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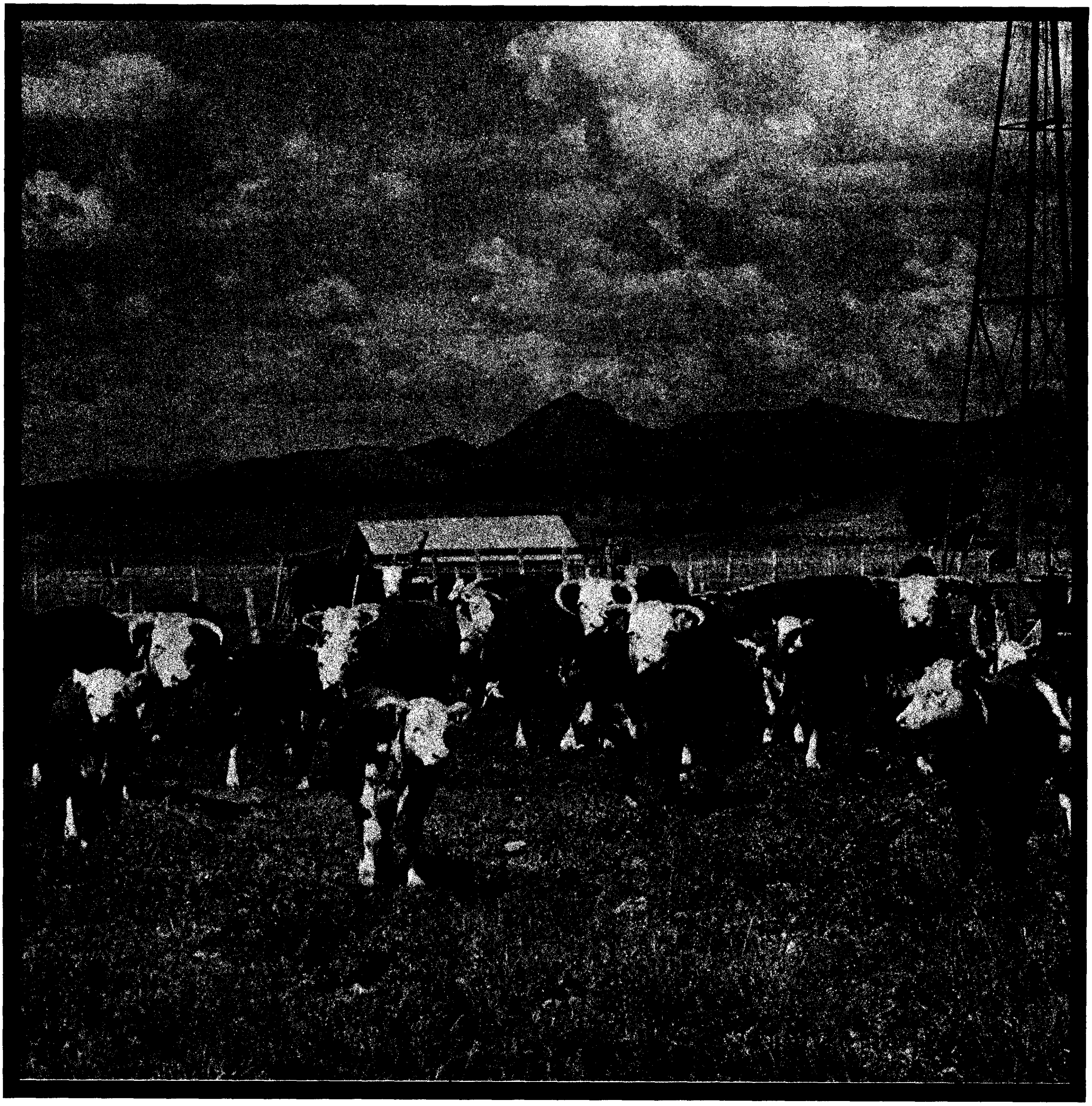
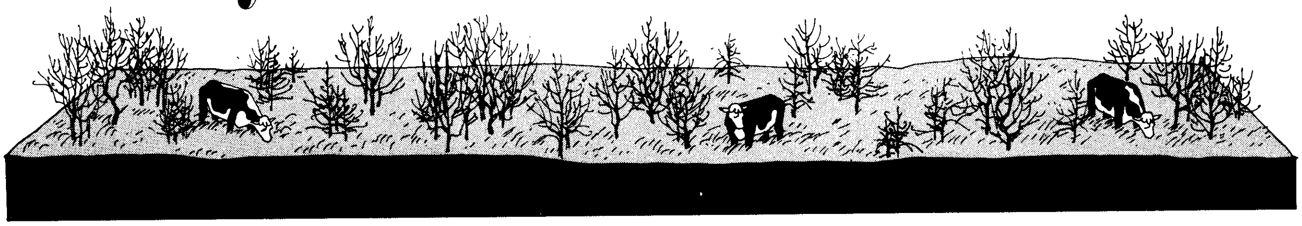
JOURNAL OF RANGE MANAGEMENT

SOCIETY FOR RANGE MANAGEMENT

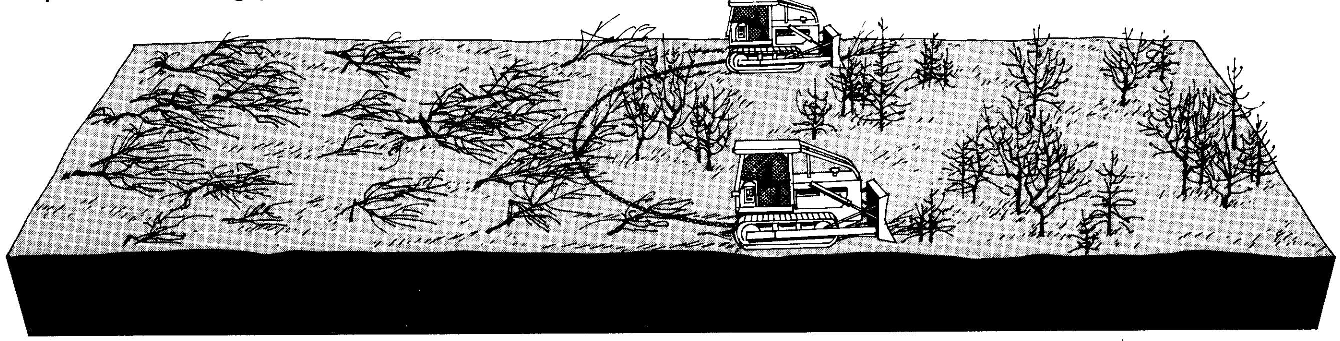


In connection with the universal problems of population (numbers and distribution), human food supplies, and environmental quality, land use plans and recommendations frequently are advanced that do not adequately consider different land types, land capabilities, or the quality and availability of resources. In such situations neither the present nor future roles of rangeland in meeting mankind's needs are well understood or appreciated. The implementation of land use plans without a full consideration of all alternatives may result in the impairment, or even virtual destruction, of the inherent productivity and value of many ecosystems. Thus, lands must be classified according to their capabilities and suitabilities as limited by climate, soil, and topography. Subsequently, land uses and treatments may be adjusted on the bases of (1) land condition and capability, (2) the level of technology, (3) economic demands, and (4) social pressures.—*BENCHMARKS, Society for Range Management*

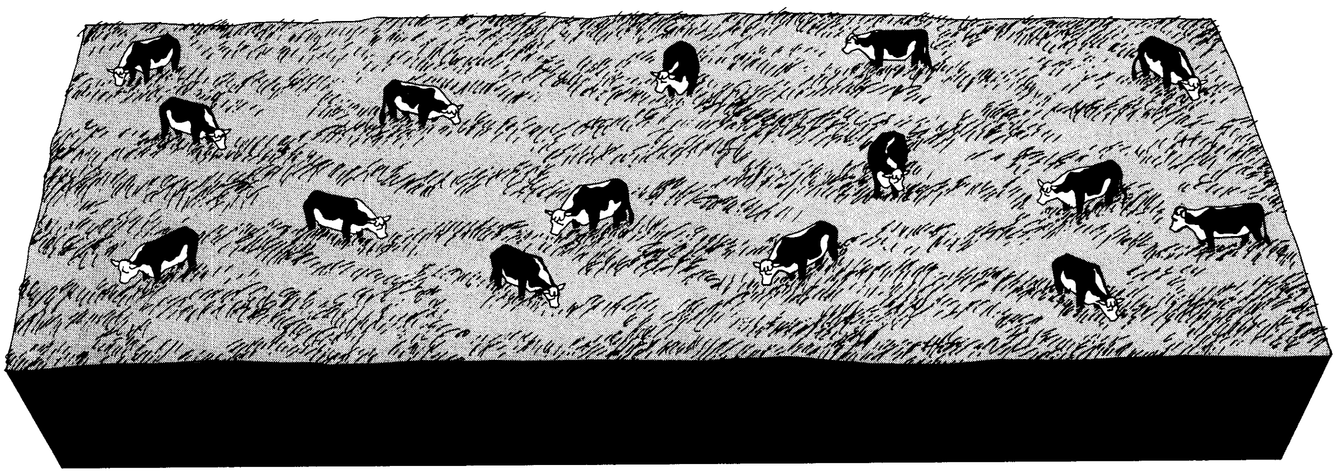
Get rid of the stuff your cattle won't eat...



What a herd you could graze if your whole range was grass! And what a profit you could make! The fact is, mesquite, sage, chapparral, pinyon or whatever inedible brush you've got growing on your range is costing you money and lots of it. Getting rid of it can be the most profitable thing you could do this year.



Call the land improvement contractor who has Caterpillar equipment. Through chaining, rootplowing, disking or grubbing, he can eliminate your brush problem and reseed your range to adapted grasses. Yes, it's rough work, but his Caterpillar-built equipment is ready for jobs like this. Efficient and economical, it helps him keep the lid on his costs and prices.



Land improvement can pay for itself. That's been the experience of many ranchers who have had their land cleared through mechanical brush control. You'll find you can run a much larger herd on the same acreage, and their weight gains are usually higher. Go over your acreage with your land improvement contractor and get the facts and figures about how mechanical brush control can turn brushland into rangeland.

And boost your profits!

Land investment today builds tomorrow's profits.

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SOCIETY FOR RANGE MANAGEMENT

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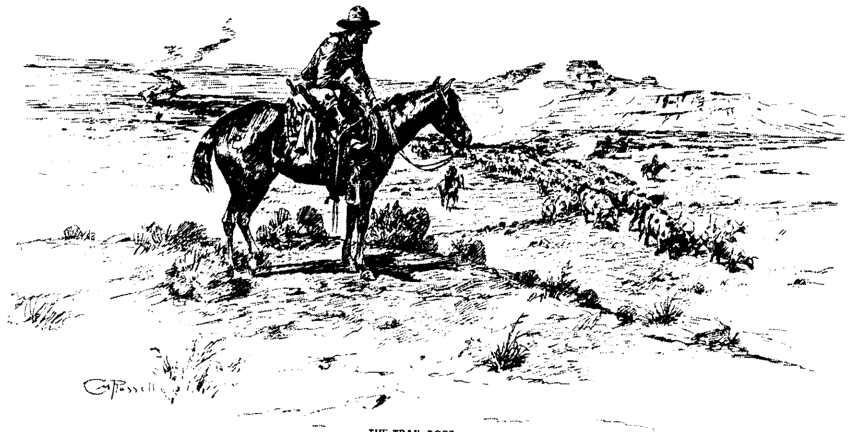

THE TRAIL BOSS

The **Society for Range Management**, founded in 1948 as the *American Society of Range Management*, is a nonprofit association incorporated under the laws of the State of Wyoming. It is recognized exempt from Federal income tax, as a scientific and educational organization, under the provisions of Section 501(c)(3) of the Internal Revenue Code, and also is classed as a public foundation as described in Section 509(a)(2) of the Code. The name of the Society was changed in 1971 by amendment of the Articles of Incorporation.

The objectives for which the corporation is established are:

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

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

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

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

—to promote professional development of its members.

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 Secretary for details.

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

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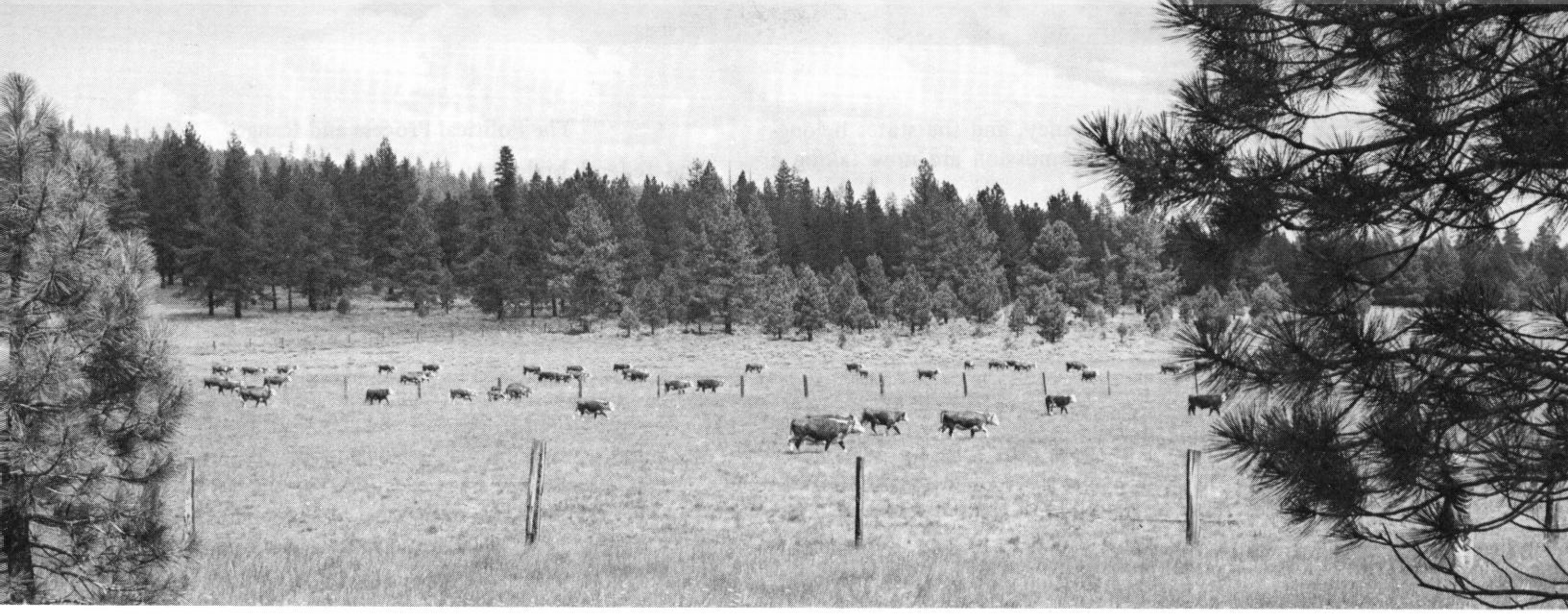
COVER: Long Meadow Ranch, Arizona. (Photo by Matt Culley, Prescott, Arizona.)

Status and Outlook for Range in the New Politics

JOHN R. McGUIRE



Highlight: *Continued need is predicted for livestock grazing from the nation's forests and ranges. However, more consideration must be given to desires of people for all the goods and services range provides. This is the new politics of range management and development. Program goals must consider enhancing the environment while planning more efficient use of the range for livestock production.*

The theme "Rangeland Resources and Politics" is timely. The role that range can and should play in a changing, environmentally-awakened society needs more discussion. It needs exposure to the forum of the Society for Range Management and beyond its membership—exposure that it can sponsor.

I would like to start by explaining a couple of terms. By the term *new politics* is meant the various new institutional arrangements made in recent years to deal with questions of public policy. There are new laws, such as the National Environmental Policy Act. There are new court decisions, particularly relating to standing to sue. There are new government organizations, such as the Regional Commissions. And there are shifts of political emphasis, particularly from the rural areas to the cities.

In the term *rangeland*, I include, as the Society for Range Management does, natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows.

The Society for Range Management is concerned about ". . . understanding range ecosystems, . . . whose resources include tangible products and intangible values." Thus, we share a common concern about natural systems and understanding of how systems operate and how their components interrelate. The Society for Range Management recognizes (and I quote from its *Benchmarks: a statement of concepts and positions*), ". . . that intelligent use of range resources must be based on economic and social decisions compatible with the capabilities of the biological system." With this we certainly agree. It is the interaction of the resource with politics that I want to discuss.

The author is chief, Forest Service, U.S. Department of Agriculture, Washington, D.C.

The paper was presented at the 26th Annual Meeting of the Society for Range Management, Boise, Idaho, February 5, 1973.

General Outlook

Increased numbers of people and their activities and consumption are causing increased demands for goods and services. Although population projections recently have been lowered due to sharp declines in fertility and birth expectations, demographers say that zero population growth is still some years away. By 1980 our population may rise to between 222 and 231 million, about 8 to 13% over 1970. Higher levels of spendable income contribute to the increasing demand for goods and services.

Consumption of industrial wood in the United States (i.e., all products except fuelwood), increased 70% to a level of 13 billion cubic feet between 1940 and 1971, and our studies indicate further increases—to nearly 23 billion cubic feet by the year 2000, assuming 1970 price levels. We also expect higher demands for wildland recreation. Recent estimates indicate that between 30 and 40 million people now camp, compared to about 11 million in 1960. Camping, however, may be approaching a temporary saturation. Increased hunting, off-road recreation vehicle use, skiing—all important outdoor recreational activities—are projected. Water flow requirement from the nation's wildlands also is projected to increase significantly in the years ahead. Needs for energy are increasing, particularly for production of electricity and for gas and other fossil fuels.

I offer these observations because I believe we can intelligently consider range only in the context of society's needs and desires. We must be prepared to consider the need for trade-offs among the many resources of the nation's forest and range ecosystems, as society's needs and opportunities to meet those needs change.

For example, fossil fuels provide much of our energy for heating, as well as for production of electrical energy. Environmental problems arise in the process of mining of coal and its conversion to fuel and to electricity. Some argue in favor of dampening the demand for energy as a means of dealing with these environmental problems by raising prices. Others favor more use of nuclear energy sources. The issue is well illustrated by the prospective development of the low-sulfur coal deposits of the Northern Plains areas and the probable development of oil-shale lands which appear to be in the offing. The Departments of the Interior and Agriculture, the Environmental Protection Agency, and the states belonging to the old West Regional Commission are now taking a look at this situation.

Possible trade-offs between range grazing and alternative sources of energy for livestock production also need to be understood. In many places, range is the most efficient source of livestock forage. Cropland may often compete economically, but always with a greater expenditure of energy. As fuels become scarce and their total environmental costs are assessed, range may be called on to produce far more forage than now.

Allocating Range Use

These and similar national issues are of concern to all of us who must evaluate prospective levels of land and resource use in relation to public need. For example:

National Forest grazing has been in strong demand for the 68 years there has been a Forest Service. Ranchers and farmers have grazed their livestock either seasonally or year-long upon grazing allotments under paid term permit. We considered the need of the grazier for the grass and environment of the range. He contributes substantively to meat production, and from his operation derives income which helps turn the economic wheels of his local or regional area. A principal factor limiting the number of permitted livestock has been the grazing capacity, even though research has yielded many ways favoring increased livestock use.

Stocking of National Forest ranges was too heavy in the early years, especially during World War I when increased grazing was allowed to help meet national needs for meat and fiber. Since then, adjustments have been made to bring the grazing load back into line with the capability of the land for sustained production. We were not always as successful as we wanted to be in balancing livestock use with resource capability. There was competition for range in some areas, but essentially it was competition between two groups of herbivores–livestock and big game.

As population increased over the years and public needs and customs changed, new pressures began to affect the range. Increasingly the public has made use of the range. No longer is the problem simply one of allocating grazing among the ranchers and farmers who want to graze livestock. The problem now is to allocate range among a host of uses, including off-road vehicle travel and wild horse grazing.

Not only are there new demands for the resource, but there are also stiffer requirements for its management.

Public land administrators in the past were ruled by an ethic of conservation–a land ethic–that called for protecting the soil while the resource was being used for the public good. But today they must also manage for environmental quality, and this includes more values–esthetics, scenery, solitude, to name but a few. This intensified public interest has resulted in such new legislation as the National Environmental Policy Act of 1969.

This new political climate affects not only livestock grazing on the National Forests but also the management of timber, wildlife, recreation, watersheds, wilderness, minerals, and the rest. It requires the development and evaluation of a broad range of land use alternatives and program mixes. It requires public involvement in planning and decisionmaking. Citizen expressions of environmental, social, and economic concern today influence more than ever the development and administration of public policies. The citizen, the legislator, the court, the public land manager are involved together as never before.

The Political Process and Range

The federal budgetary process is a good example of this process. In the Forest Service we maintain long-range plans for production of specific resource outputs. Each year the Forest Service requests the manpower and funds to attain the specified goals.

The Federal Budget, submitted annually to the Congress, presents a proposed level of federal spending that the President believes would best meet national goals of all kinds. The proposed budget for the fiscal year 1974 to begin July 1, 1973, was presented to the Congress on January 29, 1973.

In preparing this budget, each program of each agency was evaluated in relation to the contributions it could make toward achievement of national goals. Dollars were apportioned among the various programs in accordance with national priorities and within the total budget ceiling. Trade-offs were considered at each level of the budget review to cut and fit dollar levels to the size of the total outlay.

In the formation of the budget, Welfare competes with Foreign Assistance; Defense with Transportation; Agriculture with Housing; and so on.

Guiding construction of the President's budget are policy and other direction spelled out in the law. The Congress acts upon each element of the President's budget and also cuts and fits it according to its judgment. Interest groups normally voice their needs through the Congress.

Once the Congress is satisfied with the budget, it authorizes expenditure of agreed-upon monies and appropriates these funds through the legislative process. Thus, budgetmaking is essentially a political process. Throughout the process the citizen can and does make his opinions and needs known to both the legislative and executive branches.

Some Forest Service Concerns

In developing the annual budget, we must answer several key questions. How much of the Forest Service dollar should be used for range grazing purposes in the National Forest System? How much, if any, in support of non-federal forest-range grazing via our State and Private Forestry effort? And, how much for research on pressing problems.

Once the goals and funding decisions are made for range programs, we must search out the more productive National

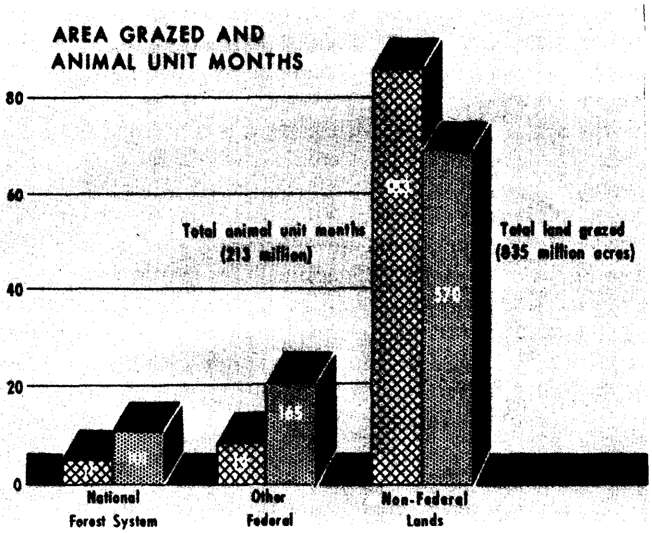


Fig. 1. *Livestock grazing and AUM production on US forests and ranges in 1970 (48 states).*

Forest System range areas where costs of maintenance and development are reasonable. At the same time, we must give specific attention to range areas with special social and environmental problems. Our objective is to use the public funds among all areas in such a way that the range programs will contribute more efficiently toward the nation's overall goals.

National Range

We predict a continued high demand over the next 10 to 20 years for forest-range grazing. Our projections suggest an increase of 20% between 1970 and 1980 and 50% between 1970 and the year 2000.

There are 1.2 billion acres of forest and rangeland in the 48 conterminous states. Of this area, 835 million acres at present are being grazed by livestock during part or all of each year (Fig. 1). Some 265 million acres of this is in public ownership, principally under jurisdiction of the Forest Service and the Bureau of Land Management.

The 835 million acres of forest and range being grazed are producing 213 million animal unit months (AUMs) of grazing annually. This is the equivalent of supplying the year-long forage requirements for about 17 million cows. The public lands comprise 32% of the area grazed and provide 14% of the animal unit months of grazing.

In the face of changing technology of beef production and apparent untapped productivity of pasture forage and other feed production sources, it might appear that forest-range may not be "needed" for livestock production. No doubt it is possible that other feeds and feed sources have the potential to provide the feed now supplied by grazing the forest-range. However, we believe that forest-range lands can compete as they do now in providing the additional feeder cattle needed in the next 10 to 20 years if range costs do not increase relative to costs of other feed sources. Forest-range also can continue to support domestic production of lambs and wool.

There are other indicators that suggest continued high demand over the next 10 to 20 years for use of the nation's forest and range lands for livestock grazing. Historically, cattle and sheep have been the principal marketable outputs of forest-range lands. The most consistent feature of the historic role of the forest-range has been its use as a low-cost feed source. Furthermore, many rural economies are substantially dependent on production of livestock from forest and range. Increasing the production of range livestock may help strengthen these local or regional economies.

We estimate that the range resource of the United States has a reasonable potential to produce 566 million animal unit months annually or the equivalent of providing the yearlong forage requirements of 47 million cows. Coincidentally, this is one projection of the size of the total beef cow herd in 1980. However, our demand projections indicate that it is not likely that all of this capacity could be developed or used. Range grazing would not be a competitive source of energy for livestock production above about 320 million AUM's. Other forage and feed sources would meet those higher needs. Furthermore, achieving the higher capacity level of 566 million AUM's would involve some significant tradeoffs.

Although about one-fourth of the total range, public and private, is estimated to be in poor condition, significant progress has been made in correcting the errors of past overgrazing. In addition, significant improvement of environmental quality together with wood growth can come from better management of forested areas for livestock, using existing technology. We have estimated that about 72 million acres of eastern forests are being improperly grazed at an estimated cost of more than 800 million cubic feet of wood growth annually. Associated environmental values also are being degraded by this grazing use. Disturbingly, this kind of use continues when we have the technology and experience to maintain grazing without these losses (Fig. 2).

Fig. 2. *Grazing, wood growth, and quality forest and range environment can go hand-in-hand.*

Some of the most significant range management work, in my opinion, is that of the grassroots organizations comprised of local landowners. Working with their local county and state governments and through cooperative efforts of their colleges and universities, they are establishing needed range improvements and implementing intensive range management.

The rancher, the economist, and the ecologist are rolling up their sleeves and demonstrating in their rural community that here is where the science and art of range management gets down to business. Some tremendous gains already have been made. The momentum for quality management at the grassroots, where it should be, is in many cases setting the pace for public agency range development programs.

This response may be the greatest testimony that people who make their living from the land are also deeply concerned and capable of maintaining its quality.

Conclusion

The need will continue for livestock grazing on the nation's forest and range lands and range grazing can be carried out while at the same time achieving improvements in environmental quality. That grazing can remain a legitimate and important use of public lands.

The new politics does not change this situation. What it does change is the way in which plans and decisions are made. No longer can we assume that we are dealing with an uninformed public. No longer can we rest our case solely on professional judgment or technical facts. Many other people have a strong interest in everything we do in range and the strength to challenge everything with which they disagree. Our job is to learn to understand the new politics and to work with it. There is no other way.

The Work of FAO in Range Management

ROALD A. PETERSON

Highlight: *The central aim of making better use and preventing deterioration of rangelands in developing countries depends primarily upon improving the management of these lands. This in turn calls for vastly increased investments in research and development. Significant progress has been made in creating a wider appreciation of the grazing resource, increasing technical competence, and improving knowledge of the resource. Less progress has been made in developing organizations competent to manage grazing lands. However, experience to date has clearly shown the importance and feasibility of more coordinated and comprehensive approaches to overcome this obstacle. As effective organizations are built, the opportunities and incentives for investment in range research and development should sharply increase.*

Almost one-half of the earth's land surface is used for grazing, and the great bulk of animal feed comes from such lands in developing countries. Management levels are generally totally inadequate. If management is to be improved, the current low level of investments in research and development will need to be increased very substantially.

The author is chief, Crop and Grassland Production Service, Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

The paper was presented at the 26th Annual Meeting of the Society for Range Management, Boise, Idaho, February 1973.

The consequences of the neglect of rangelands are too well known to need elaboration. This applies particularly to the arid and semiarid lands (Peterson, 1970). The considerable unexploited potential for rangeland improvement and increased production is also widely appreciated. What needs to be more fully appreciated is that in much of the developing world the growth of the human population is bound to acutely accentuate the pressures on rangeland—both through increased animal numbers and through reduction in the area available for grazing. The tendency to use arable lands more and more exclusively for food crops and high value crops will increase, despite the wider use of higher yielding varieties. Intensive forage production on arable lands will be more and more limited to fattening out young stock and to milk production. Rangelands will be of crucial importance for providing cheap feed for breeding stock. The growing demand for livestock products (one of the few agricultural products for which the likelihood of surplus is not a worry) cannot but add to the pressures on the rangelands. This growing demand and the increasing monetary value of livestock, however, also has its positive effect in making more evident the economic importance of rangelands which, in turn, should help governments to see the need for an appropriate policy for research and development. It is within this context that I would like to discuss FAO's work in range management.

FAO's Goals

In order to help create conditions which would further a more appropriate policy of investment in rangeland research and development, FAO's program over the years has been very largely concerned with:

1) Creating general awareness within each country of the importance and particular role of natural grazing lands and their link with other agricultural production,
2) Furthering technical competence at the national level,
3) Increasing knowledge of the grazing resources and developing approaches for practical transformation of management, taking into account the prevailing ecological, cultural, and economic circumstance, and
4) Assisting member countries in creating organizations able to help bring about the needed modifications in current range practices.

