976, Tritton and Hornbeck 1982, Smith and Brand 1983). The generally high R^2 values indicate a good fit, and many equations predict phytomass well (e.g., Crow 1978, Payandeh 1981, Tritton and Hornbeck 1982).

Allometric equations have also been fitted to grass and forb data (e.g., Ohmann et al. 1981, Smith and Brand 1983), but are less common than those for trees and shrubs. The R^2 values are generally low, which may be the result of inappropriate predictor variables, regression model, or both. Percent cover is the most common independent variable used in phytomass prediction equations for grasses and forbs. Large coefficients of variation are associated with low vegetation cover estimates (less than 40% cover) (Hatton et al. 1986), which are common for grasses and forbs. In addition, foliage density and height, and thus phytomass, can be quite variable for any given cover value, introducing still more variation and contributing to a poor fit. An alternative predictor variable is canopy volume, which has not been widely used but which has a strong theoretical relationship to phytomass (Tausch 1980). Canopy volume has shown promise for several grasses and a forb, with coefficients of determination for grasses exceeding 0.80 for both linear and allometric regression equations (Tausch 1980).

Phytomass estimation of grasses and forbs is an important problem in range research and is crucial in evaluation of production and utilization. Considerable effort has gone into examination of relationships between measurable plant attributes and phytomass, and there is a great need for identification of those relationships that will allow accurate prediction of phytomass. The objectives of this study were (1) to describe the relationship between crown volume and phytomass for a single caespitose grass species, crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link)Schult.) using nonlinear regression analysis, (2) to evaluate the accuracy of these equations in predicting phytomass, and (3) to determine whether these allometric equations varied over time.

Methods

The study was conducted in Tintic Valley, approximately 8 km southwest of Eureka, Utah, on a research area maintained cooperatively by Utah State University and the Bureau of Land Management (U.S. Department of Interior). The area has an elevation of approximately 1,830 m and an average precipitation of 320 mm, the majority of which falls in winter and spring (Cook 1966). Twenty-four improved pastures (28 ha each) were established on the area in the late 1940's and early 1950's on land previously dominated by sagebrush (*Artemisia tridentata* Nutt. spp. *tridentata* Beetle) and juniper (*Juniperus osteosperma* [Torr.] Little). The 9 improved pastures utilized in this study had been seeded to crested wheatgrass either in monoculture or in combination with 1 or more other grass species following removal of the woody species.

Crested wheatgrass plants were protected from livestock grazing and sampled during the 1981, 1983, and 1984 growing seasons. Since genetically distinct individuals are difficult to distinguish in caespitose grasses, a plant was defined as a clump of continuous grass cover that is spatially distinct from its neighbors. Plants selected at each sampling date were chosen to represent the range of plant sizes (based on basal area) in the pasture sampled. Standing plant height and 2 or more diameters were measured on each plant. Diameter measurements excluded dead areas of the plant crown greater than 1 cm in diameter. The plants were then clipped to the crown and any dead material from previous growing seasons was removed. Each plant was placed in a paper bag, oven dried at 70° C, and weighed. Data collection methods varied between years, especially as regards diameter measurements, pastures sampled, and sampling dates. The following sections provide additional information on collection methods.

1981 Data

Approximately 35 plants were collected on each of 5 dates in pasture 17 (13 May to 9 June at about 1-week intervals), on each of

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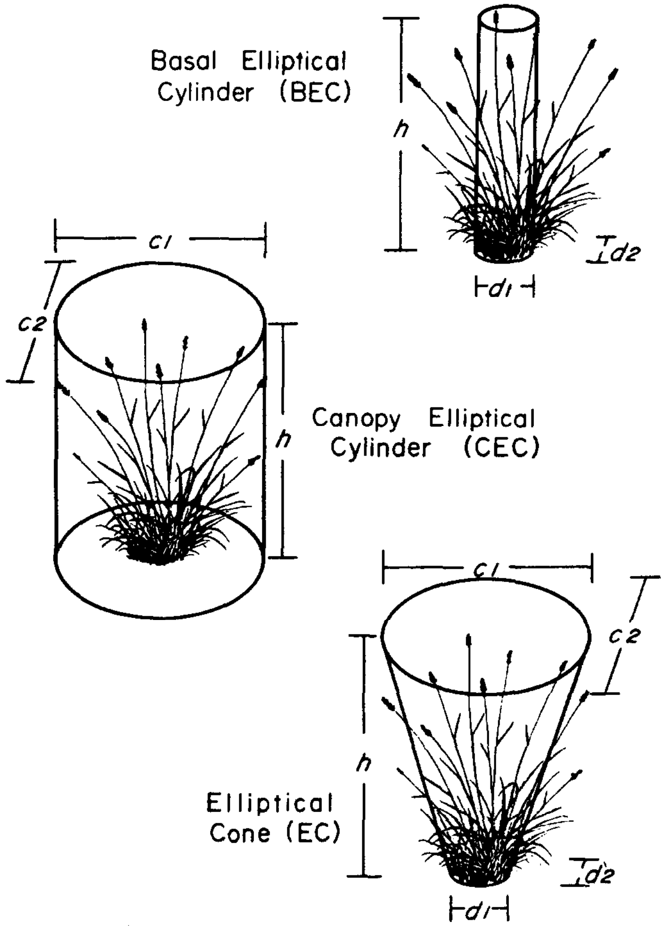

Fig. 1. *Diagrammatic representation of a crested wheatgrass plant and three models for describing its volume.*

9 dates in pasture 19 (6 May to 10 July at about 1-week intervals) and on each of 5 dates in pasture 8 (17 June to 15 July at about 1-week intervals). Total sample size was 669. Two basal (crown) diameters for each plant were measured (the greatest and the greatest perpendicular to the first) and averaged, and the average basal diameter was recorded in the field.

1983 Data

Approximately 15 plants were collected from each of 4 pastures (2, 8, 18, and 22) on each of 4 dates: 26 May, 31 May, 8 June, and 23 June. An additional 15 plants were collected from each of 2 pastures (14 and 19) on all but the first sampling date. Total sample size was 324. Diameter measurements recorded in the field for each plant included:

d_1 = longest basal diameter
d_2 = longest basal diameter perpendicular to d_1
c_1 = longest canopy diameter
c_2 = longest canopy diameter perpendicular to c_1

1984 Data

A total of 43 plants were collected on 13 May from pastures 8, 14, 18, and 19 and a total of 50 plants were collected on 28 June from pastures 9, 10, 17, 18, and 19. Total sample size was 93. Diameter measurements were determined as in 1983.

Analyses

Three models (Fig. 1) were used to describe the volume occupied by the aboveground portion of crested wheatgrass plants: (1) basal elliptical cylinder (BEC) calculated using basal diameters and plant height, (2) canopy elliptical cylinder (CEC) calculated using canopy diameters and plant height, and (3) elliptical cone section (EC) calculated using plant height and both canopy and basal diameters. Equations for calculating these volumes are:

$$BEC = \frac{\pi d_1 d_2 h}{4}$$

$$CEC = \frac{\pi c_1 c_2 h}{4}$$

$$EC = \frac{\pi h}{6} \left(\frac{d_1 d_2}{4} + \frac{d_2 c_1}{4} + \frac{c_1 c_2}{2} + \frac{d_1 d_2}{2} \right)$$

where: d_1 = longest basal diameter ($d_1 = d_2$ for 1981 data)
d_2 = longest basal diameter perpendicular to d_1
c_1 = longest canopy diameter
c_2 = longest canopy diameter perpendicular to c_1
h = standing plant height

Allometric equations of the form:

$y = a + bV^c$
where y = phytomass (g)
V = canopy volume (cm^3) defined as BEC, CEC or EC, above and
a, b and c = nonlinear regression coefficients,

were fitted to data using a Simplex algorithm (Caceci and Cacheris 1984). Goodness of fit was measured by R^2 and standard error of the estimate (SEE) was used to express precision of estimation. Residuals for these analyses were determined to be approximately normally distributed.

The 9 plant size classes of Norton and Johnson (1981, 1986) were reduced to three: (1) small (basal area < 80 cm^2), (2) medium (80 $cm^2 \leq$ basal area < 180 cm^2), and (3) large (basal area $\geq$ 180 cm^2). Data from 1983 were divided according to these classes for analysis by size.

The data sets for the 3 years as well as data for the 3 size classes in 1983 were each randomly divided into 2 groups. The first (the fitted data) consisted of approximately 70% of the data from an original data set and were used to generate a nonlinear regression equation. The remaining 30% (the test data) were used to validate the regression equation (Snee 1977). SEE was calculated separately for the

Table 1. Comparison of 3 volume models for crested wheatgrass plants for 1983 and 1984 using nonlinear regression analysis.

Year	Volume[1]	Nonlinear regression coefficients[2]				SEE
		a	b	c	R^2	
	BEC	2.547147	0.001011	1.120109	0.8463	7.9629
1983	CEC	0.113934	0.000028	1.299936	0.7982	9.1247
	EC	4.429602	0.000007	1.485287	0.8817	6.9871
	BEC	0.080242	0.013790	0.777349	0.7957	4.7705
1984	CEC	−0.468961	0.006120	0.797446	0.7664	5.1016
	EC	−0.269877	0.006946	0.812984	0.7963	4.7644

[1]Volume models are basal elliptical cylinder (BEC), canopy elliptical cylinder (CEC) and elliptical cone section (EC).
[2]Nonlinear regression model is $y = a + bV^c$ where y = phytomass, and V = plant volume (calculated as BEC, CEC, or EC).

Table 2. Comparison of nonlinear regression equations for small, medium, large and all size classes of crested wheatgrass plants collected in 1983, using data to which equations were fitted (70% of each data set) and test data (remaining 30% of each data set).

Size	Nonlinear Regression coefficients[1]			Fitted Data statistics				Test Data statistics		
Class	a	b	c	n	R^2	SEE_{sc}	SEE_{all}	n	SEE_{sc}	SEE_{all}
S	1.3780	0.000031	1.6301	110	0.795	1.964	2.723	50	2.584	2.725
M	4.8534	0.000005	1.7478	72	0.721	5.768	7.463	30	6.183	6.220
L	2.6373	0.000293	1.2344	46	0.873	13.982	14.465	14	21.478	19.912
ALL	2.5298	0.000797	1.4111	228	0.873	7.149	7.843	94	8.872	8.207

[1]Nonlinear regression model is $y = a + bV^c$ where y = phytomass and V = plant volume calculated as BEC.

fitted data and the text data for all years; SEE was also calculated for each size class for the 1983 data using size class-specific equations (SEE_{sc}) and for the equation in which all size classes were combined (SEE_{all}). In order to determine SEE for an entire fitted or test data set (all size classes combined) when size class-specific equations were used, the equation to calculate SEE was expanded:

$$SEE = \left(\frac{\Sigma(y_i - \hat{y}_i)^2 + \Sigma(y_j - \hat{y}_j)^2 + \Sigma(y_k - \hat{y}_k)^2}{n_i + n_j + n_k - 6}\right)^{1/2}$$

where $y\hat{r}$ = the observed phytomass and
$\hat{y}_r = \hat{a} + \hat{b}V_r^{\hat{c}}$
for:
the ith small plant when r = i,
the jth medium plant when r = j, and
the kth large plant when r = k,
where:
$\hat{a}$, $\hat{b}$ and $\hat{c}$ = nonlinear regression coefficients of the size class-specific equations, and
n_i, n_j, and n_k = sample size for small, medium and large size classes, respectively.

Residuals for these analyses were determined to be approximately normally distributed.

Results and Discussion

The fit of each model of crested wheatgrass plant volume (basal elliptical cylinder, canopy elliptical cylinder and elliptical cone) was tested using only the 1983 and 1984 data because canopy diameters, and thus CEC and EC, were unavailable for 1981. The results of nonlinear regression analysis (Table 1) indicated that the elliptical cone model provided the best fit, canopy elliptical cylinder the poorest, and basal elliptical cylinder was intermediate. The shape of a crested wheatgrass plant is more conical than cylindrical (Fig. 1), so it is not unlikely that the relationship between EC and phytomass would produce the best results. The improvement in SEE and R^2 when equations in which EC rather than BEC was the independent variable is not as great as might be expected. This is likely due to the fact that calculation of conical volume requires canopy diameters, which are subject to more measurement error than basal diameters. Canopy boundaries are seldom well defined, and windy conditions increase the subjectivity of measurement. Basal diameter measurements, on the other hand, are much easier to obtain and the results are more reliable, as indicated by the higher R^2 and lower SEE for BEC compared to those for CEC.

The error associated with estimating canopy diameters can reduce the advantage gained by calculating plant volume using the more realistic elliptical cone equation. The expense of measuring canopy diameters in addition to basal diameters makes it apparent that, of the models considered, the basal elliptical cylinder provides a good compromise of realism, reliability and expense. Thus we have chosen to use volume calculated as BEC for the data presented in this paper.

Results of nonlinear regression analysis for plants collected in 1983 and separated into 3 size classes are presented in Table 2. As would be expected, each SEE_{sc} for the fitted data was smaller than SEE_{sc} for the test data. A comparison of the size class-specific equations with the equation generated for all size classes in terms of their ability to predict phytomass for each size class (SEE_{sc} versus SEE_{all}) produced mixed results (Table 2). Phytomass was best predicted using size class-specific equations rather than the equation for all size classes combined in all cases except for large test plants. The difference between SEE_{sc} and SEE_{all} was usually relatively small, which indicates only a small advantage in producing separate equations for each size class.

Another comparison of the precision of estimation of size class-specific equations versus the equation for all size classes combined was made using plants of the entire (all size classes combined) fitted and test data sets (Table 2). Again, there were only small differences between SEE_{sc} and SEE_{all} for both the fitted and test data. For the fitted data, SEE_{all} exceeds SEE_{sc}, with the reverse being the case for the test data. The small differences between SEE_{sc} and SEE_{all}, both for size class specific and combined size class data, indicate there is no great advantage in developing equations specific to plant size, especially when phytomass must be predicted for plants from a wide range of size classes. If, however, phytomass of only small and medium sized plants is to be predicted, the greater precision of prediction may be sufficient justification for collection of sufficient data to generate 2 separate nonlinear regression curves.

Ideally a nonlinear equation relating plant volume to phytomass for 1 year would be valid for all years. However, this does not appear to be the case for crested wheatgrass. The coefficient c (the

Table 3. Comparison of nonlinear regression equations for 3 years using R^2 and SEE for data to which equations were fitted (70% of each data set) and SEE for test data (remaining 30% of each data set).

Year	Nonlinear Regression coefficients[1]			Fitted Data statistics			Test Data statistics	
	a	b	c	n	R^2	SEE	n	SEE
1981	−0.749803	0.302264	0.337041	460	0.6790	1.5978	209	1.6146
1983	2.529759	0.000797	1.141111	228	0.8734	7.8425	96	8.2074
1984	0.145643	0.015307	0.759322	65	0.8253	4.2548	28	6.2266

[1]Nonlinear regression model is $y = a + bV^c$ where y = phytomass and V = plant volume calculated as BEC.

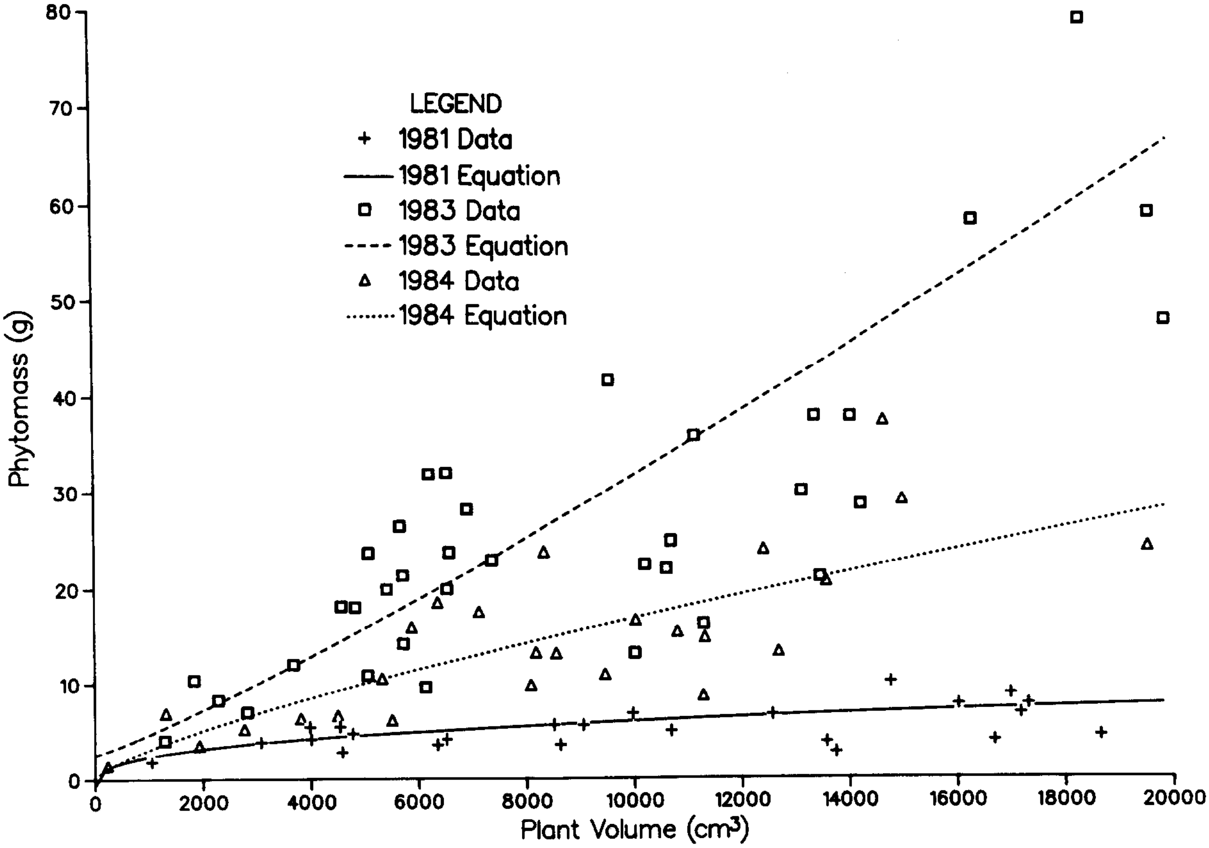

Fig. 2. *Plots of random subsets of 1981, 1983, and 1984 plant volume (basal elliptical cylinder) and phytomass data, and the curves developed for those data using allometric equations.*

power of the volume) ranged from 0.337041 to 1.14111 over the 3 years (Table 3). These functions were plotted over a range of canopy volumes typical for plants found at the study site (Fig. 2). Obviously the predicted phytomass for any given canopy volume changes markedly with a change in equations, and an equation fitted to data from 1 year will not accurately predict phytomass for a different year. This may be due in part to the fact that the aboveground structure of grasses is reconstructed every growing season and is subject to environmental perturbations which may affect the volume-to-weight relationship. Equations developed for shrubs and trees are probably more stable, due to the presence of a perennating structure which more regularly defines plant volume.