FAO's Activities

Accordingly, FAO's activities, especially during the last decade, have concentrated on field programs to provide advice and to supplement the efforts of governments to provide practical in-service and advanced training as well as to identify problems and evolve programs adapted to local conditions. Field work has emphasized applied research, survey, and range improvement along with pilot programs to work out practical application of proven practices. Special consideration has been given to close coordination with work on planted pastures and animal production. This has included a number of projects with universities. At the same time FAO has, in collaboration with other institutions and organizations, placed great emphasis on improving yields of crops to meet basic food needs and to reduce the need for further extension of cropping into marginal lands that can best serve for grazing.

FAO field projects, for the most part, are financed by the United Nations Development Program. These are based upon approved requests made by member governments. Approval is frequently preceded by feasibility studies. Financing normally includes cost of foreign specialists, fellowships for national counterparts for study abroad, and the equipment needed to carry out the project effectively. Government contributions may include counterpart staff, land, buildings, animals, and locally produced materials. More recently some cooperative activities with bilateral agencies such as US AID have opened up possibilities for more comprehensive and better coordinated programs and more consistent follow-up.

Assistance in range management has increasingly been provided as a component of integrated projects including specialists in animal production, economics, water development, extension, and other pertinent fields, including sociology, as it has become increasingly clear that solutions must take into account complex interrelated systems.

During the last decade some 35 countries in which range grazing is of major importance have received technical assistance. These include 8 in Latin America, 9 in the Near East, 11 in Africa, and the rest in Southern Europe and Asia, including Mongolia. Individual projects usually run for a period of four or five years. However, countries may request continuation of assistance over a longer period. A number of countries have availed themselves of this opportunity—and it is in these countries that the most evident progress has been made. Some few countries, of which Kenya is an outstanding example, have concentrated both multilateral and bilateral assistance on range management and livestock production with exceptional results. Kenya has also integrated training, research, survey, extension, and development activities into a national range management organization.

At the present time FAO has some 30 field officers working primarily with range management and a similar number working on various facets of pasture production. In addition to on-the-job training, some 72 fellowships for advanced studies in range and pasture have been granted during the last decade. Approximately one-half have been in range management.

In addition to the field program, FAO's activities include the organization of meetings to further intercountry activities and exchange of experience, training courses, and studies designed to lay the basis for the more systematic development of range and livestock resources. The latter has included a survey of livestock production (including range and pasture aspects) in the Near East countries and studies of individual countries (FAO, 1972; Blydenstein, 1971). Range handbooks have been aimed at the problems of particular countries or ecological regions (e.g. Allred, 1968). Other accounts of FAO's work in range management and the problems encountered have been given in a number of publications (Pearse, 1966; Peterson, 1964 and 1968; Blydenstein, 1972; Norris, 1972).

Assessing Accomplishments and Some Future Needs

In assessing accomplishments to date in terms of the objectives mentioned earlier, one can make the following observations:

1) General Awareness of Rangelands

General awareness of the importance of rangelands has increased. In virtually all countries a considerable number of people appreciate the significance of the natural grazing lands. However, the critical role of rangelands in livestock production and their vulnerability to degradation is still not sufficiently understood by many countries and funding agencies to lead to the policy changes and action required to cope with the problem. The growing awareness of the environment and creation of the Environment Fund by the United Nations, following the Stockholm Conference in 1972, has helped to focus attention on land (including range) deterioration. Nevertheless, there is a continuing need for broadening understanding of rangelands. In this the Society for Range Management can continue to play an increasingly important role.

In addition to the day-to-day work of creating awareness through projects, meetings, etc., there is need for concerted action on a global scale. This could be furthered by a world-wide meeting on range deterioration. Such a meeting would bring together the best knowledge available on the current situation, identify the more critical areas, and make concrete proposals for effective action. FAO would be prepared to organize such a meeting if the necessary financial support could be found.

2) Technical Competence at the National level

Most countries in which range grazing is important now have a nucleus, however small, of rather well-trained technical people working in research, teaching, or development. This is, I believe, the most significant advance that has been made over the past few years. However, no country has the number of range specialists needed to cope with the multitude of problems they face. Training therefore needs continuous emphasis. This need is widely appreciated by member countries—but available finances limit the rate of progress. This is an area in which the Society for Range Management could play a particularly effective role, as could universities which offer education in range science through fellowships, special courses, and interchange of staff.

It is also essential to increase effectiveness of existing staff, for example through better communication among the technical people in countries with common problems and through cooperative research programs to improve the quality, efficiency, and wider use of research results. In this approach it would be highly desirable to tie in expertise in developed countries—including expertise in grassland modelling—to help orient the research more meaningfully, especially toward management problems. FAO is placing increasing stress on this cooperative approach to research.

3) Improved Knowledge of the Resources

The emphasis which FAO and some other organizations have placed on resource evaluation has been of fundamental importance in helping to create an orientation of research and development more appropriate to the local ecological, cultural, and economic environment. Both nationwide studies to provide a general assessment and detailed integrated surveys have been carried out. This work, however, needs more emphasis at both nationwide and field survey level. FAO intends to develop a model based on the study of several nations, which any country could use to assess its grazing resources at the national level. Very considerable experience on different types of integrated surveys is available. Some American universities have already taken a special interest in certain countries and in survey methodology. A cooperative effort in this important work would be welcomed by FAO.

4) Building a Range Management Organization

The long and difficult struggle that the pioneers of range management in the United States went through in developing organizations reasonably effective for coping with range problems is well known. Age-old, tradition-bound, pastoral systems in most developing countries, poor communications, a shortage of financial and human resources, political instability, lack of centralization of responsibility for rangelands, and other factors inevitably make building an effective range management and research organization even more difficult. It is not surprising, therefore, that hardly more than half a dozen developing countries have made reasonable advances in this direction. This lack of organization not only limits the possibility of a significant impact on management practices, but it also inhibits other subsidiary activities, such as the inclusion of range science in the university curricula, because of the limited opportunities for employment. This is a matter which concerns not only member countries but also international, and probably national, financing agencies, as well as FAO.

Faster progress might come through a more coordinated and comprehensive approach among assistance agencies combining various types and sources of aid toward a continuous goal. The feasibility of such collaboration has been well proved in Kenya, where an FAO/UNDP project has provided survey, research, and extension guidance for the development of a national Range Management Division (FAO, 1971). At the same time the project has given technical support for a World Bank project for ranch development, while US AID has provided a professor for training of Kenya staff. US AID has also helped in the development of the northern part of the country. Additionally, another FAO/UNDP project has been carrying out research and demonstration on feeding to increase animal production and permit earlier removal of young stock from the range. The Dutch Government is providing assistance in grass breeding, and Norwegian Aid is financing a project for the collecting and screening of native forage plants. All these programs add up to a comprehensive whole that is bound to have a highly significant impact on the country's economy.

In this connection it is worth noting that research, survey, training, and other activities are hardly justified unless they are aimed at assisting development. Thus, FAO and UNDP have put great emphasis on linking these types of activities as closely as possible to development problems and to encourage investment follow-up in the application of results. This means that the field experts, and especially the project managers, need to know not only their field of specialization but have a clear understanding of the dynamics of development so that they can direct their work toward weak links in the chain of development.

Conclusion

The effort to make the most effective use of biological resources for food production, particularly for the production of high quality protein, is the basic long-term problem in agriculture. Range management has a key role in this overall effort—both to increase and to stabilize yields from natural grazing lands. The prevailing awareness of the importance of animal protein and the human environment creates opportunities which did not exist in the past. At the same time the accumulated knowledge and recently developed expertise in emerging nations provide essential building blocks. What is needed is a concerted action by all concerned to build on these circumstances to help emerging countries develop organizations which can carry out well formulated range development policy. This in turn will help open the way to greater investments for research and development or rangelands.

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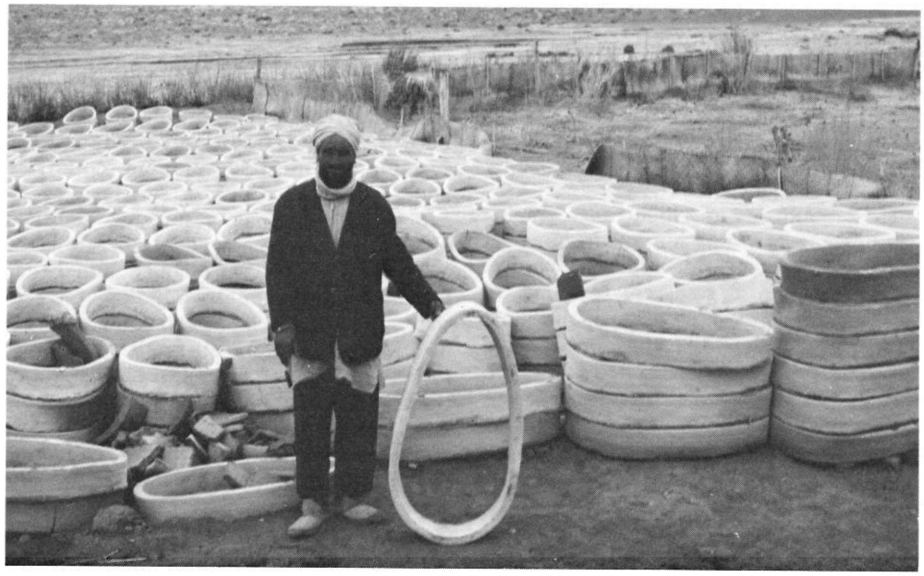

Fig. 2. *Sun baked clay collars used to line sandy parts of the qanat tunnel at Estahard. These indicate the size of the shaft.*

Qanats in the Old World: Horizontal Wells in the New

C. KENNETH PEARSE

Highlight: *Horizontal wells make use of the principle of the qanat developed in Persia about 2,500 years ago and still widely used there and in other arid regions of the world. The driven horizontal well offers several important advantages over the hand dug qanat especially for livestock watering places.*

Horizontal wells as a source of livestock water are a recent development in the southwestern United States (Welchert and Freeman, 1973). They should have an important place on arid and semiarid ranges throughout the western part of North America and elsewhere.

The basic concept of the horizontal well or qanat originated in Persia some 2,500 years ago. The expansion of the Persian Empire, beginning in the fifth centruy B.C., carried the idea from the Indus to the Nile and into Afganistan and China. Then the Islamic conquest extended the qanat to Cyprus, West Africa, Spain, and the Canary Islands. Similar structures are found in Mexico, Peru, and Chile, perhaps brought by the Spaniards, but perhaps an independent discovery by pre-Columbian New World people.

The author is a consultant, 634-D Avenida Sevilla, Laguna Hills, California.

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Numerous publications have described the origin, development, spread, construction, and use of "qanats," "karez," "foggaras," or "galerias" as they are variously called in different parts of the old and new worlds. These have been well summarized by English (1968).

Fig. 1. *Method of digging mother well and cleaning qanats at Estahard, Iran.*

In Persia qanats made possible and served as the basis for agricultural and livestock development and even now constitute the most important source of water supply for most rural as well as metropolitan areas in modern Iran. From one third to one half of the irrigated area of the country is watered by qanats, and most of the major cities rely on qanats for domestic water.

Qanats are ingeniously but laboriously constructed by hand digging. The site selected is usually an alluvial fan near the top of which a mother well is dug to the water table (Fig. 1). Then a tunnel, large enough to admit a man, is dug from the lower end of the fan so as to connect with the mother well on a very gentle slope. Where the tunnel passes through sand, sunbaked clay collars are used to form a lining (Fig. 2). Vertical shafts are constructed at intervals of 50 to 100 meters to provide ventilation for the workers, dispose of spoil, and provide access for maintenance (Fig. 3, 4). This results in a chain of spoil piles stretching across the arid slopes that is especially striking when viewed from the air. Some

Fig. 3. *Opening of ventilation and access shaft of a qanat at Estahard. Other shafts are indicated by spoil piles in the background.*

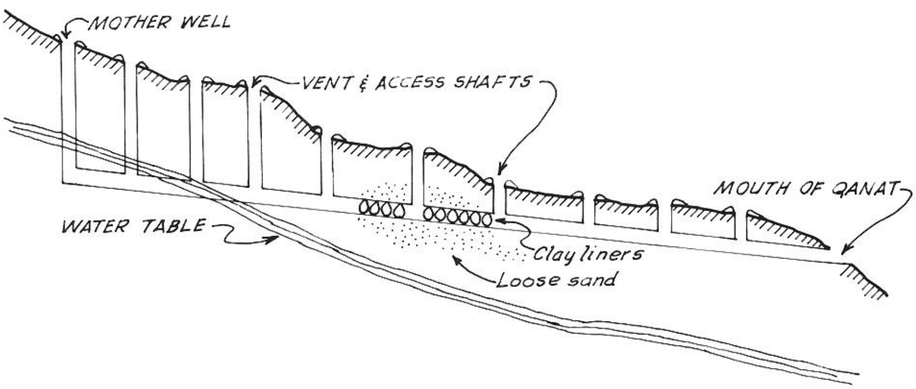

Fig. 4. *Schematic cross section of alluvial fan showing construction of a typical qanat.*

qanats extend for only a few kilometers but the length of many exceeds ten kilometers and some exceed 50 kilometers. The depth of the mother well is usually at least 50 meters and in some qanats is more than 300 meters.

Qanats are expensive to build. Skilled workers are required and the work is hazardous. The average cost is probably more than $10,000 per kilometer, but where much sand is encountered and lining is necessary much greater expenditures are made. Annual maintenance is also expensive, and extensive repairs are frequently made necessary by floods, earthquakes, and other major disasters. Another serious drawback of qanats is their inefficient use and waste of water. Although they do not seriously lower the water table, the flow is more or less constant throughout the year, and during the nonirrigating season tremendous quantities of water go unused.

Deep wells are being driven throughout the area where qanats have been important. Cost of development and maintenance are less and the rate of withdrawal can be controlled. However, deep wells almost always significantly lower the water table, and this can and does have serious social, economic, and political repercussions. The cost of pumping, which is nil in the case of qanats, is considerable.

Horizontal wells as described by Welchert and Freeman (1973) seem to offer opportunities to overcome the shortcomings and to retain the advantages of qanats. There are doubtless many situations throughout arid and semiarid regions where driven horizontal wells are adapted. Their location will be somewhat limited by the terrain and the nature of the water table, and the horizontal drilling method of construction may make it impractical to achieve the lengths as well as water yields of hand dug qanats. These limitations should have little effect on their value for livestock water. Stockmen and land administering agencies should give serious consideration to making more use of them.

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30 Years of Vegetal Change Following Burning of Sagebrush-Grass Range

ROY O. HARNISS AND ROBERT B. MURRAY

Highlight: *A sagebrush-grass range was burned according to plan in 1936. Long-term results show that sagebrush yields have increased while most other important shrub, grass, and forb yields have decreased. Evaluation by subspecies of sagebrush was helpful in interpreting sagebrush behavior. The return of sagebrush shows the need for planning sagebrush control on a continuing basis for maximum forage qualities.*

Fire has been responsible for improving or damaging lands dominated by sagebrush (*Artemisia tridentata*). Haphazard burning and improper grazing practices after burning have resulted in serious deterioration of vegetation and soil; however, planned burning of sagebrush-grass range followed by good grazing practices has resulted in marked improvement of forage yields and availability (Pickford, 1932; Hanson, 1939; Pechanec et al., 1954).

During August 1936, 640 acres of sagebrush-grass range on the Upper Snake River Plains in Clark County near Dubois, Ida., were burned according to plan. Blaisdell (1953) discussed the ecological changes in vegetation and soil on this range 12 years after burning. The purpose of this paper is to report on important vegetation changes that have occurred since 1948. In doing so, it is necessary that we also report on some of the changes that have occurred since data were collected before burning in 1936.

Methods and Procedures

Four hundred permanent 100 ft^2 weight-estimate plots (Pechanec and Pickford, 1937) were located on a grid pattern before the burn in 1936. After the burn, the range was given complete protection for one full year. Since then, sheep have grazed this range in the spring and fall, at a rate of about 2 acres per sheep month, except for 1948 and 1966, when grazing was limited to the fall months only.

The plots were separated into classes—unburned and lightly, moderately, and heavily burned. Weight-estimate data were collected on all species before the burn in 1936, as well as after the burn in 1937, 1939, 1948, and 1966. In addition, big sagebrush plants were counted in 1948 and 1966.

Blaisdell's (1953) analysis was based on differences in yields from the four classes into which the study plots had been grouped. We found that by 1966 the differences among the burned plots were negligible; consequently, we combined yield data from the three burned classes in making our analysis. Moreover, Blaisdell's analysis was based on data taken from 268 plots, but we resampled only 93 plots in our analysis because a portion of the burn had been sprayed with 2,4-D in 1961.

The authors are associate range scientists, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, Utah.

They are stationed at Intermountain Forest and Range Experiment Station, Dubois and Boise, Ida., respectively.

They appreciate the contributions of early workers on this study; Joseph F. Pechanec, James P. Blaisdell, William A. Laycock, and, especially, Henry A. Wright, who developed the study plan and who collected the 1966 data. They also express appreciation for the support and cooperation of the Agricultural Research Service on sagebrush burning at the U.S. Sheep Experiment Station, Dubois, Ida.

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Before treatment the herbage production naturally differs between burned and unburned areas and from year to year. To account for these inherent variations, we used relative instead of absolute values. The relative value was calculated in two steps:

1) A preliminary value (V) was computed for the air-dry production (P) of a species for each year (y):

$$Vy = Py \text{ on burned}/Py \text{ on unburned}$$

2) The final relative value (RV) was then computed for each species each year (1937, 1939, 1948, and 1966):

$$RVy = (Vy/Vy_{1936}) \times 100$$

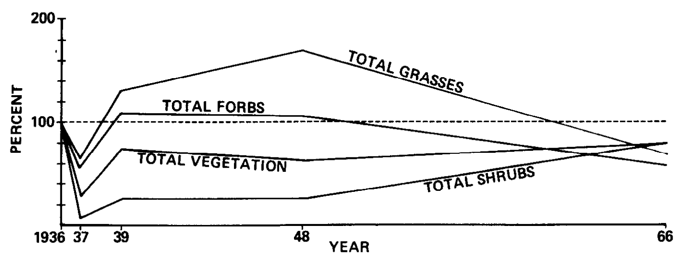

Fig. 1. *Trends of species classes on a planned burn near Dubois, Ida., 1936–1966. Values on burned plots are adjusted for the natural variation between years.*

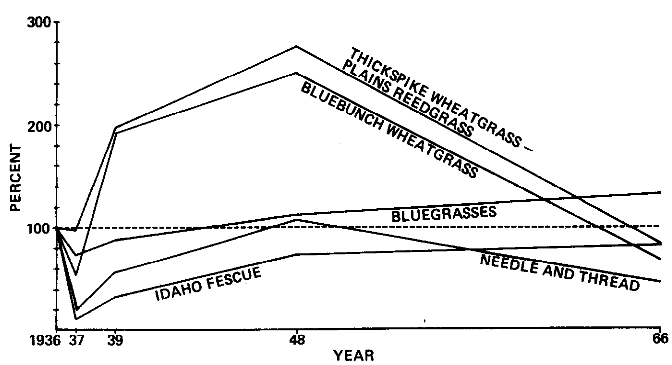

Fig. 2. *Trends of important grass species on a planned burn near Dubois, Ida., 1936–1966. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years.*

Table 1. Comparison of annual herbage production (lb/acre, air-dry) on unburned (UB) and burned (B) areas for 5 selected years following burning during 1936.

Species	1936 UB	1936 B	1937 UB	1937 B	1939 UB	1939 B	1948 UB	1948 B	1966 UB	1966 B
Shrubs										
Big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)	187	178	398	2	358	3	611	22	334	286
Rabbitbrush (*Chrysothamnus viscidiflorus*)	14	43	18	26	14	70	11	92	9	10
Horsebrush (*Tetradymia canescens*)	12	33	12	10	8	38	8	70	8	36
Other shrubs	1	2	1	0	0	0	2	1	10	6
Total	214	256	429	38	380	111	632	185	361	338
Grasses										
Thickspike wheatgrass-plains reedgrass (*Agropyron dasystachyum-Calamagrostis montanensis*)	87	63	117	81	175	249	90	179	152	92
Bluebunch wheatgrass (*Agropyron spicatum*)	18	32	30	29	32	106	8	36	13	15
Idaho fescue (*Festuca idahoensis*)	6	6	23	3	51	17	37	29	6	5
Bluegrasses (*Poa secunda* and *P. nevadensis*)	7	10	12	12	33	39	58	88	8	15
Other grasses	13	23	26	14	44	37	19	32	23	17
Total	131	134	208	139	335	448	212	364	202	144
Forbs										
Perennial forbs	9	17	32	35	41	85	70	142	66	72
Annual forbs	19	26	1	1	1	1	26	2	2	1
Total	28	43	33	36	42	86	96	144	68	73
Total vegetation	373	433	670	213	757	645	940	693	631	555

The first step is an attempt to account for the year-to-year fluctuation in vegetation yield by using the unburned-yield data each year as an expression of the variation resulting from different precipitation and temperature patterns. The second step adjusts the data so that species originate from a common base.

Results

The trends shown for the period 1936 to 1948, which are based on our analysis, are similar to those reported by Blaisdell (1953), even though we used only 93 plots (Figs. 1 to 3). These trends show only the general direction of change and do not show peak production years or rates of change.

Many trends reported by Blaisdell following planned burning were reversed during the period 1948 to 1966, as shown in Figures 1 to 3 and Table 1. Yields of "total grasses" and "total forbs" were higher in 1948 on the burned plots than on the unburned plots, but lower in 1966 (Fig. 1). In contrast, the "total shrub" yield was lower in 1948 on the burned plots, but nearly similar on the burned and unburned plots in 1966. In 1966, "total vegetation" yield on the burned plots appeared to be slightly lower than the preburn yield of 1936 when compared to the yield from the unburned plots. Figure 4 shows pictorially some changes that occurred on one of the burned plots from 1936 to 1966.

Yields of the most abundant grasses—thickspike wheatgrass, plains reedgrass, and bluebunch wheatgrass—were lower on the burned plots in 1966 than in 1948, but similar to the yields of these species before the burn in 1936 (Fig. 2).[1] Yields of Idaho fescue and bluegrass were similar in 1966 and 1936.

The number of forb species as well as their yields increased since 1936 on both burned and unburned plots. However, lupine yields were higher on the heavily burned plots, especially in 1948 and 1966. The increase in the number of forb species probably is related to this area's history of use. Before 1936, the area was used as lambing range, which resulted in heavy utilization of forbs, and possibly, a decrease

Table 2. Density of sagebrush in 1948 and 1966 (average number of plants per 100-ft² plot).

Height class	1948 Unburned	1948 Burned	1966 Unburned	1966 Burned
Seedling	2.8	.3	5.1	1.2
Under 6 inches	5.5	2.7	13.2	23.9
Mature	17.4	.7	22.7	9.2
Total	25.7	3.7	41.0	34.3

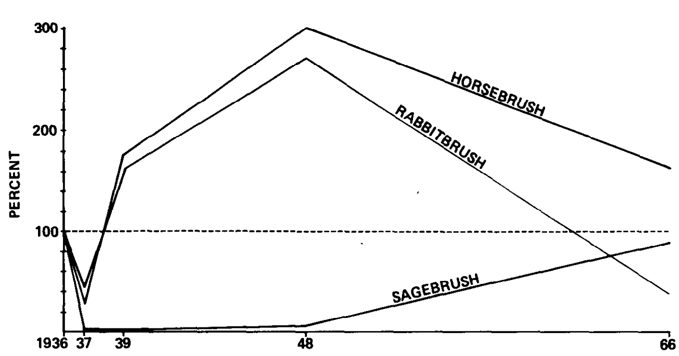

Fig. 3. *Trend of important shrub species on a planned burn area near Dubois, Ida., 1936–1966. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years.*

[1] For scientific names, see Table 1. Also, yields of thickspike wheatgrass and plains reedgrass were grouped to allow rapid field identification.

in the number of species. Since 1936, moderate grazing use later in the season probably contributed to the increased numbers and yields of forb species.

In 1966, sagebrush yields were about the same on the burned and unburned plots, although in 1948 these yields were much lower on the burned plots than they were on the unburned plots (Fig. 3). Conversely, in 1948, yields of rabbitbrush and horsebrush were much higher on the burned plots than on the unburned plots; this shows the stimulating effects of burning. However, in 1966, the yield of rabbitbrush was lower than in 1948 on the burned plots. The yield of horsebrush was also lower on the burned plots in 1966 (nearly similar to the preburn yield) than in 1948. In 1936, bitterbrush (*Purshia tridentata*) occurred only on the heavily burned plots; by 1948, small amounts had appeared on the unburned plots as well. However, by 1966 bitterbrush had appeared on plots in the other two classes. This increase might be related to the area's history of use or to weather factors

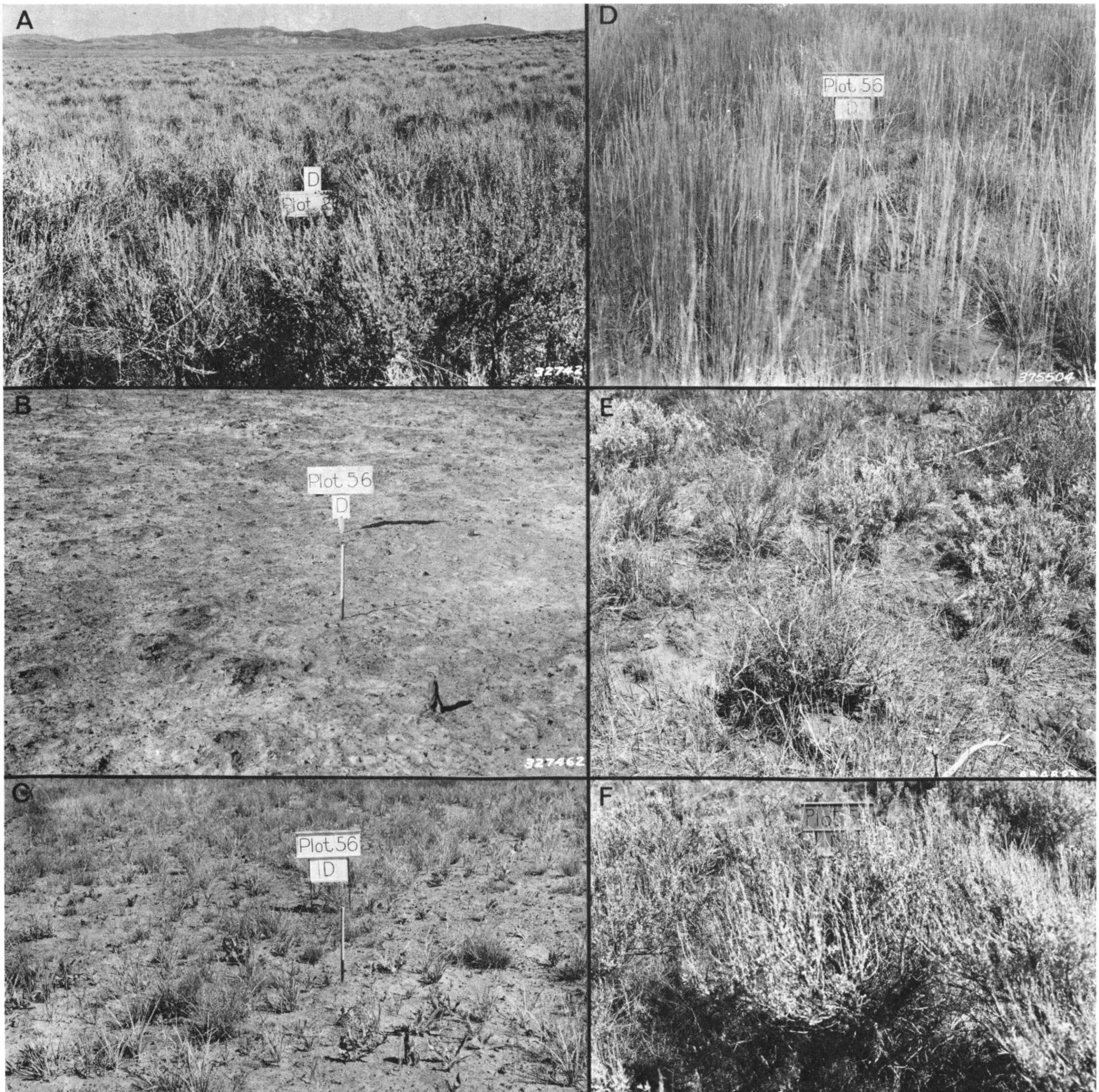

Fig. 4. *Plot depicting vegetation changes in sagebrush-grass range after a planned burn: (a) 1936 (before burning), sagebrush cover extremely dense, grass and forbs unavailable for grazing; (b) 1936 (after burning), complete removal of sagebrush-grass vegetation; (c) 1937, return of forbs and grasses with little brush apparent; (d) 1938, excellent grass and forbs stand with little brush apparent; (e) 1948, grass and forbs readily available to grazing intermixed with a few shrubs; (f) 1966, return of dense sagebrush cover and unavailable understory of grass and forbs.*

that allowed the invasion of a thick sagebrush stand.

The recovery of sagebrush is reflected by the increase in the average number of plants per plot. In 1948, the average number of sagebrush plants on the burned plots (3.7) was only about 14% of the average number of plants on the unburned plots (25.7). By 1966, the average number of plants on the burned plots (34.3) had increased to about 83% of the average number of plants on the unburned plots (41.0).

As shown in Table 2, the unburned plots had the highest number of mature sagebrush plants in both 1948 and 1966. The burned plots had the highest number of plants in the "under 6-inch" class, especially in 1966. These differences indicate that the plant community is not climax on the burned plots.

Discussion

Vegetation trends through 1966 show the overwhelmingly dominant role of big sagebrush on this sagebrush-grass range near Dubois, Ida. Almost all important species of shrubs, grasses, and forbs decreased in yield from 1948 to 1966 as the big sagebrush recovered its dominance after the burn.

The ability of the sagebrush to reinvade the vigorous grass stand that became dominant following the burn was not unexpected; however, the magnitude of the reinvasion was surprising. Frischknecht (1968) indicated that in wet years sagebrush will invade grazed or ungrazed stands of crested wheatgrass (*Agropyron cristatum*). Similarly, Johnsen (1962) reported that one-seed juniper (*Juniperus monosperma*) has invaded dense grass stands. These reports indicate that during wet years the competition for moisture may be reduced enough to allow sagebrush and juniper to become established. However, Beetle (1960) suggested (a) grasses may kill sagebrush seedlings by shading them and (b) drought reduces the grasses, thus permitting sagebrush to become established.

Once established, sagebrush must compete directly for soil moisture and nutrients with most other species in the community. Apparently, sagebrush must also use soil water and nutrients that are not utilized or are not available to these other species, because maximum vegetation yields result when sagebrush is present (Fig. 1, Table 1). Other studies have shown similar results (Blaisdell, 1949, 1953; Mueggler and Blaisdell, 1958). Our observations indicate sagebrush root depths are deeper than grasses' on mature stands; thus, sagebrush would have access to soil water and nutrients unavailable to grasses.

The climax vegetation of the Snake River Plains had been pictured as a grassland by Weaver and Clements (1938). More recently, however, it has been pictured as a vigorous stand of perennial grasses and forbs interspersed with sagebrush and miscellaneous shrubs (Pechanec, 1941; Daubenmire, 1952; Blaisdell, 1953). Tisdale et al. (1969) concluded that the sagebrush type or various successional types cover nearly the same geographic areas that they did before they were extensively grazed by livestock. The recent recognition of sagebrush subspecies (Beetle, 1960; Beetle and Young, 1965) within the *Artemisia tridentata* complex has led to more intensive examination of habitat types that are separated by the subspecies of sagebrush (Tisdale et al., 1969; Winward, 1970; Marchand, 1964).

The sagebrush on the Dubois study site is within the *Artemisia tridentata* subspecies *vaseyana* habitat type. In his study of the taxonomy and ecology of big sagebrush, Winward (1970) found (a) the *vaseyana* subspecies tended to become dense on both sprayed and burned areas, and (b) control of sagebrush is desirable to insure forage production and better animal distribution. He suggested that the need for sagebrush control should be evaluated by subspecies and/or by habitat type.

Our findings support Winward's (1970) views for evaluating sagebrush by subspecies. From observation, sagebrush in the *vaseyana* habitat type sometimes reinvades an area immediately following a burn; so control benefits do not always exist as long as they have on the 1936 burn. The length of time between control measures depends on grazing practices and the undefined weather variables that favor sagebrush seedling survival and establishment. Seed production before control may also be a factor in rate of reinvasion.

Apparently, sagebrush control measures should be applied before the community climax because our findings with regard to plant size showed that the community is not climax on the burned plots.

Although our studies showed that good grazing management will not prevent sagebrush reinvasion, Pechanec et al. (1954) showed that heavy grazing and haphazard burning will accelerate such reinvasion, as well as soil erosion and loss of desirable forage plants. The reestablishment of sagebrush to the detriment of forage and livestock qualities indicates the need for planning sagebrush control measures on a continuing basis, at least in the *Artemisia tridentata* subspecies *vaseyana* habitat type.

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Effects of Fire on an Ashe Juniper Community

ROBERT L. WINK AND HENRY A. WRIGHT

Highlight: *In an ashe juniper (*Juniperus ashei*) community a minimum of 1,000 kg/ha of fine fuel was needed to carry a fire to kill juniper seedlings and burn piles of dozed juniper. Grasses recovered quickly and soil erosion was minimal when burning was done during a wet winter and spring. During a dry winter and spring, however, burning increased drouth stress on plants, reduced herbaceous yields, and exposed soil to wind and water erosion for a long period of time when soil moisture was low.*

After nonsprouting juniper species are dozed or chained, unwanted juniper seedlings abound and the piles of dead juniper suppress growth of herbaceous plants and are an obstacle to livestock. Fire can be used as an effective tool to remove dead juniper and to kill young juniper trees, but there is no information on the amount of fine fuel (less than 0.3 cm in diameter) necessary for effective broadcast burning. Also, the effect of fire on herbaceous plants has not been documented for ashe juniper (*Juniperus ashei*) communities in central Texas. This study was designed to determine the minimum amount of fine fuel necessary to effectively broadcast burn these communities and to determine the effects of fire on the dominant grass species.

Nature of Juniper and Juniper Invasion

Junipers usually occupy rocky slopes, such as escarpments, ridges, or rimrocks (Wells, 1970). During the last 50 years, however, juniper has become more prevalent on grasslands (Johnsen, 1962). The most commonly accepted causes for the spread of junipers into grasslands are (1) lack of fire, which kills many small trees and some larger ones; (2) overgrazing, which reduces competition between grasses and seedling juniper; (3) a shift in climate favoring juniper; and (4) increased spread of seed by livestock (Johnsen, 1962).

Juniper invades grassland slowly if a good grass cover exists (Johnsen, 1962). However, if juniper becomes established, grass production generally decreases. Emerson (1932) found that juniper roots compete directly with grass and forbs for moisture and nutrients.

Jameson (1961) showed that water extracts from juniper foliage reduced growth of wheat radicles 79% to 85%. Similar effects on the growth of blue grama (*Bouteloua gracilis*) radicles have been demonstrated (U. S. Forest Service, 1963). Lavin et al. (1968) found that juniper extracts decreased the germination of some range grasses.

Effect of Fire on Juniper

Fire is the worst natural enemy of eastern redcedar (Arend, 1950), a nonsprouting species similar to ashe juniper. The species cannot maintain itself in areas that burn frequently, the bark being so thin that heat from one surface fire usually kills all trees. Fire has similar effects on other non-sprouting juniper species.

Prescribed burning has given successful results in controlling ashe juniper in Oklahoma (Dalrymple, 1969). With 500 to 1,000 lb/acre (560 to 1,120 kg/ha) of herbaceous fuel, he obtained a 100% mortality of trees less than 2 ft (60 cm) tall, 77% mortality of trees 2 to 6 ft (60 to 180 cm) tall, and 27% mortality of trees over 6 ft tall (180 cm), for an average mortality of 68%.

Grass fires readily kill one-seeded juniper up to 3 ft (90 cm) in height; mortality decreases as tree size increases (Arnold et al., 1964). Dwyer and Pieper (1967) reported that 70% of the juniper trees exposed to high temperatures of a summer wildfire, eventually died by the following year.

Effect of Fire on Grass

The response of grass to prescribed burning can be favorable or unfavorable, depending on moisture conditions at time of burning. Aro (1971) reported that recovery of grasses on burned sites was excellent following the burning of pinyon-juniper woodland in the Southwest. Burned areas produced 300% more herbage than control areas on all sites. By contrast, Dwyer and Pieper (1967) found that blue grama yields decreased the first year after a wildfire in the pinyon-juniper type in New Mexico but had recovered by the second year.

In the mixed prairie, little bluestem (*Schizachyrium scoparium*) yields gener-

Fig. 1. *The large juniper trees had been dozed in 1965 and those too small to be dozed remained alive to renew the original problem at a later date.*

The authors are research assistant and associate professor of range management, Texas Tech University, Lubbock. The senior author's present address is 1105 Ninth Street, Canyon, Texas 79015.

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ally increase following prescribed burning (Aldous, 1934), whereas sideoats grama (*Bouteloua curtipendula*) is not affected (Dix and Butler, 1954). Yield of little bluestem has decreased on some burns because of the season or low soil moisture at the time of the burns (McMurphy and Anderson, 1965). Box et al. (1967) found that meadow dropseed (*Sporobolus asper* var. *Hookeri*) increased following burning. Cool season grasses are usually damaged by spring burns (Old, 1969).

Methods and Procedures

This study was conducted on 1,053 ha of the Beckham Ranch in Callahan County, 24 km southeast of Baird, Texas. One pasture of 405 ha was burned in March, 1970; two pastures making up 648 ha were burned in March, 1971. Average annual precipitation is 60 to 70 cm. Topography is level to undulating with some slopes greater than 20%. Elevation is 365 to 425 m above sea level. The average minimum January temperature is -5°C and the average maximum July temperature is 35°C. The average growing season is 232 days.

Sandy loam and how stony hill range sites are found in the study area. The sandy loam site has deep soils with fine sandy loam surfaces 15 to 36 cm thick and sandy clays and sandy loam subsoils. The soils are slowly to moderately permeable. They store moderate amounts of available moisture and are fertile enough to support good grass production. The low stony hill site consists of very shallow, moderately permeable, calcareous, stony clay soils. Depth ranges from 15 to 31 cm with limestone rocks and boulders present on the surface and in the profile in varying amounts. The underlying limestone bedrock is cracked and fissured, forming deep pockets of fine earth capable of supporting deep-rooted grasses and trees. The large amount of rock in the soil improves plant-water relations and makes small rains effective.

Vegetation consists of mixed prairie grasses interspersed with ashe juniper and several species of oak (*Quercus* spp.). Little bluestem and sideoats grama are the dominant decreasers. Buffalograss (*Buchloe dactyloides*), vine-mesquite (*Panicum obtusum*), Texas wintergrass (*Stipa leucotricha*), tall grama (*Bouteloua pectinata*), and meadow dropseed are important increasers. All large juniper trees were dozed in 1965, but many small juniper trees were not dozed (Fig. 1).

Two areas, one to be burned and a control, were selected on similar sites in each of two pastures. Yields of total herbage and of five major grass species—vine-mesquite, little bluestem, tall grama, sideoats grama, and meadow dropseed—were taken in July, 1970 and 1971, on burned and unburned areas. After several late summer and fall rains, the major species were resampled in October, 1971. Fifty 0.22-m^2 plots were clipped in 1971 for the representative samples; ten 0.22-m^2 plots were clipped in pure stands of each major species. Current growth of herbage was clipped only in areas between the juniper piles. Samples were weighed in the field and later converted to oven-dry weight. Vegetative cover on burned piles and burned areas without piles were compared by estimating the cover on 100 random 0.22-m^2 plots in each of the areas.

In the 1971 burn fourteen 0.4 to 0.8 ha plots with uniformly fine fuels varying from 768 to 3,568 kg/ha were randomly selected to test the effectiveness of fire to burn piles of juniper and to kill young

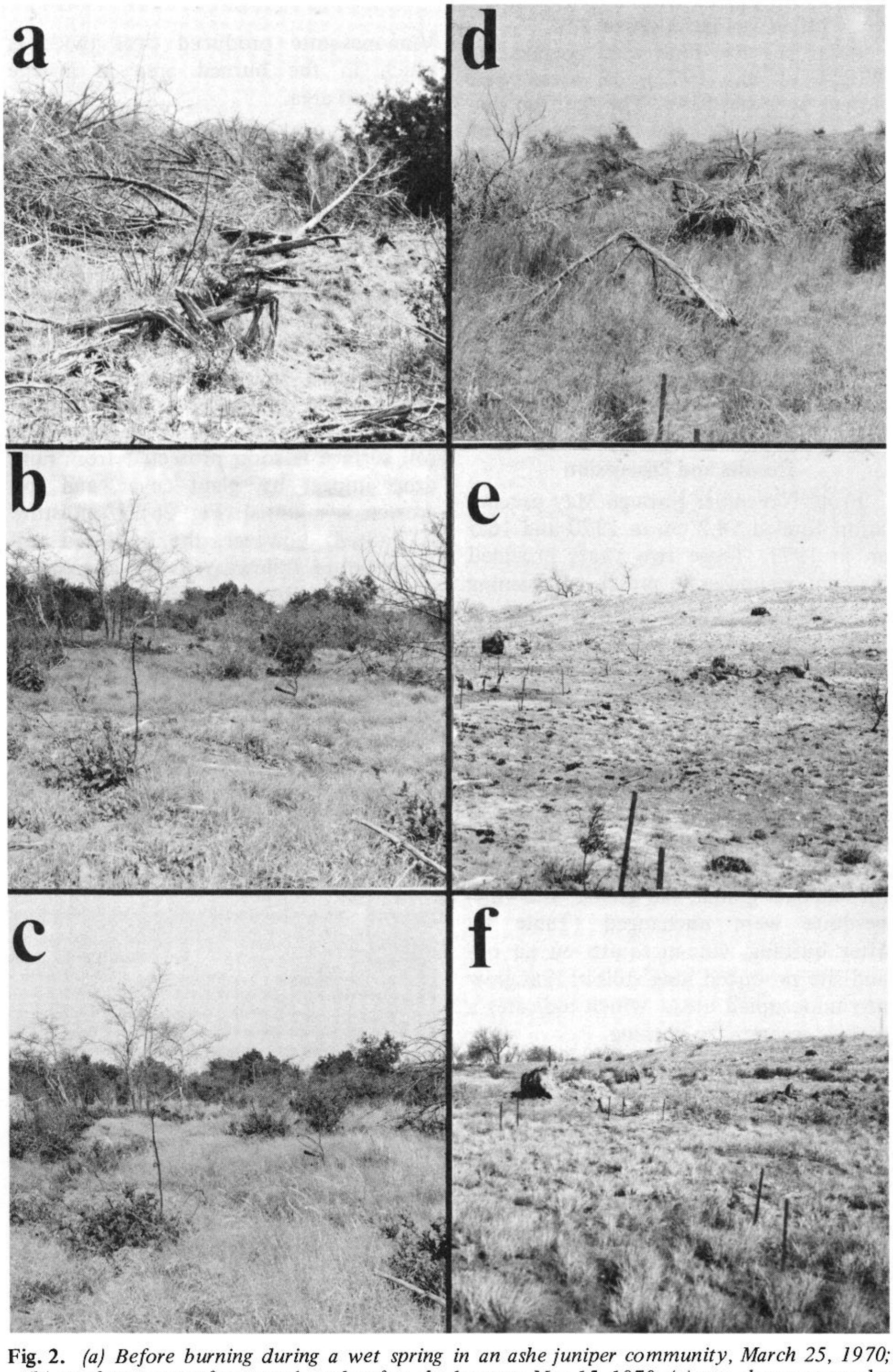

Fig. 2. *(a) Before burning during a wet spring in an ashe juniper community, March 25, 1970; (b) good recovery of grasses 6 weeks after the burn on May 15, 1970; (c) complete recovery by July 15, 1970; (d) before burning during a dry spring in an ashe juniper community, March 27, 1971; (e) poor recovery 8 weeks after the burn; (f) still poor recovery on July 16, 1971. Plant growth is comparable to 6-weeks growth during a wet spring (b).*

juniper trees. Twenty-five piles and/or 25 living trees were marked in each site to measure pile consumption and tree mortality.

The amount of fine fuel on each plot was determined by clipping twenty 0.22-m^2 frames on each site. The herbaceous vegetation was clipped to the mineral soil surface, dried, and weighed. The estimated amount of heavy fuel (piles of juniper) varied from 44,800 to 67,200 kg/ha and occupied from 0 to 85% of the area with an average cover of 22%.

After the fire lines were constructed (Wright et al., 1972), all areas were burned with headfires. The ignition pattern was a combination of perimeter and strip headfiring. In each pasture, the leeward sides were backfired before the headfires were ignited. The air temperature was 24 to 30°C, humidity 25 to 35%, and wind speed 16 to 25 km/hr.

Group comparisons (*t*-test) were used to determine differences in production of the five major grasses in the burned and unburned areas. Chi-square analyses were used to test for differences in pile consumption and tree mortality on the different fuel sites.

Table 1. Production of five grass species (dry weight) following planned spring burns on the Beckham Ranch in 1970 and 1971 (kg/ha).

	1970 (Wet year)			1971 (Dry year)		
Species	Burned	Unburned	Difference	Burned	Unburned	Difference
Little bluestem	4405	2429	+81%*	2289	3946	–42%*
Tall grama	2031	1447	+40%	977	2460	–60%*
Sideoats grama	1060	1208	–12%	408	829	–51%*
Vine-mesquite	4458	3434	+30%	7777	3669	+112%*
Meadow dropseed	5631	3670	+53%*	3714	3006	+24%*

*Significant at the 0.05 level of probability.

Results and Discussion

From November through May precipitation totaled 58.2 cm in 1970 and 16.5 cm in 1971. These two years provided different responses to prescribed burning and provided good examples of when to burn and when not to burn.

Effect of Fire on Herbage

Herbaceous yield of the burned area was 41% more ($P<0.05$) than the control in 1970 (1853 vs 1312 kg/ha) and 13% less ($P<0.05$) than the control in 1971 (900 vs. 1029 kg/ha). During the wet spring in 1970, burning increased yields of little bluestem and meadow dropseed, but sideoats grama, tall grama, and vine-mesquite were unchanged (Table 1). After burning, vine-mesquite on an upland site produced long stolons that grew into unoccupied areas, which indicates a positive response to burning.

Burning during the dry spring in 1971 decreased little bluestem, sideoats grama, and tall grama yields by 50%. These grasses were on uplands, and the removal of litter by the fire and the remaining black ashes following burning resulted in a hotter and drier environment than in the unburned control. Vine-mesquite and meadow dropseed increased in production in the burned area. These two grasses were on a lowland site and received runoff water from occasional intense storms, which allowed these grasses to take advantage of the higher soil temperatures and litter removal after burning. Vine-mesquite produced over twice as much in the burned area as in the unburned area.

During a wet year, prescribed burning generally accelerates plant growth (Fig. 2a to c) because it improves soil fertility and raises the soil temperature 2 to 18°F (1.2 to 10°C) (Kucera and Ehrenreich, 1962). Raising the soil temperature, providing moisture is not limiting, probably enables soil micro-organisms to begin converting nitrogen to a nitrate form sooner, and thus plants grow rapidly (Fowels and Stephenson, 1934; Burns, 1952). With a rapid rate of recovery, the soil surface is soon protected from raindrop impact by plant cover, and soil erosion is minimal (Fig. 2b). If moisture is limited, however, the increased soil temperature following a fire appears to increase the drouth stress on plants (Fig. 2d to f) and more of them are apt to die or be severely harmed by fire. Also, since there is very little plant growth to protect the soil from rain for 2 to 3 months after the fire (Fig. 2e), soil erosion can be significant when rain finally comes. During these dry years, litter serves a very important function as an insulator to minimize the extreme effects of drouth.

When rains finally come 4 to 7 months after a drouth following a burn, plants seem to recover very rapidly. In October following 40 cm of summer precipitation on the 1971 burn, little bluestem had fully recovered and tall grama was near full recovery (Fig. 3) as shown in the following tabulation: **Little bluestem** (burned) 6527 kg/ha; (unburned) 5448. **Tall grama** (burned) 2043 kg/ha; (unburned) 2486. The other three species remained unchanged from the July clipping.

Vegetation on the burned juniper pile areas was very different from the surrounding vegetation (Fig. 4), since the piles burned much more intensely than fine fuels. Silver leaf nightshade (*Solanum elaeagnifolium*) and Carolina horsenettle (*Solanum carolinense*) were dominant plant species on the burned pile areas; vegetative cover was 9.1% compared with 37.0% on the surrounding areas. Smooth leaf sumac (*Rhus glabra*) also became more prominent on burned areas and seemed to thrive after burning, even after very hot fires.

Pile Consumption and Tree Mortality

The fire did not carry through two plots, which had 768 and 952 kg/ha of fine fuel. Where fine fuels were above

Fig. 3. *With excellent late summer rains following the spring drouth, little bluestem was completely recovered by October 21, 1971 (same photo point as Fig. 2d, e, and f).*

Fig. 4. *Juniper piles burn much more intensely than grass areas and are occupied by weeds for the first few years after the burn.* Left—*before burning.* Right—*weeds established on burned area.*

1,000 kg/ha, 99% of the piles were consumed by fire. This is a higher consumption than that reported by Arnold et al. (1964) on juniper slash; however, the fire in our study followed 6 months of very dry weather and was conducted under the lowest humidities and highest winds that could be tolerated for prescribed burning.

The arrangement of fine fuel is also important in determining its effectiveness to carry a fire. A 1,037 kg/ha plot carried a good fire over a continuous turf of buffalograss and Texas grama (*Bouteloua rigidiseta*). A 952 kg/ha plot that did not carry a fire had widely spaced bunches of tall grama. Thus, the minimum amount of fuel necessary to carry fire in sod grasses is probably less than for bunchgrasses. Cable (1967) and Dwyer and Pieper (1967) reported less fuel to carry fire than was reported in our study.

Where large juniper piles were within 12 m of each other, firebrands would ignite the piles downwind, and fine fuel was not necessary to carry the fire. In general, this is not a safe way to burn high concentrations of juniper piles because they may behave as one large pile and project live firebrands over 300 m.

Mortality of ashe juniper was high where adequate fine fuel was present to carry the headfire (1,000 kg/ha). In the areas that burned, only one of 368 marked trees remained alive. Trees over 1.8 m tall were not marked, but it was observed that many of them were killed by the fire. When the amount of fine fuel was 2,240 kg/ha or greater, there was a good kill on all trees present. Dwyer and Pieper (1967) and Dalrymple (1969) found tree mortality to decrease as tree size increased. However, both studies followed fires with less than 1,000 lb/acre (1,120 kg/ha) of fine fuel.

Summary and Conclusions

Ashe juniper communities were burned in the spring of 1970 and 1971 near Baird, Texas, to determine the effect of fire on yields of five dominant grass species and the amount of fine fuel necessary for a fire to consume piles and kill young juniper trees. Winter and spring were very wet in 1970 but very dry in 1971.

Burning increased the yields of little bluestem and meadow dropseed after the wet winter and spring of 1970. Yields of sideoats grama, vine-mesquite, and tall grama remained unchanged. Numerous vine-mesquite stolons grew into unoccupied areas. In 1971, after a dry winter and spring, yields of little bluestem, sideoats grama, and tall grama decreased about 50% after burning. Vine-mesquite and meadow dropseed increased on bottomland sites.

During a dry spring where the amount of fine fuel was 1,000 kg/ha, 99% of the piles were consumed and 99% of the juniper trees less than 1.8 m tall were killed by headfires.

Soil moisture should be a primary consideration before conducting a prescribed burn. With good soil moisture, plants can begin to grow immediately after the burn; recovery is rapid and soil erosion is minimal. Without good soil moisture, which is usually the case when wildfires are common, burning increases the drouth stress on plants and herbaceous yields are reduced. The soil may also remain bare for several months and be subjected to severe wind and water erosion.

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Water Repellency of Soils under Burned Sagebrush

MOHAMED S. A. SALIH, FAISAL KH. TAHA, AND GENE F. PAYNE

Highlight: *Burning of sagebrush produces water repellency in soils. Maximum repellency occurs at soil temperatures between 1400 and 1800°F. The field test indicated that repellency is produced as a result of the burning of the sagebrush leaf mulch under the shrub rather than the burning of the live plant material.*

DeBano (1969) defined water repellency in terms of the time required for a drop of water to be absorbed by the soil. If a water droplet fails to penetrate within 5 seconds, the soil is classified as being water repellent.

Foggin & DeBano (1971) have discussed the nature of water repellency in some detail. According to these authors, water repellency is caused by an organic coating on the soil particles. The chemical nature of this organic coating is still unidentified. These authors go on to state that factors affecting water repellency include "...the composition of the micro-organic community, the nature of the vegetation, physical characteristics of the soil, and the fire history of the area."

During the course of studies by the Montana Agricultural Experiment Station on sagebrush control, it was noted that the soils immediately under burned sagebrush plants remained bare for 3 years or more. This phenomenon has been observed in several other sagebrush burns. Water repellency was suspected. Two limited studies to test water repellency following burning were conducted.

Test I

This test was conducted in the laboratory. One set of soil samples was collected from under large, mature sagebrush plants. The mulch overlying these soil samples was discarded. A second set of soil samples was collected from immediately adjacent areas not having a sagebrush mulch. All samples were from the 0-3 inch layer of the soil profile. The texture was sandy loam. All soil samples were tested for water repellency by applying a drop of distilled water on the soil surface and timing absorption. No water repellency was exhibited by any of the samples.

The samples were divided into eight groups, each group with three samples to be heated without a mulch cover and three samples to be heated with a mulch cover of about 1 inch of leaves and small twigs taken from live sagebrush plants. Each group was heated for 15 minutes in a muffle furnace at one of the following temperatures: 600, 900, 1200, 1300, 1400, 1500, 1800 and 2100°F.

The heated samples were cooled for 15 minutes. Those with mulch were then thoroughly mixed. Repellencies again were tested with distilled water drops. Results are shown in Table 1.

No water repellency was exhibited in soils heated without sagebrush mulch. Heat alone, then, apparently is not a factor in developing water repellent soils. Adequate organic matter also must be present.

Temperatures of 600 and 900°F did not produce repellency in soils with sagebrush mulch. The mulched soils heated at 1200 and 1300°F exhibited repellency averaging about 5 seconds or borderline repellency based on DeBano's (1969) classification. Mulched soils heated at 1400 and 1500°F showed increasing repellency, with samples heated at 1500°F having about five times the repellency of those heated at 1200°F.

The soils heated at 1800°F had reduced repellency; at 2100°F there was no repellency at all.

Table 1. Water repellency[1] of soils heated with and without sagebrush mulch in the laboratory.

Treatment	With Mulch[2]	Without mulch
600°F (316°C)	0.0 d	0
900°F (482°C)	0.0 d	0
1200°F (649°C)	4.3 c	0
1300°F (704°C)	5.0 c	0
1400°F (760°C)	10.0 b	0
1500°F (816°C)	25.0 a	0
1800°F (982°C)	6.0 bc	0
2100°F (1149°C)	0.0 d	0

[1] Time in seconds required for a drop of distilled water to be absorbed by the soil sample.

[2] Means with one or more letters in common are not significantly different, according to Duncan's Multiple Range Test, at 0.05 level.

Test II

This was a field test of the effect of burning on water repellency. One set of three sagebrush plants having a natural residual mulch approximately 2 inches deep underneath and one set of three plants with the natural residual mulch completely removed were burned. Diesel oil was used on all plants to start the fires. The soil was a gravelly sandy loam.

The burned spots were left to cool for 1 hour. Soil samples were then taken at depths of 0-1, 1-2, and 2-3 inches. Water repellency was tested with distilled water drops. The results of the trial are shown in Table 2.

Table 2. Water repellency[1] of soils under sagebrush plants burned with and without natural residual sagebrush mulch.

Soil depths (inches	With mulch[2]	Without mulch
0-1	40.0 a	0
1-2	18.0 b	0
2-3	1.3 c	0

[1] Time in seconds required for a drop of distilled water to be absorbed by the soil sample.

[2] Means with one or more letters in common are not significantly different, according to Duncan's Multiple Range Test, at 0.05 level.

The nonmulched soils were nonrepellent at all three profile levels. In the soils covered with natural residual mulch during burning, water repellency was highest in the 0-1 inch layer. The 1-2 inch samples averaged about half the repellency of the 0-1 inch level. The 2-3 inch samples of the mulched soils were nonrepellent.

Discussion

Clear evidence is presented that the burning of sagebrush produces water repellency in soils. Maximum repellency occurs at soil temperatures between 1400 and 1800°F. The field test indicated that repellency is produced as a result of the burning of the sagebrush leaf mulch under the shrub rather than the burning of the live plant material.

From a practical standpoint, it appears that burning sagebrush while the soil and

The authors are graduate research assistants and professor of range science at Montana State University, Bozeman.

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mulch are cool and damp is not likely to cause water repellency. The drier the soil and mulch, and hence the hotter the fire, the more likely it is that water repellent spots of soil will be formed.

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Fire in Medium Fuels of West Texas

ALAN L. HEIRMAN AND HENRY A. WRIGHT

Highlight: *Chained and unchained mesquite in medium fuels were burned to measure the effect of prescribed burning on noxious brush species and on the production and utilization of major forage species. The fire did not kill any living mesquite trees. Very few standing dead mesquite stems burned down. Chained mesquite stems were easily consumed by fire with 2,000 lb/acre of fine fuel. Pricklypear and cholla mortality exceeded 50% by the end of the second growing season. Burning greatly increased production and utilization of tobosa grass; production of buffalograss was unaffected. Most annual forbs were harmed by burning.*

Fire has the potential to burn down and kill honey mesquite (*Prosopis glandulosa* var. *glandulosa*) in heavy fuel types (4,000 to 7,000 lb/acre) in west Texas (Britton and Wright, 1971), but knowledge concerning the effects of fire in light to moderate fuels (1,000 to 4,000 lb/acre of fine fuel) is lacking. This study was designed to measure: 1) the effect of planned burning on the mortality of mesquite, cholla (*Opuntia imbricata*), and pricklypear (*Opuntia* phaeacantha); 2) the burndown of standing mesquite trees previously top-killed by aerial spraying; 3) the percent consumption by fire of mesquite logs previously chained; 4) the effects of burning on the composition and production of a High Plains grass community; and 5) the utilization of tobosa (*Hilaria mutica*) and buffalograss (*Buchloe dactyloides*) in burned and unburned plant communities.

The authors are research assistant and associate professor of range management, Texas Tech University, Lubbock. The senior author is at present range conservationist, Soil Conservation Service, Little Rock, Arkansas.

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Mesquite trees are relatively tolerant of fires, although some usually die after fires, especially if they are young (Glendening and Paulsen, 1955; Cable, 1961). Glendening and Paulsen (1955) reported that summer fires killed 52% of the young velvet mesquite (*Prosopis velutina*) that were 0.5 inches or less in basal stem diameter. However, after mesquite trees develop beyond the "young" stage, they are very difficult to kill. Only 8 to 15% of the velvet mesquite trees larger than 0.5 inches are killed by summer fires, although the percentage of those top-killed varies from 62 to 99% (Glendening and Paulsen, 1955). If the trees have been top-killed before burning, mortality of honey mesquite has varied from 0 to 32% after the first growing season (Stinson and Wright, 1969; Britton and Wright, 1971).

Cleaning up dead brush is another asset from prescribed burning. Britton and Wright (1971) found that weather, fine fuel, diameter of trees, surface characteristics, and borer activity influenced percent of dead mesquite stems that burned down. Relative humidity, wind, and fine fuel accounted for 86% of the variation. Burndown increased from 38% for 2-inch trees to 67% for 5-inch or larger trees.