For the 3 years, R^2 ranged from 0.6790 in 1981 to 0.8734 in 1983 (Table 3). The low R^2 in 1981 is at least partially due to the use of average basal diameter in calculating plant volume. Since $d_1 = d_2$, plant volume was calculated as a circular cylinder (a special case of an elliptical cylinder), which is often an inappropriate model of crested wheatgrass plant volume. The improvement in R^2 for equations using 1983 and 1984 data reflects the use of actual diameter measurements and the use of an elliptical cylinder (rather than circular) to describe volume.

Conclusions

Theoretically, a cone may be the most realistic model of the volume occupied by a crested wheatgrass plant; however, our results indicate that an elliptical cylinder calculated using plant basal diameters may be a more practical choice. Errors associated with measuring canopy diameter and the additional expense of these measurements make the potentially more accurate cone model less desirable. Production of nonlinear regression equations for each plant size class appears unnecessary when the phytomass of plants of a wide range of size classes is to be estimated. It may, however, be beneficial if the goal is to predict phytomass for only small and medium-sized plants. Extreme annual variation in the coefficient estimating the power of the allometric equation for crested wheatgrass indicates that the relationship between volume and weight was extremely variable. Thus, allometric equations for grass species should be generated yearly.

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Methods of ytterbium analysis for predicting fecal output and flow rate constants in cattle

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Abstract

Continuous or pulse doses of Yb-labeled feedstuffs with subsequent fecal sampling can be used to estimate digesta passage rates and fecal output in ruminants. However, the validity of such estimates is affected by mineral elements in fecal samples that interfere with atomic absorption analysis of Yb. A procedure was developed involving co-precipitation (CoP) of Yb with lanthanum (La) oxalate at pH 1.0 to separate Yb from interfering elements present in the fecal matrix. The procedure was tested for accuracy of Yb determination, repeatability, and for validity of predicting fecal output. Repetitive analysis of the same sample resulted in a coefficient of variation of 2.2% for the CoP technique. An experiment using 12 mature Angus cows offered 1 of 4 diets tested the accuracy of predicting fecal output using one- and two-compartment models. Cows were pulse-dosed with Yb-marked orchardgrass neutral detergent fiber, and fecal samples were collected from the rectum at 9, 12, 15, 18, 24, 32, 40, 48, 60, 72, 84, and 96 h after dosing. Ytterbium content of fecal samples was determined by neutron activation (NA) or atomic absorption spectrophotometry after slow oscillation of the fecal ash for 12 h in 3 M nitric and 3 M hydrochloric acid (acid leaching; AL) or CoP of Yb with La oxalate. For fecal Yb concentrations fit to the one-compartment model, the k_0 parameter (scaling factor related to initial marker in the age-dependent compartment) was greater ($P<.05$) for CoP than for AL or NA. Likewise, calculated first appearance of marker (Tau) and the age-dependent rate constant (k_1) were greater ($P<.05$) for CoP than for NA. For the two-compartment model, the initial marker concentration estimate (λ_0) was greater ($P<.05$) for CoP than for NA or AL, and Tau was less ($P<.10$) for NA than for CoP. Rate constant estimates (λ_1, λ_2) were not affected by method of analysis. For both models, fill and retention time estimates differed ($P<.05$) between CoP and NA. Fecal output estimated from both models was similar to actual fecal output for CoP, but the one-compartment model estimate of fecal output for AL and NA over-estimated ($P<.05$) actual fecal output. Likewise, the two-compartment model estimate of fecal output for NA was greater ($P<.05$) than actual fecal output. Co-precipitation of Yb with La oxalate appears to be a valid analytical procedure that may yield more accurate estimates of fecal output than other reported procedures.

Key Words: ytterbium analysis, external markers, digestibility, fecal sampling

Accurate determination of particulate passage rate, fecal output and voluntary intake requires accurate measurement of external digesta-marker concentrations. Presently, a number of procedures exist for the solubilization of ytterbium (Yb) from fecal matter before atomic absorption spectrophotometry. Ellis et al. (1982) proposed a procedure in which the Yb is "leached" from ash residue with a mixture of 3 N nitric acid (HNO_3) and 3 N hydrochloric acid (HCl). The use of ethylenediamine-tetraacetic acid (EDTA; Hart and Polan 1984) or diethylenetrinitrilo-pentaacetic acid (DTPA; Firkins et al. 1984) have also been proposed as leaching agents for Yb. Iron, Ca, Mg, Na, Al, K, Ba, and Sr have suppressive effects on the atomic absorption spectrophotometric determination of Yb (Mazzucotelli et al. 1982) that are curvilinearly dependent upon the interfering element to Yb ratio. Solutions of .1 M HCl or .1 M EDTA have been used to extract Ca, Mg, K, Cu, Mn, Zn, Fe, Al, P, B, and Sr from plant tissues (Baker and Greweling 1967). The problem of solubilizing interfering elements can be addressed by preparing standards from fecal samples taken before Yb dosage (Ellis et al. 1982, Firkins et al. 1984, Hart and Polan 1984). This approach, however, assumes solubilization of a constant amount of interfering elements from each fecal sample. The purpose of this study was to develop an atomic absorption spectrophotometric technique for Yb analysis which replaces a matrix of unknown element fluctuation between sampling times with one of consistent and known elemental composition. The new technique was compared to an acid leaching procedure (Ellis et al. 1982) and neutron activation (Gray and Vogt 1974) for determining particulate passage rate constants and predicting fecal output in cattle.

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Materials and Methods

Trial 1. Analytical Technique

A procedure involving co-precipitation (CoP) of Yb and lanthanum (La) with oxalic acid was developed and tested in the following manner.

1. Fecal samples were collected, dried at 55° C for 48 hr, allowed to equilibrate to atmospheric moisture, then ground to pass through a 1-mm screen using a Wiley mill.
2. Approximately 1 g air-dry feces was weighed into dry 50-ml narrow mouth, heavy glass plasma containers or 50-ml narrow mouth Kimax erlenmeyer flasks (Kimble 26500).
3. Samples were dried at 100° C for 6 h to determine the sample dry matter then ashed at 500° C for approximately 10–12 h to ensure complete ashing of the sample in the narrow-mouth containers.
4. The ash residue was boiled in 5 ml concentrated HCl for 15 minutes with occasional swirling, then transferred to 50-ml volumetric flasks, diluted to volume with deionzied water and mixed thoroughly. The solution was allowed to stand for a minimum of 6 h to allow undissolved ash residue to settle.
5. A 25-ml aliquot was removed from the upper portion of each flask and placed in a 50-ml graduated screw-cap centrifuge tube (38 × 114 mm; Corning 25339).
6. One milliliter of La (20,000 ug/ml) was added to the solution and pH adjusted to 1.0 ± .05 using dilute (1:1; v/v) ammonium hydroxide with deionized water or concentrated HCl. The pH electrode was soaked in pH 1 buffer for 1–2 d prior to use and at all times between uses.
7. Two milliliters of a 5% (w/v) aqueous solution of oxalic acid were added to the tube resulting in formation of a cloudy white precipitate. The solution was stirred vigorously with a glass rod.
8. Tubes were placed in a 90° C water bath for 25 min, cooled for 25 min and centrifuged for 20 min at 3,000 rpm.

9. Supernatant fluid was decanted and .5 ml concentrated perchloric acid ($HClO_4$) was added and swirled to dissolve the precipitate. Tube walls were rinsed with approximately 4–5 ml of deionized water.

10. Three drops of 5% (w/v) aqueous potassium permanganate ($KMnO_4$) were added and the tube swirled using a vortex until the purple $KMnO_4$ color disappeared. Tubes were inspected to insure that all the precipitate was in solution. If not, the tubes were vortexed until the precipitate dissolved. The titration procedure was repeated with dropwise additions until the solution was no longer colorless, indicating the oxalic acid had been consumed. At this point, swirling by hand was sufficient.

$$2MnO_4^- + 5H_2C_2O_4 + 6H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

11. One drop (.04 ml) of 30% hydrogen peroxide was added to reduce excess MnO_4^- to Mn^{2+} and the solution was swirled. Deionized water was added to dilute the final solution to 25 ml total volume. Because the Yb standard curve was nonlinear above 6 ug/ml, solutions estimated as having greater than 6 ug/ml Yb were diluted to 50 ml with deionized water and compared with standards which were similarly prepared.

12. Ytterbium concentrations of the final solutions were determined by atomic absorption spectrophotometry at a wavelength of 398.8 nm using a nitrous oxide/acetylene flame.

Validation of the CoP procedure was evaluated using fecal samples obtained from cattle offered a range of Yb-free diets

Table 1. Absorbance readings of various fecal matrices to which 4 ug/ml Yb were added before extraction of Yb by a La oxalate co-precipitation procedure.

Animal diets (% of each ingredient)	Absorbance units	% of standard
Corn:Corn silage:Soybean meal (70:25:5)	.166	94.9
Corn:Timothy hay (25:75)	.173	98.9
Silage:Soybean meal (95:5)	.180	102.8
Timothy hay	.173	98.9
Corn gluten feed:Timothy hay (30:70)	.177	101.1
Fescue pasture	.179	102.3
Alfalfa haylage	.183	104.7
Alfalfa haylage:Corn (40:60)	.172	98.2
Mean	.175	100.2
Standard error	.0019	1.10
4-ppm Yb standard	.175	100

(Table 1). Approximately 1 g dried (55° C for 72 hr) feces was ashed, boiled for 15 min in concentrated HCl, and diluted to a final volume of 50 ml. One hundred micrograms of Yb were added to a 25-ml aliquot of the Yb-free solution to provide a final Yb concentration of 4 ug/ml. Ytterbium concentrations were determined using the described CoP technique. Fecal composite samples were obtained by mixing equal quantities of each of the previously used fecal samples. Composite samples were ashed and 100 ug Yb added to the 25-ml aliquot prior to CoP to estimate a coefficient of variation (Snedecor and Cochran 1980) for the procedure. All standards were prepared using the CoP technique without the addition of fecal ash to the original solutions.

Trial 2.

Twelve mature Angus cows that were in their last third of gestation were used in a total collection study to evaluate the accuracy of fecal output prediction from Yb data when dietary composition varied. Chopped (10-cm screen) orchardgrass (*Dactylis glomerata* L.) hay was fed ad libitum and was either offered as the only dietary source or was supplemented once daily with isocaloric and isonitrogenous supplements consisting of either 1,360 g chopped alfalfa (*Medicago sativa* L.) hay, 419 g soybean meal plus 502 g cracked corn, or 60 g urea plus 1,315 g liquid cane molasses. Cows were grouped by age and body weight and randomly assigned to 1 of 4 dietary treatments. A dietary adaptation period of 16 d was followed by 5 d of total feces and urine collection. Feces were collected daily, weighed, mixed, subsampled and dried at 55° C to determine fecal output. At 1800 hr of the first day of total collection, cows were pulse-dosed with 200 g (air dry basis) of Yb-marked orchardgrass hay which had previously been extracted with neutral detergent fiber solution (Goering and Van Soest 1970) without EDTA. Hay was marked according to the immersion technique of Teeter et al. (1984). Fecal samples were collected from the rectum at 9, 12, 15, 18, 24, 32, 40, 48, 60, 72, 84, and 96 hr after dosing and dried at 55° C. Total fecal output was corrected for the amount of dry feces taken via rectal samples. Ytterbium content was determined by neutron activation (NA; Gray and Vogt 1974), or by atomic absorption spectrophotometry after; (1) acid leaching (AL; Ellis et al. 1982) with standards made from similar fecal matrices, or (2) CoP with standards processed similarly to samples but without addition of fecal ash. Ytterbium content of the ground (1mm) marked forage was determined by the 3 previously described techniques using smaller sample sizes. Marked forage analyzed by the acid leaching technique was compared with standards made from matrices of orchardgrass hay NDF diluted similarly to the marked forage sample.

Statistical Analyses

Concentrations of Yb in fecal samples determined from each procedure were fitted to one- and two-compartment models proposed by Pond et al. (1982) and further described by Judkins et al. (1987). These models produced rate constants that were used to estimate particulate passage rates, gastrointestinal tract fill, and fecal output. With the exception of fecal output, orthogonal contrasts (Snedecor and Cochran 1980) were used to compare CoP with NA and AL. Orthogonal contrasts were also used to compare fecal output estimated by total collection with that predicted by each model and analytical technique.

Results and Discussion

Analytical Methods

Absorbance readings from a known quantity of Yb added to various fecal matrices and compared with a pure chemical standard prepared according to the CoP technique are shown in Table 1. These data indicate that Yb may be quantitatively recovered from a broad range of fecal matrixes by CoP of Yb with La oxalate and that this procedure may be used to overcome matrix interference. When a known quantity of Yb was added to the same fecal samples following ashing and acid solubilzation but analyzed before the CoP step of the procedure, Yb absorbance readings ranged between 55 and 89% of that of a pure chemical standard (Coffey and Pickett, unpublished data). The CoP procedure is not protected from matrix interference, having in the final solution elements which may either suppress or enchance the absorbance signal of Yb (Mazzucotelli et al. 1982). However, by quantitative addition of reagents and titration with $KMnO_4$, interfering elements should be in similar quantities in each sample. Also, comparisons of pure chemical standards prepared by the CoP technique with pure chemical standards which were not prepared by the CoP technique indicated a 98% recovery of Yb by the CoP technique. Therefore, the matrix remaining after co-precipitation of Yb with La oxalate does not appear to cause absorbance interferences, but preparing samples and standards similarly should standardize the matrix and eliminate any concerns. Precipitation of other elements is prevented by adjusting the pH to 1.0 ± .05 preceding oxalic acid addition. Calcium, the most common precipitated element was not precipitated in measurable quantities at a pH below 1.4.

Results of analyses on samples having a similar matrix (Table 2) suggest that acceptable precision and accuracy may be attained by the CoP procedure when samples are compared with similarly prepared standards. The differences in absorbance reading between the standards used in Tables 1 and 2 resulted from daily variation of the atomic absorption spectrophotometer or minor optimization differences because the samples were compared with the same prepared standard. Standard errors of absorbance readings across sample types (Table 1) and within a constant sample type (Table 2) were similar, indicating the variation between samples in Table 1

Table 2. Precision of Absorbance readings from the same fecal matrix to which 4 ug/ml Yb was added before extraction of Yb by a La oxalate co-precipitation procedure.

Sample	Absorbance units	% of standard
1	.178	103.5
2	.170	98.9
3	.168	97.6
4	.176	102.5
5	.172	100.0
6	.175	101.8
Mean	.173	100.7
Standard Error	.0016	.92
Coefficient of variation	2.21%	2.23%
4-ppm Yb standard	.172	100

was more likely due to variation in technique rather than variation in the ability to overcome matrix interferences.

Fecal Output and Passage Rate

Mean values for each parameter derived from both the one- and two-compartment models (Pond et al. 1982) were evaluated by dietary treatment. Although numerical differences were present among dietary treatments, no significant ($P>.10$) diet effects were observed for any of the variables measured. Therefore, data were pooled across diets within each analytical technique. Parameters k_0 (scaling factor related to initial marker in the age dependent compartment), k_1 (age dependent rate constant) and tau (calculated time of first appearance of marker in the feces) derived from the one-compartment model differed ($P<.05$) between CoP and NA. Likewise, k_0 and tau differed ($P<.05$ and $P<.10$, respectively) between CoP and AL (Table 3). Ellis et al. (1982) reported 98.8% solubilization of Yb from feces by the AL technique. Therefore differences in parameter estimates probably resulted from matrix fluctuations. Ellis et al. (1982) attempted to reduce matrix problems by preparing standards from a zero-hour sample matrix, an approach that assumes a constant matrix at each sampling time. Gray and Vogt (1974) minimized matrix interference by allowing a decaying period to permit deterioration of shorter-lived isotopes. It is possible, however, that these allowances are not completely effective.

Table 3. Parameter estimates from one- and two-compartment analysis of cow fecal Yb excretion data with Yb analysis by 3 analytical techniques.

Item	Technique: Acid leaching	Co-precipitation	Neutron activation	SE[a]
	one-compartment model			
k_0[bc]	29933	33642	26150	1694.2
k_1[c]	.048	.048	.042	.0022
Tau[cd]	18.5	20.1	17.8	.81
	two-compartment model			
λ_0[bc]	887	1156	742	112.9
λ_1	.156	.131	.126	.1062
λ_2	.029	.033	.027	.0043
Tau[e]	16.5	16.1	14.4	.85

[a]Standard error (N=12).
[b]Co-precipitation vs Acid leaching ($P<.05$).
[c]Co-precipitation vs Neutron activation ($P<.05$).
[d]Co-precipitation vs Acid leaching ($P<.10$).
[e]Co-precipitation vs Neutron activation ($P<.10$).
k_0 = concentration of marker in the feces if instantaneously mixed.
k_1 = age dependent rate parameter.
Tau = time delay.
λ_0 = concentration of marker if instanteously mixed in the rumen.
λ_1 = time-dependent turnover rate.
λ_2 = time-independent turnover rate.
Tau = time lag.