Cactus plants in mesquite communities have shown considerable variability in their response to fire. In Arizona the mortality for pricklypear the first year after burning varies up to 32% (Cable, 1967). Cane cholla (*Opuntia spinosior*) mortality, however, is usually higher – about 45% (Cable, 1967). Cane cholla less than 1-ft tall is much more susceptible to mortality than cholla over 1-ft tall (Dwyer and Piper, 1967).

The effect of burning on grassland production varies from one area to another. Cable (1967) stated that, "fire may kill or damage individual perennial grass plants, or may indirectly increase grass growth by reducing the density of competing shrubs." Other researchers have found that burning reduced grass production for the first few years (Reynolds and Bohning, 1956; Trilica and Schuster, 1969).

Aldous (1934) studied the effects of burning on bluestem pastures in eastern

Kansas and concluded that burning about every other year seemed to be highly desirable if not essential on bluestem pastures. Annual spring burning has been found by Curtis and Partch (1948) to be essential in the re-establishment of native prairie in southern Wisconsin. Wright (1969), reporting on the effects of burning a tobosa community during "wet" years on the plains of Texas, found that fire increased production of tobosa from 56 to 256% and decreased the yield of forbs, particularly annual broomweed *Xanthocephalum dracunculoides*). Moreover, utilization of coarse plants can be greatly increased following burns because the lush green growth is free from dead carry-over growth (Klett et al., 1971).

Methods and Procedures

Three-hundred acres of the Post-Montgomery Estate in Lynn County, Tex. were burned with a natural headfire on March 23, 1970. The burned area had been aerially sprayed with 2,4,5-T in 1963. A 95% top-kill was obtained with the spray, but less than 5% of the trees actually died. A portion of the sprayed area was chained in 1969, but few trees were killed by chaining. In both areas (chained and unchained) the trees were dense and had resprouts 3 to 6 ft tall. A control area, which had also been aerially sprayed in 1963, but not chained, was located near the burned area.

Vegetation within the study areas is dominated by nearly pure stands of tobosa and buffalograss. Mesquite, cholla, and pricklypear are dominant brush species.

Relief of the study area is level to gently undulating. Elevation ranges from 3,000 to 3,300 ft. Geographically, this area lies within the Southern High Plains. Deep hardland soils of the Amarillo loam series occupy 75% of the study area. These soils are moderate to high in fertility, surface drainage is slow, and internal drainage is medium. The average annual precipitation, which falls primarily in the spring and fall, is 19 inches.

Sixty 2.4 ft^2 quadrats were clipped in each of the chained, unchained, and control areas to determine the quantity of fine fuel and grass production before burning. All samples were oven-dried at 160°F for 24 hours and weighed.

Before burning, 150 live mesquite trees were permanently marked in each of the chained, unchained, and control areas and classified according to basal diameter: 1) less than 2 inches and 2) 2 to 6 inches. Half of the trees were randomly located in tobosa fuel and half in buffalograss fuel.

Dead mesquite stems (killed with 2,4,5-T in 1963) were erect in the unchained area and horizontal in the chained area, but were attached to a living basal bud zone in both cases. After the burn, mesquite stems were classed according to severity of damage: 1) mesquite stems (previously killed by 2,4,5-T) burned down and no resprouting; 2) mesquite stems burned down and resprouting; 3) and mesquite stems not burned down and resprouting. A burndown was recorded if the main trunk of the tree was still attached to the living basal bud zone and was burned in half.

Within each fuel type 20 to 30 mesquite logs, unattached to a living base, were marked in the chained area. They were classified according to diameter: 1) less than 2 inches and 2) 2 to 6 inches. The amount of fuel around each log was estimated in the buffalograss fuel type. After the burn, the percentage of each log consumed by fire was recorded in both fuel types within the chained area. A correlation was made between the amount of fuel present and the percentage of each log consumed.

Prior to burning, 120 cholla plants in each of the three treatment areas were marked and classified according to height: less than 1 ft and greater than 1 ft. Sixty plants of each size class were within each treatment area. Half the plants in each size class were located in tobosa fuel and half in buffalograss fuel.

Before treatment, 120 pricklypear were marked within the chained, unchained, and control areas and classed according to the number of pads: 1) less than ten pads and 2) ten or more pads. Half of the plants in each size class for each area were located in the tobosa and buffalograss fuel types.

The effect of burning on species composition, production, and utilization was measured using caged plots. Paired plots, 5 ft in diameter, were located randomly within the chained, unchained, and control areas. Ten cages were located in each tobosa and buffalograss site. Caged and uncaged plots were clipped June 19, August 28, and November 6, 1970. After each clipping date, the cages were moved to a new sampling site. About 110 cows were stocked on 2,400 acres. During spring and fall the cattle concentrated on the burned 300 acres.

The fire of March 23, 1970, was spotty and incomplete because of insufficient fuel in some areas, especially in heavily-grazed buffalograss. The oven-dry weight of herbaceous fuel before burning averaged 1,234 lb/acre on the buffalograss area, and 4,306 lb/acre on the tobosa area. These weights included all herbaceous plant material down to the mineral soil surface.

The fire was started about 3:30 p.m. and was completed by 4:30 p.m. Maximum air temperature at the time of burning was 75°F. Winds were from the southwest, gusting from 12 to 20 mph. Relative humidity was 25% and fuel moisture of grasses was 15%. Surface soil moisture was 20% and spring forbs were emerging. Rainfall received in the general area from March 1 until the day of burning ranged from 2.60 to 3.28 inches.

Maximum temperatures were taken at the soil surface with tempil cards. The average maximum soil surface temperatures for tobosa area was 460°F and 220°F for the buffalograss area.

A Chi-square analysis was used to test for mortality between treatments applied to mesquite, cholla, and pricklypear. Student's *t*-test was used to determine differences in herbage yields and utilization between caged and uncaged plots.

Results and Discussion

Mesquite Mortality and Resprouts

Most mesquite trees were top-killed but survived the burn by sprouting from the basal stem buds just below the ground surface. Height of the resprouts ranged from a few inches to over 4 ft 6 months after the burn. Rabbits, small mammals, and insects kept some resprouts low by continually feeding on them.

Burndown

A 60% burndown of dead mesquite stems burned off at base of living trees was obtained in the chained area and 6% in the unchained area (Table 1). The chained mesquite trees lying near the soil received reradiation from the soil and therefore burned more easily than the standing stems in unchained areas.

Table 1. The effect of prescribed burning on burndown of mesquite trees top-killed by aerial spraying.

Treatment	Total number of trees	Number burned down	Percent[1] burndown
Chained & burned			
Tobosa			
0–2 inches	13	9	69 b
2–6 inches	32	27	84 a
Buffalograss			
0–2 inches	16	4	25 d
2–6 inches	27	13	48 c
Total	88	53	60
Unchained & burned			
Tobosa			
0–2 inches	31	2	6 ef
2–6 inches	34	6	18 de
Buffalograss			
0–2 inches	28	0	0 f
2–6 inches	42	0	0 f
Total	135	8	6

[1] Means within a column followed by the same letter are not significantly (P<0.05) different.

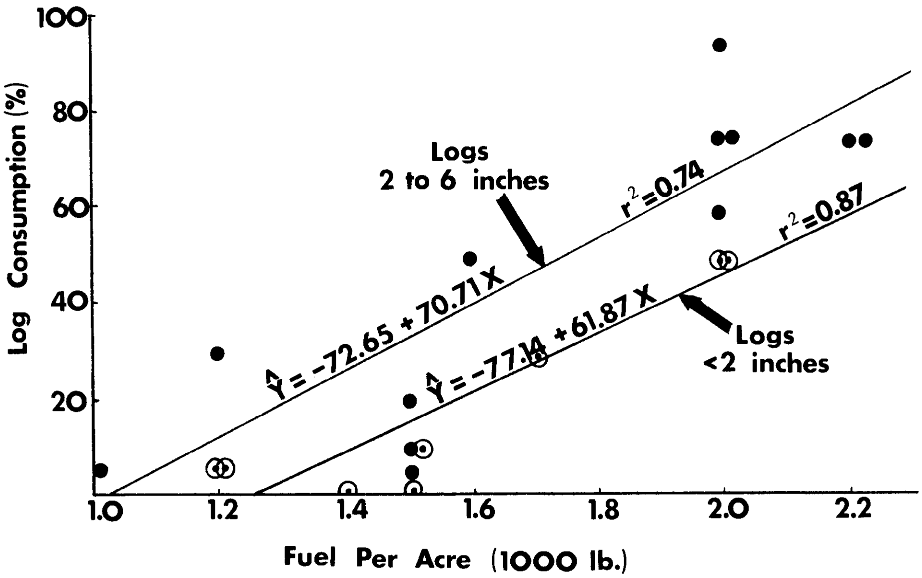

Fig. 1. *Log consumption in relation to size of log and pounds of buffalograss per acre in a chained burned area.*

Large trees lying near the soil surface were easier to burn than small trees, probably because the large trees received more reradiation than small trees. Also, the large trees had rough or broken bark, which gave a higher surface to volume ratio of exposed fuel than the small trees.

As a result of higher burning temperatures, the burndown of mesquite trees was higher within the tobosa fuel type than the buffalograss fuel type in both the chained and unchained areas (Table 1). Higher temperatures lower ignition time and increase burndown.

Log Consumption in Chained Area

Within the tobosa fuel, the consumption of dead stems not attached to a living base was 43% and 68% for the less-than-2-inch and 2- to 6-inch size classes, respectively. In the buffalograss fuel 14% and 52% log consumption occurred in the same size classes. The higher percentage of logs consumed in the tobosa fuel was attributed to the higher quantity of fine fuel in this type compared with buffalograss.

Also, as noted above, log consumption was greater for the 2- to 6-inch size class than the 0- to 2-inch size class. The reasons for better consumption of the larger logs are the same as those cited above for the higher percentage burndown of 2- to 6-inch chained stems.

Within the buffalograss fuel type, log consumption increased linearly as fuel increased (Fig. 1). When less than 1,200 lb/acre of fuel was present, no logs were consumed by the fire. When 2,000 lb/acre of fine fuel was present, 50% of the logs were consumed in the less-than-2-inch size class. For logs 2 to 6 inches in diameter, 75% of them were consumed with 2,000 lb/acre of fine fuel.

Table 2. Percent mortality of cholla plants after a prescribed burn.

Treatment	Sept. 1970	July 1971
Chained		
Tobosa		
Less 1-ft	32	93
Over 1-ft	20	80
Buffalograss		
Less 1-ft	25	75
Over 1 ft	18	50
Unchained		
Tobosa		
Less 1-ft	33*	81*
Over 1-ft	6	45
Buffalograss		
Less 1-ft	15*	48*
Over 1-ft	0	4
Control	0	0

*Different from the over 1-ft height class at the 0.05 level of probability.

Effect of Fire on Cholla

The higher percentage of cholla plants killed by fire in tobosa grass than in buffalograss in the unchained area (Table 2) was attributed to higher temperatures. In the chained area, there was no difference in cholla mortality between the two fuel types because most of the cholla plants were lying close to the soil surface and nearly all plants were equally engulfed by flames.

In the unchained area, a higher percentage of cholla plants less than 1 ft high were killed than those over 1 ft high, as a result of flame heights of 1½-ft high in buffalograss and 4 to 6 ft high in the tobosa grass. No differences occurred in mortality between heights in the chained area because most cholla plants over 1 ft high were lying near the soil surface.

There was a dramatic increase in mortality of cholla the second year after the burn (Table 2). Insect activity, induced by the fire, was responsible for most of the mortality, but drought and small mammal damage were also contributing factors.

Effect of Fire on Pricklypear

First year mortalities of pricklypear plants was 40% in the chained area and 22% in the unchained area (Table 3). After the second growing season, this mortality increased to 85% and 68%, respectively. No mortality occurred in the control.

A difference in pricklypear mortality between chained and unchained areas was evidenced only in the buffalograss fuels. Chaining brings all pricklypear pads in close proximity to the soil surface, thus exposing them to the 1½-ft flames from buffalograss. Furthermore, logs and other debris in chained areas provided protection for buffalograss that ultimately generated a good fire. Thick patches of buffalograss were encountered frequently in the chained area, but not in the unchained area.

During the first growing season after burning, more pricklypear plants with fewer than 10 pads died compared with plants having 10 or more pads (Table 3). The higher mortality for plants with fewer than 10 pads was apparently a result of the fire's exerting maximum temperatures on all the pads, whereas the outer pads of larger pricklypear plants shielded the inner pads from maximum heat. However, there were no differences

Table 3. Percent mortality of pricklypear after a prescribed burn.

Treatment	Sept. 1970	July 1971
Chained		
Tobosa		
Less 10 pads	50*	89
10 or more pads	24	89
Buffalograss		
Less 10 pads	48*	85
10 or more pads	21	74
Average	40	85
Unchained		
Tobosa		
Less 10 pads	54*	86
10 or more pads	11	79
Buffalograss		
Less 10 pads	23*	53
10 or more pads	6	53
Average	22	68
Control	0	0

*Different from the 10 or more pad class at the 0.05 level of probability.

in mortality between those with more than 10 pads and those with fewer than 10 pads by the end of the second growing season.

Following the burn, numerous insects and rodents fed upon pricklypear pads. In many instances, all of the pads were removed. Following removal of the pricklypear pads, rodents sometimes excavated the root system. Furthermore, a mild drought during this study undoubtedly increased the mortality.

Table 4. Herbage yields (lb/acre) following prescribed burning.

	Chained		Unchained		Control	
Species	Tobosa	Buffalograss	Tobosa	Buffalograss	Tobosa	Buffalograss
Grasses	3,468	1,617	3,058	1,974	1,974	1,971
Forbs						
False mesquite	79	126	120	102	28	53
Broomweed	22	18	15	19	79	69
Silver nightshade	1	4	9	1	21	2
Warty euphorbia	0	0	0	0	6	3
Western ragweed	0	0	0	0	18	0
Horsetail conyza	0	4	2	2	1	59
Evax	0	0	0	0	2	3
Wooly plantago	0	2	1	0	1	4
Other	23	42	18	10	30	20

Composition and Production

Spring burning generally decreased the production of annual broomweed, western ragweed (*Ambrosia psilostachya*), and horsetail conyza (*Conyza candensis*) (Table 4). Warty euphorbia (*Euphorbia spathulata*), silverleaf nightshade (*Solanum elaeagnifolium*), evax (*Evax multicaulis*), and wooly plantago (*Plantago purshii*) were either not affected by burning or data were insufficient to detect significant were insufficient to detect significant differences. The only forb favored by burning was false mesquite (*Hoffmanseggia densiflora*). Burning can be an effective method in controlling several species of annual weeds if initiated at the proper time.

Burning increased yields of tobosa threefold, but had no effect on yields of buffalograss (Table 4). The large increase in tobosa resulted from the fire's removing large accumulations of litter that otherwise depressed tobosa production.

Grass Utilization

By June 19, 1970, 1,852 lb/acre of tobosa and 565 lb/acre of buffalograss were utilized by cattle within the burned areas (Fig. 2). No appreciable amount of either grass species was eaten by cattle in the unburned control area.

Buffalograss was relished by cattle, but three times more tobosa was utilized. Tobosa was preferred by cattle after the burn because the unpalatable, old growth had been removed by burning and the new growth of tobosa was tender, succulent, and palatable (Fig. 3).

Rainfall was light between May and August 28; consequently, the vegetation was dry, little growth occurred, and only the chained-burned area received any significant utilization. Tobosa and buffalograss were utilized 12% to 21%, respectively, in this area. Other grass species that absorbed some of the grazing pressure were blue grama (*Bouteloua gracilis*), Arizona cottontop (*Digitaria californica*), windmillgrass (*Chloris verticillata*), bush muhly (*Muhlenbergia porteri*), vine mesquite (*Panicum obtusum*), white tridens (*Tridens albescens*), and various threeawn species (*Aristida* spp.).

Several inches of rainfall occurred during September; the pastures greened up; and all three areas were significantly utilized during the fall (Fig. 2). Only 122 lb/acre of tobosa was removed from the control area, whereas 431 lb/acre was utilized in the two burned areas (Fig. 2). Consumption of buffalograss was 201 lb/acre on the burn and 182 lb/acre on the control (Fig. 2).

When the cages were clipped in the fall, 872 lb/acre of tobosa remained on the burned area and 1,064 lb/acre on the unburned control; whereas 561 lb/acre of buffalograss was present on the burn and 655 lb/acre on the unburned control (Fig. 2). Total amount of tobosa grazed for the year was 2,388 lb/acre on the burned area and 371 lb/acre on the control. Total amount of buffalograss grazed was 873 lb/acre on the burned

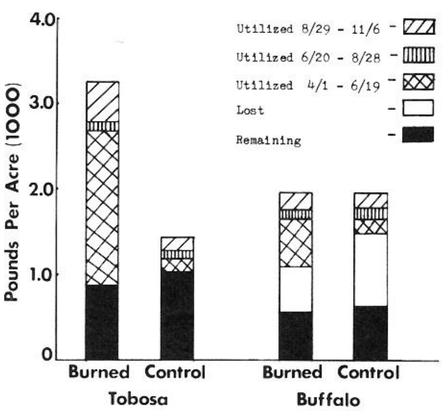

Fig. 2. *Pounds of oven-dry forage produced and utilized on burned and control tobosa and buffalograss areas from April 1 to November 6, 1970.*

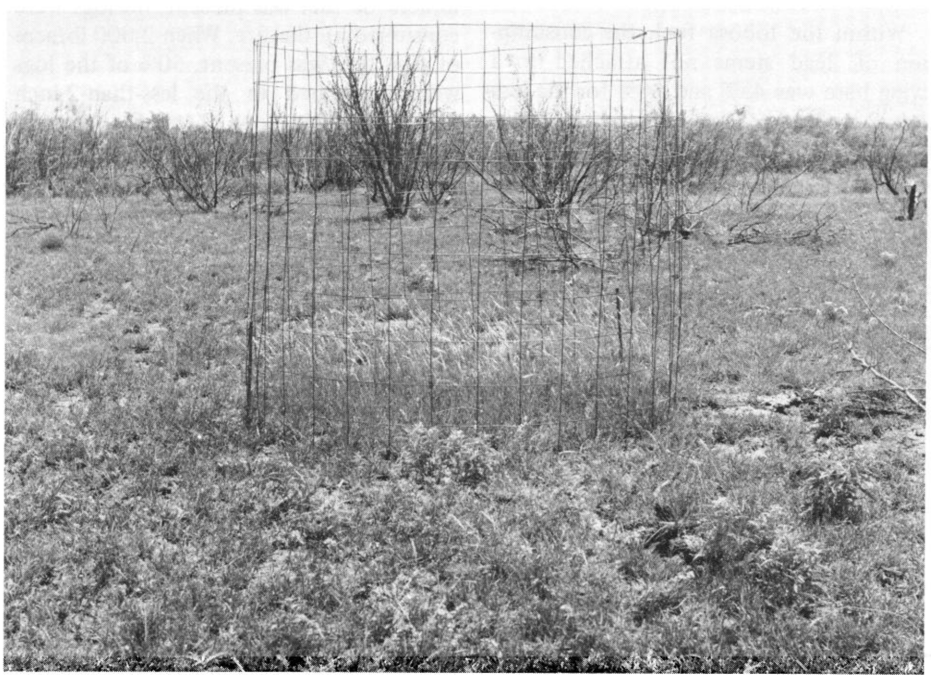

Fig. 3. *Cattle preferred tobosa grass on burned areas in the spring and fall. They ate a total of 2,388 lb/acre on the burned area compared with 371 lb/acre on the unburned area.*

area and 473 lb/acre on the control.

Between the June and August clipping dates, 539 lb/acre of buffalograss in the burned areas and 843 lb/acre on the control were lost (Fig. 2). Some of this loss was probably associated with the very dry summer. A portion of this loss might be attributed to oxidation, decomposition, small mammals, and particularly, termite activity. This loss should be given attention in future studies since it hardly seems logical to ask a rancher to rest his pasture during summer months only to come back in the fall to find that much of the grass "disappeared."

Summary and Conclusions

Burning did not kill any mesquite trees in moderate fuel types. When mesquite was aerially sprayed and then chained, a substantial number of dead stems were consumed by the fire. Little burndown occurred when aerially sprayed trees were standing.

Log consumption within the chained area was greater for logs in the 2- to 6-inch size class than those in the less-than-2-inch size class. Fire consumed 50 to 75% of each log where 2,000 lb/acre of fuel was present; but where 1,200 lb/acre of fuel was present, log consumption was negligible.

By the second year after burning, over 50% of all pricklypear plants died in all treated areas. Chaining increased mortality about 17% in light fuels. High mortality of pricklypear was due to a combination of fire, drought, insects, and small mammals.

Burning caused high mortalities in cholla. Chaining greatly increased the mortality of large chollas in tobosa grass and all chollas in buffalograss.

Burning decreased annual weeds such as broomweed, western ragweed, and horsetail conyza. Only false mesquite was definitely favored by burning.

Utilization and production of tobosa grass was increased by burning. Cattle consumed 2,016 lb/acre more tobosa on the burned than on the control area, whereas the amount of ungrazed material remained about the same for all areas. Grazing pressure was shifted from buffalograss to tobosa during spring and fall months; thus, more buffalograss was available for summer and winter feed.

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Phenology and Forage Production of Cool Season Grasses in the Southern Plains

J. L. SCHUSTER AND RICARDO C. DE LEON GARCIA

Highlight: *Thirteen varieties of cool season grasses were tested under dryland and irrigated conditions in the Southern High Plains. All introduced varieties out-produced the two native species. Peak percent of forage protein content corresponded with peak growth periods. Sandia orchardgrass and NM-384 tall fescue were the most productive varieties under irrigation but did not survive limited irrigation. Luna pubescent wheatgrass and largo tall wheatgrass were the most resistant to limited moisture conditions and are recommended for irrigated, cool season forage planting.*

The prolonged dry winters and the summer pattern of precipitation of the Southern Plains favor warm-season over cool-season plant growth. Only one perennial cool-season grass, western wheatgrass (*Agropyron smithii*), is persistent on the Southern Plains. Its production, however, is limited to swales and other low places that receive runoff water. Winter wheat (*Triticum* spp.) also provides some grazing during the winter, but ranchers have to move the cattle off early in the year, usually about the middle of March, to allow grain production. Removal of stock from the winter pastures comes when most of the warm-season grasses are not yet ready for grazing. Availability of green forage during April, May, and June would greatly improve profits from livestock grazing in the Southern Plains. Increased stocker operations in this region make year-round green forage even more desirable.

Because of the need for extension of the green forage period, a study was established in 1966 to determine the adaptability and productivity of cool-season grasses. The objective was to determine phenological development and seasonal forage yields of 13 cool-season grasses under irrigated and dryland conditions.

Methods

The study was conducted on the Texas Tech University Research Center, 12 miles northeast of Amarillo, Texas. The continental climate and topography of the Research Center are typical of the Southern Great Plains. The soil on the study area is a Pullman silty clay loam, which is found extensively throughout the Amarillo area. Precipitation averages 20 inches per year, coming mostly as spring and summer rain showers (Fig. 1). The average maximum temperature of 93°F occurs in July while the average minimum of 25°F occurs in January.

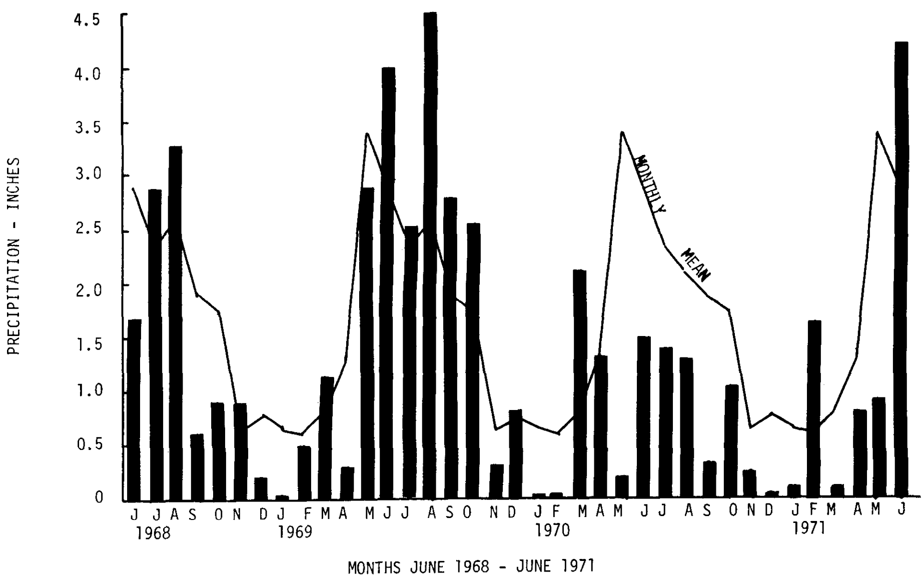

Fig. 1. *Mean monthly precipitation and the amounts recorded during the period of the study at Amarillo, Texas, 11 miles west of the study area (from U.S. Weather Bureau records).*

At the time of the research, the authors were professor of range management and research assistant, Department of Range and Wildlife Management, Texas Tech University, Lubbock. J. L. Schuster is now professor and head, Department of Range Science, Texas A&M University, College Station, R.C.D. Garcia is at present at the Chief Forage Section, National Seed Products Company, Cortazor, Mexico.

The study is Texas Tech University, College of Agricultural Sciences, Publication No. T-9-103.

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Table 1. Species and strains of cool season grasses tested, and the height (inches) of monthly clipping used.

Common name	Scientific name	Strain	Clipping height Proper	Heavy[1]
Intermediate wheatgrass	*Agropyron intermedium*	A-12496	6	3
Tall wheatgrass	*Agropyron elongatum*	Largo	7	4
Orchardgrass	*Dactylis glomerata*	Sandia	5	–
Pubescent wheatgrass	*Agropyron trichophorum*	A-11701	5	–
Intermediate wheatgrass	*Agropyron intermedium*	Amur	6	–
Tall wheatgrass	*Agropyron elongatum*	Alkar	7	4
Tall wheatgrass	*Agropyron elongatum*	Jose	7	4
Pubescent wheatgrass	*Agropyron trichophorum*	Luna	5	3
Pubescent wheatgrass	*Agropyron trichophorum*	A-1488-MC	5	–
Tall fescue	*Festuca arundinacea*	NM-384	5	–
Western wheatgrass	*Agropyron smithii*	Common	4	2
Orchardgrass	*Dactylis glomerata*	Common	5	–
Canada wildrye	*Elymus canadensis*	Common	5	–

[1]The heavy clipping height was used only on 6 species.

Extremes of 109°F and minus 10°F have been recorded at Amarillo. The growing season is approximately 191 days. The elevation of the study area is approximately 3440 ft. Yearly soil temperatures measured at the U. S. Department of Agriculture's Southwest Great Plains Experiment Station, 20 miles west, average 50.4°F and 51.8°F at a depth of 2 to 6 inches, respectively.

During the winter of 1966-67, 14 varieties (Table 1) of cool-season grasses were seeded in 40 inch rows with eight replications of 4 rows 30 ft long. First and second year stands were good to excellent except for McGregor hardingrass (*Phalaris tuberosa*). It did not survive the first winter season, so was deleted from the study.

All replications were irrigated to enhance establishment and growth through the 1967 growing season. Irrigation was continued as needed for optimum growth after 1967 on four replications while three replications received no more additional water. Two applications of 60 lb of nitrogen in the form of ammonium sulfate were applied as top dressing to all plots in August and again in March each year, providing 120 lb nitrogen/acre/year during both seasons of the study.

One part of the study dealt with the forage yield of plants as affected by monthly and annual clipping under irrigation and dryland conditions; the second with phenology and general observations of each species. Forage production was determined under both dryland and irrigated conditions for all 13 varieties. Six of the irrigated varieties were clipped at two heights to simulate proper and heavy use at monthly intervals throughout the season (Table 1). Three 2.9 row-ft samples per species in the four replications under irrigation were clipped at monthly intervals from August, 1968, to July, 1970. After oven-dry weights were obtained, small portions of each grass sample were taken for each clipping level to make a composite sample for protein analyses using the Kjeldahl method.

Additionally, all 13 species were compared under dryland and irrigated conditions. For this trial three replications were clipped at the proper level and irrigated as soil moisture indicated. Three replications were clipped at the proper level but not irrigated except by rainfall. Three 2.9 row-ft samples were collected from each replication for each species (Fig. 2).

During the 1968-69 season, monthly measurements of plant height, leaf length, leaf width, and number of leaves per shoot were made. Flowering period, general growth, characteristics, and tenderness of foliage were observed throughout the study. Plant height was measured from the crown to the base of the spike, or tip of the growing point when the spike was absent. Leaf length was measured on the second leaf from the top. Leaf width was measured on the same leaf, using the mid portion of the blade. Two sets of such observations were made per species per replication.

Fig. 2. *Ricardo de Leon compares proper clipping height of Jose tall wheatgrass on his left with heavy clipping height on his right.*

The experimental design was a randomized block, and treatment differences were evaluated using standard analysis of variance techniques at the .05 level of significance.

Results and Discussion

Phenology and Growth Pattern

The growth patterns of the grasses were judged in the irrigated plots only. All species began fall growth by September 1. Each had a short growth period in early fall with the peak growth occurring in late spring (Fig. 3). Only western wheatgrass stopped growth completely during the winter under irrigation. This may be why this native species is able to survive the dry winters under dryland conditions in this region. Amur intermediate wheatgrass stopped growth and became completely dormant during the middle of the winter dry period under dryland conditions.

Both strains of orchardgrass and NM-384 tall fescue flowered twice during the year; once in the fall and once at the beginning of the summer. Fall flowering produced fewer flower stalks than the summer flowering. Seed shattered from orchardgrass and tall fescue as soon as they matured. This would probably cause difficulty in seed harvest of these species.

The tall wheatgrasses produced many viable seeds and vigorous seedlings. Seedlings from all three varieties invaded other plots. We believe this species easiest to establish of all species tested. Largo tall wheatgrass leafage appeared softer and more tender than that of the other two tall wheatgrasses.

Leaf width was relatively uniform for all species, although all were slightly smaller under dryland conditions. Maximum leaf widths were obtained about the time of most rapid growth in April.

Protein Content

Protein, on a dry matter basis, was determined for six varieties for both the proper level and the heavy level of clipping in 1968-69, but only for the proper level in 1969-70 (Table 2).

All species, though varying slightly in protein content, show similar patterns throughout the study period for both years. No obvious differences occurred in percent protein between the heavy and the proper height treatments. Generally the protein content was lowest at or just after the end of the flowering period

Table 2. Average crude protein content (%) of irrigated grasses by date of clipping.[1]

Grass	Oct. 1	Nov. 1	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1	June 1	July 1	Aug. 1[2]
A-12496 intermediate wheatgrass	26	23	21	18	18	21	28	19	14	16	21
Largo tall wheatgrass	23	21	20	18	21	21	25	16	13	15	17
Alkar tall wheatgrass	24	20	20	17	19	21	27	19	13	15	18
Jose tall wheatgrass	23	22	21	18	18	20	27	19	14	16	19
Luna pubescent wheatgrass	24	23	21	18	22	20	29	19	14	15	21
Western wheatgrass	22	20	24	(–)[2]	(–)[2]	(–)[2]	22	20	17	17	16

[1] Twenty-four samples for each species were composited for each sampling date through two seasons (1968-1969 and 1969-1970) except August data was collected only in 1969.
[2] No height growth occurred above clipping level.

when most of the species matured. The protein percentage generally reached peak amounts during the periods of most active growth. It was highest at the April clipping for all species except for western wheatgrass in 1968-69 season. Western wheatgrass did not reach its peak protein content until the May clipping in 1968-69. Its highest protein content was in the April, 1970, cutting, however. Protein content generally declined for all species after the April 1 clipping date. This coincides with the beginning of the spring flowering period for most of the species.

Effect of Clipping Height

The two clipping levels caused little difference in total annual forage production. Yields for the heavy use clipping height averaged slightly over 100 lb per acre more than for the level considered proper. Apparently the clipping levels selected did not detrimentally affect growth of the species for the 2 years of clipping. Observations made in June, 1971, indicated, however, that the vigor of the tall wheatgrasses was reduced by both clipping heights. General observations indicate that the intermediate and pubescent wheatgrasses may be able to withstand defoliation better than the tall wheatgrasses at the levels of clipping used. On the other hand, intermediate wheatgrass has been found to have little grazing resistance in Colorado (Dahl et al., 1967; and Currie and Smith, 1970). Because of this evidence and since little is gained at the low levels of clipping, we recommend the moderate clipping heights in judging proper grazing use of these species (Table 1). Because of the insignificant differences in production between clipping heights, the proper use height is used to discuss productivity.

Forage Yields

Three replications of each species were clipped at the proper level at monthly intervals under irrigated and nonirrigated conditions. The cumulated annual production was averaged for the 2-year period for species comparison (Table 3).

Although a first and second year comparison is not shown, production during 1968-1969 was approximately 50% higher than for 1969-70. The reduction in yields could be due to the residual effects of the clipping treatment, but we feel suboptimum irrigation and lack of natural precipitation (Fig. 1) caused the differences. Also, the average production used should better represent the conditions that occur under normal management situations. Under optimum irrigation and management conditions, species yields should be higher than reported here.

The yields under irrigation should reflect the species' relative productive potential. Under irrigation, Sandia orchardgrass and NM-384 tall fescue were the most productive species, while the two native species, Canada wildrye and western wheatgrass, were the least productive.

The tall wheatgrasses generally produced more than the intermediate and pubescent wheatgrasses, but the differences were not statistically significant. Largo tall wheatgrass produced as much

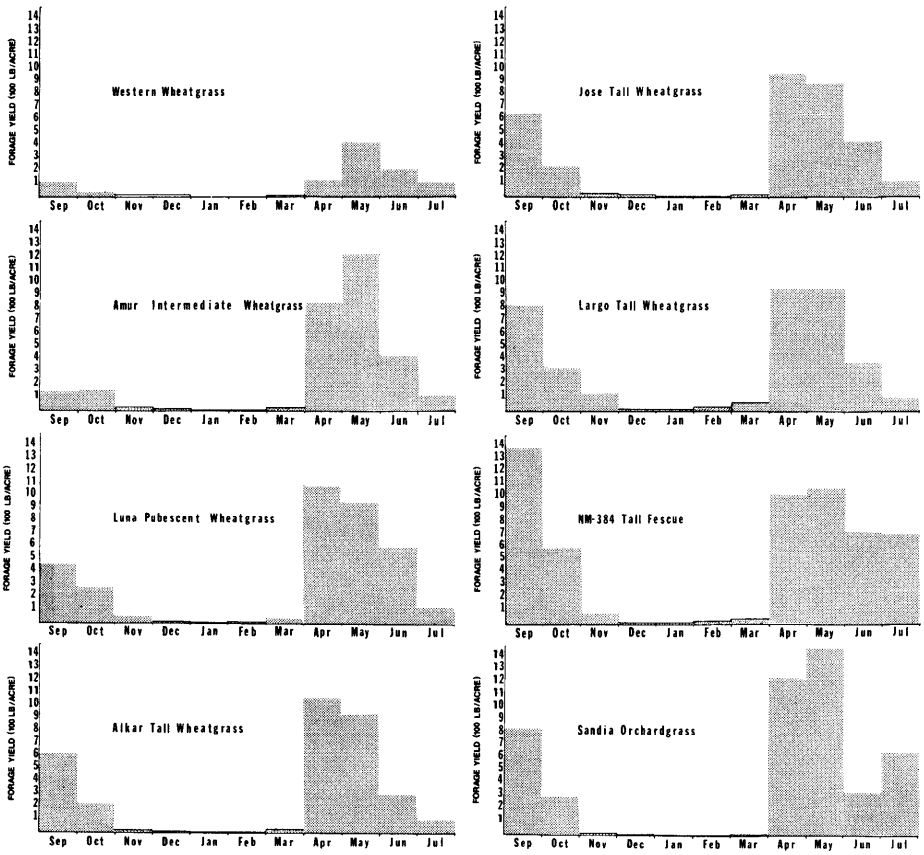

Fig. 3. *Growth pattern and average monthly forage yields for eight cool-season grasses under irrigation, Amarillo, Texas.*

Table 3. Average total annual forage yield (lb/acre, oven-dry) of grasses under irrigated and dryland conditions.[1]

Species	Irrigated production[2]	Dryland production[2]
Sandia orchardgrass	5341 a	1609 abed
NM-384 tall fescue	4817 ab	2127 a
Common orchardgrass	3777 bc	1029 defg
Largo tall wheatgrass	3699 bcd	1788 ab
Jose tall wheatgrass	3332 cd	1464 bcde
Alkar tall wheatgrass	3173 cd	1740 abc
Amur intermediate wheatgrass	2898 cd	1057 defg
Luna pubescent wheatgrass	2868 cd	1146 cdef
A-11701 pubescent wheatgrass	2691 cd	836 efg
A-12496 intermediate wheatgrass	2638 cd	1000 defg
A-1488-MC pubescent wheatgrass	2457 d	953 efg
Western wheatgrass	828 e	475 g
Canada wildrye	693 e	589 fg

[1] For each column, means not sharing a common symbol are significantly different ($P<0.05$) from all others.
[2] Represents herbage produced above a specified height of clipping considered proper to maintain productivity.

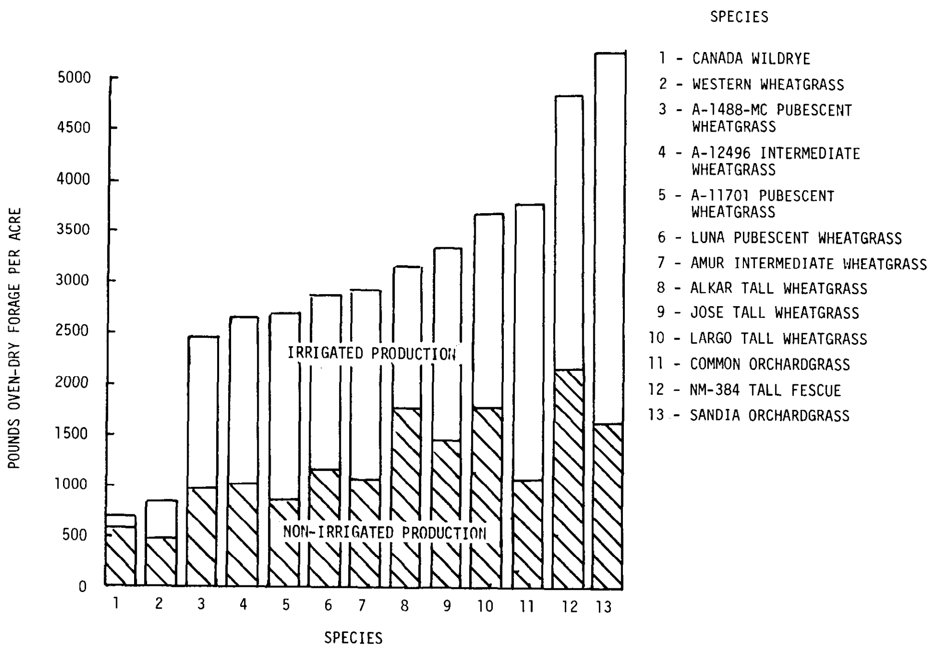

Fig. 4. *Forage yields of 13 cool-season grasses under irrigated and dryland conditions.*

as common orchardgrass and NM-384 tall fescue but not as much as Sandia orchardgrass under irrigation. Under dryland conditions, however, common orchardgrass produced little more than the two native species and less than the tall wheatgrasses.

The three tall wheatgrasses and common orchardgrass produced similar amounts of forage. Although Largo tall wheatgrass produced over 300 lb more than Jose and 500 lb more than Alkar, the difference was not statistically significant.

The three intermediate wheatgrasses and two pubescent wheatgrasses produced similar amounts of forage. They produced 1600 to 1800 lb more forage under irrigation than the two native species.

Sandia orchardgrass and NM-384 fescue show a greater potential for production than the wheatgrasses and the two native species. Their increase in production due to irrigation was relatively much greater than the other species' (Fig. 4). Therefore, if forage production is the criterion for selection, these two species are recommended over the others.

All species were limited by lack of moisture under dryland conditions. They showed differential adaptability to drought conditions, however. Common orchardgrass, which was highly productive under irrigation, produced little more than the two native species under dryland conditions (Fig. 4). Of even more significance is the reaction of the orchardgrass and NM-384 tall fescue under limited irrigation. Irrigation was continued at infrequent intervals during the third season, but clipping was discontinued on all plots. By June 1971 no species survived under dryland conditions, while common orchardgrass, Sandia orchardgrass, and NM-384 tall fescue died out under limited irrigation. On the other hand, the wheatgrasses survived under limited irrigation. Luna pubescent wheatgrass and Largo tall wheatgrass appeared most productive and most resistant to limited moisture of all the species. Because of their productivity and phenological behavior, these species would fit well into a forage system which combines irrigated winter cereals with irrigated cool-season grasses in this region.

These grasses could be used for grazing in late September to November until wheat grazing is ready about December 1. They would again be ready to furnish high protein forage from April, when wheat must be rested for grain production, to June, when summer range would be ready for grazing. With proper proportions of wheat fields, native pasture, and these cool-season perennial grasses under irrigation, a year-round green forage system could be developed.

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Developmental Morphology of Blue Grama and Sand Bluestem

PHILLIP L. SIMS, ROBERT K. LANG'AT, AND D. N. HYDER

Highlight: *The purpose of this investigation was to study the normal growth and development of blue grama and sand bluestem. Blue grama and sand bluestem exhibited contrasting forms of growth, regrowth, and perenniality. Blue grama had culmless vegetative shoots and 12% reproductive shoots. Sand bluestem had culmed vegetative shoots and 36% of the shoots became reproductive. Regrowth of blue grama from active shoot apices proceeded rapidly after cutting when soil moisture was adequate. Good productivity, however, depended greatly on essentially free expansion of the leaf blades of phytomers 3 through 6. Good leaf growth and early drying of lowermost leaves when not utilized made sand bluestem suitable for grazing in June, when prompt regrowth of leaves from apical meristems occurred. Close harvesting in early July stopped all active shoot expansion. After grazing sand bluestem in June, a rest period in July should allow good plant development under dry land conditions. With favorable soil moisture conditions in July a close harvest near mid-July stopped first crop growth and promoted development of new tillers and high productivity of second-crop herbage of sand bluestem in late summer and fall.*

Information about the developmental morphology of plants is needed to explain their responses to defoliation. Such information might define appropriate seasons or sequences of grazing, where an intensive control over land and livestock can be attained. This requirement of intensive control omits extensive situations of poorly distributed grazing where the rotation of deferred grazing and rest-rotation grazing prevents the destruction and sacrifice of critical sites such as drainage systems.

Grazing is not only a means of harvesting vegetation, but a treatment that affects subsequent herbage quantity and quality. At a given time and place, grazing might be conducted primarily to produce a strong tillering response, harvest a maximum quantity of nutrients per unit area, improve forage quality for subsequent grazing, manipulate botanical composition, protect and improve adjacent range, or create some other desirable effect. All desired responses or effects cannot be produced on rangeland at one time or in one way. Thus, information about the developmental morphology of plants can help define opportunities and alternatives for application in grazing management.

The subject of developmental morphology is new in the field of range management. Research methods and observational techniques need further development, but the primary objective is clear: how do plants grow? Growth can be measured grass unit (phytomer) by unit to help answer this question.

A phytometer consists of leaf blade, leaf sheath, culm internode (although the internode may not become visibly enlarged), and node with potential for axillary bud and adventitious roots (Evans and Grover, 1940; Hyder, 1969, 1971; Sims, et al., 1971). Vegetative shoots can produce an indeterminate number of phytomers: whereas, reproductive shoots are determinate (Sharman, 1947; Cook and Stoddart, 1953; Hyder and Sneva, 1963). The growth or regrowth of any shoot can be described phytomer by phytomer. However, the process of destructive sampling and differences in ages and types of shoots complicate the study. Therefore, any detailed study of developmental morphology can advance our knowledge of how to study plant morphology and growth.

Blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud) is probably the most important native forage species on the Great Plains. This warm-season shortgrass is nutritious, widely adapted to many soil types, and palatable to all classes of livestock. Blue grama withstands heavy grazing and drouth. Sand bluestem (*Andropogon hallii* Hack.), a native, warm-

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The authors are associate professor and graduate student, Department of Range Science, Colorado State University; and range scientist, Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colorado. Lang'at's present address is Range Management Division, Ministry of Agriculture, Box 30028, Nairobi, Kenya, Africa.

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season, rhizomatous, perennial tallgrass, is an important forage grass on sandhill rangeland in Colorado, Kansas, Nebraska, and Oklahoma. These important forage grasses justify intensive study and development.

The primary purpose of this investigation was to study the growth and development of Lovington blue grama and Elida sand bluestem. The study also included some measurements of regrowth after mowing closely at successive stages of development.

Methods and Materials

The study was conducted at the Eastern Colorado Range Station, located on the Central Great Plains near Akron in the sandhills of northeastern Colorado. The elevation is 1,303 m (4,275 ft) with the topography varying from nearly level to slightly rolling dunes. Study plots were located on a nearly level area of Davona loamy sand.

The climate is semiarid with cold, dry winter; moist, cool springs; hot, occasionally dry summers; and mild, usually dry autumns. Annual precipitation averages about 38 cm (15 inches), most of which falls as rain from April to September. During 1967, 38 cm of precipitation occurred, with one-half coming in May and June and two-thirds between May and August, inclusive. This was an exceptionally good growing season.

Both species were planted in May, 1965, and had developed into relatively closed communities at the time of sampling. Four randomly selected clumps of each grass species were collected on April 11 and May 1 and then weekly until August 25, 1967. The soil was excavated from around the clumps so as not to destroy the crowns, which are the stem bases having two or more closely spaced nodes. Each clump was washed, placed in a plastic bag, and frozen. Subsequently,

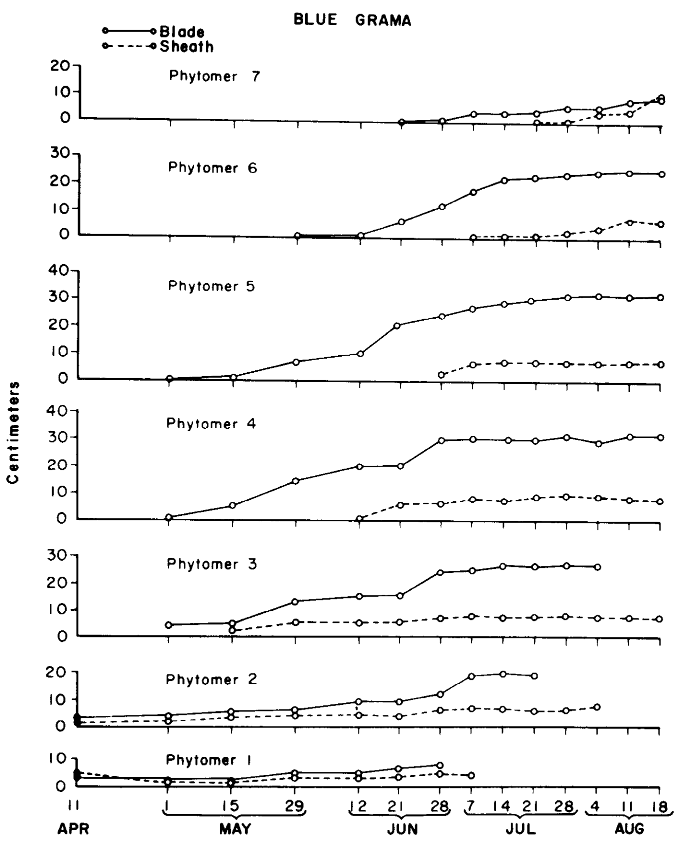

Fig. 1. *Phytomer growth by vegetative shoots of Lovington blue grama.*

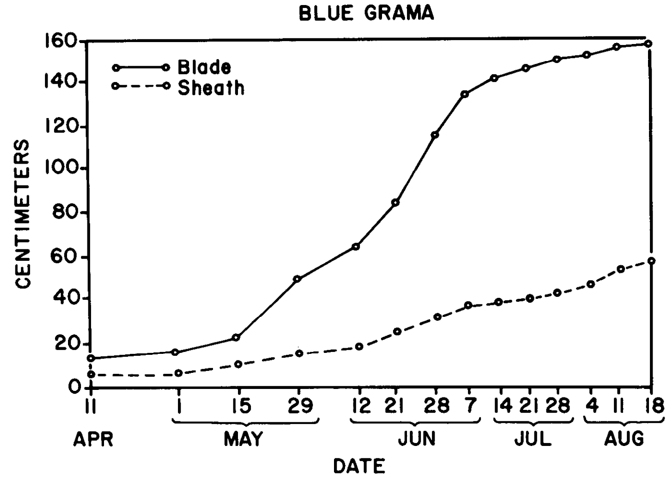

Fig. 2. *Shoot growth curve by vegetative shoots of Lovington blue grama.*

the frozen plants were subdivided into individual shoots for observation and measurement. Beginning with the first (lowermost) phytomer, each blade, sheath, and internode of a shoot was measured separately. When a blade, sheath, and internode had been measured and recorded, the blade and sheath were removed to expose the next phytomer. This operation was continued until the smaller and more delicate blades and sheaths were measured. The exserted parts of the phytomer, however, were not measured separately. The internodes were measured individually when they were over 1 mm long or collectively when they were less than 1 mm long. The average lengths of phytomer parts define the growth curves for each phytomer, and total lengths among phytomers define the growth curve for a shoot. The shoots were observed to determine if they originated from rhizomes, axillary buds of the crown, or shoot apices of older vegetative shoots. In mid-October, when the heads of reproductive shoots had exserted, several clones were selected at random, excavated, and broken apart to count the numbers of reproductive and vegetative shoots.

To study the effects of mowing blue grama and sand bluestem at different growth stages, 11 plots, approximately 1 x 6 m, were staked out across a strip of each species. Beginning May 29, a new plot was mowed each week at a height of 3.5 cm with a rotary mower for 11 consecutive weeks. Comparative observations were made of mowed and unmowed plants. On August 16 and October 14, three clones from each plot were collected and the general pattern of the development of axillary buds of the crown and rhizomes was observed. Stems were also examined for any sign of increased axillary bud activity, changes in internodal elongation, increases or decreases in tillering, and the removal of growing points of inflorescences.

Results

Lovington Blue Grama

Vegetative Growth

Shoot apices, enclosed by three or four successive intercalary meristems of immature leaves and finally by the dead leaf sheaths of parent shoots, survived the winter in a quiescent state. Viable meristematic tissues resumed growth in the spring. Some green growth, topped by dead leaf tips, was evident on April 11, Subsequent growth by overwintering shoots was measured in detail. The vegetative shoots of blue grama produced 6 to 9 (average 7) phytomers during the growing season (Fig. 1). Four leaves, one or two of which had exserted the previous year as indicated by dead leaf tips, resumed slow growth in April. The first one or two leaves matured and dried by the end of June, and two additional leaves dried before August 18. The fourth and fifth blades were longer than others and together provided 42% of blade length. Blades 3 through 6 provided 76% of blade length. Good plant productivity must depend on essentially free expansion of these major leaf blades. Thirty percent of blade elongation occurred by May 29; whereas, 73% occurred by June 30, and 96% by July 28.

Summations of phytomers provide mean growth curves of leaf blades and leaf sheaths of vegetative shoots (Fig. 2). About half of the blade elongation was essentially sigmoidal. Blade growth decreased in early July and became insignificant by mid-July. Leaf sheaths of this warm-season grass elongated at a near linear rate from the first of June until measurements were terminated on August 18.

The internodes of vegetative shoots failed to elongate at any time. Therefore, this sequence of growth produced a small central axis or "crown" of (by average) seven nodes, ranging from 4 to 7 mm long, with its complement of adventitious roots, axillary buds, and tillers. Headless or "blind" shoots having elongated internodes were found. These were considered to be shoots. Small unidentified larvae were found on some rudimentary inflorescences and shoot apices, but the death of these structures might have been caused by other factors as well.

Reproductive Growth

Twelve percent of the overwintering shoots of blue grama became reproductive. Floral initiation was first observed on June 30. Internode elongation began at the time of floral initiation, but may not have followed closely after floral initiation in an individual shoot. Elongation occurred in three or four internodes, including the uppermost internode or peduncle, leaving an average of seven nodes in the crown section at the base. Since the total of 10 or 11 phytomers exceeded the maximum found in vegetative shoots, it appears that some reproductive shoots, by overwintering twice, remained vegetative until June of their third growing season, or attained competitive advantage over those that remained vegetative. Since newly seeded stands can produce reproductive shoots the first year, wintering seems unnecessary for the purpose of vernalization. The average lengths of elongated culm internodes were as follows:

Peduncle and inflorescence	13 cm
Internode 3	6 cm
Internode 2	7 cm
Internode 1	4 cm
Total	30 cm

Internode elongation was slow until July 21. Subsequently, the rate of elongation increased greatly until anthesis. Heading began July 18 and continued for about 30 days. Anthesis began August 4 and continued about 2 weeks. Mature caryopsis were found by September 15. Thereafter, the entire shoot above the crown died.

Tillering and Perenniality of Shoots

The first new tillers appeared during the week of June 5 to 12. They originated from the first and second axillary buds of parent shoots. Reproductive shoots gave rise to more tillers than did vegetative shoots. Among the vegetative shoots, the larger ones, found primarily at the edges of clumps, generally produced tillers. New tillers continued to arise until July 28. By October 14, the new tillers had exserted one to four leaf blades ranging up to 12 cm in length, but the longest blades average 4 to 5 cm. Shoot apices remained below the soil surface because there was no internode elongation or differentiation to reproductive status by new tillers.

Mowing in late June and early July stimulated additional tillering, mostly from reproductive shoots that had elevated above the height of cut. Earlier mowing depressed tillering. Mowing in late July and early August also stimulated tillering, but insufficient growing season remained for complete development of these late tillers. Tiller populations were not counted to determine survival rates and obtain exact comparisons among cutting treatments.

In late summer and early fall, the exserted leaves of new tillers died back leaving basal green material, leaf intercalary meristems, and shoot apices enclosed and protected by the dead leaf sheaths of parent shoots. The next spring, these new tillers would be prepared to resume leaf growth, pushing up the dead tips of previously exserted leaves and initiating additional leaves from leaf primordia of the shoot apex. Older vegetative shoots appear to survive the winter in the same way, and attain sufficient status to become reproductive. However, we do not have a complete account of the perenniality and longevity of individual shoot apices. The main point is that an individual tiller is not an annual structure that initiates in the spring and dies in the fall. Perenniality derives from overwintering shoot apices of culmless vegetative shoots, overwintering intercalary meristems of immature leaves, and axillary buds of the crowns.

Elida Sand Bluestem

Vegetative Growth

The shoots of sand bluestem originated primarily from axillary buds and apical meristems of short, terminal rhizomes, which turned upward in late summer or fall to initiate negative geotropic growth. A crown section was formed where the rhizomes turned upward and the internodes failed to elongate. Each node of the crown attained capacity for adventitious roots and axillary buds, which could produce either rhizomes or shoots.

To maintain consistency in numbering the phytomers of a shoot, the last scale leaf was counted as leaf number 1, and the first leaf with a blade was counted as number 2. Some such arbitrary procedure was necessary for shoots arising from apical meristems of terminal rhizomes because the point of origin of that apical meristem was the axillary bud of the parent crown or rhizome. Transformation from horizontal or diageotropic to negative geotropic growth by a rhizome began with the upward thrust. Then a sequence of phytomers established the lower part of the crown before growth appeared aboveground.

The vegetative shoots produced as many as 9 phytometers (Fig. 3). Five leaves were evident on April 11, but only the third one had green growth exserted from surrounding sheaths. Throughout the season, the shoots contained two or three leaves that were beginning growth but still completely enclosed by the sheaths of older leaves. Four to six leaves showed green growth by July 7. Leaf blades 5 and 6 attained greatest lengths, and together accounted for 41% of total blade length. Blades 4 to 7, inclusive, accounted for 74% of the total blade length and maintained active growth until late July.

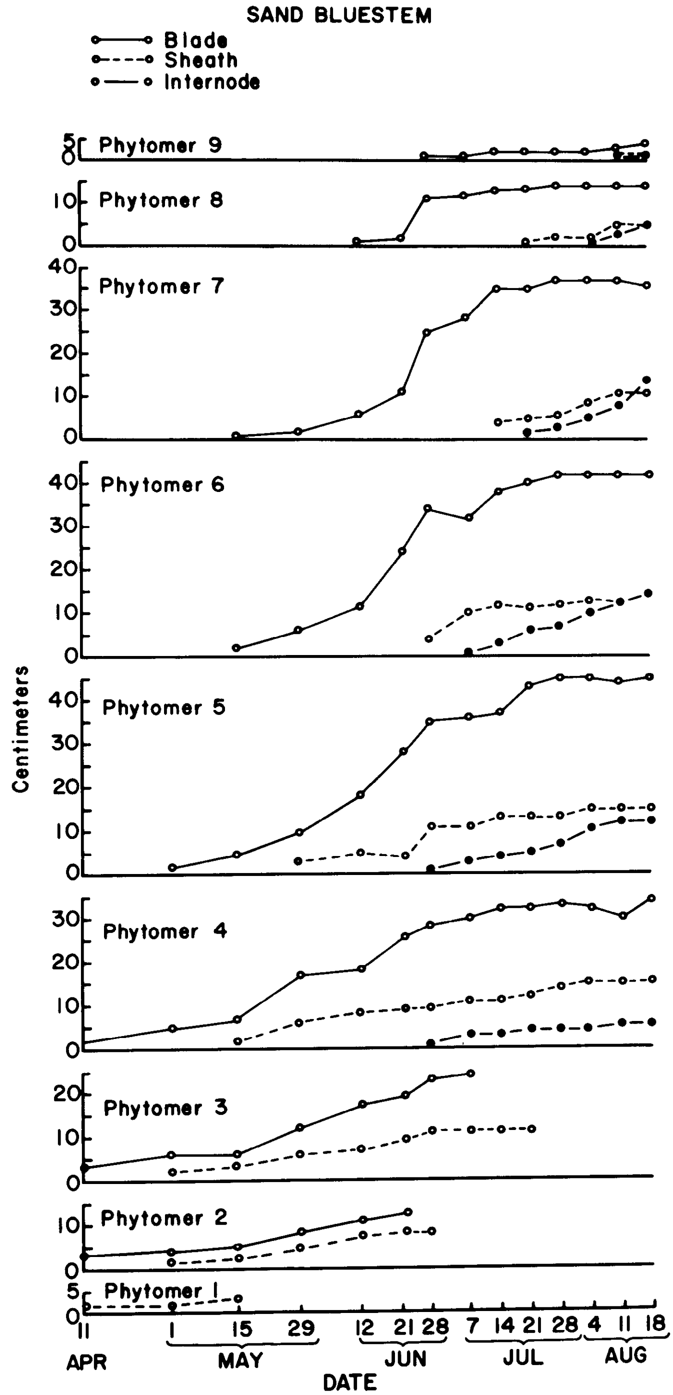

Fig. 3. *Phytomer growth by vegetative shoots of Elida sand bluestem.*

Over all phytomers of vegetative shoots, blade elongation was essentially sigmoidal (Fig. 4). Only 26% of blade growth occurred by May 29, but 81% occurred by June 30 and 99% by July 28. The growth rate of sheaths was nearly linear.

Portions of nine leaves remained green when measurements were terminated on August 18. The first leaf dried early in the season, and two or three more dried by mid-July. Most leaves were dry by September 5, and all exposed parts were dry by October 14.