The parameter estimate k_0 is used to calculate undigested dry matter fill and fecal output. Therefore, inaccurate values for k_0 result in erroneous values for fill and fecal output. Particulate flow rates are estimated using k_1, from the one-compartment model and therefore may be similar between AL and CoP, depending upon the degree of matrix fluctuation from the zero-hour sample. Tau represents the estimated time, postdosing, at which the marker first appears at detectable levels in the feces and is used to calculate retention time of the marked feedstuff in the intestinal tract.

Lambda$_0$ values derived from the two-compartment model and estimated from Yb concentrations determined by CoP were greater ($P<.05$) than those estimated by AL and NA techniques. Tau values estimated by CoP were similar ($P>.10$) to those estimated by AL but tended to be greater ($P<.10$) than those estimated by NA. Values for λ_1 and λ_2 estimated by CoP were similar ($P>.10$) to those estimated by AL and NA.

Fecal output predictions using parameter estimates derived from both the one- and two-compartment models are shown in Table 4. Orthogonal contrasts were used to compare values estimated by each technique with actual fecal output (avg. 3,781 g/day). When one-compartment values are considered, fecal output values estimated by CoP were similar statistically ($P = .27$) to total collection but overestimated by 7%. Fecal outputs estimated by AL overestimated ($P<.05$) actual fecal output by 13.9% while NA over-estimated ($P<.05$) fecal output by 27.4%.

Table 4. Fecal output, flow rates, fill and retention time in cows as estimated by one- and two-compartment models and 3 techniques for Yb analysis.

Item	Technique: Acid leaching	Co-precipitation	Neutron activation	SE[a]
Actual fecal output, g/day		3781		
	one-compartment model			
Fecal output, g/day	4306[b]	4051	4816[b]	243.4
Flow rate, h^{-1}[c]	.028	.029	.025	.0013
Fill, g[c]	6317	5883	8111	361.4
Retention time, h[c]	61.3	61.6	66.0	1.73
	two-compartment model			
Fecal output g/day	4092	3871	4552[b]	254.6
Fill, g[c]	6023	5171	7453	503.7
Retention time, h[c]	66.2	65.1	71.9	2.66

[a]Standard error (N=12).
[b]Values followed by superscript differ ($P<.05$) from total collection (avg. 3781 g/day).
[c]Co-precipitation vs Neutron activation ($P<.05$).

Two-compartment model values appeared to more closely estimate actual fecal output. Fecal output values estimated by CoP and AL were similar ($P = .73$ and .23, respectively) to total collection, over-estimating actual fecal output by 2.4 and 8.2% respectively. Neutron activation values were 20.4% greater ($P<.05$) than total collection estimates of fecal output. Hunt et al. (1984) and Mader et al. (1984) have reported acceptable agreements between actual fecal output and fecal output estimated using Yb concentrations from a pulse dose. However, Mader et al. (1984) corrected for matrix fluctuations by use of the standard additions technique (Beukelman and Lord 1960). Other workers have not been able to repeat these results (Paterson, J.A., R.R. Worley and W. Martin, unpublished data) with grazing animals or have otherwise obtained questionable results from Yb generated data (Turner, K.E., J.A. Paterson, C.S. Saul, unpublished data; W.G. Bergen, personal communication). These discrepancies possibly result from a greater degree of fluctuation in the fecal mineral content than was present in the study by Hunt et al. (1984).

One-compartment model estimates of passage rate, as well as one- and two-compartment model estimates of undigested dry matter fill and retention time estimated by CoP differed ($P<.05$) from those estimated by NA. All values for flow, fill and retention time were similar ($P>.10$) between CoP and AL.

Co-precipitation of Yb with La oxalate appears to be a viable technique for determination of Yb concentration in fecal samples. The method provides a means of standardizing the sample matrix as well as reducing the number of and quantity of interfering elements. Others have proposed to minimize matrix interferences by using dilute solutions of solubilizing agent and preparing standards from matrices of similar composition. The AL procedure specifies dilute acids and slow solubilization of Yb to decrease extraction of undesirable salts (Ellis et al. 1982). However, Baker and Greweling (1967) used .1 M HCl to extract many of the interfering elements from plant material. Hart and Polan (1984) attempted to minimize the fecal matrix by extracting with dilute (.05 M) EDTA and by using a small sample size (200 mg). Furthermore, atomic emission has been used to attain greater sensitivity (Kniseley et al. 1969) than atomic absorption. However, the increased sensitivity would only be expected from a flame emission spectrophotometer with specifications similar to that indicated by Kniseley et al. (1969). It is suspected that interfering elements are solubilzed by dilute EDTA (.05M) and that the solubilization of these elements may fluctuate, resulting in matrix differences.

The effect of the presence of foreign elements on the atomic absorption spectrophotometric characteristics of Yb are vastly different from those effects on other elements in the Lanthanum series (Mazzucotelli et al. 1982). These authors concluded that only a few of the differing effects could be explained by usual spectral considerations such as spectral buffering or other general optical causes. Although a number of elements interfere with the atomic absorption signal of Yb (Mazzucotelli et al. 1982), it is presently unknown how the elements interact when combined in a solution such as a fecal matrix. In one example, single element additions of 5,000 ug/ml La or potassium (K) enhanced the atomic absorption signal of a 4-ug/ml Yb solution (Coffey and Pickett, unpublished data). These results are expected in light of the data by Mazzucotelli et al. (1982). However, when a mixture of 5,000 ug/ml La plus 5,000 ug/ml K was added to a 4-ug/ml Yb solution, the atomic absorption signal was highly suppressed, indicating undesirable and unpredictable effects of mixed solutions on the absorption reading of Yb. Therefore, to correct for matrix interference, Yb shall be carefully precipitated from the fecal matrix unless the technique of standard addition is used.

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The use of comparative yield and dry-weight-rank techniques for monitoring arid rangeland

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Abstract

The comparative yield (CY) method for estimating pasture dry weight and the dry-weight-rank (DWR) method for determining species composition were applied in a variety of arid vegetation types by several operators. The methods were evaluated for their suitability in a range monitoring program, on the basis of consistency of estimates and the time taken. Four calibration regressions for the CY technique were compared initially and, of these, linear regression of untransformed data is recommended. Differences among operators' yield estimates were unacceptably large, and the procedure of standard selection and calibration was too slow. We suggest that photographic standards can reduce the time taken and improve precision. The DWR technique was recommended because operators achieved consistent estimates of species composition within 80 minutes, which we regarded as a reasonable time for a monitoring procedure. Weighted multipliers did not improve composition estimates. The technique was easy to use but initial training of operators was important. While fixed quadrats would probably reduce differences caused by spatial variability, time spent relocating quadrats could be excessive.

Key Words: pasture yield, composition, consistency, time

Methods for determining herbage species composition and yield are basic requirements for interpreting seasonal and management effects in most native pastures. For the purposes of range monitoring, methods need to be rapid and capable of sampling adequately across the spatial heterogeneity in vegetation distribution. Methods must also be effective regardless of seasonal conditions, and different operators should be able to use them consistently.

There have been many studies of particular methods (e.g., van Dyne et al. 1963, Bonham 1976, Santillan et al. 1979, Strauss and Neal 1983), usually focussing on the size, shape, or number of sampling units. In general they have not compared the performance of several operators with the same technique. Fewer studies have investigated the comparative performance of several methods at once (Hyder and Sneva 1960, Walker 1970, Poissonet et al. 1973, Reese et al. 1980). This may not be an important consideration in relatively uniform, high yielding vegetation; but, in arid and semi-arid rangelands where vegetation is sparse and very unevenly distributed, some commonly used methods fail.

Working in the arid rangelands of central Australia, Friedel and Shaw (1987) compared several operators using 3 techniques for pasture cover or yield and 4 for pasture composition. The techniques were: aerial cover with a wheelpoint apparatus, yield from quadrat clipping, and yield from whole-site estimation after clipping; pasture composition was estimation with the same techniques and with frequency quadrats. No technique was found in which operator differences were reduced to acceptable levels within realistic time limits. Using single operators was essential, to minimize errors. With this proviso, the wheelpoint method for aerial cover and composition was the best of the methods tested. It was, however, a difficult technique to use in shrubby areas and consequently impractical for lengthy use in a monitoring program.

Since there were no published reports of a satisfactory method for estimating pasture amount and composition in extensively managed arid rangelands, studies were extended to 2 complementary techniques. The dry-weight-rank (DWR) method for species composition was devised by 't Mannetje and Haydock (1963) for tropical pastures and improved by Jones and Hargreaves (1979). Statistical tests have demonstrasted its robustness (Sandland et al. 1982) and it has been widely applied (Tothill et al. 1978, Kelly and McNeill 1980, Barnes et al. 1982, Gillen and Smith 1986). The comparative yield (CY) estimation of pasture dry weight (Haydock and Shaw 1975) could be readily combined with the DWR estimation of species composition (Tothill et al. 1978, Kelly and McNeill 1980). Both procedures were potentially useful because they were rapid, but no tests had been reported for arid environments.

The study examines the value of CY and DWR methods, by determining the extent of among-operator differences in a range of arid vegetation types. Available time is generally a limiting factor in range monitoring procedures, and staff turnover in monitoring agencies is such that repeated assessments are likely to be made by different operators. Methods must enable us to rapidly estimate yield and composition, and to detect change from one occasion to the next, despite a change in operator. While consistency from one occasion to the next is important for a single operator, we perceive that consistency among different operators is a more critical problem.

In addition, the accuracy of a yield estimate (that is, its proximity to the actual yield of a site) is not readily determined without harvesting the greater part of the site. Actual yield can vary markedly in a limited area and in a short time, so that its accurate determination is neither feasible nor necessary. We assume that precision is more important, so that, with different operators, a reasonably consistent estimate of current yield is achieved, and change over extended time can be detected. Consequently, we do not attempt to compare estimates with actual values.

Vegetation types were chosen for their different spatial distributions of pasture and for contrasting structure and composition. The tests were not repeated over time. Other estimates of yield and composition were not compared but the tests were planned to enable comparison with the earlier study by Friedel and Shaw (1987).

Methods

The experimental area was located on Atartinga Station (22° 26′S, 134° 14′E), 150 km north-north-east of Alice Springs, in the 250-mm annual rainfall zone of the Northern Territory of Australia. The area experiences hot summers and cool winters, and on average over 70% of the rain falls in the summer months, October to March. At the time of the study, July 1985, the preceding summer had been dry and there had been no effective winter rain.

Five sites were selected in range types preferred by grazing cattle (Table 1), and varied from 2 to 9 ha, depending on the area available. The sites differed from one another in pasture composition and yield and in the spatial distribution of vegetation.

The methods to be tested depended on dry weights of plant material and so, in a preparatory exercise, a wide variety of pasture

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Table 1. Landform, soil and vegetation description of 5 experimental sites. Soil descriptions follow Northcote (1971).

Range type	Landform and soils	Vegetation
Calcareous shrubby grass-land (CSG)	Gently undulating calcareous plain with reddish-brown calcareous sandy clay loam (Gc 1.12)	Very sparse *Acacia kempeana* F. Muell. and *A. victoriae* Benth. over *Enneapogon* spp. and *Tripogon loliiformis* (F. Muell.) C.E. Hubbard.
Cottonbush flat (CBF)	Flat alluvial plain with scalded texture contrast soil, reddish-brown sandy loam over clay loam (Db. 3.53).	Very sparse *Maireana aphylla* (R. Br.) P.G. Wilson and *Cassia* spp. with *Sida* spp., *Enteropogon acicularis* (Lindl.) Lazar and *Tripogon loliiformis.*
Open woodland (OWG, OWP)	OWG: Alluvial plain with gradational soil, dark reddish-brown sandy loam over sandy clay loam (Gn 2.43).	OWG: Very sparse *Cassia* and *Eremophila* spp. over *Enneapogon polyphyllus* (Domin.) N.T. Burb., *Aristida contorta* F. Muell. and *Enteropogon acicularis.*
	OWP: Gentle slope with shallow uniform soil, reddish-brown sandy loam (Uc 1.21).	OWP: Very sparse *Acacia kempeana* and *Cassia* spp. over *Aristida contorta* and *Enneapogon polyphyllus.*
Perennial grassland (PGR)	Alluvial plain with uniform soil, reddish-brown clay loam (Uf 6.12).	Very sparse *Eremophila* spp. and *Acacia aneura* F. Muell. ex Benth. over mid-dense *Enteropogon acicularis* and *Eulalia fulva* (R. Br.) Kuntze.

species were collected, dried and weighed, and their proportional moisture content was calculated. Summaries of these data were used by operators making their estimates during the main experiment.

Sub-shrubs such as *Sclerolaena* spp. were included in the tests but larger shrubs were not. Seven operators undertook all tests, with one exception in which there were 6 operators, and the time taken for the various tasks was recorded.

Comparative Yield

Detailed descriptions of the method are provided in Haydock and Shaw (1975) and Tothill et al. (1978). In summary, there were 3 stages. Operators selected five 1-m² reference standards by consensus, to represent an equal-interval scale from least to highest dry matter yield, after clipping and weighing vegetation from numerous quadrats to gauge their approximate yields. Next, each operator selected 100 1-m² quadrats on a stepped-out grid, and rated them according to the reference standards on a 17-point scale of 1, 1.25, 1.5 up to 5. The grid spacing depended on the size and shape of the site, but resulted in an even distribution of quadrats over the whole site. Finally, twelve 1-m² quadrats were selected by 2 or 3 members of the group to represent the range from low to high yield, and all members independently rated them on the 17-point scale. The quadrats were clipped, dried, and weighed to establish a calibration scale for each operator.

Alternative procedures were also followed at some sites. At CBF, an eroded site with obvious spatial heterogeneity in vegetation distribution, all members of the group independently rated a fixed set of 100 quadrats as well as their own individually selected set, in order to investigate the differences among operators independently of vegetation distribution. At OWG, a relatively uniform site, the same test was performed but with only 50 fixed quadrats, due to time limitations. At OWP, operators increased their number of individually selected quadrats from 100 to 200, to more fully investigate how many quadrats might ultimately be necessary to minimize differences among operators.

Dry-weight-rank

Operators also estimated which species occupied first, second, and third place in terms of dry weight for each quadrat. These rankings were to be converted to percent composition by a set of multipliers provided by Jones and Hargreaves (1979). Recommended procedures for treating equal-ranked species, less than 3 species, and species which consistently formed a high proportion of the biomass were followed: details of the method are available in 't Mannetje and Haydock (1963), Tothill et al. (1978) and Jones and Hargreaves (1979).

Data Analysis

Comparative Yield

All data were initially analysed with the MSDOS version of the BOTANAL program (Hargreaves and Kerr 1978, revised 1981), modified to allow processing of selected quadrat increments. Four different curves were fitted to each operator's calibration data from each site, using the 4.04B version of GENSTAT (copyright Lawes Agricultural Trust: Rothamsted Experimental Station 1984). These were linear regressions of untransformed, log transformed and square root transformed data, and quadrat regression of untransformed data. The regressions were weighted according to the numbers of quadrats in each yield rank at 100 quadrats, and they were calculated for the individually chosen quadrats only. The different calibration regressions were compared according to their percentage of variation accounted for, and according to the number of negative yield estimates obtained for low-yield quadrats. The term "yield estimates" is used throughout to denote estimates derived from individuals' calibration regressions from each site.

To determine whether the differences among operators were minimized after a certain number of quadrats, the coefficient of variation (CV) of all individuals' yield estimates was calculated at 20, 40, 60, 80, and 100 quadrats. CVs were based on variation from the mean of all individuals. For OWP and the OWG fixed quadrats, CVs were calculated up to 200 and 50 quadrats, respectively. The increments in quadrat numbers were achieved by random selection from the rows of quadrats on the sampling grid.

The degree of significant difference among operators was investigated in greater detail on a more limited number of quadrat intervals: yield estimates of all operators for the first 40 and 60 quadrats were subjected to analysis of variance (ANOVA) after log transformation to normalize skewed distributions of data.

ANOVA was not appropriate for the fixed sets of quadrats because the data were not randomized. Instead, a regression equation was calculated for the individual quadrat yield estimates of every possible observer-pair combination, and analysis of covariance (Zar 1984, p. 300-2) was used to test whether the slopes and elevations of the pair-wise regression combinations were different. Yield estimates were log transformed to normalize the data distribution, before the analyses.

Dry-Weight-Rank

DWR data were also analysed with the MSDOS version of the BOTANAL Program (Hargreaves and Kerr 1978, revised 1981), modified to allow processing of selected quadrat increments. Following the same progression of data analysis outlined for CY, differences among the species composition estimates of operators

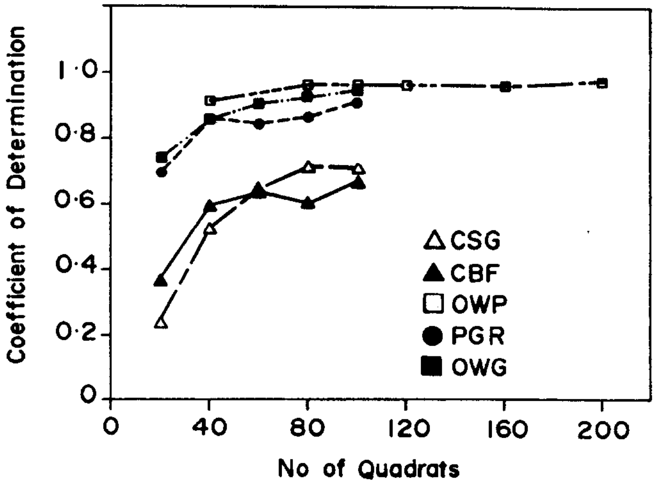

Fig. 1. *Effect of increasing numbers of quadrats on the differences among species composition estimates of 7 operators, as indicated by group mean coefficients of determination (r^2) on calcareous shrubby grassland (CSG), cottonbush flat (CBF), open woodland with shallow uniform soil (OWP), open woodland with gradational soil (OWG), and perennial grassland (PGR).*

were compared at the same increments in quadrat number. Linear regression of arcsine transformed, percent composition data from every possible observer-pair combination was used to produce a matrix of coefficients of determination (r^2), from which means of r^2 were derived. Three different estimates of species composition were included: 1 calculated with unweighted multipliers and 2 calculated with weighted multipliers (see Jones and Hargreaves (1979) for a discussion of weighting), where the weighting factors were yield estimates derived from the linear untransformed and square root transformed calibration regressions for each site. These procedures were followed for both the individually selected quadrats and the fixed sites of quadrats.

Results

Data in the Tables are presented in the same order that the sites were visited.

Comparative Yield

Effect of Calibration Regression

The log transformed regression accounted for the least variation in the calibration data (41.4 to 67.6%), and the quadratic regression produced negative estimates of yield on low-yield quadrats, for most operators at 3 of the 5 sites. Consequently, only the linear untransformed (50.5 to 82.2% variance accounted for) and square root transformed (47.0 to 81.0%) regressions were used in all later analyses. In general, if the regression accounted for 50% or more of the variance in the data, it was regarded as satisfactory. An exception was made for the 47% value, since all others obtained from the linear square root transformed regression were above 57%. Any negative yield values were set to zero.

Effect of Linear Square Root Transformation

Use of the transformation reduced the variability among operators at some sites but not at others, in the various data analyses that were performed. The conclusions to be drawn from the data were the same, with or without the use of the transformation, and so only the analyses of linear untransformed data are reported here.

Effect of Increasing Numbers of Quadrats

Differences among operators had not stabilized after 100 quadrats and the CVs were generally large (Table 2). However, between 40 and 60 quadrats, differences decreased in all sites except CBF and so the nature of the differences was examined at these intervals by ANOVA (Table 3). It was clear that while overall estimates had approached one another more closely at 60 quadrats (Table 2), the variation within the 60 quadrats was generally greater than at 40 quadrats (Table 3). The degree of significant difference actually increased.

Table 2. Effect of increasing numbers of quadrats on the mean yield estimates (g/m²) of 7 operators. Coefficients of variation (%) are given in brackets.

No. of quadrats	Range Type				
	CSG	CBF	OWP	PGR	OWG
	g/m²(% c.v.)				
20	47.7(26.5)	17.6(19.7)	—	169.7(22.9)	67.3(23.6)
40	44.1(28.9)	16.4(12.6)	17.1(23.2)	166.7(13.2)	67.3(26.7)
60	40.7(27.0)	17.0(21.7)	16.6(20.9)	161.9(6.9)	70.6(22.1)
80	43.9(36.6)	16.7(28.6)	16.7(19.5)	174.0(9.0)	68.7(22.1)
100	50.8(34.5)	16.3(25.5)	16.6(18.7)	182.6(9.3)	67.9(20.1)
120	—	—	16.9(19.8)	—	—
160	—	—	16.6(23.1)	—	—
200	—	—	16.7(21.2)	—	—

Table 3. F values[1] for ANOVA of 7 operators' yield estimates, at 40 and 60 quadrats.

No. of quadrats	Range Type				
	CSG	CBF	OWP	PGR	OWG
40	8.82	6.89	10.38	3.25	7.38
60	17.50	17.03	17.09	3.71	8.44

[1]Levels of significance at $p<0.01$ and 0.001 are:
40 quadrats – 2.86 and 3.86
60 quadrats – 2.85 and 3.83

Individually Selected vs. Fixed Quadrats

When all operators estimated yield from the same quadrats, the variability among individuals' estimates of OWG was considerably less at 40 quadrats and above, than if the operators had selected their own quadrats (Table 4). Unexpectedly, the reverse was the case at the strongly patterned CBF site.

Table 4. Comparison of mean yield estimates (g/m²) of 7 (CBF) or 6 (OWG) operators for individually-selected and fixed quadrats. Coefficients of variation (%) are given in brackets.

No. of quadrats	Range Type			
	CBF (individual)	CBF (fixed)	OWG (individual)	OWG (fixed)
	g/m² (c.v.%)			
20	17.6(19.7)	24.0(21.5)	68.8(24.4)	54.0(25.2)
40	16.4(12.6)	19.0(29.5)	68.5(28.2)	63.0(18.8)
50	—	—	70.0(29.1)	64.7(17.3)
60	17.0(21.7)	18.0(33.2)	—	—
80	16.7(28.6)	16.7(36.0)	—	—
100	16.3(25.5)	17.6(34.6)	—	—

Did fixed quadrats confer an advantage? Differences among operators were significant with fixed quadrats: where slopes were not significantly different, elevations were (Table 5). Although Tables 3 and 5 are not directly comparable, the inferences from both are the same: regardless of the way quadrats were chosen, individuals' estimates of yield differed significantly.

Table 5. F values[1] for covariance analysis of 7 (CBF) or 6 (OWG) operators' yield estimates at 60 or 50 fixed quadrats respectively.

	CBF		OWG	
Operator	Slope	Elevation	Slope	Elevation
1	6.40	32.59	19.07	13.74
2	7.09	36.26	13.60	9.75
3	10.09	48.03	—	—
4	2.34	30.15	39.62	20.39
5	2.53	34.16	55.85	19.44
6	6.50	34.64	21.49	15.50
7	10.91	31.42	33.54	10.85
Mean	6.55	35.32	30.53	14.95

[1]Levels of significance at $p<0.05$, 0.01 and 0.001 are:
CBF - 2.24, 3.08 and 4.22
OWG - 2.41, 3.40 and 4.79

Dry-Weight-Rank

Effect of Weighting

Unweighted multipliers were satisfactory. Weighted multipliers did not maker operators' estimates of species composition more alike, with the exception of the "untransformed" weighting of PGR data. The improvement for PGR was marginal; at some other sites, weighted multipliers conferred a marginal disadvantage. Only the analyses with unweighted data are presented here.

Effect of Increasing Numbers of Quadrats

Correlation among operators' estimates increased markedly between 20 and 40 quadrats. Subsequent increases were less with every 20-quadrat interval, so that improvements were only small from 60 to 100 quadrats (Fig. 1).

Individually Selected vs. Fixed Quadrats

When all operators assessed the same quadrats, species composition estimates were more closely correlated than they were when quadrats were selected by each individual (Fig. 2 and Table 6). The correlation was particularly improved at CBF, the site where vegetation distribution was clearly patterned.

Time

Excluding CSG, where operators were least experienced, the mean time to assess 100 quadrats for both yield and species composition was 2 hours 15 mins (from Table 7). The time taken by the group to select yield standards ranged from 1 to 2 hours, and to select and later harvest the calibration quadrats was 30 mins. Once again excluding CSG, the mean time for individuals to assess the calibration quadrats was 12 mins. Thus, the process of standard

Table 7. Mean time taken ± SE (min) for comparative yield and dry-weight-rank procedures, by 7 operators (DF = 6).

	Range Type				
	CSG	CBF	OWP	PGR	OWG
	min±SE				
Individual's 100 quadrats	206±18	136±9	130±8	134±8	141±6
Individual's calibration quadrats	29±2	12±1	13±2	11±1	12±2

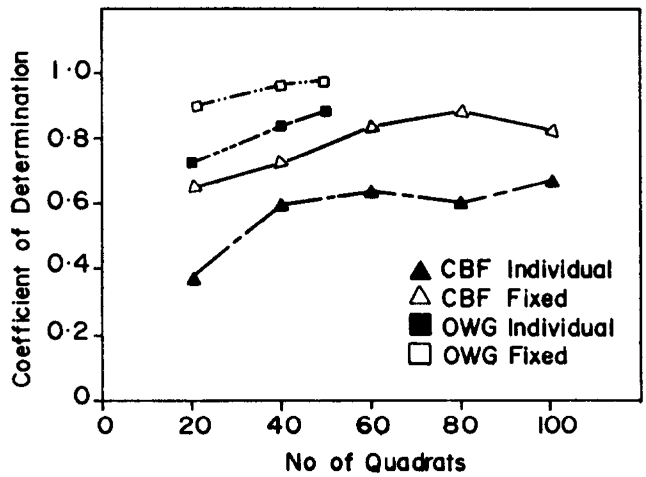

Fig. 2. *Comparison of species composition estimates of 7 (CBF) or 6 (OWG) operators for individually selected or fixed quadrats, as indicated by group mean coefficients of determination (r^2). CBF is cottonbush flat; OWG, open woodland with gradational soil.*

Table 6. Estimates of percentage species composition in CBF from 60 individually-selected or fixed quadrats. Group mean coefficients of determination (r^2) are 0.64 and 0.84 respectively.

	Operator						
Species	1	2	3	4	5	6	7
(a) Individually-selected	%						
Chloris scariosa F. Muell.	4	6	6	10	5	10	6
Enteropogon acicularis	20	31	28	13	20	21	11
Fimbristylis dichotoma (L.) Vahl	8	2	1	10	6	5	9
Sclerolaena divaricata (R. Br.) Domin	2	2	4	5	9	0	3
Sclerolaena lanicuspis (F. Muell.) Benth.	8	4	7	8	4	8	3
Sida sp.	25	27	30	23	22	28	36
Tripogon loliiformis	22	15	12	24	20	15	20
Other species (each contributing <5%)	11	13	12	7	14	13	12
(b) Fixed							
Chloris scariosa	9	9	8	10	9	8	10
Enteropogon acicularis	21	23	17	18	20	17	20
Fimbristylis dichotoma	1	1	2	7	4	8	6
Sclerolaena divaricata	9	7	6	8	7	6	7
Sclerolaena lanicuspis	16	19	18	13	16	18	18
Sida sp.	29	25	29	22	21	27	24
Tripogon loliiformis	4	7	7	9	11	7	5
Other species	11	9	13	13	12	9	10

selection and calibration took on average about 2 hours, giving an overall time of 4 hours 15 mins for the complete procedure.

Discussion

Pasture in arid rangelands is very patchy distributed and yield in particular can fluctuate a great deal in a short time. Short-term variation in yield is such that accurate estimates for monitoring purposes are not worth the time spent attaining them. It is sufficient for trained operators to obtain reasonably consistent estimates of both yield and long-term change in yield.

The CY method tested in this study did not meet these requirements within the time constraints of a monitoring program, but it is possible to modify the procedure, to achieve useful estimates (Friedel and Bastin 1988). The CY method is worth adapting because it is compatible with DWR, which we recommend over other techniques for estimating species composition.

As tested here, CY had several weaknesses. Differences among operators were generally large (Table 2) and significant (Table 3), so that only the grossest changes in yield could be confidently determined if different operators were responsible for assessments on different occasions. We might expect that a series of assessments over time would be subject to less error if undertaken by the same operator throughout, but this was not tested.

Differences among operators' yield estimates were not simply due to sampling differences in a spatially variable environment; variation among operators' estimates remained high when the same quadrats were assessed by everyone (Table 4). It would be relatively simple to correct for the disparity if operators consistently over- or under-estimated yield in comparison with one another, but they did not. Both the slopes and the elevations of pair-wise regressions of observers' estimates were different (Table 5), indicating that some observers were over-estimating high yields and under-estimating low yields, in comparison with others.

Assessing 100 quadrats for both yield and composition took an average of 2 hours 15 mins (Table 7, excluding CSG), after initial experience with the methods. The mean CV for yield estimates was 18.4% (from Table 2, excluding CSG). In a comparable test, Friedel and Shaw (1987) reported that point-based aerial cover and composition could be estimated in a similar time, with a mean CV for cover estimates of only 10% for 6 operators, and that an acceptable level of accuracy could be achieved by a single operator in 40 to 70 minutes. To match this latter time, the number of quadrats would have to be reduced to about 50, and CVs would remain high. The disadvantages of aerial cover estimates are that they are not matched by satisfactory cover-based estimates of species composition (Friedel and Shaw 1987), and that cover is less useful than yield for assessing forage quantity.

The process of CY standard selection and calibration was too time-consuming to be of use in a monitoring program and we suggest the efficiency of the method can be improved by using photographic standards, which are used for calibration as well (Friedel and Bastin 1988). A wide variety of photographs, representing different vegetation structure, distribution, yield, composition, and phenology can be substituted for the 5 reference standards. Since photographic standards can be carried by operators for constant checking against quadrats in the field, it is likely that precision of estimates will improve.

The dry-weight-rank method is recommended for determining species composition firstly because operators could apply the ranking scheme consistently; increasing the number of sampling units (quadrats in this case) increased the similarity among operators' estimates (Fig. 1). By contrast, Friedel and Shaw (1987) found that, when a point-based measure of cover and composition was used, differences among operators became more entrenched with extra sampling units, and so estimates of composition diverged. Secondly, correlations of operators' estimates from the dry-weight-rank technique were high (Fig. 1) after 60 quadrats in about 80 mins: that is, within a realistic period of time for monitoring. However, in our opinion, the species compositions which gave rise to an r^2 value of 0.64 (Table 6) would be too different from one another to be acceptable for monitoring, whereas those which gave $r^2 = 0.84$ would be satisfactory. The options for increasing the similarity of operators' estimates include increasing the number of quadrats (and the time taken), more training, and the use of fixed quadrats.

The improvement in r^2 values when all operators assessed the same quadrats (Fig. 2, Table 6) indicates that differences among individuals' estimates were considerably influenced by spatial pattern. We suggest that monitoring a set of fixed quadrats would reduce the effect of spatial variability, but this advantage may be offset by the extra time spent on relocating quadrats in difficult terrain.

Like Gillen and Smith (1986), we found that weighted multipliers did not improve composition estimates, and that operator training was important. P.E. Novelly, D. Despain, E.L. Smith and W.E. Frost (pers. comm.) showed that weighted multipliers were useful in some of their desert grasslands, so the decision to use weighting will depend on pasture type.

DWR is easy to use and can be combined with recording the frequency of less common species. It has the advantage that, being dry-weight based, the estimates are directly related to forage quantity, which cover-based estimates are not. It is also potentially very useful in combination with the comparative yield technique, if the efficiency of the latter is improved as we propose.

Griffin and Bastin (1988) have devised a program for a hand-held computer which will collect and check data from a modified comparative yield and an unweighted dry-weight-rank technique, and will calculate estimates of pasture yield, composition and frequency in the field. This package of methods and analytical tools enables data to be interpreted immediately in the field, which we believe is an important prerequisite of an effective monitoring system.

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Optimal stocking rate for cow-calf enterprises on native range and complementary improved pastures

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Abstract

Complementary pasture-native range systems are known to increase production per cow and per hectare of cow-calf enterprises, but the proper ratio of complementary pasture to range and the optimum stocking rate on each has not been established. From 1978–1985, crested wheatgrass [*Agropyron desertorum* (Fisch.) Schult.]-native range and meadow bromegrass (*Bromus biebersteinii* Roem. and Schult.)-alfalfa (*Medicago sativa* L.)-native range systems were grazed by cow-calf pairs and yearling heifers at a range of grazing pressures. Gains of all classes of cattle and conception rate of cows remained constant across a range of low grazing pressures, then declined linearly as grazing pressure increased. These response functions were used to calculate economically optimum pasture-to-range ratios and stocking rates at 1980–1984 average costs and prices. The optimum ratio of crested wheatgrass to range at estimated yields, costs and prices was 1:3.94 (0.66 ha of wheatgrass and 2.60 ha of range per animal unit), which returned $35.70/ha to land, labor, and management. Usual ratios of 1:8 to 1:12 were much less profitable. At optimum stocking rates, the brome-alfalfa-native range system returned only $3.38 more per hectare than the crested wheatgrass-native range system, not enough to pay additional cost of irrigation. Optimum ratios, stocking rates, and returns will vary with levels of forage production, production costs, and livestock prices.

Key Words: pasture systems, gains, reproduction, profitability, crested wheatgrass, alfalfa-bromegrass

Cow-calf herds grazing crested wheatgrass [*Agropyron desertorum* (Fisch.) Schult.] in spring and native range the remainder of the grazing season generally produce greater calf crops, weaning weights, and pounds of weaned beef per hectare (Houston and Urick 1972, Hart et al. 1983b) than herds grazing native range season-long. Similar results have been reported from cow-calf herds grazing other types of complementary pastures in conjunction with range (McIlvain and Shoop 1973, Sims 1984, Manske and Conlon 1986). Cattle gains and carrying capacity have been greater on crested wheatgrass-range systems than on range alone (Cook et al. 1983, Jefferies et al. 1967, Lodge 1970, Smoliak and Slen 1974).

Kearl (1984) and Cordingly and Kearl (1975) cited a number of studies showing increased forage production, calf crop, and calf weight gains, plus lengthened grazing season, reduced winter feed requirement, and development of special use pastures as benefits of seeding crested wheatgrass complementary pastures. They calculated that seeding 385 ha of a 5,844-ha ranch to crested wheatgrass would, within 5 years, increase net ranch income 26% and the return to capital 35%. Godfrey et al. (1979) used estimated rates of gain before and after seeding crested wheatgrass to estimate the economic returns from seeding. Spielman and Shane (1985) concluded it was profitable to seed crested wheatgrass pastures if meadow hayland and range forage resources were not limiting on the ranch in question.

These studies did not consider the functional relationships among stocking rate, livestock performance, and profitability; data on these relationships are seldom available. The grazing studies compared range and range-complementary pasture systems at a single stocking rate on each. Often the stocking rates were different for the 2 systems, and were less than those required to maximize profits. Because stocking rate has an over-riding impact on profitability of grazing systems (Quigley et al. 1984, Hart et al. 1988), comparisons of systems are valid only at the optimum stocking rate or grazing pressure (GP) on each. Determining this rate depends upon reliable estimates of biological responses.

We concluded that the superiority of complementary pasture systems over native range alone had been adequately demonstrated, but that optimum management of each system, in terms of the area and stocking rate of each component, had not been defined. Our objective was to quantify these parameters for complementary pasture systems combining dryland crested wheatgrass or irrigated bromegrass-alfalfa pastures with native range, and to

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demonstrate how these parameters could be used for economic analysis.

Materials and Methods

The study site was on the High Plains Grasslands Research Station located 7 km northwest of Cheyenne, Wyo. Climate at the Station is semiarid continental. Mean January and July temperatures in Cheyenne are -3 and 20° C, respectively, and mean (1871-1986) annual precipitation is 338 mm, with 55% falling April-July (NOAA 1987). Average frost-free season is 127 days (Stevenson et al. 1984).