The internodes of both vegetative and reproductive shoots began elongation between June 21 and June 30, and attained sufficient total length (7cm) to elevate shoot apices to heights which made them removable by grazing by July 7. At that time, leaf blade elongation amounted to 84% of the total attained during the season. There was great variability in internode elongation among vegetative shoots. Average lengths among shoots indicated that six internodes made substantial elongation (Fig. 3), but most shoots (modal tendency) had only four (range from two to seven) internodes elongated. Internodes of phytomers 5, 6, and 7 attained greatest lengths, and together accounted for about 80% of total vegetative culm length.

Reproductive Growth

Thirty-six percent of the shoots of sand bluestem became reproductive. Floral initiation was first observed on July 14, which was 2 to 3 weeks after the initiation of internode elongation. Growth proceeded as for vegetative shoots until July 28. Thereafter the growth of reproductive shoots accelerated. Heading (head exsertion) was first observed on August 15, anthesis on September 5, and ripe seeds on October 14. Ten internodes attained substantial elongation, with average length as follows:

Peduncle plus inflorescence	14cm
Internode 9	8 cm
Internode 8	11 cm
Internode 7	14 cm
Internode 6	17 cm
Internode 5	18 cm
Internode 4	16 cm
Internode 2	9 cm
Internode 1	5 cm
Total	127 cm

The uppermost 4 phytomers generally produced lateral inflorescences from the axillary buds, but these lateral inflorescences developed later than terminal inflorescences.

Rhizome Growth, Tillering, and Perenniality

Tillering was scarce in the absence of mowing, but rhizomes began growing from axillary buds of the crowns in late June and continued into July. The primary tendency was for diageotropic (rhizome) growth from axillary buds in June and July and for geotropic (tiller) growth in August. Rapid elongation of reproductive stems occurred after the most active period of rhizome growth. The short rhizomes turned upward in late summer and were then prepared for shoot growth the following year.

After mowing in June, regrowth occurred promptly from, as yet, nonelevated shoot apices. A few shoot apices were elevated to cutting height by July 1 and nearly all of them by July 7. Thereafter, regrowth after mowing was much delayed because growth was dependent on the initiation of new tillers. Tillering proceeded in two ways: (1) tillers grew from axillary buds at the base (crown) of the shoots which had their elongation stopped by mowing, and (2) the rhizomes turned upward to begin negative geotropic growth. Mowing after July 1 eliminated the first set of shoots, both vegetative and reproductive, but some new tillers attained reproductive status. Most late inflorescences did not develop beyond the boot stage because soil moisture was insufficient to sustain prolific growth in late summer. Thus, by September, there was a great distinction between plots mowed before and after July 1. Regrowth by new tillers was very short, but with adequate moisture could probably have provided a highly productive second crop.

All shoots were annual structures, dying back to the base at

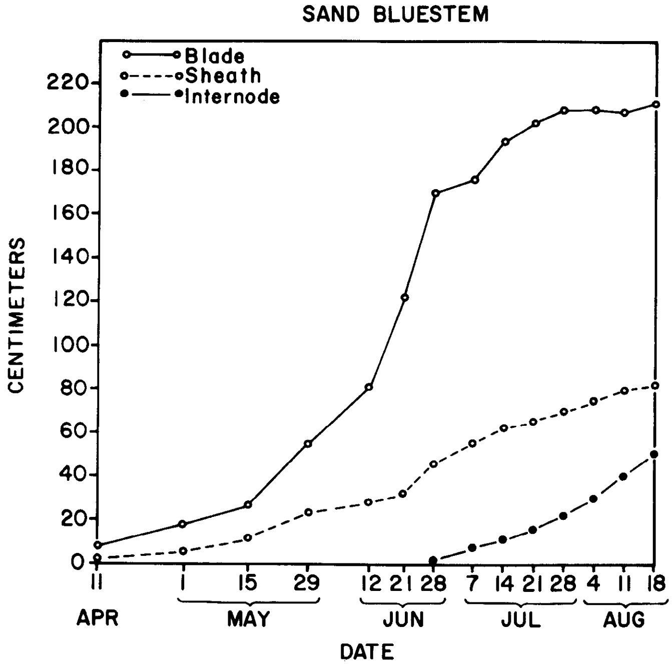

Fig. 4. *Shoot growth curve by vegetative shoots of Elida sand bluestem.*

the end of the growing season. Therefore, perenniality derived from the short, terminal rhizomes and axillary buds of the crowns.

Discussion

Blue grama and sand bluestem provided contrasts in form of growth, regrowth, and perenniality. Blue grama had culmless vegetative shoots and a small proportion (12%) of shoots becoming reproductive. This percentage is about the same as the 13% reported for blue grama by Branson (1953). Regrowth from active shoot apices proceeded quickly after cutting when growing conditions were favorable. Nevertheless, good productivity depended greatly on essentially free expansion of the leaf blades of phytomers 3 through 6. This grass is well adapted to continuous grazing, but the prompt regrowth of leaves from active shoot apices and abundant tillering from axillary buds of small, compact crowns provide tolerance of heavy grazing, even though close harvest reduces productivity.

Sand bluestem had culmed vegetative shoots with an intermediate proportion (36%) of shoots becoming reproductive. That percentage is about the same as the 32% reported for sideoats grama (*Bouteloua curtipendula*), less than the 76% reported for little bluestem (*Andropogon scoparius*), and greater than the 26% reported for big bluestem (*A. gerardi*) (Branson, 1953). Good leaf growth and early drying of lowermost leaves when not utilized made sand bluestem suitable for grazing in June, when regrowth of leaves from active apical meristems was prompt. However, close harvest in early July stopped all active shoots and drastically reduced growth. Thus, after grazing in June, a rest period for 2 or 3 weeks in July should allow good plant development under native sandhill-range conditions. With adequate soil water provided by precipitation or irrigation in July, and perhaps nitrogen fertilization as well, a close harvest about July 10 would stop first-crop growth and promote good development of new tillers and high productivity of second-crop herbage for late summer and fall.

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Individual Sustaining Members

The following names were inadvertently omitted from the list of Individual Sustaining members published in the July *Journal*. These members are recognized, with sincere appreciation, for their voluntary additional financial support of the Society for Range Management for the 1973 membership year.

María Luisa Piñol Gómez
Arturo Acosta González

Relationship of Range Quality to Range Condition in the Chilcotin Region, British Columbia

DENNIS A. DEMARCHI

Highlight: *Bluebunch wheatgrass and needleandthread plants were clipped from three different condition classes and six different growing periods in a wheatgrass/bluegrass association. The collected samples were chemically analyzed for crude protein, total ash, calcium, and phosphorous. The results were tested against the condition classes. There were no statistical differences for the components in needleandthread; however, bluebunch wheatgrass showed highly significant differences in the crude protein levels of ungrazed and overgrazed plants. It was also determined that even though the overgrazed wheatgrass had the highest percentage protein, the total weight of protein per unit area was much greater in ungrazed wheatgrass plants.*

One of the preferred forages in the Lower Chilcotin River region of British Columbia is bluebunch wheatgrass (*Agropyron spicatum*). Undoubtedly it was the most abundant forage plant prior to the introduction of livestock to the area. Heavy grazing has caused bluebunch wheatgrass to decline and needleandthread (*Stipa comata*) to increase with a consequent decline in the grazing value of this range.

Bluebunch wheatgrass can be considered a valuable but fragile resource. This grass is larger than needleandthread and is more readily available under winter snows. The fruits of needleandthread have a long, wiry awn and a sharp callus which aids the grass in seedling establishment but which also can cause mechanical injury to grazing ungulates. Therefore, compared to bluebunch wheatgrass, needleandthread is relatively poor forage for summer as well as winter.

The grasslands of the riverbreaks and terraces in the Lower Chilcotin River region support a population of 350 to 400 California bighorn (*Ovis canadensis californiana*). Sugden (1961) postulated that this population has fluctuated over the years with a major low about 1915. Unlike most other bighorn herds which make annual migrations between summer and winter ranges, The Chilcotin population occupies the same general area at all seasons.

At present, three ranches are grazing domestic livestock on this range. Two ranches use their holdings along the Fraser River for wintering approximately 500 brood cows. The other ranch winters about 2,000 yearling steers on the Fraser Plateau along the Chilcotin and Fraser Rivers.

If wildlife and livestock resources are to continue to exist in this area, a better understanding of the effects of grazing on the grassland and the two dominant grasses, bluebunch wheatgrass and needleandthread, is needed.

The purpose of this study was to determine the chemical composition of bluebunch wheatgrass and needleand-

Table 1. Canopy cover (%) of major plant species at study sites in three plant communities in the wheatgrass/bluegrass zone.

	Wheatgrass/bluegrass			Needlegrass/wheatgrass bluegrass			Needlegrass/bluegrass		
Study site	1A[a]	1B	1C	2A	2B	2C	3A	3B	3C
Grasses									
Bluebunch wheatgrass	40	27	33	7	6	10	1	4	6
Junegrass	2	8	14	–	1	2	–	t[b]	1
Needleandthread	21	–	t	30	14	25	60	24	30
Sandberg bluegrass	7	13	12	13	1	2	6	–	2
Shrubs									
Big sagebrush	6	–	–	–	–	–	1	–	–
Pasture sage	13	8	7	4	8	2	4	6	2
Forbs									
Bastard toadflax	7	–	3	–	–	2	5	t	–
Lambs-quarters	1	–	–	2	t	3	3	1	–
Pricklypear cactus	–	–	–	t	t	t	1	t	t
Dwarf pussytoes	–	–	1	1	t	3	1	t	t
Pink pussytoes	1	4	4	3	t	1	t	t	t

[a] Study site.
[b] t Trace (<0.5%).

At the time of the research, the author was a graduate student, College of Forestry, Wildlife and Range Sciences, Moscow, Idaho. At present he is wildlife biologist, British Columbia Fish and Wildlife Branch, Victoria, British Columbia.

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thread and relate this to range condition.

Study Methods

In order to relate the chemical composition of the two grasses to range condition, three plant communites had to be identified. Prior to the field study, aerial photographs of the area were studied. Vegetation types were identified by means of tonal and textural differences in the photos. Potential sample sites were located on the aerial photographs, and final selection of the sample sites was made in the field following a general reconnaissance.

It was predetermined that statistical analysis of the collected data would be a split-plot-in-time design. Thus three areas were chosen to represent blocks; within each block one each of three levels of range condition or plant community succession were to be found. The three blocks occurred within the wheatgrass/bluegrass zone, and the three plant communities within each block were presumed to represent differences brought about by grazing.

Within each of the nine study sites the following information was collected: the canopy-coverage of the plants; the density of bluebunch wheatgrass and needleandthread; ungulate fecal droppings; soil profile descriptions; and samples of bluebunch wheatgrass and needleandthread for chemical analyses.

The nine sites were studied intensively using the macroplot technique of Poulton and Tisdale (1961). The macroplots were modified from 30 by 100 ft to 15 by 30 m with five randomly selected, parallel, 15-m transects located in each. At 1½-m intervals along each transect, a tenth of m^2 frame was employed to determine the canopy-coverage according to the method of Daubenmire (1959 and 1968). Densities of bluebunch wheatgrass and needleandthread were recorded in 1-x 15-m strips along each transect in each macroplot. The macroplots and transects were parallel to the contours of the terrain surrounding the study sites.

Ungulate fecal droppings were counted in each macroplot to assess the relative amount of grazing use of each plant community. The fecal counts were conducted within three 100-m^2 circles (5.64 m in radius) in each macroplot. All fecal groups that were at least 50% inside the circles were recorded.

Fecal groups were related to ungulate units, based on the relative weight of the species. One bighorn sheep equals one; one cow equals six ungulate units (Stoddart and Smith, 1955: 192).

Soil profiles were described at nine of the ten study sites. Description and classification of the profiles were conducted according to the methods adopted by the National Soil Survey Committee of Canada (1965).

Two plant species, bluebunch wheatgrass and needleandthread, were sampled for chemical composition. Bluebunch wheatgrass was sampled only in the excellent and fair condition sites, while needleandthread was sampled in the fair and poor condition sites. Bluebunch wheatgrass was almost nonexistent in the poor condition sites and needleandthread did not occur in the excellent condition sites.

In order to obtain the seasonal chemical change in the plants, the sampling dates were based on the phenological development of the grasses. Sampling was conducted in: late May, 1968, leaf stage; early June, 1968, flowering heads out; late June, 1968, seeds ripe; late July, 1968, seeds disseminated; middle October, 1968, plants cured; late March, 1969, plants weathered.

The number of plants sampled varied for each species as the earlier clippings did not provide enough material for analyses. For the late May clipping only four plants per species per site were clipped. This was increased to six, eight or ten bluebunch wheatgrass plants and to ten, 20, or 40 needleandthread plants per site per clipping date. All plants were clipped to ground level and only the growth from the 1968 growing season was kept. The plants were bulked to constitute one sample for each species at each plot for each sampling date.

The plant samples were weighed, air dried in the field; in the fall of 1968 they were transported to the University of Idaho Range Sciences Laboratory, where they were oven dried at 55°C, ground in a Wiley mill, and passed through a 40-mesh screen. (Samples collected in October, 1968, and March, 1969, were taken to the University of Idaho within 1 week of being clipped.) The samples were analyzed according to the methods of the Agricultural Official Association of Chemists (1960) for crude protein, total ash, calcium, and phosphorus. Results were based on the weight of material measured at an oven-dry temperature of 105°C. (Chemical analyses were conducted during the winter of 1968-69 and spring of 1969).

Study Areas

The area chosen for study is situated near the northern limit of grasslands in central British Columbia. Specifically, the study area is the river break and terraced area lying west of the Fraser River and north of the Chilcotin River below the edge of the Fraser Plateau, approximately 1,006 m (3,300 ft) elevation.

The vegetation in the Lower Chilcotin River region consists mainly of grasslands and coniferous forests. The grasslands are well established on the south-facing slopes and terraces, while coniferous forests occur on northerly exposures. A smaller community dominated by big sagebrush (*Artemisia tridentata*, subsp. *tridentata*) occupies only the lower terraces above both rivers and some steep, windswept slopes.

Although certain habitat factors of this region were relatively constant, the grazing use of each plant community was not uniform. Access was the main cause for this discrepancy of use. Gullies, ridges, and fences blocked access to cattle on several of the slopes and terraces. While this limitation was not of serious consideration to the bighorn, they were limited in their distribution by lack of escape terrain and habitual avoidance of certain areas. Because of these differences in the use of certain areas, the wheatgrass/bluegrass zone does not have a uniform plant community in this region.

Orthic Dark Brown Chernozemic Soils were described for nine sites in the Lower Chilcotin River region. This soil is derived from Aeolian material that overlies basal till. Much of the parent material has been modified by movement of the till down the slopes. The soils had an Ah horizon that varied in thickness from 4.5 to 9.5 inches. This horizon was a very dark greyish brown when moist. The boundary between this horizon and the next, the Bm horizon, was clear. The Bm horizon varied from 5 to 9 inches in thickness and was a dark greyish brown when moist. At two sites this horizon was strongly lithologic. The boundary between the Bm horizon and the next, the Cca horizon, was clear. The Cca horizon began from 12 to 21 inches below the surface and was brown when moist. There was a $CaCO_3$ coating on the underside of stones in this horizon. At three sites this horizon was strongly lithologic.

Wheatgrass/bluegrass Community

The wheatgrass/bluegrass association was dominant on isolated terraces and steep slopes. The community was described at three sites. The dominant plant species in this association were bluebunch wheatgrass and Sandberg bluegrass (*Poa sandbergii*) (Table 1). Common species included Junegrass (*Koeleria cristata*), pasture sage (*Artemisia frigida*) and pink pussytoes (*Antennaria rosea*). In addition to these species, one site contained big sagebrush, needleandthread, and bastard toadflax (*Comandra umbellata*). The latter two species were represented by high canopy coverage values, due in part to relatively recent use of the area by cattle. This one site was no doubt not in pristine condition. However, it was not in the degraded condition of other communities. In this community bluebunch wheatgrass had an average density of 8.8

plants per m² (Table 2). The density of needleandthread was almost zero although one site had 10.4 plants per m².

Needlegrass/wheatgrass/bluegrass Community

The needlegrass/wheatgrass/bluegrass community formed the dominant community on areas that had animal grazing on accessible gentle slopes. This community was described at three sites. Dominant plant species in this community were needleandthread, bluebunch wheatgrass, and Sandberg bluegrass (Table 1). Associated plant species were Junegrass, pasture sage, dwarf pussytoes (*Antennaria dimorpha*), pink pussytoes, lambs quarters (*Chenopodium album*), peppergrass (*Lepidium densiflorum*), and pricklypear cactus (*Opuntia fragilis*). Bluebunch wheatgrass had an average density of 4.2 plants per m² (Table 2). The density of needleandthread averaged 22.5 plants per m², although one site only had 9.0 plants per m².

Needlegrass/bluegrass Community.

The needleandthread/bluegrass community formed the dominant community over the majority of the grasslands in the Lower Chilcotin River region. This community was found on gently rolling hills and the broad extensive terraces common to the region and was described at three sites. Dominant plant species in this community were needleandthread and Sandberg bluegrass (Table 1). Associated plant species were bluebunch wheatgrass, pasture sage, dwarf pussytoes, pink pussytoes, lambs quarters, and pricklypear cactus. One site also contained big sagebrush and bastard toadflax. Bluebunch wheatgrass had an average density of 2.2 plants per m² (Table 2). The average density of needleandthread was 32.4 plants per m².

Animal Distribution

Fecal group counts in the nine macroplots indicated that the grazing intensity of cattle and bighorn varied in each community. The highest ungulate unit values per m² for bighorn were found in the wheatgrass/bluegrass and needlegrass/wheatgrass/bluegrass communities (Table 3). The ungulate unit values per m² for cattle were highest in the needlegrass/bluegrass community and successively lower in the needlegrass/wheatgrass/bluegrass and wheatgrass/bluegrass communities. This trend was consistent, except for one site in the wheatgrass/bluegrass community where recent increased use by cattle had occurred.

Table 3. The use (fecal groups per m² weighted by metabolic rate of the ungulate) of sites in three plant communities in the wheatgrass/bluegrass zone by cattle and bighorn.

Animal	Wheatgrass/bluegrass			Needlegrass/wheatgrass bluegrass			Needlegrass/bluegrass		
	1A[a]	1B	1C	2A	2B	2C	3A	3B	3C
Cattle	1.00	0.32	0.32	0.52	0.82	0.60	0.94	1.02	0.54
Bighorn	0.06	0.08	0.14	0.27	0.09	0.07	0.07	0.04	0.08
Total	1.06	0.40	0.46	0.79	0.91	0.67	1.11	1.06	0.61

[a]Study site.

Results

Percentages of crude protein and phosphorous of the bluebunch wheatgrass and needleandthread in all three condition classes of the wheatgrass/bluegrass association were highest in the leaf stage (late May and early June) and declined with advancing maturity (Table 4). Percentages of total ash in both species were moderate in the leaf stage but declined slightly in the seed setting stage and increased in the weathered stage.

These results are similar to those of other investigators who have analyzed bluebunch wheatgrass or needleandthread plants from various habitats (Demarchi, 1968; Johnston and Bezeau, 1962; McIlvanie, 1942; McLean and Tisdale, 1960; and Smoliak and Bezeau, 1968).

Grazing affected the chemical composition of bluebunch wheatgrass plants. The results of an analysis of variance for all chemical analyses of bluebunch wheatgrass revealed highly significant differences ($P<0.01$) in crude protein percentages. The plants from sites in fair condition had the highest percentages of crude protein. No significant differences were found between either bluebunch wheatgrass or needleandthread for the other two condition classes of each species. Percentage crude protein differences were highly significant between needleandthread plants and bluebunch wheatgrass plants from the excellent condition sites. However, differences between needleandthread and bluebunch wheatgrass from the fair condition sites were not significant. Bluebunch wheatgrass plants from the excellent condition sites had the lowest crude protein percentages.

Grazing had an effect on the weights of bluebunch wheatgrass plants (Table 5). Analysis of variance showed that differences between bluebunch wheatgrass plants in excellent and fair condition sites were significant ($P<0.05$). Differences between needleandthread plants from the two different sites were not significant. Differences for percent total ash were highly significant ($P<0.01$) between species. Bluebunch wheatgrass plants had higher percentages of total ash than did the needleandthread plants. Differences for calcium were significant ($P<0.05$). Again bluebunch wheatgrass plants had the higher percentages. Tests for differences between species for percent phosphorous were not significant.

Table 2. Density (plants per m²) of bluebunch wheatgrass and needleandthread at study sites in three plant communities in the wheatgrass/bluegrass zone.

Species	Wheatgrass/bluegrass			Needlegrass/wheatgrass/ bluegrass			Needlegrass/bluegrass		
	1A	1B	1C	2A	2B	2C	3A	3B	3C
Bluebunch wheatgrass	8.1	7.7	9.5	4.5	3.0	5.1	0.9	2.4	3.3
Needleandthread	10.4	0.0	0.3	28.4	9.0	30.0	43.5	17.2	38.2

Discussion and Conclusions

Grazing appeared to have a beneficial effect on the nutrient content of bluebunch wheatgrass. However, the overgrazed plants were smaller than those which had been lightly grazed. These results are similar to those observed by Cook, Stoddart and Kinsinger (1958). Working with crested wheatgrass (*Agropyron desertorum*) they found that early and close clipping resulted in high quality herbage, but the quantity declined rapidly each year the plants were harvested.

A possible explanation for the higher percentages of crude protein in the overgrazed bluebunch wheatgrass plants is that these had a greater proportion of leaves than did the lightly grazed plants. Clarke and Tisdale (1945) found that Junegrass and needleandthread in the cured stage had twice as much crude protein in the leaves as in the culms. Whittingham (1965) says that nitrogen is taken up through the plant to the leaves in the inorganic from and is converted to the organic form in the leaves. From here the organic nitrogen moves to other parts

Table 4. Chemical composition (%) of bluebunch wheatgrass and needleandthread by range condition classes of the wheatgrass/bluegrass zone.

Component	Growth stage	Bluebunch wheatgrass by condition class		Needleandthread by condition class	
		Climax	Fair	Fair	Poor
Crude protein	Leaf	12.7	15.1	15.8	14.7
	Flowering heads out	9.5	12.7	13.2	12.0
	Seed-ripe	6.8	9.4	9.8	9.2
	Seeds disseminated	5.5	6.7	8.2	7.1
	Plants cured	2.6	3.3	4.5	4.3
	Plants weathered	2.7	2.8	4.7	4.4
Total ash	Leaf	8.3	8.3	6.4	7.1
	Flowering heads out	7.6	7.8	5.8	6.6
	Seed-ripe	6.7	7.2	5.5	6.0
	Seeds disseminated	5.7	6.6	4.8	4.9
	Plants cured	10.3	10.7	8.3	7.9
	Plants weathered	9.9	11.0	7.1	7.9
Calcium	Leaf	0.33	0.43	0.40	0.37
	Flowering heads out	0.33	0.38	0.39	0.27
	Seed-ripe	0.35	0.40	0.31	0.27
	Seeds disseminated	0.32	0.37	0.30	0.24
	Plants cured	0.51	0.54	0.39	0.41
	Plants weathered	0.46	0.55	0.39	0.37
Phosphorous	Leaf	0.22	0.22	0.18	0.19
	Flowering heads out	0.17	0.18	0.16	0.20
	Seed-ripe	0.13	0.12	0.14	0.15
	Seeds disseminated	0.08	0.08	0.10	0.10
	Plants cured	0.03	0.03	0.05	0.04
	Plants weathered	0.03	0.03	0.04	0.05

of the plant. This would tend to concentrate the nitrogen in the leaves.

As a result of the depleted bluebunch wheatgrass plants having relatively more leafy material and a higher percentage of crude protein these plants may be subjected to yet heavier grazing. This would perpetuate the overgrazed condition of the plant. Also this may increase the carbohydrate utilization in the plant and further reduce the size.

While the relative values of crude protein were lower in bluebunch wheatgrass from excellent condition sites than from fair condition sites, the absolute values were opposite (Table 5). Values of crude protein expressed as g/m^2 were much lower in bluebunch wheatgrass from fair condition sites than from either bluebunch wheatgrass from excellent condition sites or needleandthread. Needleandthread from the fair condition sites produced more crude protein per unit area than did bluebunch wheatgrass from the excellent condition sites. Needleandthread from the poor condition sites produced slightly less crude protein per unit area than did bluebunch wheatgrass from the excellent condition sites. When the crude protein production per unit area for bluebunch wheatgrass and needleandthread was combined, the plants on sites in fair condition produced a greater amount of crude protein per unit area than did bluebunch wheatgrass on the excellent condition sites.

Although bluebunch wheatgrass from the climax condition sites did not produce more crude protein than needleandthread on sites in fair condition, the quality of the range must be judged with regard to the foragers. Needleandthread has a mechanically injurious fruit in early summer and the plant is relatively unavailable under winter snows. Thus, bluebunch wheatgrass, which provides yearround grazing, must be considered a better species for bighorn sheep. This judgement is enhanced by the fact that overgrazing by livestock caused the decrease in bluebunch wheatgrass and not some other factor. That action by grazing ungulates is interpreted as a preference for that grass over needleandthread.

Table 5. Weight (g, oven dry) of individual plants of bluebunch wheatgrass and needleandthread and of crude protein of these plants per m^2 from three condition classes of the wheatgrass/bluegrass zones.

Species and range condition	Plant weight at growth stage[a]						Crude protein at growth stage					
	1	2	3	4	5	6	1	2	3	4	5	6
Bluebunch wheatgrass												
Climax	6.5	7.7	7.0	8.6	7.6	4.2	6.5	5.6	3.9	3.8	1.6	0.9
Fair	2.3	3.0	5.4	4.0	3.6	1.4	1.6	1.6	2.3	1.1	0.5	0.2
Needleandthread												
Fair	2.2	1.8	2.6	1.8	1.6	0.9	7.9	5.3	5.9	3.1	1.4	0.9
Poor	1.1	1.2	1.6	1.6	1.1	0.9	5.2	4.6	4.6	3.5	1.4	1.1

[a]Growth stages: 1-leaf; 2-flowering heads out; 3-seed-ripe; 4-seeds disseminated; 5-plants cured; and, 6-plants weathered.

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Use of a Crested Wheatgrass Seeding by Black-tailed Jackrabbits

MARK WESTOBY AND FREDERIC H. WAGNER

Highlight: *Black-tailed jackrabbit grazing pressure on a seeding of crested wheatgrass surrounded by native shrub vegetation has been estimated by the use of pellet counts. Grazing pressure falls off rapidly away from the edge of the field, 70% of the total being concentrated in a 300-m band around the edge of the field. By calibrating the pellet counts against others taken in an area of known jackrabbit density, and by using values available in the literature for forage consumption of jackrabbits, an estimate has been made of the absolute grazing pressure on the field in the 300-m band which is predominantly used. The forage removed by jackrabbits in this zone is estimated to be in the order of 60 kg/ha/yr. This is less than 10% of nearly all the yield values found, including those in poor years, in comparable seedings in this area. Apparently jackrabbits do not cause serious damage to established seedings of wheatgrass even when jackrabbit densities are high, as they were at the time of this study.*

It is well known that black-tailed jackrabbits (*Lepus californicus*) invade cultivated or managed fields during the nocturnal feeding period (Lewis, 1946; Bronson and Tiemeier, 1958).

This grazing behavior is difficult to observe directly. R. D. Anderson (personal communication) observed significant numbers of hares crossing the boundary of a seeding of crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) by watching a sector of it. Routes to the edge of the field offering cover were preferred, and the hares were easily disturbed by activity or noise on the part of the observer, returning rapidly to cover at the field's edge.

It has also been widely remarked in the literature (Taylor et al., 1935; Phillips, 1936; Orr, 1940; Taylor and Lay, 1944; Lechleitner, 1958) that black-tailed jackrabbits appear to favor habitats which provide an interspersion of tall cover with open spaces.

These observations suggest that there might be a tendency for jackrabbit grazing to be concentrated near the edges of seedings. It was thought that if this effect could be quantified, implications might become apparent for the sizes and shapes of seedings which would most effectively limit jackrabbit use.

It was also of interest to know whether the extra food supplied by the seeding would support a larger jackrabbit population around its borders than elsewhere.

Thus the objectives of the work described here were (1) to describe any decrease in the intensity of jackrabbit use with distance into the seeding from its edge; (2) to test whether jackrabbit populations tend to be larger in the immediate vicinity of the seeding than at a distance from it; (3) to try to estimate whether jackrabbit utilization of the seeding might remove an important fraction of its yield.

Study Area and Methods

The seeding studied is in the southern half of Curlew Valley on the Utah-Idaho

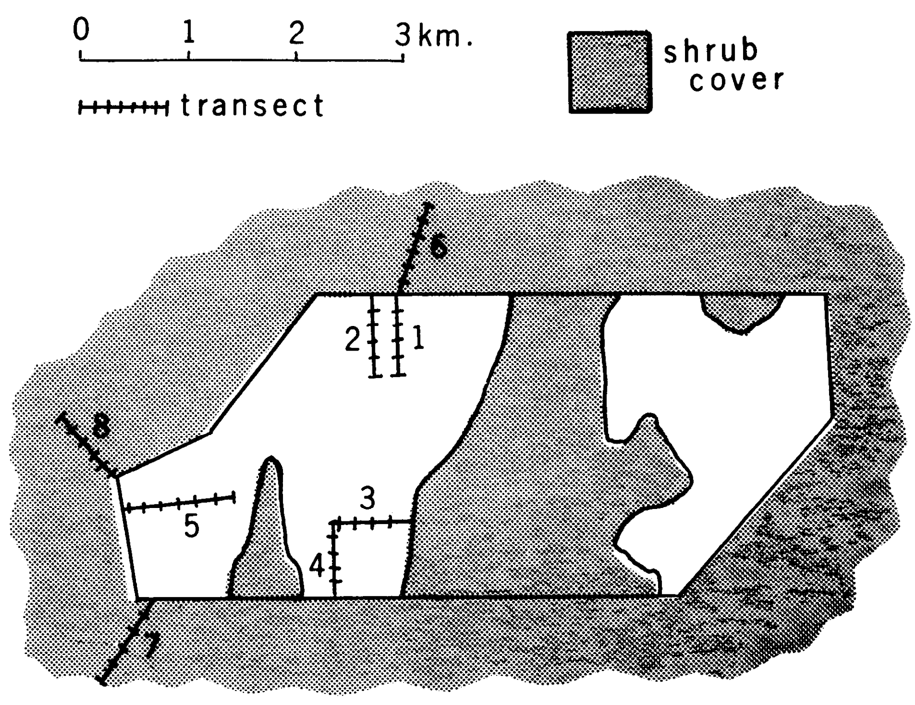

Fig. 1. *Schematic map of the study area, showing the locations of sampling transects.*

The authors are research assistant, Ecology Center, and associate dean, College of Natural Resources, Utah State University, Logna. Dr. Westoby's present address is Department of Entomology, Cornell Univeristy, Ithaca, N.Y. 14850.