Pasture Management

Four crested wheatgrass pastures, established 30-40 years before the study began in 1978, were grazed. The 2 pastures grazed in 1978-1979 were on Nucla loam (fine-loam, mixed, mesic Aridic Haplustoll) and Ascalon loam, (fine loamy, mixed, mesic Aridic Argiustoll). The 2 pastures grazed 1980-1985 were on Wheatridge loam, a fine-loamy over sandy, mixed, mesic Aridic Argiustoll. Crested wheatgrass and smooth bromegrass (*Bromus inermis* L.) provided about 90 and 10% of the forage from the pastures grazed in 1978-1979, with only traces contributed by other species. Forage from the pastures grazed 1980-1985 was 98% crested wheatgrass with traces of several native grasses and forbs.

The irrigated 'Regar' bromegrass (*Bromus biebersteinii* Roem. and Schult.)-alfalfa (*Medicago sativa* L.) pastures were established in 1976 on Wheatridge loam. Brome and alfalfa were seeded in rows 20 cm apart at 6 and 7 kg/ha, respectively. Superphosphate was applied at 20 kg/ha of P before seeding and annually thereafter. Irrigation was by flooding as needed. During the years the pastures were grazed, forage composition averaged 28% alfalfa and 72% bromegrass.

The native range pastures were on mixed-grass prairie. Botanical composition averaged approximately 50% blue grama [*Bouteloua gracilis* (H.B.K.) Lag ex Griffiths], 17% western wheatgrass (*Agropyron smithii* Rydb.), 19% other graminoids (chiefly needle-andthread (*Stipa comata* Trin. and Rupr.) and needleleaf sedge (*Carex eleocharis* Bailey), and 14% forbs and half-shrubs [chiefly scarlet globemallow, *Sphaeralcea coccinea* (Pursh.) Rydb.; Drummond milkvetch, *Astragalus drummondi* Dougl.; and fringed sagewort, *Artemesia frigida* Willd.]. Topography is rolling hills at altitudes of 1,915 to 1,975 m. Soils are predominantly Altvan, Ascalon and Ascalon Variant loams (fine-loamy, mixed, mesic Aridic Argiustolls), with smaller areas of Albinas loam (fine-loamy, mixed, mesic Pachic Argiustoll), Cascajo gravelly loam (sandy-skeletal, mixed, mesic Aridic Calciorthid), and Larim Variant gravelly loam (loamy-skeletal, mixed, mesic Ustollic Haplargid).

The bromegrass-alfalfa pasture was grazed as a single unit in 1978. In 1979 it was subdivided into 2 pastures, each further divided into 2 paddocks and managed as a 2-pasture 1-herd system. Grazing and rest periods were 5 to 10 days, depending on forage supply and growth rate. Crested wheatgrass pastures were not subdivided but pastures used in 1978 and 1979 were different from those used in 1980 through 1985. The native range area originally consisted of 2 pastures. In 1982 a portion of the larger pasture which had been fenced off and excluded from the study in 1980 was brought into the experiment to provide a third and heavier stocking rate. In 1985 this area was again excluded, and the smaller of the 2 original pastures was subdivided into 4 units to provide a total of 5 stocking rates. Pasture sizes and stocking rate are presented in Table 1.

Table 1. Pasture size, forage production (standard error in parentheses) and stocking rate (SR).

	Bromegrass-alfalfa			Crested wheatgrass			Native range		
Year	Ha/ pasture	Forage, kg/ha	SR, AUD/ha	Ha/ pasture	Forage kg/ha	SR, AUD/ha	Ha/ pasture	Forage, kg/ha	SR, AUD/ha
1978	8.1	2740	90	7.6	2420	103	191.4	—	30
		(210)		10.3	(340)	76	283.3		20
1979	3.5	4270	106	7.6	1820	82	191.4	—	30
	4.6	(430)	81	10.3	(190)	60	283.3		20
1980	3.5	2200	136	11.3	1650	49	191.4	—	27
	4.6	(310)	103	14.6	(190)	38	248.9		21
1981	3.5	2720	180	11.3	980	42	191.4	—	25
	4.6	(430)	146	14.6	(160)	35	248.9		22
1982	3.5	2570	170	11.3	1030	50	34.4	1180	44
	4.6	(380)	97	14.6	(60)	23	191.4	(270)	32
							214.5		13
1983	*			*			34.4	1450	60
							191.4	(260)	40
							202.4		11
1984	*			*			34.4	1280	47
							191.4	(600)	30
							202.4		13
1985	*			*			24.3	950	50
							24.3	(260)	42
							24.3		37
							118.6		28
							202.4		26

*In 1983-1985, all cattle grazed together on 8.1 ha bromegrass-alfalfa and 25.9 ha of crested wheatgrass during the improved pasture grazing season.

Appendix Table 1. Program for calculating response of average daily gain to grazing pressure, with constant ADG below critical grazing pressure; sample data set; and sample response curve. Coded in Compaq[1] BASIC, Version 3.

```
10 DIM X(64), Y(64)
20 PRINT "REGRESSION OF ADG ON GRAZING PRESSURE"
30 INPUT "TITLE ",Q$
40 INPUT "MEASURE OF GRAZING PRESSURE (X) ",X$
50 INPUT "UNITS OF ADG ",Y$
60 INPUT "NO. OF DATA POINTS ",N
70 PRINT "INPUT X & Y, WITH X'S IN ORDER FROM SMALLEST
   TO LARGEST"
80 FOR I=1 TO N:PRINT "X"; I:INPUT X(I):PRINT "Y"; I:INPUT
   Y(I):NEXT I
90 FOR I=1 TO N:S1=S1+X(I):S2=S2+Y(I)
100 S3=S3+X(I)^2:S4=S4+Y(I)^2:S5=S5+(X(I)*Y(I)):NEXT I
110 S7=S4-(S2^2/N):B=(N*S5-S2*S1)/(N*S3-S1^2):A=(S2-B*S1)/N
120 R=(S5-((S1*S2)/N))^2/((S3-S1^2/N))*(S4-(S2^2/N)))
130 LPRINT Q$:LPRINT :LPRINT "ADG (";Y$;") = ";B;"(";X$;") +";A
140 LPRINT "R SQUARED =";R:LPRINT
150 FOR M=2 TO (N-1)
160 S1=0:S2=0:S3=0:S4=0:S5=0:S6=0:R2=0
170 FOR I=M TO N:S1=S1+X(I):S2=S2+Y(I)
180 S3=S3+X(I)^2:S4=S4+Y(I)^2:S5=S5+X(I)*Y(I):NEXT I
190 B1=((N-M+1)*S5-S2*S1)/(N-M+1)*S3-S1^2):A1=(S2-B1*S1)/
    (N-M+1)
200 FOR I=1 TO M-1:S6=S6+Y(I):NEXT I:S6=S6/(M-1):Z1=(S6-A1)/B1
210 FOR I=1 TO N:IF X(I)>Z1 GOTO 230
220 R1=(S6-Y(I))^2:GOTO 240
230 R1=(Y(I)-(B1*X(I)+A1))^2
240 R2=R2+R1:NEXT I:R2=(S7-R2)/S7
250 IF R2<R GOTO 270
260 R=R2:A=A1:B=B1:Z=Z1:S8=S6
270 NEXT M
280 IF Z=0 GOTO 340
290 LPRINT "IF GRAZING PRESSURE IS LESS THAN"; (INT(Z*100))/
    100;X$;" THEN"
300 LPRINT" ADG (";Y$;") =";S8
310 LPRINT "IF GRAZING PRESSURE IS MORE THAN"; (INT(Z*100))
    /100;X$;" THEN"
320 LPRINT " ADG (";Y$;") = ";B"(";X$;") +";A
330 LPRINT "R SQUARED = ";R
340 END
```

Grazing pressure AUD/t DM	ADG, kg	Test
11	0.98	ADG (kg) = -8.409248E-03 (AUD/ tonne DM) + 1.192086
28	0.97	R SQUARED = .9342105
32	1.01	
45	0.86	
62	0.69	IF GRAZING PRESSURE IS LESS THAN 33.22 AUD/tonne DM THEN ADG (kg) = .9866667
89	0.48	IF GRAZING PRESSURE IS MORE THAN 33.22 AUD/tonne DM THEN ADG (kg) = -1.009543E-02 (AUD/ tonne DM) + 1.322086
101	0.26	R SQUARED = .9880446

Herbage dry matter yields and utilization were estimated by clipping inside and outside exclosures. In 1978-1982, 5 exclosures were located at random on each crested wheatgrass pasture. Two 0.18-m^2 quadrats were clipped inside and 2 outside each exclosure at the end of grazing each year. In the same years, 6 exclosures were located on each brome-alfalfa pasture, 3 in each half of each pasture. Two quadrats inside and 2 outside each exclosure were clipped whenever cattle were removed from that half of the pasture; if cattle were to be rotated back to that half later, the exclosures were moved a few meters to another location.

On the native range pastures, production was not estimated until 1982. Four, 9, and 7 exclosures were placed on the small, intermediate, and large pasture in 1982–1984. In 1985, 3, 6, and 7 exclosures were placed on each 24.3-ha, the 118.6-ha, and the 202.4-ha pasture, respectively. Locations of exclosures were stratified by soil type each year. Herbage production inside the exclosures was measured in August at the approximate time of peak standing crop. Standing crop outside the exclosures was clipped after the cattle were removed from the pastures in late fall when possible, although in some years snow prevented clipping outside some or all of the exclosures on the range pastures. Two 0.18-m^2 quadrats were clipped inside and outside each exclosure in 1982–1984; in 1985 one quadrat per exclosure was clipped after herbage standing crop was estimated on both quadrats with an electronic capacitance meter (Neal et al. 1976). Correlations (r^2) between clipped yields and meter estimates were 0.90 in August and 0.74 after grazing; n=18. Estimated herbage dry matter yields are shown in Table 1.

Cattle Management

All pastures were grazed with mixed herds of Hereford cows with calves, yearling heifers, bulls in breeding season, and in 1978–1981, esophageally fistulated steers (the latter were used in a diet study reported by Samuel and Howard 1982 and Hart et al. 1983a). In some years dry cows were included in the herds on the most lightly stocked pastures. Grazing on the improved pastures began between 13 and 23 May and ended between 13 June and 6 July when cattle were moved to range pastures. Cattle were removed from the range to winter pasture between 7 and 21 November, except in 1985 when snow forced removal on 9 October. Cattle were assigned randomly to improved pastures, then randomly reassigned to range pastures. Stocking rates on all pastures are shown in Table 1. Stocking rates and grazing pressures were calculated assuming each cow-calf pair, dry cow or bull was 1 animal-unit (AU) and each yearling heifer or steer was 0.75 AU.

Cattle were wintered together on a large pasture, partly native range and partly crested wheatgrass and smooth bromegrass. They were fed good quality grass-legume hay ad lib and 0.5 to 1.0 kg of concentrate daily to maintain gains of approximately 0.5 kg/day during the third trimester of pregnancy. In all years but 1984, estrus was synchronized with Lutalase[1] or similar products. The breeding season began between 26 May and 10 June and ended between 21 July and 14 August. Cows were artificially inseminated at the first estrus after synchronization; bulls were present for the entire breeding season. All cattle were weighed every 2 weeks, after an overnight shrink without feed or water. Pregnancy was determined by palpation in late summer or early fall each year.

Experimental Design and Data Analysis

The experiment was designed and analyzed as a non-replicated sampling study. Responses of weight gain and conception rate to grazing pressure (GP, animal-unit days per tonne of herbage dry matter produced) were fitted to the model of Hart (1978) by regression; see Appendix Table 1 for the program used. Replications are superfluous in regression analysis, although they provide additional data points. Validity of the model used is supported by the SMART model of forage growth, forage intake by cattle, and cattle gains (Hart 1986).

[1]Mention of a trademark or proprietary product does not constitute its approval by USDA to the exclusion of similar products.

Expressing the independent variable as grazing pressure rather than stocking rate eliminated effects of years on forage production, but effects of year-to-year variation in nutritional quality of cattle diets (Hart et al. 1983a) were necessarily confounded with those of grazing pressure. Variation in cow weight and condition at the beginning of the breeding and grazing seasons was minimized by maintaining a high plane of nutrition during each winter. Differences in potency and enthusiasm of bulls also may have contributed to variation.

Available land limited the number of grazing pressures which could be tested each year and the number of animals which could be carried at each grazing pressure; it would have been desirable but not practical to have greater numbers of both. For example, to estimate conception rate to the nearest 4% within each experimental pasture would require 25 cows per stocking rate. If all stocking rates were tested each year, a minimum of 4 stocking rates on each type of improved pasture would be needed, for a total of 200 cows. Our average stocking rates were 123 AUD/ha on brome-alfalfa and 48 AUD/ha on crested wheatgrass, and average length of grazing season on improved pastures was 32 days. Thus this ideal experiment would have required 26 ha of brome-alfalfa and 67 ha of crested wheatgrass. Average stocking rate and grazing season on range were 30 AUD/ha and 141 days; 940 ha of range would be needed to accomodate the 200 cows. And these areas do not include the requirements of 40 to 50 replacement heifers necessary to maintain the herd. Such an ideal experiment was impractical in terms of land, cattle, and money. However, we felt that estimates of production based on less precise data from a less-than-ideal experiment were preferable to estimates based on no data at all as a basis for economic analysis.

Economic Analysis

The functions defining the response of gain and conception rate to grazing pressure were used to calculate the most profitable stocking rate on a matrix of improved pasture-native range combinations. These calculations demanded certain assumptions about returns and costs.

Returns derive from the sale of calves and dry cows. Certain fixed costs, including but not limited to interest, veterinary and supplement costs, death losses, and transportation, are incurred to maintain an animal unit.

When cows lose weight and condition, estrus may be delayed and conception rate reduced (Dunn and Kaltenbach 1980, Herd and Sprott 1986). Thus a simplified objective might be to end the grazing season with cows at the same weight as at the start of the season. If cows have lost weight, additional feed must be provided to restore that lost weight; on the other hand, if they have gained weight, less winter feed will be needed and this weight gained can be considered a return.

Finally, a cost is incurred if a cow does not conceive. In the simplest case, this is the cost of buying a replacement heifer times 1.09 (in the study reported here, 109 bred yearling heifers were needed to produce as many live calves as 100 bred cows), minus the price received when the open cow is sold.

Results and Discussion

Liveweight Gains

Gains of lactating cows, yearling heifers, and calves declined linearly with increasing grazing pressure (GP) on irrigated bromegrass-alfalfa pastures (Fig. 1, Table 2). There was no indication that any of the grazing pressures imposed were below the critical grazing pressure (i.e., the grazing pressure heavy enough to reduce gains). On dryland crested wheatgrass pastures, on the other hand, critical grazing pressure was estimated as approximately 40 animal-unit days (AUD) per tonne (1 tonne = 1,000 kg) of forage dry matter produced (Fig. 1, Table 2). Below the critical grazing pressure, cow, heifer, and calf gains remained approximately constant at 1.27, 1.16, and 0.97 kg/day, respectively. Above the critical grazing pressure, gains declined linearly with increasing grazing pressure as on brome-alfalfa, but the rate of decline was more rapid for all age classes. Thus gains were higher on crested wheatgrass at intermediate grazing pressure but higher on brome-alfalfa at high and low grazing pressures (in the case of calves, the difference between pasture types was extremely small).

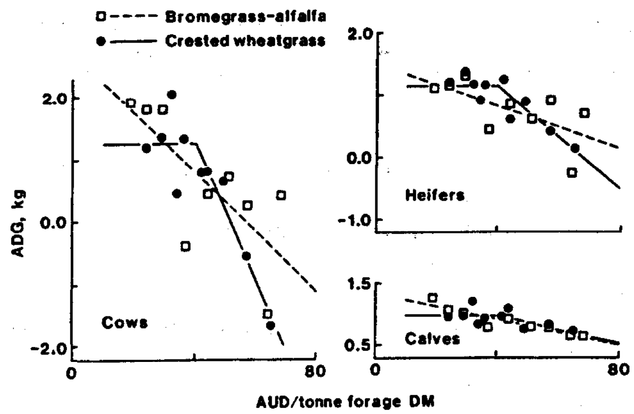

Fig. 1. *Grazing pressure and average daily gains (ADG) of lactating cows, yearling heifers and calves on irrigated bromegrass-alfalfa or dryland crested wheatgrass pastures, 1978–1982.*

Calf gains decreased very slowly with increasing grazing pressure, because milk provided most of their nutritional needs. Because of the nutritional demands on the cow for milk production, cow gains declined precipitously with increasing grazing pressure. Cows lost weight at the highest grazing pressures in this study, even though quality of crested wheatgrass and brome-alfalfa usually are assumed to be excellent.

On native range, critical grazing pressure and gains below critical grazing pressures of cows and heifers were much lower than on the improved pastures (Fig. 2, Table 2). Maximum gains of calves were nearly the same on range as on crested wheatgrass but lower on both than on brome-alfalfa. Again, cow gains declined sharply with increasing grazing pressure above the critical grazing pressure, and cows lost weight at the highest grazing pressures. Yearling heifers, which still had the potential for rapid growth, showed a higher rate of gain below the critical grazing pressure than did cows, and heifer gains declined more slowly with increasing grazing pressure, as they did on improved pastures.

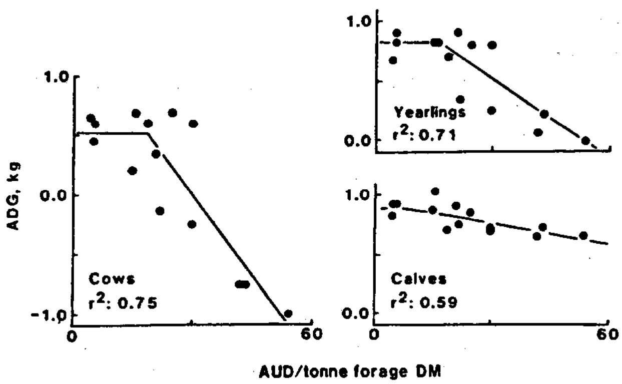

Fig. 2. *Grazing pressure and average daily gains ADG) of lactating cows, yearling heifers, and calves on native range, 1981–85.*

Conception Rates

Data on conception rate do not include first-calf heifers, which

Table 2. Relationship of average daily gains (ADG) of lactating cows, yearling heifers, and calves, and conception rate (C) of cows, to grazing pressure (GP, animal-unit-days/tonne of herbage dry matter produced) on irrigated bromegrass-alfalfa, dryland crested wheatgrass, and mixed-grass native range pastures.

Pasture, parameter and sample size (n)	Critical GP, AUD/t	Units	Estimates of performance: Below critical GP	Estimates of performance: Above critical GP	r^2
Bromegrass-alfalfa (n = 9)					
Cow ADG	—	kg	—	ADG = 2.69 - 0.0477 GP	0.52*
Heifer ADG	—	kg	—	ADG = 2.50 - 0.0170 GP	0.40+
Calf ADG	—	kg	—	ADG = 1.33 - 0.0104 GP	0.84*
Conception rate	41.1	%	100	C = 129 - 0.708 GP	0.86*
Crested wheatgrass (n = 10)					
Cow ADG	40.2	kg	1.27	ADG = 5.77 - 0.112 GP	0.84**
Heifer ADG	40.1	kg	1.16	ADG = 2.85 - 0.0421 GP	0.84**
Calf ADG	42.0	kg	0.97	ADG = 1.47 - 0.0119 GP	0.44*
Conception rate, 1979	28.1	%	100	C = 117 - 0.67 GP	0.83**
Conception rate, 1980	6.6	%	100	C = 104 - 0.67 GP	0.91**
Conception rate, 1981 & '82	47.0	%	100	C = 129 - 0.67 GP	0.96**
Conception rate, 1979, '81 & '82	41.0	%	100	C = 125 - 0.67 GP	0.81**
Native range (n = 14)					
Cow ADG	18.9	kg	0.52	ADG = 1.39 - 0.0459 GP	0.75**
Heifer ADG	15.6	kg	0.81	ADG = 1.16 - 0.0222 GP	0.71**
Calf ADG	9.3	kg	0.94	ADG = 1.00 - 0.00607 GP	0.59**

+, * and ** indicate regression is significant at the 10, 5 and 1% probability level, respectively.

were bred at the University of Wyoming, Laramie, in 1978–1979 to calve in January and February rather than in March and April with the older cows. In later years heifers were bred at the High Plains Grasslands Research Station, but numbers in all years were too small to provide reliable data on conception rate.

Cow breeding data from 1978 also were excluded from calculations of the response function because of reproductive problems in newly purchased cows. Only 17 of the 32 cows purchased in 1978 calved in 1979, while 28 of the 34 cows raised at High Plains Grasslands Research Station calved.

Timing and length of breeding season had no apparent effect on conception rate. The response of conception rate to grazing pressure followed the same model as did liveweight gain. On brome-alfalfa, conception rate was 100% below the critical grazing pressure of 41.1 AUD/tonne of herbage dry matter produced, then declined linearly with further increases in grazing pressure (Fig. 3, Table 2).

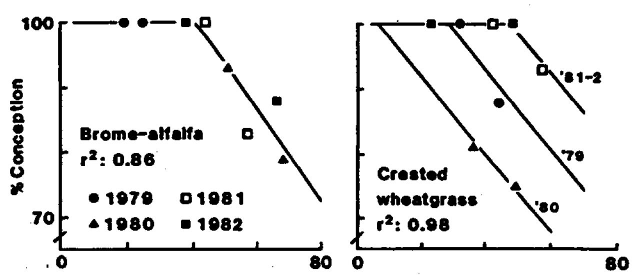

Fig. 3. *Grazing pressure and conception rates of cows on irrigated bromegrass-alfalfa or dryland crested wheatgrass spring pastures, 1979–1982.*

The response on crested wheatgrass was more complex. The rate of decline in conception rate with increasing grazing pressure seemed to be similar in all years, but the critical grazing pressure varied widely, from 6.6 AUD/tonne in 1980 to 47.0 AUD/tonne in 1981 and 1982.

Annual variation in the rate of maturity of crested wheatgrass, caused by variation in temperature and precipitation, may be responsible. In 1980 conception rates began to decline at a very low grazing pressure. June of 1980 was the driest June in 104 years of records. As a result, crested wheatgrass matured early with a resulting rapid decline in quality. Crude protein concentration of crested wheatgrass was 9.8% on 12 June 1980 vs. 12.5% on 11 June 1981 (Adams 1986). Brome-alfalfa, under irrigation, maintained higher crude protein levels in both years and showed less difference between years, 13.8% and 15.4% respectively. Because weather conditions during 1980 deviated substantially from normal, the mean response of conception rate to grazing pressure over 1979, 1981, and 1982 was used to calculate optimum stocking rate on crested wheatgrass.

Calculating the Most Profitable Stocking Rate

The most profitable stocking rate can be calculated by an expansion of the equations presented by Hart et al. (1988), but it is simpler to compute conception rate and cow and calf gains over a range of stocking rates and at the same time calculate values, costs, and net return per hectare. The information in Figure 4 was so

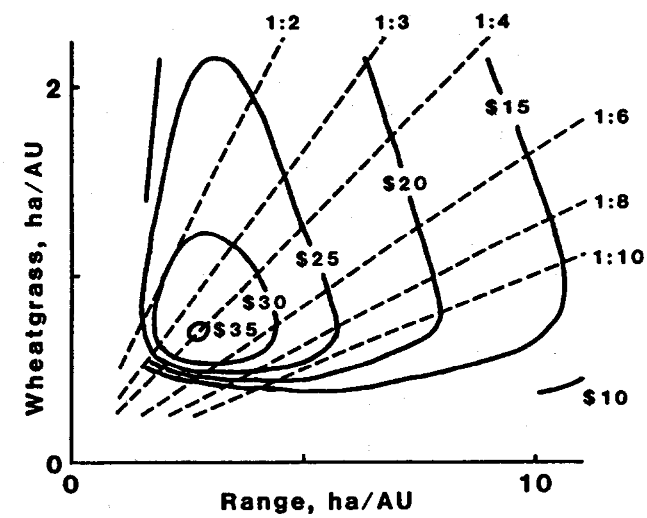

Fig. 4. *Contours of net return/ha to land, labor, and management (solid lines) from cows and calves grazing a crested wheatgrass-native range complementary pasture system; effects of ratio of wheatgrass to range (broken lines) and stocking rates.*

generated. Optimum stocking rate and ratio of crested wheatgrass to native range will depend upon range types, forage production, grazing season, production costs, and livestock prices. Level of management (Wilson et al. 1987) and marketing strategies (Ethridge et al. 1987) also influence returns. Finally, these calculations are based on short-term studies and do not consider possible long-term effects of stocking rate (Torell and Hart 1988).

A 42-day grazing season from 1 June to 12 July was assumed on the improved pasture, with forage production of 2,500 and 1,600 kg/ha of dry matter on brome-alfalfa and crested wheatgrass, respectively, during the time. Cattle would graze native range for 112 days from 13 July to 1 November. Calves would be weaned 20 September so would be on range only 70 days. Forage production on range was set at 1,200 kg/ha.

Livestock prices of $1.50 per kg for weaned calves, $438 for a 500-kg dry cow in September, and $478 for a pregnant 360-kg heifer at the same date were taken from the 1980–84 averages given in Kearl (1985). Thus the total cost of replacing an open cow is $40 times 1.09 or $43.60. Herd and Sprott (1985) indicate 4.1 kg of shelled corn or its energy equivalent are required for 1 kg of gain by a mature cow. The average price of corn was $0.105/kg in 1980–84 (USDA 1984); 1 kg of cow gain was valued at 4.1 times $0.105 or $0.43. Daily fixed costs per AU were estimated at $0.30 from data in Jose et al. (1985) and Kearl (1984); these include interest costs of $0.25 per day.

On improved pastures, conception rate remained at 100% until stocking rate increased beyond the point of maximum net return (Fig. 3). A conception rate of 100% did not mean a 100% weaned calf crop. We found that 95% of the cows and 84% of the heifers which tested pregnant in late summer produced live calves the following spring. Of those producing live calves, 95% of the cows and 98% of the heifers weaned those calves. Thus 90% of the pregnant cows and 82% of the pregnant heifers weaned calves the following year or, as stated in Material and Methods, 109 bred heifers are needed to produce as many calves as 100 bred cows.

Loss of weight by cows limited the stocking rates which could be sustained. At stocking rates in the permissible range of cow gains or losses, conception rate remained at 100%. Calf weaning weights, assuming a calf weight of 100 kg at the start of grazing on 1 June, varied only from 188 to 170 kg over all stocking rates and crested wheatgrass/range ratios simulated, reflecting the relative insensitivity of calf gains to stocking rate.

The optimum combination of 0.66 ha of crested wheatgrass and 2.60 ha of range per animal unit, equal to 1 ha of crested wheatgrass per 3.94 ha of range, returned $35.70/ha to land, labor, and management (Fig. 4). This is a much higher ratio of crested wheatgrass to range than is usually used or recommended. Cordingly and Kearl (1975) based their calculations for "a typical northern plains ranch" (range type and productivity unspecified) on 1 ha of crested wheatgrass per 12.1 ha of range. Houston and Urick (1972) used 1 ha of crested wheatgrass-alfalfa per 8.6 ha of range in Montana; botanical composition was similar to our range, but average production was only 740 kg/ha. Hart et al. (1983b) used 1 ha of crested wheatgrass per 11.3 ha of the same range used in this study; average forage production was 1,020 kg/ha. Our calculations indicate production at such a wide ratio of crested wheatgrass to range would be greater than that on optimally stocked native range alone but less than that from the optimum ratio and stocking rate on a crested wheatgrass-range system. For example, maximum return at a 1:10 ratio of crested wheatgrass to range was calculated as $23.67/ha, on 0.53 ha of crested wheatgrass and 5.3 ha of range per AU (Fig. 4). This return is 20% higher than the $19.77/ha return calculated for optimally stocked range alone (at 4.53 ha/AU) but 33% less than the return of $35.70/ha from the optimum stocking rate (3.26 ha/AU) and optimum ratio of crested wheatgrass to range (1:3.94).

Two factors may account for the large increase in net return formerly predicted from a ratio of crested wheatgrass to range of 1:10. First, net returns from range alone were underestimated because the range was understocked. Houston and Urick (1972) provided 10.4 ha of range per AU and Hart et al. (1983b) provided 10 ha/AU, but our calculations predict maximum return at 4.53 ha/AU. Predicted net return at a stocking rate of 10 AU/ha for a 154-day grazing season was $14.62/ha. The combination of 0.53 ha of crested wheatgrass and 5.3 ha of range per AU (A 1:10 ratio) should return $23.67/ha or 62% more. This is in line with previously cited estimates of increased returns which can be expected from seeding 1 ha of crested wheatgrass complementary pasture per 8 to 12 ha of range.

Secondly, other analyses may have over-estimated the cost of an open cow, considering each open cow equivalent to loss of income from 1 calf. But if open cows are detected at the end of the grazing season, they can be sold for almost enough to cover the cost of replacements. Figures cited earlier (Kearl 1985) indicated each open cow can be replaced at a net cost of $43.60. Thus the 9% reduction in conception considered by Cordingly and Kearl (1975) would cost only $0.87/ha at the optimum stocking rate of 4.53 ha/AU on range.

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Simulation and management implications of feral horse grazing on Cumberland Island, Georgia

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Abstract

Cumberland Island National Seashore, Georgia, is inhabited by a population of feral horses that intensively graze the island's salt marshes. Based on 18 months of experimental grazing studies, a carbon flow simulation model was developed for a medium height *Spartina alterniflora* marsh and used to estimate an acceptable population size of feral horses. Five-year simulations indicated a threshold of 2,700 kg/ha aboveground *Spartina* biomass below which the system did not recover if intensive grazing continued. The difference between this threshold and annual peak biomass of ungrazed *Spartina* was used to estimate horse densities that would not cause marsh degradation. Results suggest the horse population should number between 49 and 73 horses if excessive damage to the salt marshes is to be prevented. Thus, the current population of 180 horses should be reduced.

Key Words: simulation model, salt marsh, *Spartina alterniflora*, feral horses, *Equus caballus* population size, Cumberland Island National Seashore

The impacts of exotic species, including feral animals, have been documented in numerous ecosystems (e.g., Bratton 1975, Petrides 1975, Rudge and Campbell 1977, Turner 1984). During the last century, horses *(Equus caballus)*, pigs *(Sus scrofa)*, and cattle *(Bos taurus)* have ranged free on Cumberland Island National Seashore, Georgia. The U.S. National Park Service removed the cattle in 1974 and has greatly reduced the hog population through trapping. The horse population, however, remains unmanaged and appears to be increasing at a rate of approximately 5% annually. The population has increased from a minimum of 144 horses in 1981 (Lenarz 1983), to 154 horses in 1983 (Ambrose et al. 1983), and 180 horses in 1985 (Finley 1985).

Feral horses on Cumberland Island feed primarily in salt marshes, dunes, interdune meadows, and lawn areas. Lenarz (1983) reported that 51.7% of his observations of feral horse feeding occurred in salt marshes, which encompass 34.1% of the island (Hillestad et al. 1975). Vertebrate herbivory in salt marshes may alter the structure of the vegetation (Chabreck 1968, Shanholtzer 1974), reduce net aboveground primary production (Reimold et al. 1975), reduce standing stocks of belowground biomass (Smith and Odum 1981), result in a network of paths (Howell 1984), or reduce invertebrate populations (Reimold et al. 1975). In mixed species marshes, relative species abundance or successional patterns may be changed (Ranwell 1961, Bakker 1978, 1985, Dijkema 1984). With ungulate grazing, plant regeneration may be slow because of trampling (Chabreck 1968, Jensen 1985).

Horses presently remove up to 98% of the aboveground standing stock of *Spartina alterniflora* in heavily grazed marshes on Cumberland Island, and trampling alone can decrease net aboveground primary production (NAPP) by 40% (Turner 1987). Horses may also be having significant impacts on other plant communities on the island (Turner and Bratton 1987). Management of the horse population requires an estimate of the number of horses that can be maintained without excessive damage to natural ecosystems. Based on 18 months of experimental field studies, an ecosystem simulation model of the salt marsh was developed to examine the effects of various grazing intensities on standing stocks of *Spartina*. The objective was to determine an acceptable population size of horses based on impacts on the salt marsh, their major foraging community. The simulation model and its management implications are described in this paper.

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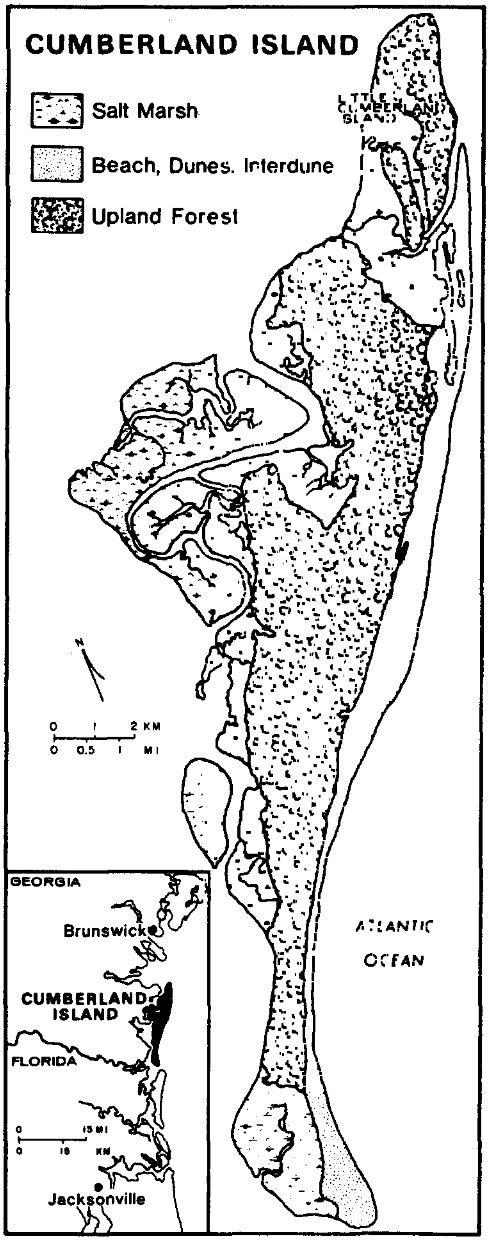

Fig. 1. *Map of Cumberland Island, Georgia, showing major vegetation communities.*

Study Area

Cumberland Island, Georgia (30°48′ N. lat., 81°26′W. long.) is the largest and most southern of the Georgia barrier islands (Fig. 1), measuring 25 km in length and 9 km across at its widest point. Designated a National Seashore in 1972, the federal boundaries encompass approximately 14,500 ha, owned, and administered by the U.S. National Park Service. The geology, soils, water resources, vegetation, and fauna of Cumberland have been described by Hillestad et al. (1975). The interior of the island is of Pleistocene origin whereas the seaward portion is of the more recent Holocene. Except in dune areas which may reach elevations of 18 m, the island is generally of low relief (5–8 m above sea level). The climate is warm temperate to subtropical and is characteristically warm and humid. Major plant communities are those typical for Georgia barrier islands (Johnson et al. 1974). Salt marshes occur throughout the tidal land on the mainland side of the island, characterized by a dominant macrophyte, the smooth cordgrass *Spartina alterniflora*. The upper margin of the marsh grades into a grass-forb community composed primarily of glass wort *(Salicornia virginica)*, salt grass *(Distichlis spicata)*, and occasional stands of needle rush *(Juncus roemerianus)*.