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border. It was ploughed and seeded in 1965 and is roughly 7 km by 3 km (Fig. 1). Annual mean precipitation is about 20 cm. The surrounding native shrub vegetation is of several types, lying in a broad transition zone between big sagebrush (*Artemisia tridentata* Nutt.) and the more halophytic shadscale (*Atriplex confertifolia* (Torr. and Frem.) S. Wats.). The black-tailed jackrabbit is the only *Lepus* species found on the study area. A count of the standing crop of pellets per unit ground area was used as an estimator of jackrabbit grazing pressure at each location. All pellets still recognizable as such were counted within 1/4 m^2 circular quadrats; eight such quadrats were positioned randomly at each "location." Locations were placed at intervals of 160 m along arbitrarily chosen transects oriented perpendicularly into the field from its edge. Transects were also situated along roads leading away from the seeding; in these cases the eight quadrats were placed after walking 50 paces to one side of the road. A further transect was run through a 1-square-mile site located about 6 km west of the western end of the seeding. This site is regularly used for estimates of the absolute density of jackrabbits. The animals are estimated by "jackrabbit drives" (Gross, 1967), as part of continuing studies of jackrabbit demography (Stoddart, 1971).

All pellet counts were completed between March 25 and April 10, 1972.

Results

Patterns of Use

The locations of the transects taken are shown in Figure 1. Transects 1-4 show a similar pattern, and these results have been pooled. The trend of pellet density with distance into the field for these pooled results is shown by line *A* in Figure 2. Under the conditions represented by these transects, about 70% of the total pressure of jackrabbit use on the field is concentrated in a 300-meter band around its edge.

Transect 5 represents a different situation (line *B* in Fig. 2). This transect occurs close to a corner of the field and at its end reaches the tip of a tongue of invading shrubs; so hares feeding at locations more than about 400 m along this transect would have access to cover closer than the beginning of the transect. This presumably accounts for the failure of the pellet density to fall to near-zero values. The absolute densities of pellets may be higher because hares are entering the field from more than one direction. There is no evidence of a higher population in the native vegetation adjacent to this particular transect; that is, transect 8 does not show higher pellet counts than transect 7 and 6 (Table 1).

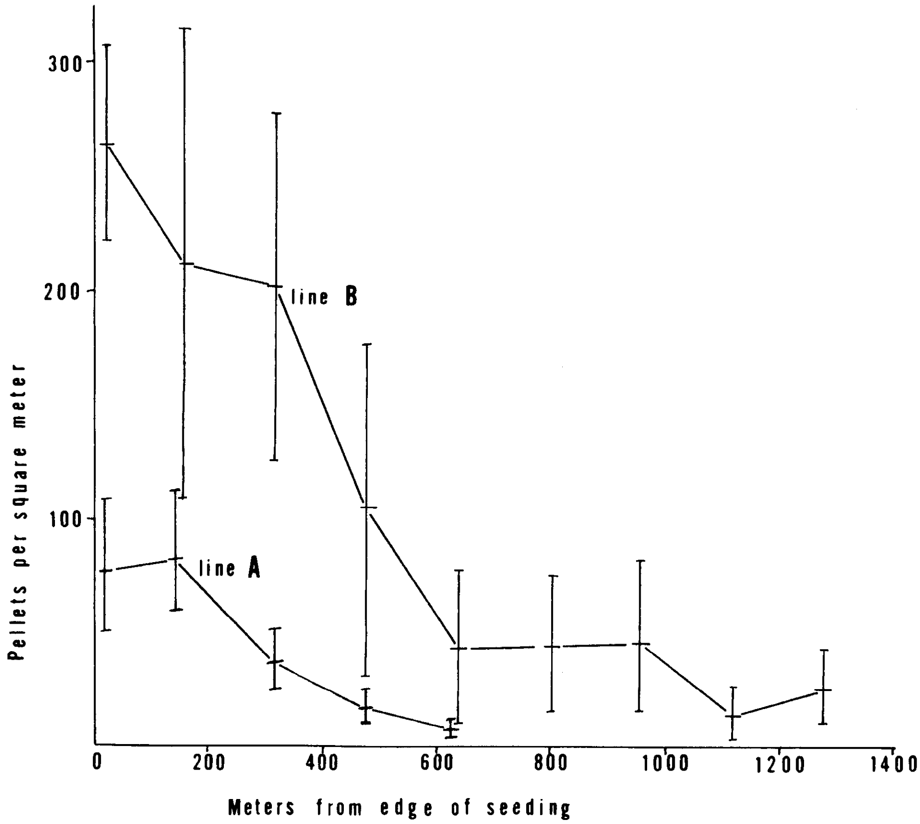

Fig. 2. *Number of pellets per m² (mean and 95% confidence limits) at various distances into a field. Pooled results from transects 1-4 (line A), and results from transect 5 (line B).*

There is no obvious trend toward higher populations in the native vegetation immediately adjacent to the wheatgrass field, compared to those up to 900 m away (Table 1). The low values in the first two locations on transect 6 come from open patches dominated by the annuals *Lepidium perfoliatum* L. and *Halogeton glomeratus* (Bieb.) L. A. Meyer rather than from shrub vegetation.

Assumptions

Three assumptions are necessary to the calculations which follow.

The first is that the pellets found represent at least one whole year's history of pellet deposition. This assumption is necessary because the calculations which follow compare the demography research area, where jackrabbits are present year-round, to the seeding, which they use seasonally; the calculations would be wrong if the pellet counts in the seeding were heavily weighted by any one season. Arnold and Reynolds (1943) give an average daily pellet count of 531 ± 27 for a jackrabbit, irrespective of age, sex, size, or species. Cochran and Stains (1961) found comparable values for cottontails (*Sylvilagus audubonii*) on natural diets, ranging down to 100 on various artificial diets. The value of 531 is probably near the upper end of the likely range. In the autumn of 1971 there were estimated to be 691 hares per square mile, or 2.7/ha, on the jackrabbit demography research area (F. H. Wagner and L. C. Stoddart,

Table 1. Number of pellets per m² (mean and 95% confidence limits) at various distances along transects leading away from the field.

Transect number	Distance (m) along transect from seeding's edge: 16	160	320	480	640	800	960
6	69 ± 32	49 ± 20	82 ± 39	240 ± 113	154 ± 52	155 ± 35	
7	123 ± 108		66 ± 36		104 ± 87		83 ± 64
8	101 ± 47		104 ± 62		86 ± 41		

unpublished datum[1]). (The number of rabbits in autumn probably overestimates the year-round mean.) If each animal is depositing 531 pellets/day, this implies a yearly deposition of about 52 pellets/m^2. This yearly deposition is well below the actual measured density of 143 ± 76/m^2, so that pellets are apparently persisting for at least a year after deposition.

Secondly we assume that the number of pellets found at a location is proportional to the pressure of the jackrabbits on the vegetation there. This can be divided into three subsidiary assumptions. First, animals on a natural diet produce pellets predominantly while feeding, and at a reasonably constant rate (Lechleitner, 1957; Flux, 1967). Second, pellets are not moved after deposition over distances (hundreds of meters) great enough to account for the distributions observed. There is no evidence of movement by wind or water; pellets are not found in aggregations against natural wind-breaks, and the absence of any system of channels shows that there is little net water movement on the study area. Third, any variation in the rate at which pellets disintegrate and become unrecognizable is insufficient to account for the distribution pattern observed. Flux (1967) has observed a six- to tenfold variation in that rate, but the variation was strongly correlated with an altitudinal gradient. In his opinion, pellets do not normally break up until they are overgrown by vegetation. If so, there should be little systematic variation in the rate of disappearance of pellets inside the field. The difference between the rate inside the field and that in shrub vegetation should not be great, since the species composition of the herb layer, the elevation, and probably precipitation and temperature, are similar for the two situations.

A third assumption is that jackrabbits waste little or no material when eating the leaves of perennial grasses (Vorhies and Taylor, 1933; Arnold, 1942; Currie and Goodwin, 1966). This is in contrast to their behaviour when eating shrubs or tall crops, when they may waste as much as or more than they actually consume. Serious wasting of grass leaves could occur if a situation arose in which the bases of stems or leaves remained green and succulent while the leaves were dry.

Estimation of Impact

All samples from transect 9, situated on the jackrabbit demography research area, have been pooled. The mean number of pellets per square meter is 143 ± 76 (95% confidence limits).

There is good agreement in the literature that the adult *Lepus californicus* consumes 100–130 grams of "native air-dry forage" per day (Arnold, 1942; Arnold and Reynolds, 1943; Haskell and Reynolds, 1947; Currie and Goodwin, 1966). Two and seven-tenths (2.7) individuals/ha, working year-round, would consume about 108 kg/ha/yr of native air-dry forage. This is the situation which is found on the jackrabbit demography site, where the pellet density is 143/m^2. If we can assume that pellet density is proportional to grazing pressure, then 143 pellets/m^2 represents removal of 108 kg/ha/yr, or 10 pellets/m^2 represents removal of 108/14.3 = 7.5 kg/ha/yr.

Mean pellet density in the 300 m at the perimeter of the field where jackrabbit use is concentrated is about 80/m^2 (Fig. 2, line *A*). The pressure on this area is therefore about 80/10 x 7.5 = 60 kg/ha/yr.

Hull and Klomp (1966) give a total of 108 years of yield records for eight different crested wheatgrass seedings in southern Idaho. The mean yield is 1305 kg/ha, with a range of 347-3080. Only 5 years of the 108 have yields less than 600 kg/ha. The highest grazing pressure exerted by jackrabbits on the field, then, near its edge, by what is a 10-year-high population density of jackrabbits (Stoddart, 1971), corresponds to less than 10% of the yield of comparable seedings in all but the very poorest years.

This estimate has dealt with values for entire years; it is possible that if all 60 kg/ha were removed at the very beginning of the growing season the damage might be severe. However, use of the seeding is spread through the whole period during which there are green leaves on the plant (R. D. Anderson, unpublished observations). This low estimate of grazing impact agrees with the subjective observation that there is no striking diminution in vigor of the grass toward the periphery of the field.

Although the current jackrabbit density is as high as any since 1962, there are anecdotal reports of much higher densites at earlier peaks such as that in 1958. Actual measurements of densities reported in the literature, however, range from 0.7 to 2.7 hares/ha (Stoddart, 1972).

Conclusions and Management Implications

1) About 70% of the total forage removal by jackrabbits from the field is concentrated in a band 300 m wide around its edge.

2) There is no obvious tendency for jackrabbit densities to be higher in the immediate vicinity of the field than at distances 500 to 900 m from it.

3) Within the band 300 m wide at the field's perimeter where most grazing is concentrated, the forage removed by the highest density of jackrabbits for at least a decade is on the order of 60 kg/ha/yr. This is less than 10% of all but the very lowest yields recorded from comparable seedings, which suggests that jackrabbits do not damage established seedings even near their edges.

A jackrabbit population density such as the one currently being experienced in Curlew Valley could conceivably affect the establishment of a new wheatgrass seeding in its first year. It may be advisable to seed, when possible, during periods of low jackrabbit density.

Since the pressure of jackrabbit use is concentrated around the edges of seedings, the mean pressure over the field as a whole will be reduced by making fields as large and as circular as possible and by taking action to destroy shrub invasions. However, these results also indicate that jackrabbit grazing pressure is not so heavy as to make this an important criterion in the design of new seedings.

Damage due to jackrabbits in arable crops could conceivably be very much more severe. This is partly because they may be willing to penetrate more deeply into a field in which the crop provides more cover, and partly because the wastage may become very high when jackrabbits are eating tall crops (Arnold, 1942).

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Control of Rocky Mountain Iris and Vegetation Response on Mountain Meadows

RICHARD E. ECKERT, JR., ALLEN D. BRUNER, GERARD J. KLOMP, AND FREDERICK F. PETERSON

Highlight: *Application of 2, 3, or 4 lb/acre of 2,4-D in mid-June or 3 or 4 lb/acre in early July gave 91 to 100% control of iris. Iris phenology at treatment ranged from late vegetative to late bloom. The 2 lb/acre rate applied when seed capsules were forming controlled 73 to 85% and control was not uniform. Reduction in iris yield ranged from 398 to 1568 lb/acre and averaged 925 lb/acre. Iris control gave a significant increase in production of grass and grasslike species of from 274 lb/acre (58%) to 2364 lb/acre (360%) with an average of 1173 lb/acre (180%). Slender wheatgrass and Nevada bluegrass were the most responsive species. Yield of sage grouse food plants, dandelion and yarrow, was severely reduced the first year after all treatments. Total forb production was deficient or minimal for sage grouse, and dandelion was deficient. Total forb production and dandelion component appeared adequate for existing sage grouse populations in the second and subsequent years after treatment.*

Mountain meadows occur adjacent to streams and seeps in mountainous topography in northern and central Nevada. Information on vegetative characteristics, importance for livestock and sage grouse (*Centrocercus urophasianus*), range condition, and improvement by seeding has been presented (Eckert et al., 1973). One range condition described was fair meadows with desirable species suppressed by Rocky Mountain iris (*Iris missouriensis*).

The authors are range scientist, Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture; junior range ecologist, Nevada Agricultural Experiment Station; range scientist, Plant Science Research Division, Agr. Res. Serv., U.S. Dep. Agr.; and associate professor of plant, soil, and water science, College of Agriculture, University of Nevada, Reno.

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Iris is a common weed of native meadows and pastures in Nevada and adjacent states (Cords, 1960). Competition on good condition pastures and mowing on hay meadows restrict iris increase. However, the plant is a serious problem on poorly managed pastures and mountain meadows because it is unpalatable to livestock (Pryor and Talbert, 1958). Iris reproduces from seed and underground rootstocks. These rootstocks enable the plant to withstand heavy trampling and to spread rapidly when competitive vegetation is weakened (Dayton, 1960). Iris is well adapted to soils with the potential to support species of much greater forage value. Iris reduces the yield of palatable forage through competition and also limits utilization because livestock avoid forage in and around iris clumps.

Pryor and Talbert (1958), Cords (1960, 1972), and Robocker (1966) indicated the superiority of 2,4-D for iris control. Cords (1960), obtained over 90% control with 4 lb/acre of ester formulations of 2,4-D applied soon after bloom. However, none of these authors evaluated the effects of treatment on nontarget species.

Savage (1968), Savage et al. (1969), and Oakleaf (1971) showed the importance of meadows for sage grouse habitat and particularly the importance of meadow forbs as food plants during the summer. Therefore, we needed to find a rate of 2,4-D and application date to maximize iris control and minimize forb damage.

Objectives of this study were to 1) evaluate rates of 2,4-D and dates of application for iris control; 2) determine the response of livestock forage plants; and 3) determine the effect of treatment on sage grouse food plants, common dandelion (*Taraxacum officinale*) and western yarrow (*Achillea lanulosa*).

Experimental Areas and Procedures

Studies were conducted at two locations from 1965 to 1971. Willow Creek is in central Nevada at 7400 ft elevation. Precipitation averaged 17.0 inches with a range of 8.1 to 33.2 inches. Soil is a member of a fine-loamy, mixed, frigid family of Cumulic Haplaquolls. Long Meadow is in northcentral Nevada at 6600 ft elevation. Precipitation averaged 20.1 inches with a range of 15.6 to 25.8 inches. Soil is a member of a fine-silty, mixed, frigid family of Typic Haplaquolls.

The best treatment suggested by Cords (1960) was evaluated at Long Meadow in 1965. Propylene glycol butyl ether ester of (2,4-dichlorophenoxy) acetic acid (2,4-D) at 4 lb/acre was applied in 10 gpa water with 0.1% X-77 in mid-July. Plot size was 12 x 20 ft with four replications. Basal area of iris was estimated the year of treatment and the following year to determine control. Herbage production was measured by clipping two 12-ft^2 subplots each year. Subplots for grass, grass-like, and forb yield were rotated yearly. Iris was harvested on adjacent areas of similar infestations since experience had shown that clipping, even for 1 year, can result in near eradication.

The first 2-year results indicated some problems associated with species response and application date. Treatment with 4 lb/acre 2,4-D gave excellent iris control but severely reduced the yield of forbs, especially dandelion and yarrow. In addition, recommendations for time of treatment ranged from bud stage to post bloom. Iris phenology is easily seen. However, stages do not occur as regularly on meadows in narrow canyons or at high elevations as on wide, valley meadows where previous work had been conducted. Cold air drainage and frost may almost eliminate expression of phenology. Therefore, timing of 2,4-D application by calendar date with some phenology would be more pertinent for high elevation meadows than would a phenologic stage which may not appear in some years or may be expressed by only a few plants.

A study was designed to resolve these two problems. Plots at two locations were treated in 1968 and 1969 with 2, 3, and 4 lb/acre 2,4-D in mid-June and early July. Plot size was 12 x 12 ft with three replications. Iris control was evaluated by tiller count. Yield of iris and forage species was determined for 2 years on the check and on plots treated with 3 lb/acre applied on the early date and 4 lb/acre applied on the late date. Yield from these two treatments was representative of other treatments with excellent iris control. Forb yield was determined for 2 years on all treatments.

Water-table observation wells were dug to 20 ft, cased with perforated pipe, and back-filled with gravel.

Data were analyzed by analysis of variance; treatment means were compared by Duncan's Multiple Range Test. Probability of 0.05 was accepted as significant.

Results and Discussion

Iris Control

Excellent iris control (91 to 100%) was obtained with 2, 3, or 4 lb/acre 2,4-D applied in mid-June or early July at Long Meadow, or with 3 or 4 lb/acre at Willow Creek. Iris phenology at time of treatment ranged from late vegetative to late bloom. The 2 lb/acre treatment in early July at Willow Creek gave from 73 to 85% control. This treatment appears near the minimum concentration of 2,4-D needed for excellent iris control when applied after seed capsules start to form. Reduction in iris yield on successful treatments ranged from 398 to 1568 lb/acre and averaged 925 lb/acre.

Production of Grass and Grass-Like Species

Iris control in 1965 gave a significant yield increase of grass and grass-like species in subsequent years (Table 1). Yield increase over the check ranged from 274 lb/acre in 1966 to 1352 lb/acre in 1970 and averaged 837 lb/acre or 143%. Yield of iris on the check in these 2 years was 558 and 760 lb/acre, respectively.

Table 1. Production (lb/acre) of grass and grasslike species and precipitation (inches) for 5 years after treatment with 4 lb/acre 2,4-D at Long Meadow.

Year	Production: Treated	Production: Check	Precipitation
1966	486a[1]	212b	15.6
1967	1782a	829b	20.4
1968	776a	288b	18.7
1969	1815a	696b	25.8
1970	2296a	944b	19.9

[1] Treatment means within year followed by different letters are significantly different at the 0.05 level as determined by Duncan's Multiple Range Test.

Yields in 1966 and 1968 were similar and were significantly less than in 1967, 1969, and 1970. Productivity was greatest in 1970. Low yields in 1966 and 1968 were attributed to adverse environmental conditions. Precipitation during the first 6 months of 1966 was only 40% of normal at the two closest stations. Other stations in the northern part of the state reported from 8 to 13% of normal through April. Precipitation was near normal in 1968; however, a killing frost occurred on June 29 and 30. Minimum temperatures at nearby stations were between 25 and 30°F. With near-normal conditions, we would expect a greater yield the year after treatment than that obtained in 1966. Results in 1969 and 1970 at two locations support this speculation. Average yield increase the first and second years after treatment at Long Meadow was 1442 lb/acre (340%) and 1433 lb/acre (153%), respectively. First-year increases on two other studies were 2364 lb/acre (360%) and 1135 lb/acre (111%). At Willow Creek the average yield increase the first and second years after treatment was 728 lb/acre (92%) and 652 lb/acre (106%), respectively.

The more productive species, slender wheatgrass (*Agropyron trachycaulum*) and Nevada bluegrass (*Poa nevadensis*), dominated the higher condition sites. Density of these species was greater at Long Meadow than at Willow Creek. Meadow barley (*Hordeum brachyantherum*), bluegrasses (*Poa* spp.), mat muhly (*Muhlenbergia richardsonis*), sedges (*Carex* spp.), and dense iris dominated the lower condition sites. At Long Meadow, Nevada bluegrass and meadow barley predominated near the stream channel. Slender wheatgrass predominated on sites away from the channel and at higher elevations in the meadow. The presence of squirreltail (*Sitanion hystrix*), Junegrass (*Koeleria cristata*), and Columbia needlegrass (*Stipa columbiana*) suggests that these sites are more zeric than sites adjacent to the stream. The differences in range condition and species composition explain the variations in total and species yield between and within location.

Iris control on sites dominated by Nevada bluegrass resulted in a yield response by this species the first year after treatment (558 lb/acre) compared to the check (106 lb/acre). During the following 4 years, yield varied between 160 and 502 lb/acre on the check and between 520 and 1100 lb/acre on treated plots. Slender wheatgrass responded slowly. Average yield the first 3 years after treatment was 16 lb/acre. In 1969 and 1970 (Table 2) production had increased to 280 and 800 lb/acre, respectively. On sites away from the creek, slender wheatgrass responded the first year after treatment. Pretreatment yield in

Table 2. Production (lb/acre) of grass, grasslike, and forb species on treated and check plots in 1970 at Long Meadow. Treatment (4 lb/acre 2,4-D) was made in 1965.

Species	Production	
	Treated	Check
Slender wheatgrass	800a[1]	472b
Nevada bluegrass	960a	448b
Meadow barley	352a	16b
Other grasses	160a	0a
Sedge	24a	8a
Iris	152a	760b
Common dandelion	32a	40a
Western yarrow	128a	144a
Other forbs	128a	24a
Total herbage	2736a	1912b
Grass and grasslike	2296a	944b
Total forbs	440a	968b
Sage grouse food plants	160a	184a

[1]Treatment means followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's Multiple Range Test.

two studies averaged 88 lb/acre. After 1 and 2 years, respectively, yield was 1450 and 1300 lb/acre. Yield of Nevada bluegrass was 372 lb/acre before treatment and 650 and 600 lb/acre 1 and 2 years after treatment. Species response at Willow Creek was similar although yield was about one-third to one-half that at Long Meadow.

A significant yield response was found in 10 to 11 measurements of treatment effects. No response in 1969 was attributed to a persistent watertable at 4.5 ft. In comparison, watertable depths from 1965 to 1971 ranged from 8 to 13 ft. A capillary fringe within the root zone of perennials would result from a shallow water table. Very high precipitation (33.2 inches) in 1968-69 contributed to the high water table by moisture percolating through the soil and by underground flow from the surrounding watershed. No yield response under conditions of high precipitation and high watertable suggests that the main effect of iris control is soil moisture conservation. A comparison of 1969 and 1970 yields revealed that lack of response in 1969 was due to increased check yield not to reduced treatment yield.

Production of Forbs

Oakleaf (1971) calculated that the sage grouse population of eight birds/acre at Long Meadow would consume about 10 lb/acre of forbs during meadow occupancy. On this basis, total forb production the year after treatment (Table 3) was deficient or minimal except on plots treated with 2 or 3 lb/acre in early July. Forb production the second year appeared adequate, except perhaps on plots treated with 4 lb/acre in early July. Yield of sage grouse food plants 3, 4, and 5 years after treatment was 96, 200, and 160 lb/acre, respectively with 20, 24, and 32 lb/acre of dandelion. Two factors, other than total forb yield, need consideration. Dandelion is a preferred species (82% of meadow forbs consumed) compared to yarrow (7%) (Savage, 1968). A forb component of least preferred species will not satisfy sage grouse needs. The year after treatment, dandelion production (Table 3) was generally deficient. Therefore, even though total forb yield approached 10 lb/acre, forb composition would not be considered adequate for good sage grouse habitat. Data on total forb yield and species yield can also be misleading because sage grouse do not consume the entire plant but remove the more succulent portions. We do not know the total production necessary to supply the required intake of succulent parts.

Conclusions and Management

Iris-infested mountain meadows can be improved for livestock and wildlife. Excellent iris control was obtained with 2,4-D at 2 lb/acre applied from mid-June to early July when iris was in the late vegetative to late bloom stage. Treatment after seed capsules start to form will require more herbicide for similar control, or acceptance of less uniform or reduced control.

With near-normal environmental conditions, a large yield response by grass and grass-like species can be expected the first and succeeding years after treatment. The total and species response depend on meadow condition and species composition at time of treatment.

Yield of important sage grouse food plants, dandelion and yarrow, was severely reduced the first year after treatment, and production of the preferred species, dandelion, was not adequate for the existing sage grouse populations. Total forb production and the dandelion component appeared adequate for sage grouse the second and subsequent years after treatment.

Variability in range condition, species composition, and water table results in degrees of iris infestation. In dense iris, forbs are almost eliminated, and suppressed perennial grasses are found only in iris clumps. These dense stands might reasonably be treated first to increase grass and forb production. On most meadows, spot treatment can be done with a backpack sprayer. With such equipment the applicator has more control over nontarget areas such as good forb stands and streams. Untreated areas will supply some forbs for sage grouse while production on treated area is reduced for 1 year. In an intensive improvement program, different portions of the meadow can be treated periodically until iris is no longer a problem.

Vegetation management after iris control is important. Perennial grass in iris clumps is in low vigor. Therefore, the large response in vigor and seed production will occur the year after treatment. Livestock use should be deferred until after seed-ripe to disperse and plant grass and forb seed. This should be followed by deferment necessary for seedling establishment before normal use.

Eckert et al. (1973), suggested that large seeded meadows be fenced and managed for livestock and wildlife and that

Table 3. Forb production (lb/acre) the year of treatment (1969) and for 2 years after treatment at Long Meadow.

Plot and date	Common dandelion			Western yarrow		
	1969	1970	1971	1969	1970	1971
Check	160	272a[1]	60a	248	264a	156a
2 A[2]		5b	41ab		5c	52ab
2 B[3]		16b	35ab		136b	62ab
3 A		1b	25ab		2c	18b
3 B		6b	20ab		21c	11b
4 A		5b	22ab		5c	5b
4 B		2b	10b		2c	3b

[1]Treatment means within year followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's Multiple Range Test.

[2]*A* date, 6/17—Dandelion phenology: second or third bloom, achenes from earlier flowers mostly dehised. Yarrow phenology: leaf to early flower bud.

[3]*B* date, 7/8—Dandelion phenology: post bloom, seed mostly dehised. Yarrow phenology: late bud to early flower.

small meadows be managed exclusively for wildlife with livestock use designed to maintain quality wildlife habitat. Meadows improved by iris control, and possibly all meadows, should be managed for the same objectives. However, the kind of management needed to benefit livestock, wildlife, and the site is unknown.

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Factors Causing Losses during the Establishment of Surface-sown Pastures

M. H. CAMPBELL AND F. G. SWAIN

Highlight: *Seeds of four pasture species were surface-sown in winter, spring, and summer and losses of seeds, seedlings, and plants during germination, radicle-entry, establishment, and survival noted under various treatments. On an unprotected soil surface losses during germination, radicle-entry and establishment were least in winter and greatest in summer. Dead plant cover on the surface reduced losses during germination and radicle-entry in the summer, while sub-irrigation reduced losses during germination in summer and radicle-entry and establishment in spring and summer. Losses during survival were heavy in all seasons, usually because of moisture stress. Other reasons for losses included harvesting of seeds by ants, damage by soil fauna, residual herbicides, and competition from weeds.*

There are large areas of nonarable hill country on the Tablelands of New South Wales that support low producing native pastures. To increase productivity on these areas it would be necessary to establish improved perennial pastures by aerial methods. However, establishment of perennial pasture species from surface-sowing has been disappointing (Campbell, 1968; Nelson et al., 1970; Dowling et al., 1971). Attention has been drawn to the dearth of information explaining the reasons for such disappointing results (Cullen, 1965; McWilliam et al., 1970; Wilson et al., 1970).

Thus the aim of work reported here was to trace the fate of individual seeds from sowing onwards to determine the reasons for losses and successes. This would allow selection of treatments to assist establishment and indicate problems needing further research. This paper reports the results of three experiments in which the fate of individual seeds was traced after surface-sowing in three seasons. An attempt has been made to interrelate the experiments by having a similar "control" in each.

At the time of the research, authors were research officer, Department of Agriculture, Orange, N.S.W., and associate professor of agronomy, University of New England, Armidale, N.S.W., Australia. Swain's present address is Principal Hawkesbury Agricultural College, Richmond, N.S.W.

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Materials and Methods

The experiments were conducted on adjacent areas in the field at Armidale N.S.W., Australia. The soil was a yellow podzolic with a structureless surface. The site sloped to the west and was dominated by native perennial grasses. Armidale (altitude 1030 m) has a temperate climate with an average annual rainfall of 78 cm and mean maximum and minimum annual temperatures of 20°C and 7.2°C, respectively.