The upland portions of the marsh are bounded by tidal creeks that horses do not readily cross. To determine the marsh area accessible to horses, color infrared aerial photographs from 1983 (nominal scale of 1:24,000) and a Bausch and Lomb Zoom Transfer Scope were used. Area was calculated by planimetry. Results indicated that 411 ha of salt marsh were potentially available to the horse population. However, approximately half of this marsh area is only available at mean low tide and is not frequently grazed by horses. The remaining half of the marsh (approximately 205 ha) is used frequently and is already severely overgrazed *(personal observation)*. The current population of 180 animals (Finley 1985) is at a density of 0.88 horse • ha^{-1} of frequently used salt marsh.

Model Structure

The model contained 7 compartments (Fig. 2) and was developed to simulate carbon flow through the system on a yearly basis. The objectives of the model were to (1) adequately simulate the ungrazed, or nominal condition, of the salt marsh; (2) simulate current intensities of horse grazing; and (3) predict potential impacts on the marsh due to increased horse grazing.

Table 1. Differential equations used for state variables in the ecosystem simulation model.

State variable	Equation
X_1, Live aboveground *Spartina*	$dX_1/dt = F_{01}+F_{31}-F_{12}-F_{13}-F_{14}-F_{17}-F_{10}$
X_2, Dead aboveground *Spartina*	$dX_2/dt = F_{12}-F_{20}$
X_3, Live belowground *Spartina*	$dX_3/dt = F_{13}-F_{36}-F_{30}-F_{31}$
X_4, Insect grazers	$dX_4/dt = F_{14}-F_{40}$
X_5, Sediment macroorganic matter	$dX_5/dt = F_{65}-F_{50}$
X_6, Aerobic sediment heterotrophs	$dX_6/dt = F_{36}-F_{65}-F_{60}$

Notation F_{ij} indicates a flow of carbon from compartment i to compartment j.

The compartments, or state variables, are related by flows of carbon as shown in Figure 2. Changes in the state variables are calculated by a series of differential equations (Table 1) which incorporate the flows between compartments (Table 2). Season is an important control on many flows, for example, on photosynthesis and respiration. Seasonal variability is included in the model by changing relevant parameters at approximately 90-day intervals during the simulation. Two types of feedback control are also used in the model: (1) space-related feedbacks, such as overcrowding or self-shading; and (2) resource-related feedbacks, such as resource refuge levels and consumer satiation levels. The general forms of these controls are shown in Table 3, and the functions are fully described by Wiegert (1979). Values of the parameters used in the simulations are listed in Table 4. The computer program was written in BASIC, and calculations in the model are done on a daily basis. Initial conditions were obtained from field data (Turner 1985, 1987) and are set at the January values at the beginning of each simulation.

Grazing simulations were done for 5 years. The effects of horse grazing on other compartments were simulated, but the population dynamics of the herd (birth rate, death rate, etc.) were not generated internally in the model. Horse density was specified at the beginning of each simulation, either as a constant or with an annual rate of increase.

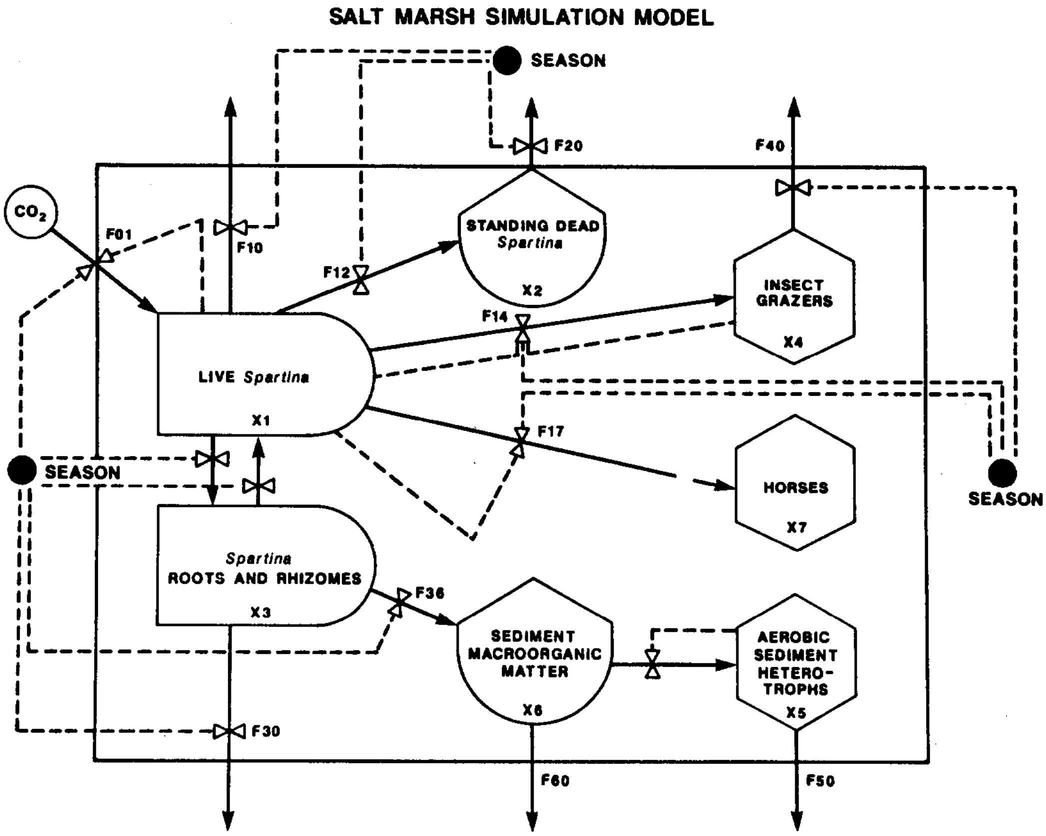

Fig. 2. *Diagram of the salt marsh simulation model. Solid lines indicate carbon flow pathways; broken lines are control pathways.*

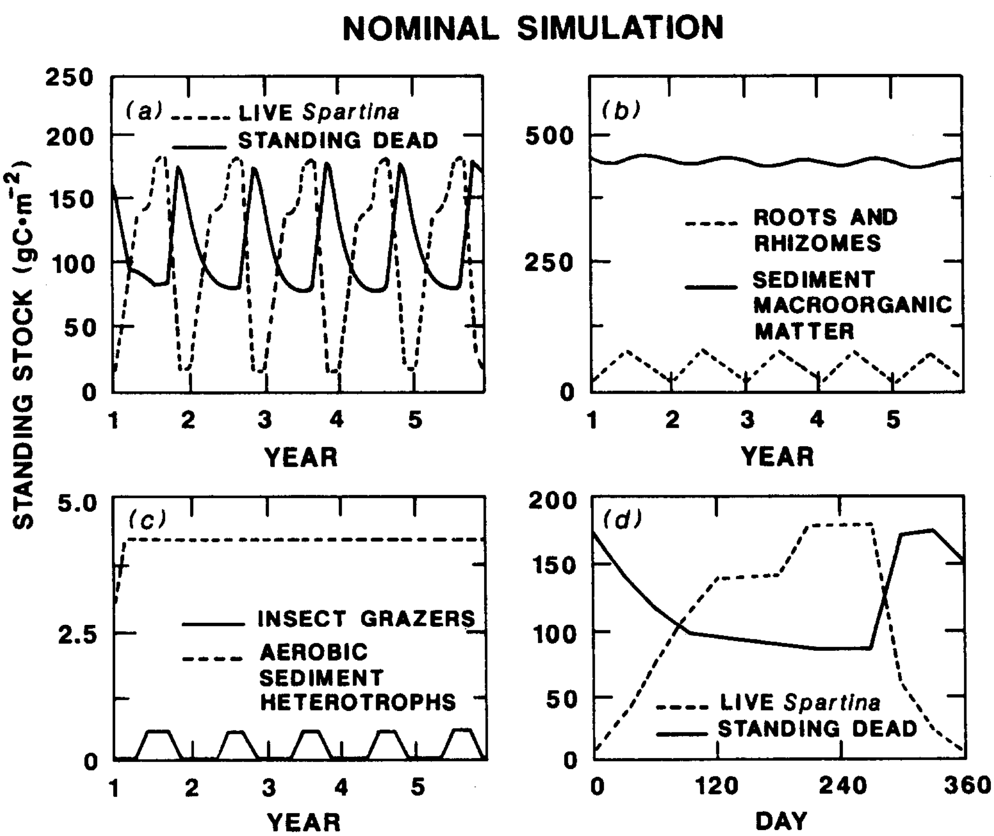

Fig. 3. *Simulation of the ungrazed marsh. Figures 3a, 3b, and 3c show dynamics of each compartment in 5-year simulations. Figure 3d is an expanded view of aboveground* Spartina *dynamics during 1 year of the simulation, showing seasonal patterns.*

Table 2. Description of flows (F_{ij}) used in the differential equations.

F_{01}	**Gross photosynthesis of *Spartina*** [(maximum gross photosynthetic rate by season)(standing stock of *Spartina*) (space related feedback control with response threshold and carrying capacity)]
F_{31}	**Translocation of carbon from roots to shoots in *Spartina*** [(specific rate of translocation per season)(standing stock of roots and rhizomes)]
F_{10}	**Respiration of *Spartina* shoots** [(specific rate of respiration by season)(standing stock of shoots)]
F_{12}	**Nonpredatory mortality of *Spartina* shoots** [(death rate of shoots by season)(standing stock of shoots)]
F_{13}	**Translocation of carbon from shoots to roots in *Spartina*** [(specific rate of translocation per season)(standing stock of shoots)]
F_{14}	**Ingestion of *Spartina* by insect grazers** [(maximum rate of ingestion)(standing stock of insects)(space feedback) (resource feedback control with satiation level and refuge level)]
F_{17}	**Ingestion of *Spartina* by horses** [(maximum ingestion rate per horse by season)(standing stock of horses) (space feedback)(resource feedback)]
F_{36}	**Death of live roots and rhizomes, becoming sediment macroorganic matter** [(seasonal death rate)(standing stock of roots and rhizomes)]
F_{65}	**Ingestion of macroorganic matter by aerobic heterotrophs** [(maximum ingestion rate)(standing stock of heterotrophs)(space related feedback term)(1-egestion)]
F_{60}	**Loss of macroorganic matter from the marsh, e.g., sinking, tidal export** [(specific loss rate)(standing stock of macroorganic matter)]
F_{40}	**Respiration of insect grazers** [(seasonal specific rate of respiration)(standing stock of insects)]
F_{50}	**Respiration of aerobic heterotrophs in the sediment** [(seasonal specific rate of respiration)(standing stock of microbes)]
F_{20}	**Loss of standing dead from the system** [(seasonal specific loss rate)(standing stock of standing dead *Spartina*)]
F_{30}	**Respiration and leaching of live *Spartina* roots and rhizomes** [(seasonal specific loss rate)(standing stock of roots and rhizomes)]

Table 3. General forms of feedback controls on rates of carbon transfer.

A. Generalized logistic for space-related controls:

$$f(X_i) = \{1 - (\lambda/\tau)\,[(X_i-\alpha_{ii})\,/\,(K_i-\alpha_{ii})]\}$$

where

λ = specific loss rate of X_i,

τ = specific rate of ingestion of X_i,

α_{ii} = density of X_i at which the density response begins,

K_i = carrying capacity of X_i,

such that the function ranges between 0 and 1, such that when $X_i < \alpha_{ii}$, $f(X_i)=1$ and when $X_i \geq K_i$, $f(X_i) = 0$; between these points the function is linear.

B. Generalized resource-related feedbacks:

$$f(X_i) = (1 - [(\gamma_{ij}-X_i)\,/\,(\gamma_{ij}-\alpha_{ij})])$$

where

γ_{ij} = the satiation level of resource X_i for consumer X_j beyond which the ingestion rate will no longer increase,

α_{ij} = the refuge level of resource X_i below which it is not available to consumer X_j,

such that the function ranges from 0 to 1, such that when $X_i < \alpha_{ij}$, then $f(X_i) = 0$ and consumption by X_j will also be 0, and when $X_i \geq \gamma_{ij}$ then $f(X_i) = 1$ and consumption by X_j will be at a maximum; between α and γ, the function is linear.

Table 4. Values of parameters used in the simulation model.

Parameter	Description	Value Winter	Spring	Summer	Fall
	Specific rates used in flow equations (day^{-1})				
TAU01	maximum photosynthetic rate of Spartina	.062	.136	.136	.044[a]
TAU13	specific rate of translocation from shoots to roots	.02	.05	.01	.02[a]
TAU31	specific rate of translocation from roots to shoots	.0001	.003	.0001	.003[b]
TAU65	maximum ingestion rate of aerobic heterotrophs in the sediment	.38	.38	.38	.38[b]
TAU14	maximum ingestion rate of insect grazers on Spartina shoots	.25	.25	.25	.25[c]
TAU17	maximum ingestion rate of horses	.0506	.0482	.06	.0808[d]
LAM10	specific rate of shoot respiration	.0035	.0048	.0026	.0019[b]
LAM20	specific rate of loss of standing dead from the system	.007	.003	.024	.01[b]
LAM30	specific rate of respiratory and leaching losses from roots and rhizomes to interstitial water	.00097,	.01148,	.007653,	.01[b]
LAM40	specific rate of insect respiration	.114	.12	.12	.114[b]
LAM50	specific loss rate of aerobic heterotrophs including respiration	.11	.11	.11	.11[b]
LAM60	specific loss rate of macroorganic matter including tidal loss and settling	.0004	.0004	.0004	.0004[b]
MU12	specific death rate of shoots	.0023	.0015	.012	.042[b]
MU36	specific death rate of roots and rhizomes	.0031	.0043	.004	.0035[b]
MU56	specific death rate of aerobic heterotrophs	.005	.005	.005	.005[d]
	Parameters in control feedback functions $(g\,C \cdot m^{-2})$				
EPS65	proportion of material egested by aerobic heterotrophs in the sediment	.25 (unitless)[d]			
ALPHA11	threshold response density of shoots	10[d]			
ALPHA44	threshold response density of insect grazers	1.25[e]			
ALPHA55	threshold response density of aerobic heterotrophs	7.44[a]			
K1	carrying capacity of shoots	200[d]			
K4	carrying capacity of insect grazers	1.25[e]			
K5	carrying capacity of aerobic heterotrophs	9.0[b]			
ALPHA17	refuge level of shoots from horse grazing	7.26[d]			
GAMMA17	satiation level of shoots with regard to horses	40[d]			

[a]Modified from Wiegert and Wetzel (1979) using data from Turner (1985,1987).
[b]From Wiegert and Wetzel (1979).
[c]From Smalley (1959).
[d]From Turner (1985, 1987).
[e]From Wiegert et al. (1975).

Results

Simulations

The nominal model simulates stable annual cycles of the components and shows no net change from year to year (Fig. 3). Seasonal growth cycles are apparent; peak biomass is reached in late summer, while peak standing dead occurs in early winter. Insect grazers increase during the summer, then decline. These simulations agree closely with field data from horse exclosures (Turner 1987), as illustrated by comparing an annual cycle of simulated and observed ungrazed live *Spartina alterniflora* biomass (Fig. 4). A series of sensitivity analyses was also done with the nominal model (see Turner 1985), indicating as expected that *Spartina* productivity was the dominant control in the marsh.

The effects of grazing on *Spartina* standing stocks with constant horse densities are shown in Figure 5a-c. With 0.136 horse/ha, *Spartina* productivity is sustained (Fig. 5a). When the horse density increases to 0.151 horse/ha, standing stocks decline gradually during the 5-year simulation (Fig 5b); and a density of 0.165 horse/ha causes a drastic reduction in *Spartina* biomass (Fig. 5c). Horse grazing also caused macroorganic matter to be lost from the system during the simulations, but the insect grazer and bacterial populations were not affected. Results of simulating the horse population using the current annual rate of increase, 0.05, and beginning with a density of 0.136 horse/ha are shown in Fig. 5d. This simulation suggests a sharp demarcation between what appear to be tolerable intensities of grazing and deleterious levels. When the aboveground peak biomass of *Spartina* falls below a threshold of about 125 g $C{\bullet}m^{-2}$ (equivalent to 2,700 $kg{\bullet}ha^{-1}$ dry weight of *Spartina*), the plants cannot recover unless grazing intensity is reduced. This occurs because primary productivity becomes insufficient to support the herbivory, and *Spartina* standing stocks fall to refuge levels; when grazing pressure is reduced, biomass will again increase.

Actual grazing patterns on the marsh vary spatially, with some areas used intensively and other areas only used sporadically. The grazing simulations correspond closely with field data from plots which had light, moderate, and high intensities of horse grazing (Fig. 6). The model generates reasonable effects of grazing, as can be seen by comparing the curves in Figure 6 with 1-year segments of the grazing simulations shown in Figure 5.

Estimating an Acceptable Horse Population Size

Biomass produced in excess of the threshold of 2,700 $kg{\bullet}ha^{-1}$ was considered a sustainable loss of *Spartina* to horse grazing. A range for the size of the horse population was then determined. This required several steps:

1. Average daily consumption of forage per horse (Table 5) was estimated at 7.7 kg dry weight per day based on standard horse nutritional requirements (National Research Council 1978) and the population structure of the herd in 1983. This value will vary with herd structure.

2. Average daily consumption of *Spartina* per horse was estimated to be 50% of total forage, based on Lenarz's (1983) observations of horse foraging. A higher (60%) and lower (40%) proportion of *Spartina* in the diet was also examined to bracket the estimates with more and less intense grazing effects. Thus, annual *Spartina* consumption per horse is:

0.60 × 7.7 kg × 365 days = 1,686 kg/year (more intense grazing)

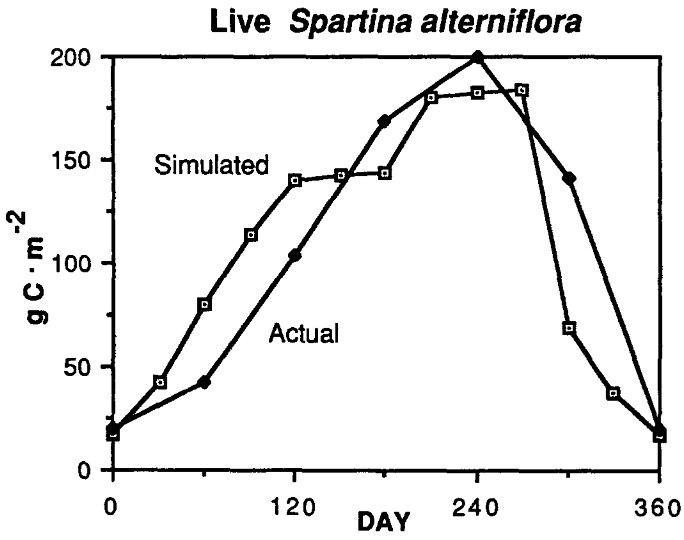

Fig. 4. *Comparison of one-year simulation of live* Spartina *and 1984 field data (from Turner 1985, 1987).*

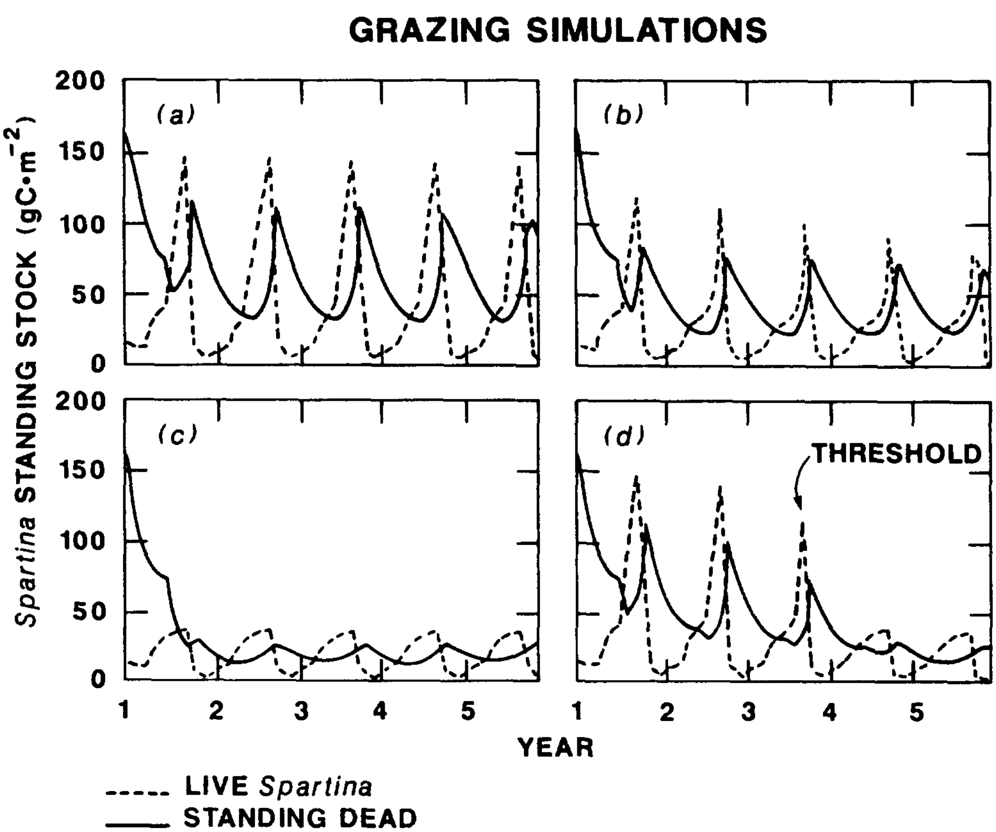

Fig. 5. *Simulated aboveground* Spartina *with different horse grazing intensities: (a) 0.136 horse/ha; (b) 0.151 horse/ha; (c) 0.165 horse/ha; (d) 0.136 horse/ha increasing at 5% per year. Note threshold level in (d) where decline in* Spartina *standing stock is quite sharp.*

Table 5. Daily forage requirements per horse for the 1984 feral horse population on Cumberland Island.

Class	Number of Horses[a]	Digestible energy required per horse[b,c] (Mcal)	Dry forage required per horse[b,d] (kg)	Total dry forage required (kg)
Mature horses	113	16.86	7.7	870.1
Lactating mares	7[e]	25.00	11.4	79.8
Foals	7	9.10	4.1	28.7
Yearlings	27	16.80	7.6	205.2
TOTAL	154	–	–	1183.8
Average	–	–	7.7	–

[a]From Ambrose et al. 1983.
[b]Data source: National Research Council (1978).
[c]Based on 400 kg mature weight, includes maintenance requirement plus 3 Mcal for walking.
[d]Based on values reported for digestible energy content of grazed grasses.
[e]Estimated from the number of foals.

0.50×7.7 kg $\times$ 365 days = 1,405 kg/year (average grazing)
0.40×7.7 kg $\times$ 365 days = 1,124 kg/year (less intense grazing)

3. From the model and field data, the amount of *Spartina* available to the horses if the integrity of the marsh is to be maintained was estimated at 400 kg/ha. This number was estimated as follows. Field data indicated a range of annual net aboveground primary production from 3,000 to 4,250 kg/ha (Turner 1987). The simulation model indicated a threshold level of 2,700 kg/ha of *Spartina*, below which the system could not be sustained if grazing continued at the same intensity. This suggests that a yearly loss to grazing of 300 to 1,550 kg/ha might be tolerable, depending on location; thus a loss of 800 kg/ha might be acceptable on average. But, because trampling causes a decrease in NAPP equivalent to that of consumption (Turner 1987), only half the 800 kg/ha should actually be consumed as forage.

4. The area of marsh required per horse could then be determined:
1,686 kg/horse/400 kg/ha = 4.2 ha/horse (more intense grazing)
1,405 kg/horse/400 kg/ha = 3.5 ha/horse (average grazing)
1,124 kg/horse/400 = 2.8 ha/horse (less intense grazing)

5. The final step then requires dividing the generally accessible marsh area (205) ha by the area required per horse:
205 ha/4.2 ha/horse = 49 (more intense grazing)
205 ha/3.5 ha/horse = 59 horses (average grazing)
205 ha/2.8 ha/horse = 73 horses (less intense grazing)

Thus, an acceptable range for the size of the horse population may be between 49 and 73 animals, which is 27% to 40% of the current population size.

Discussion

Because of the numerous potential impacts of horse grazing on Cumberland Island, the population estimates derived in this paper are probably conservative. For example, implications of horse grazing for the marsh extend beyond a reduction of *Spartina* biomass. Because accretion of sediment in marshes is a function of the density of grasses present to trap particles (Gleason et al. 1979), heavily grazed marshes may be more susceptible to erosion and storm damage. Thus, intensive grazing could create conditions that favor the loss of marsh habitat. Species distributions on the marsh may also be altered by heavy grazing, permitting *Salicornia* spp., which is unpalatable to horses, to dominate (Reimold et al. 1975). Grazing may reduce populations of fiddler crabs (Reimold et al. 1975) which are known to exert a positive influence on *Spartina* growth (Montague 1980) and are prey for consumers such as raccoons. Intense grazing by horses may also alter the detrital food web, indirectly affect other consumer populations, or change the export/import of organic matter from the marsh.

Effects on other island habitats were not considered in the model. Impacts of the horses on communities such as the interdune meadow and maritime forest should be monitored. For example, the model assumes a constant proportion of *Spartina* in the horses' diet and that switching to a different forage does not occur. As the marsh becomes more severely overgrazed, horses may select an alternative food source, which may increase their impact on other habitats.

The horse population has significance in the history of Cumberland Island, and there is public interest in maintaining the herd. This study suggests that a small horse population can probably be maintained on Cumberland Island without excessive marsh deterioration. The population must be reduced from its present size, however, to permit recovery of the overgrazed marshes. This study indicates an acceptable population of 49 to 73 animals on the island based on current grazing intensities in the marshes. A smaller horse population could also be restricted to a portion of the island and excluded from the remainder, permitting a recovery from grazing. The long-term impacts of horse grazing on the marshes and other habitats should also be monitored regularly.

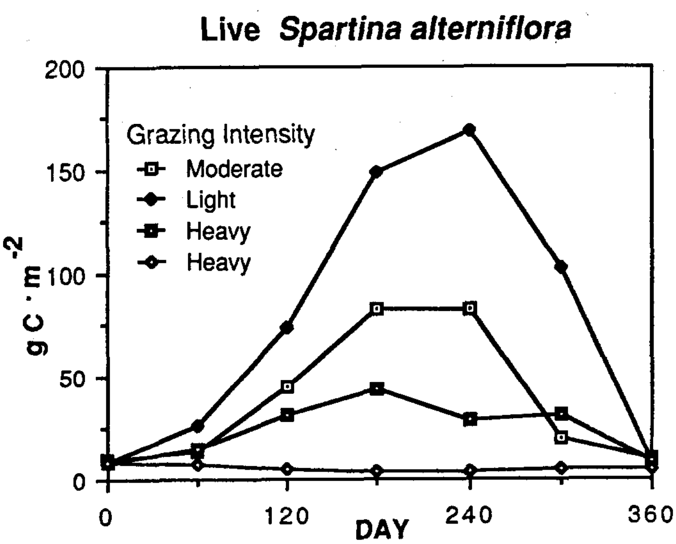

Fig. 6. *Aboveground live* Spartina *in 1984 with different intensities of horse grazing (data are from Turner 1985, 1987). These curves can be compared with one-year segments of the simulations shown in Figure 5.*

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Book Reviews

Livestock and Wildlife Management During Drought, 1985. Robert D. Brown (Ed.). Caesar Kleberg Wildlife Research Institute, Texas A & I Press $5.00 paper.

This book contains the proceedings of a workshop held at Texas A & M University on June 19, 1985. The introductory paper reviews the frequency and severity of droughts in South Texas from 1900 to 1983 and establishes a foundation for the eight papers that follow.

While the introductory paper describes the climate and emphasizes the unreliable rainfall problems of South Texas as being unique, it is obvious from world precipitation maps that serious rangeland droughts are not unique to South Texas, or even to the United States, but *tout le monde*. Personal experiences reinforce the fact that many rangelands in Northern and Southern Africa as well as portions of Australia also experience "unique" drought problems such as those described in the proceedings. Thus, conclusions in the papers regarding cattle management during times of drought are appropriate for other parts of the world. Such suggestions as lowering stocking rates during droughts as well as working cattle in early morning or late evening are sound recommendations for management in such far-away ranges as are found in Lesotho, Swaziland, or Morocco.

Several of the papers discuss the possibility of using short-duration grazing and other rotation systems to alleviate the effects of drought. The Savory Grazing method is briefly reviewed within the text. Overall, the authors suggest that "grazing systems offer possibilities of benefits for both livestock and wildlife which could not be obtained otherwise." Most of the results quoted are preliminary. Nevertheless, an important conclusion stressed later in the proceedings is that, "benefits can be derived by using a planned grazing system, especially during drought."

We were disappointed in the lack of attention given wildlife management. Inter-relationships between cattle and wildlife during and after drought are of utmost importance for the welfare of all concerned and justify full consideration. The tendency of deer to vacate pastures as cows moved in is similar to results found on other ranges. This practice is similar to the natural rotation process in Africa where one species of grazing animal is followed by another.

A recommendation that "prickly pear should be included in any range management plan in this (or) similar areas throughout the world" is debatable, particularly in relation to other parts of the world. Such a program might be an injustice to fellow herdsmen in some developing countries. Cacti already planted at the expense of grass in those countries cannot economically be made edible by burning off spines because of a lack of finances for fuel. Spineless forms of cacti are usually protected from grazing so the fruits can be sold at the market. Also, in most of these countries native vegetation is so low in protein content that the introduction of protein-deficient cacti would aggravate the situation.

In summary, the book has practical information for use by hands-on range managers. It not only includes suggestions for easing drought problems, but also offers good recommendations to aid during the recovery period when the rains return. We think it is well worth the price of five dollars and should be in every range manager's library. *Carl J. Goebel*, Washington State University, Pullman and *Jeff Goebel*, Hana Ranch Resource Manager, Maui.

Colorado Flora: Western Slope. 1987. William A. Weber. Colorado Associated Univ. Press, Boulder, CO 80309. 530p. $19.50 cloth.

Range managers, botanists, and ecologists doing field work in western Colorado have not had a single, comprehensive, current volume with which to identify vascular plants. This has changed with the publication of Professor Weber's new flora.

This flora is intended to be used in the field by both professionals and amateurs, so detailed descriptions of the species have been omitted to keep the volume reasonably portable. The book has 64 color plates and 107 figures, each containing 3 to 5 line drawings. Thus, only a fraction of the 2,150 species recognized in the book is illustrated. The book seems to be sturdily bound and is attractively priced.

The flora is organized by three major groups: ferns and their allies, gymnosperms, and angiosperms. The alphabetic arrangement of families and genera within families greatly facilitates locating taxa. Monocot and dicot families are intermingled within the angiosperm group. Also included are meanings of genus names, which can aid in remembering them.

The book ends with a glossary of terms, an index to selected common names, and an index to genera. The genus index refers the reader to the corresponding family acronym but, unfortunately, does not give page numbers. The generic index also cross-references the numerous "new" (to most readers) generic names which either replace or are subdivisions of "old" genera. The generic index does not contain the names of species, which is inconvenient when trying to locate quickly species in large genera such as *Astragalus* or *Carex*.

Professor Weber is aware that his flora will undoubtedly frustrate many readers because of its plethora of unfamiliar genus names. Weber states that he deliberately set aside his preconceptions of generic boundaries and sought a "fresh new look at the flora." Almost 200 genera appear in this flora which were not recognized in Harrington's *Manual of the Plants of Colorado*. No reasons are given for particular generic rearrangements, although a brief phrase or two of explanation could have been added in each instance without unduly burdening the book. He has concluded after 40 years of study in Colorado and around the globe that "lumping is not a virtue." He implies that his use of unfamiliar generic concepts will be vindicated in the future.

The author points out that one need not subscribe to his generic concepts in order to use this flora. In the vast majority of instances, the cross-referencing of "old" and "new" genera makes the translation of names simple. When one ends up at an unfamiliar genus or species name after using the keys, a reference to the former name appears at the end of the brief species description. Most readers should become comfortable with the keys in short order.

Colorado Flora: Western Slope will be an important tool for range scientists performing vegetation studies in western Colorado mainly because the keys are so good. Professor Weber has written a flora whose value to field workers should not be underestimated because of his use of strange generic names.—*Alan T. Carpenter,* Colorado State University.

Ecological Simulation Primer. 1987. Gordon L. Swartzman and Stephen P. Kaluzny, MacMillan Publishing Co., New York. 370p.

To quote the authors, "Simulation models are the only tool presently available for translating a collection of hypotheses for ecological processes into a representation of how the whole ecosystem functions." This fact, in itself, is sufficient justification for mastering the use of this important tool. However, there are other, perhaps even more important reasons for understanding the applications and techniques for simulation modeling. Policy decisions ranging from management of Federal lands to storage of high-level nuclear wastes are increasingly based on results from simulation models. Legal decisions may also draw heavily on these results. These facts lead one to conclude that scientists need training in simulation modeling. Not only in how to do it, but in testing and validating models, and in knowing the limitations and problems inherent in any simulation effort.

Ecological Simulation Primer, according to its authors, was written to provide a text "devoted to ecological simulation modeling that covers the basics of model development, techniques for model analysis, and methods for model evaluation...." They claim that, upon completion of study of the text, the reader "should be able to design and run a simulation model and be able to read, comprehend, and evaluate modeling articles in the literature." The orientation of the book is therefore that required to provide the working knowledge of modeling that modern ecologists need.

The book starts from an overview of simulation modeling and progresses through linear models, model processes, nonlinear models, stochastic methods, model evaluation, and applications. At each step, algorithms are presented in easily understood pseudocode as well as in nicely structured modules of Fortran 77. While Fortran is often used for model coding, it would be an easy matter to recode the modules in other languages, if desired. Simulation examples are given in the text, and exercises are given at the end of each chapter. The mathematical skills required for mastery of the materials in the book are perhaps somewhat beyond those typical of many upper-class and graduate students in biology, but appendices provide useful reviews of topics in linear algebra and statistics.

I felt that the objectives of the book were admirably fulfilled. One would not expect to be an expert at simulation modeling after completing the book, but it certainly provides a good foundation on which to build. Even if one were not to go in in this area, the material learned from the book would allow one to ask the right questions about models that are proposed as bases for management decisions or policy making. Features of the book that I especially liked were the excellent treatments of model documentation and organization and the examples of code modules and module interfaces. Most modelers could benefit greatly from a careful reading of these sections. Other features that I liked were the examples and exercises. I doubt that any student can expect to master this subject without working through the exercises. The examples provide good test cases to try before one jumps off into the unknown.

The models presented and discussed in the book are ideal for presenting the information the authors wish to present, but are, of course, much simpler than many ecosystem models which are in common use today. The book is obviously not a substitute for the extensive knowledge of biology, soils, environmental physics etc., required to be a good ecosystem modeler. It does, however, provide a sound foundation on which to build.—*Gaylon S. Campbell,* Dept. of Agronomy and Soils, Washington State University, Pullman 99163.

INSTRUCTIONS FOR AUTHORS (from revised *Handbook and Style Manual)*

Although not intended as an exhaustive presentation on manuscript preparation, this *Handbook and Style Manual* was prepared with the less experienced author in mind. Points of style, however, must be followed by all authors. Manuscripts not conforming to *JRM* style as designated here will be returned to authors for correction before being sent out for review.

From time to time, this manual will be revised. The inside back cover of the *Journal* will carry brief instructions for authors and will advise them of style changes or a new edition of the style manual.

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The *Journal of Range Management* is a publication for reporting and documenting results of original research and selected invitational papers. Previously published papers are unacceptable and will not be considered for publication. Exceptions to this criterion are research results that were originally published as Department Research Summaries, Field Station Reports, Abstracts of Presentations, and other obscure and nontechnical handout publications. Manuscripts submitted to the *JRM* are the property of the *Journal* until published or released back to the author(s). Manuscripts may not be submitted elsewhere while they are being considered for this journal. Papers not accepted for publication are automatically released to the authors.

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