The species sown were Hunter River lucerne (*Medicago sativa* L.), Woogenellup subterranean clover (*Trifolium subterraneum* L.), Ruanui perennial ryegrass (*Lolium perenne* L.), and Australian phalaris (*Phalaris tuberosa* L.). Seeds were individually dropped onto the soil surface in quadrat areas of 50 x 5 cm and their position marked with a pin. Legume seed was inoculated and lime pelleted. At sowing some seeds were placed on a supernumerary quadrat to provide similarly "weathered" replacements for those taken by ants, while others were placed in petri dishes in a louvred box sited on the ground to provide comparisons between germination under nonlimiting moisture and under field conditions.

Winter Experiment

Seeds were sown in mid-winter onto a "control" soil surface on which was 1900 kg/ha of dead native pasture. Ten seeds of each species were sown in five random quadrats in each of four blocks. At sowing the percentage ground cover of dead plant tissue and bare ground was 38% and 20%, respectively. The area had been grazed until mid-autumn, when it was treated with a mixture of short-term residual herbicides.

Spring Experiment

Seeds were sown in mid-spring onto a soil surface similar to that in the winter experiment. The quadrats were treated with a mixture of paraquat and diquat five hours before sowing. In each of two blocks, 10 random quadrats were located; five were subirrigated and five were not (controls). Ten seeds of lucerne, subterranean clover, and ryegrass and 14 of phalaris were sown per quadrat. Subirrigation, which began on October 31 and ended in mid-December, was accomplished by filling a shallow trench 2 cm above each quadrat with water three times a day.

Summer Experiment

Seeds were sown in mid-summer onto four treatments: 1) *control*—light cover and no irrigation, 2) *irrigation*—light cover with irrigation, 3) cover—heavy cover and no irrigation, and 4) cover plus irrigation—heavy cover with irrigation. The light and heavy cover treatments had 1130 and 4570 kg dry matter/ha, respectively.

A split plot design with two replications was used, with cover as the main plots and irrigation as the subplots. Each subplot contained five quadrats with ten seeds of each species. All quadrats were treated with paraquat and diquat 4 days before sowing. Subirrigation began on February 8, and ended in May, 1970.

Table 1. Percentage germination of seeds on the soil surface and in petri dishes in the field, meaned for all species.

Season and treatment	Mean germination
Winter	
Control	64***[1]
Petri dishes	75
Spring	
Control	66***
Irrigation	71 ns
Petri dish	74
Summer	
Control	51***
Irrigation	75 ns
Cover	74 ns
Cover plus irrigation	76 ns
Petri dishes	75

[1] Level of significance for contingency table comparisons between germination on the soil surface and petri dishes within each season: ***$P<0.001$; ns, not significant.

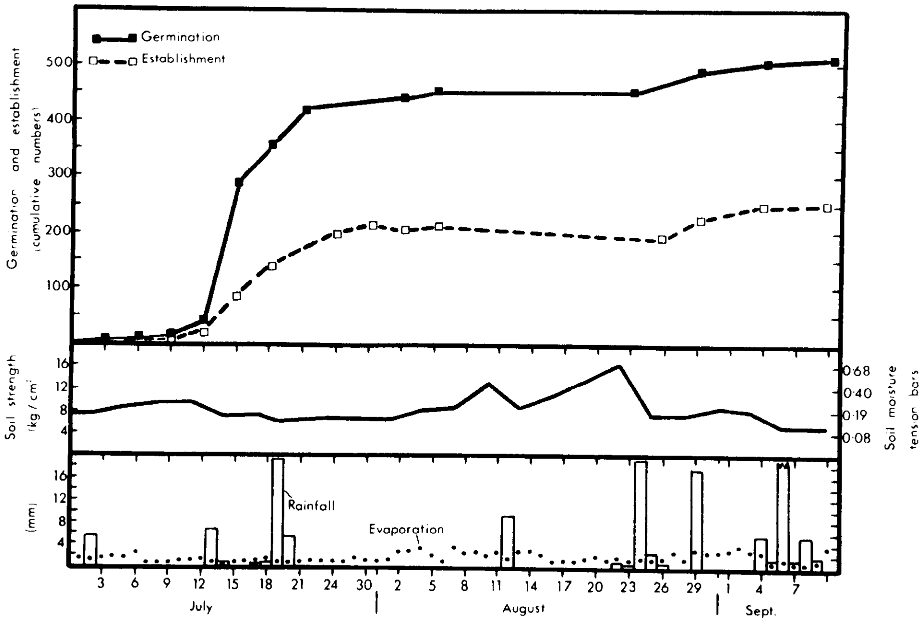

Fig. 1. *Cumulative germination and establishment (total of the four species) in winter, 1969; 800 seeds were sown.*

Measurements

In each experiment, observations were made at 3-day intervals for the first 2 or 3 months and thereafter at monthly intervals. Observations were made on germination (protrusion of the radicle through the seed coat); radicle-entry (entry of the radicle into the soil); establishment (development of the seedling for up to 3 months after sowing); and survival (development of the young plant for up to 16 months after sowing). The strength and moisture tension of the soil surface was recorded as well as environment data. A regression relationship between soil strength and soil moisture tension was established (r^2=94) which allowed expression of both parameters by a common line (Figs. 1,2,3).

Results and Discussion

Seeds Taken by Ants

In the 33, 24, and 18 days after sowing in winter, spring, and summer, ants took respectively 29, 42, and 33% of the seeds sown. Harvesting ceased in each season when seeds germinated. The ants took seed of subterranean clover, lucerne, ryegrass, and phalaris in the ratio of 10:46:52:96. It appeared ants preferred the lighter seeds. The species of ant which took most seed was *Pheidole deserticola* Forel.

Campbell (1966) demonstrated that ants can reduce the establishment of surface-sown species especially if dry conditions follow sowing. Seed-harvesting ants are widespread in Australia and other countries; thus, insecticide (Campbell, 1966) or lime-pelleting (Russell et al., 1967) treatments will be necessary to reduce losses. It is unlikely that lime pelleting will be useful in all situations as Campbell (1966) showed ants will take lime pelleted seeds in New South Wales.

Losses During Germination

In each season percentage germination was lower on the control treatments than in the field petri dishes (Table 1). Insufficient moisture was assessed as the main cause of the depressed germination on the controls because germination was higher on treatments that supplied moisture (irrigation), or protected seeds from moisture loss (cover) or did both (cover plus irrigation). In each season germination proceeded in response to a number of intermittent falls of rain (Figs. 1 and 2). Harper and Benton (1966) found that germination of surface-sown seed depended on the moisture relations between seed, soil, and atmosphere. In the results reported here, germination on an unprotected soil surface was higher in winter than in summer due to lower moisture loss from seed and soil in winter. To allow reasonable germination in summer, it appeared that cover was necessary to reduce moisture loss from seed and soil.

Failure of seeds to germinate on the soil surface was also caused by poor

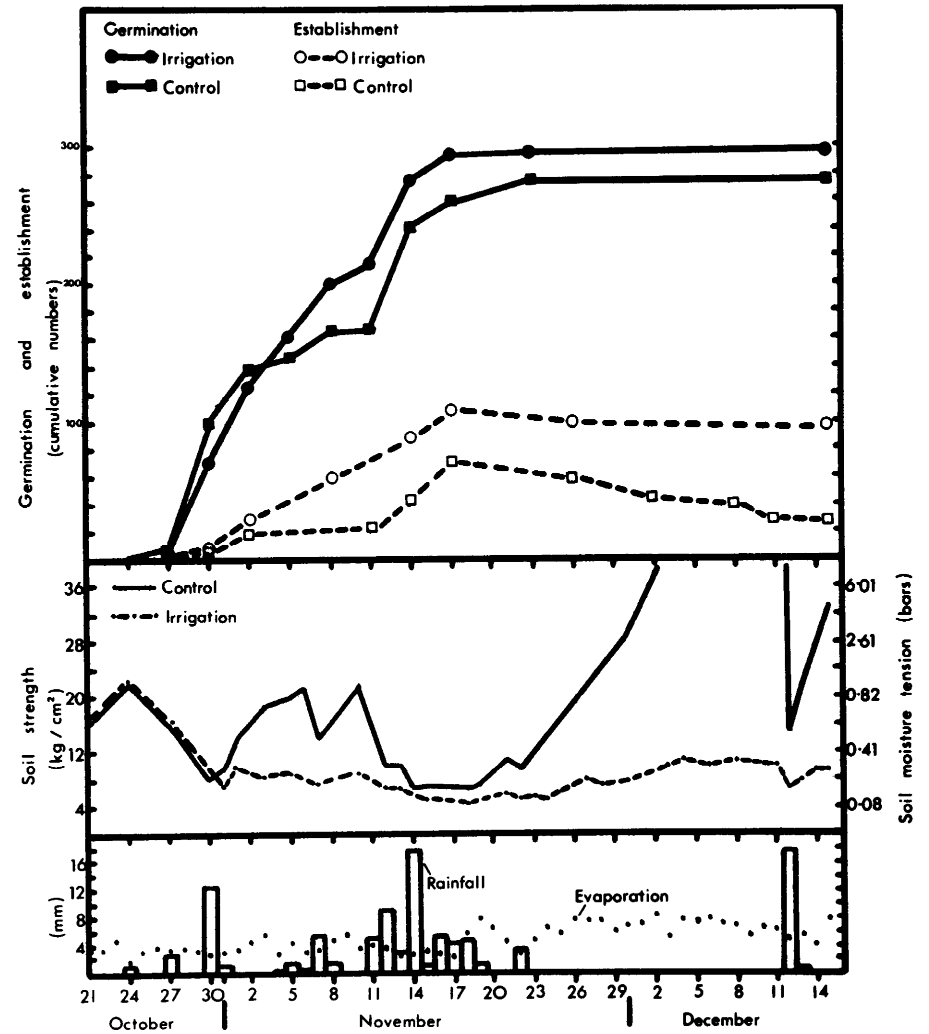

Fig. 2. *Cumulative germination and establishment (total of the four species) on irrigated and control treatments in spring, 1969; 440 seeds were sown on each treatment.*

seed/soil contact, insect damage, radicle "caught" in seed coat, and fungus infection. Losses attributed to these reasons on the control treatments were, 2% in spring, 3% in summer, and 5% in winter.

The effect of temperature on germination appeared minor, because germination in the petri dishes in the field was relatively constant for the three seasons. Moisture tension in the petri dishes would have been similar in each season; thus any difference in germination must have been due to differences in temperature. However, minimum temperatures, lower than those recorded in winter 1969 (mean minimum 0.6°C) can reduce germination (Young et al., 1970) and would have to be considered in environments colder than Armidale.

Seeds which remained ungerminated on the control treatment 3 months after sowing in summer had a mean laboratory germination of 15%, which indicated that "weathering" greatly reduced viability (Wilson et al., 1970).

Losses During Radicle-Entry

Table 2 shows that percentage radicle-entry was higher on the winter control than on the spring or summer control, due most likely to low strength and moisture tension of the soil surface in winter (Fig. 1). Most deaths on these controls occurred because radicles either could not exert sufficient force to deform the soil surface and enter or could not find a suitably sized pore to allow entry and were subsequently desiccated (Table 3). Campbell and Swain (1973) showed that radicle-entry was markedly reduced by small increases in soil strength. In winter, strength of the soil surface during radicle-entry (6.1 to 7.6 kg/cm²) was close to the minimum measured for this soil, which helps explain the high percentage radicle-entry achieved.

Subirrigation assisted radicle-entry in spring and summer (Table 2) by maintaining a softer and moister soil surface than in the respective control treatments (Figs. 2 and 3). However, losses on the irrigation treatments due to desiccation (Table 3) indicated that a soft, moist soil surface is not sufficient to allow maximum radicle-entry under moderate evaporation.

Under relatively high evaporation in summer, the cover treatment proved more effective than irrigation in assisting radicle-entry (Table 2), despite slightly less favourable soil surface conditions on the former (Fig. 3). This result can be attributed to the protective effect of cover. When cover and irrigation were combined, percentage radicle-entry was higher than on the other three treatments due to favourable surface conditions and protection from desiccation.

Evans and Young (1970) showed that cover increased the relative humidity at the soil surface and decreased the rate at which it dried out. This reduces the danger of desiccation and allows a greater period for radicle-entry. In a controlled environment, McWilliam et al. (1968) showed that radicles of five pasture species could not survive 5 hours of dry conditions. In our study it took 2 days for 50% of the grass radicles and 5 days for 50% of the legume radicles to enter the soil. Cover would also increase surface heterogeneity, reduce temperature extremes (Evans and Young, 1970), frost lift, and the rate at which the soil surface increases in strength in dry periods after rain—all factors which assist radicle-entry (Campbell and Swain, 1973).

Factors other than desiccation (obstructions, disturbance, insect damage, malformed radicles) reduced percentage radicle-entry by from 4% to 11% (Table 3).

The higher percentage radicle-entry of

Table 2. Effect of season of sowing, irrigation, and cover on percentage radicle-entry[1] meaned for all species.[2]

Season and treatment	Mean radicle-entry
Winter	
Control	66
Spring	
Control	38 b
Irrigation	49 a
Summer	
Control	7 d
Irrigation	50 c
Cover	77 b
Cover plus irrigation	90 a

[1] Expressed as a percentage of seeds that germinated.
[2] Means followed by the same letter in the spring or in the summer experiment are not significantly different at the 5% level of probability as determined by Duncan's Range Test.

Table 3. Radicle deaths, meaned for all species, expressed as a percentage of seeds that germinated.

Season and treatment	Cause of death	
	Desiccation	Other reasons
Winter		
Control	24	10
Spring		
Control	54	8
Irrigation	40	11
Summer		
Control	86	7
Irrigation	45	5
Cover	19	4
Cover plus irrigation	6	4

the grasses than of the legumes (Table 4) agrees with findings obtained in a controlled environment (Campbell and Swain, 1973). Because legume radicles have greater difficulty entering the soil, they are slower to enter and thus more subject to losses due to desiccation and soil fauna.

Losses During Establishment

Heavy losses of seedlings during establishment (2.5, 2, and 3 months after sowing in winter, spring, and summer, respectively) on all nonirrigated treatments, except the winter control (Table 5), indicated that moisture stress was the main cause of seedling deaths. The lower death rate in the winter control was due to relatively low evaporation. Death of seedlings attributed to moisture stress on the irrigated treatments was due to desiccation of an exposed part of the radicle, even though the radicle tip had entered the soil.

Losses due to soil fauna (Table 5) were mainly caused by slugs (*Milax gagates* Draparnaud) in the cover treatments in summer and slugs and insect larva in winter; legumes were eaten in preference to grasses. Losses due to residual paraquat and diquat occurred in the cover treatments mainly among grasses. Although losses of seedlings due to soil fauna and residual herbicides were small by comparison with losses due to moisture stress, they can be important in other situations (Suckling, 1951). The effect of residual paraquat in cover can be overcome by allowing an interval of 1 to 2 weeks between spraying and sowing (Warboys and Ledson, 1965). To control slugs, Sucking (1951) recommended grazing prior to sowing; but this would negate the advantages of cover. An alternative is the aerial application of a mulluscicide.

Table 4. Percentage radicle-entry[1] in each season meaned for treatments.[2]

Species	Winter	Spring	Summer
Ryegrass	95 a	63 a	67 a
Phalaris	83 a	77 a	55 b
Lucerne	49 b	15 b	52 b
Subterranean clover	38 b	19 b	51 b

[1] Expressed as a percentage of seeds that germinated.
[2] Means followed by the same letter in each season are not significantly different at the 5% level of probability as determined by Duncan's Range Test.

Losses During Survival

In the winter-sown experiment, losses during the survival period (spring 1969 to spring 1970) comprised 98% of the perennial plants present at establishment. Most (81%) of these deaths occurred in late spring and early summer, 1969, due to competition from volunteer annuals, which grew 15 cm high and reduced light intensity by 80 to 98%. Subterranean clover escaped most of this competition by senescing in summer, 1969.

Grazing has been used in New Zealand before, during, and/or after sowing to control competition and assist pasture species to establish and survive (Suckling, 1959; Cullen, 1970). Although grazing causes loss of some established plants, losses incurred by not grazing could be greater.

Table 5. Deaths of seedlings between radicle-entry and establishment, expressed as a percentage of radicles which gained entry and meaned for all species.

Season and treatment	Cause of death		
	Moisture stress	Soil fauna	Residual herbicide
Winter			
Control	10	11	0
Spring			
Control	57	1	2
Irrigation	18	4	5
Summer			
Control	97	0	0
Irrigation	17	0	2
Cover	62	6	11
Cover plus irrigation	9	9	12

In the spring-sown experiment, 70% of the perennial plants present at establishment died during the survival period (summer, 1969, to spring, 1970) due mainly to periods of moisture stress in autumn and winter, 1970. Although irrigation was continued until establishment there was little difference in percentage survival between irrigated and non-irrigated treatments (Table 6).

In the summer-sown experiment, 52% of plants present at establishment died during the survival period (autumn to

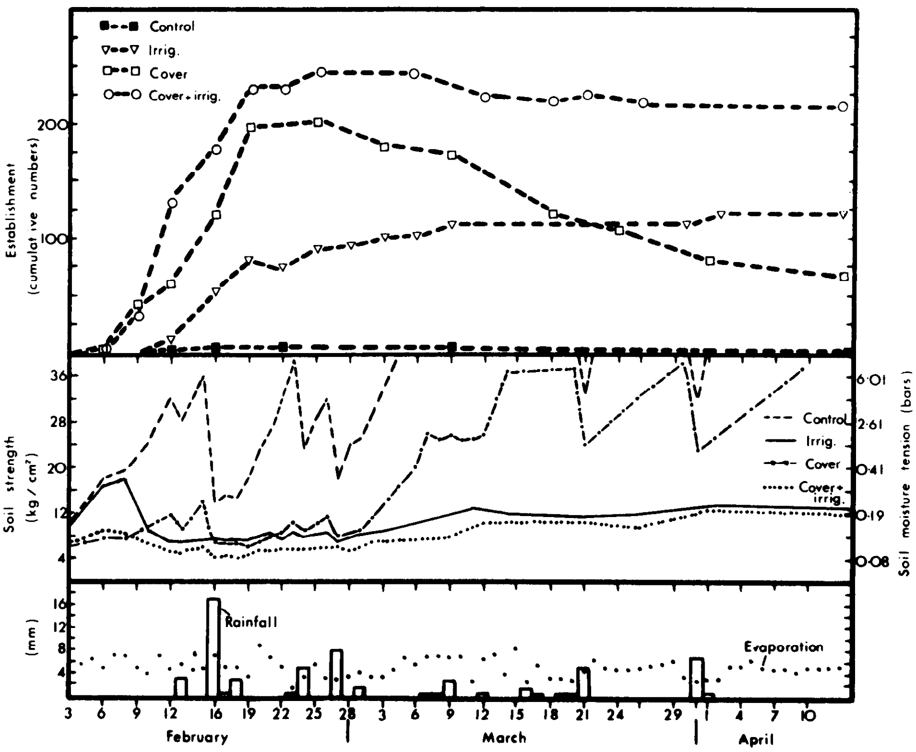

Fig. 3. *Cumulative establishment (total of the four species) on control, irrigation, cover, and cover plus irrigation treatments in summer and autumn, 1970; 400 seeds were sown on each treatment.*

Table 6. Effect of season of sowing, irrigation, and cover on survival, expressed as a percentage of the seeds that germinated on the soil surface.

Season and treatment	Species			
	Ryegrass	Phalaris	Lucerne	Subterranean clover
Winter				
Control	3.3	0	0.6	19.2[1]
Spring				
Control	3.5	5.0	3.3	–
Irrigation	5.4	8.7	6.1	–
Summer				
Control	0	0	1	0
Irrigation	40	18	14	20
Cover	3	3	9	11
Cover plus irrigation	28	51	29	34

[1] Regeneration of subterranean clover.

spring, 1970) mainly because of abnormal moisture stress in winter. The effects of irrigation and cover treatments were still evident at survival (Table 6).

Heavy losses of plants due to moisture stress after radicle-entry could be reduced by larger amounts of cover than were used in the summer experiment, but there appears to be an upper limit determined by the availability of light. Another possibility of overcoming losses in these dry periods could depend on the rapid development of young plants. Plummer (1943) showed that faster, deeper root growth through the soil assisted range seedlings to survive dry periods, while Hoen (1966) found that summer survival of larger phalaris plants was superior to that of smaller plants.

Conclusion

The results of this study provide detailed information on the dynamics of establishment of surface-sown seed. Major losses during establishment were due to ant theft of seed; poor germination; desiccation of the radicle tip; competition from weeds; and moisture stress. Dead plant cover on the soil surface, winter sowing, and other suggested treatments could reduce losses. However, no treatment could be confidently suggested to reduce losses of young plants during periods of severe moisture stress.

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Foliar-applied Urea and Ammonium Nitrate Fertilizers on Shortgrass Range

W. R. HOUSTON AND D. H. VAN DER SLUIJS

Highlight: *Liquid foliar applications of urea-N fertilizer were compared with dry and foliar applications of ammonium nitrate-N fertilizer for 3 years, 1969-71. The fertilizers were applied in December, May, June, and July each year on separate plots. Treatments were repeated each year on the same plots. The source of N was far more important than method of application. Whether applied in dry form or as foliar application, the ammonium nitrate-N was superior to urea-N for increasing herbage yields, crude-protein content, and protein yields when applied in December, June, or July. When applied in May, both sources of N were equally effective, regardless of method of application. Ammonium nitrate-N in water solution may be applied as late in the growing season as early July with favorable results. The ammonium nitrate-N applied in July increased nitrate-N in herbage in the third year, although not to toxic levels.*

Previous research in the Great Plains has shown that both yield and protein content of range herbage can be increased by the use of nitrogen (N) fertilizers (Klipple and Retzer, 1959; Rogler and Lorenz, 1957). Although both low soil moisture and N availability restrict herbage production, the N supply is the most readily increased.

Increased crude-protein content of herbage can be important for livestock production. Crude-protein levels in range forage are often low—even below required nutrient levels—for 6 to 8 months of the year. Crude-protein content is also generally associated with the important forage characteristics of palatability and digestibility (Whyte et al., 1962).

The form in which N is applied (dry, granular, or liquid) may influence the response of forage yields and crude-protein content as well as the source of N (urea-N or ammonium nitrate-N).

Over the past two decades the use of liquid N fertilizers has increased substantially. The primary use has been on horticultural and row crops and less commonly on forages. Many liquid fertilizers have a higher N content, cost less per pound of N, and are more easily handled than fertilizers in the dry form. On the other hand, liquid N fertilizers are corrosive, require special application equipment and storage containers, and are more dangerous to handle (Adams and Anderson, 1965).

The most common sources of nitrogen in liquid fertilizers are anhydrous ammonia, ammonium nitrate, and urea in various proportions. Anhydrous ammonia or water solutions of ammonia require pressure containers and injection into the soil to avoid gaseous losses. Pressure injection systems are not practical on most rangelands. Solutions containing ammonium nitrate and urea are non-pressure solutions and may be applied directly to the soil surface or to foliage.

Volk (1959) showed that 55 to 60% of the N from urea applied on the soil surface was lost as gas within 7 days, but only 20% was lost when the urea was applied to sod. Both Simpson (1968) and Simpson and Melsted (1962) found high gaseous losses of N from application of urea solutions to grasslands. However, Kresge and Satchell (1960) found little gaseous loss of nitrogen from low rates of dry urea applied on the surface of either bare acidic soil or sod on acidic soil, although substantial losses of gaseous nitrogen were found from high rates of urea applied in a water solution. Plant damage from the toxic ammonia and nitrite products of urea-N and losses in crop production have been shown by Court et al. (1964).

Foliar application of liquid fertilizers (or foliar feeding) is not a new technique. Boynton (1954) reviewed the history of the practice and showed distinct increases in total leaf N as well as leaf chlorophyll in apple orchards from application of a water solution of urea. Urea is probably the most widely used nutrient spray in crop production. It is taken up rapidly by most plants and is highly mobile in the plant. The absorption of urea, as with most nutrient sprays, is most rapid in the presence of leaf surface moisture (Volk and McAuliffe, 1954). Surfactants have been found to increase speed of entry of foliar applied nutrients (Dybing and Currier, 1961).

The objectives of this experiment were to compare the effects of urea and ammonium nitrate fertilizers as sources of N for increasing range herbage productivity, protein content, and protein yield and to compare foliar applications for urea-N with dry and foliar applications of ammonium nitrate-N.

Area and Methods

The study was conducted in north-central Colorado on shortgrass range. The soil is Ascalon sandy loam, with a pH of 6.0 to 6.7 in the surface 2.5 inches. The native vegetation is

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The authors are range scientist, Agricultural Research Service, U.S. Department of Agriculture, and graduate research assistant, Colorado State University, Fort Collins, Colorado. Dr. van der Sluijs' present address is International Bank for Reconstruction and Development, 1818 H Street N.W., Washington, D.C.

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typical of the shortgrass plains.

The dominant species is blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.). Other abundant species are sun sedge (*Carex heliophylia* Mack.), plains pricklypear (*Opuntia polyacantha* Haw.), scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.), and wooly indian-wheat (*Plantago purshii* Roem. and Schult.). Sixweeks fescue (*Vulpia octoflora* (Walt.) Rydb.) varies widely in abundance, depending on weather.

The treatments applied were 0, 20, and 40 lb of urea-N per acre and 40 lb of ammonium nitrate-N per acre. Treatments were applied in December of 1968, 1969, and 1970, and in mid-May, mid-June, and early July of 1969, 1970, and 1971. Each date of application was placed in a separate block, with three replications. Plot size was 15 by 50 ft. Treatments were repeated on the same plots each year. At each date of application, the urea-N was applied in a water solution to which 0.1 percent X-77 surfactant (v/v) was added. Rate of liquid application was 20 gal per acre. The ammonium nitrate-N was broadcast in dry form in December and in May each year. For the June and July applications, the ammonium nitrate was dissolved in water with surfactant added. A compressed-air plot sprayer was used for applying the aqueous solutions.

Total herbage was harvested from 4.8-ft^2 subplots. Plots treated in December and May were harvested in June, July, August, and September each year. Plots treated in June and July were harvested in July, August, and September. The herbage samples were oven-dried at 70°C. Samples were weighed and ground in a Wiley mill to pass through a 1 mm screen. Nitrogen content was determined by standard Kjeldahl method. Herbage samples from all harvest dates in 1969 and 1970 from the December application were analyzed for nitrate-N by the xylenol method described by Sabatka et al. (1972). In 1971, herbage samples from the first harvests of all dates of application were analyzed for nitrate-N by the method described by Johnson and Ulrich (1959). Species frequency was determined in late June each year (Hyder et al., 1965).

Statistical treatment was by conventional analysis of variance. Duncan's multiple range test (1955) was used to compare means.

Weather

During the crop-year of 1969, total precipitation was 18% above average. Precipitation was 80% above average in June (Table 1). Precipitation was well below average during the crop-year of 1970 and slightly below average during 1971. In both years moisture was below average during the growing season of May through August. A series of storms during late April-early May of 1971 occurred before blue grama had begun growth.

Results

Herbage Yields

Foliar applications of both rates of urea-N significantly ($P<0.05$) increased average yields over the 3-year period of study, whether applied in December, in May, or in June (Table 2). When urea-N was applied in July, neither rate increased average herbage yields. When applied in May, 40 lb urea-N per acre produced essentially the same average yields as did 40 lb of dry ammonium nitrate-N per acre.

The dry form of 40 lb of ammonium nitrate-N applied in December and the foliar applications in both June and July produced greater herbage yields than foliar applications of the same rate of urea-N applied at the same times. When applied in December or in June, both rates of urea-N increased average

Table 1. Monthly precipitation (inches) for the crop years (September through August) of 1969, 1970, and 1971, crop-year totals, and 33-year mean at Central Plains Experimental Range, Nunn, Colorado.

Year	S	O	N	D	J	F	M	A	M	J	J	A	Crop-Year Total
1969	0.4	1.0	0.7	0.2	0.1	0.3	0.2	1.6	2.3	4.5	1.8	1.4	14.5
1970	1.2	2.9	0.1	T	T	T	1.4	1.4	0.8	1.1	1.6	0.2	10.7
1971	1.5	1.2	0.2	0.2	0.4	0.3	0.9	2.9	1.7	1.2	0.6	0.4	11.3
33-year mean, 1939–1971	1.1	0.8	0.2	0.2	0.3	0.2	0.6	1.1	2.1	2.5	1.8	1.4	12.3

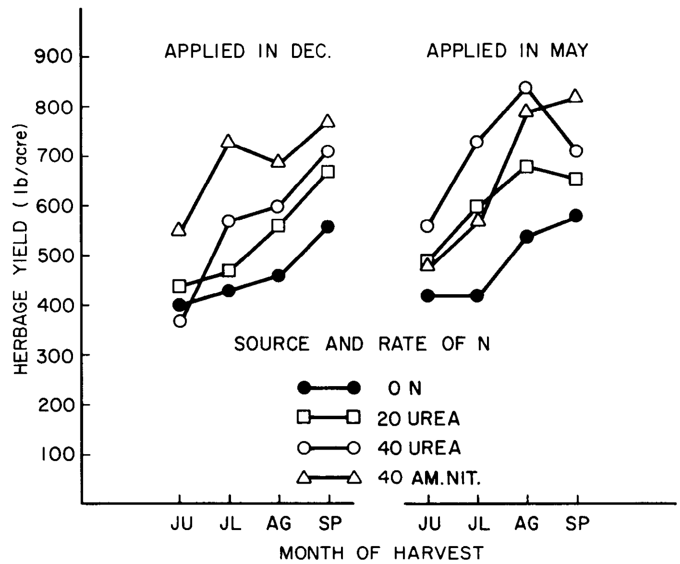

Fig. 1. *Average herbage yields (lb per acre) over 3 years (1969–71) by month of harvest at four N treatments and two dates of application.*

Table 2. Yield of total herbage (lb/acre) in 1969, 1970, and 1971 and 3-year average from 0, 20, and 40 lb per acre of N as urea (U) and 40 lb per acre of N as ammonium nitrate (AN). Treatments applied in December, May, June, and July on separate plots and repeated each year. Yields averaged over 4 monthly harvests each year for December and May applications and over 3 monthly harvests for June and July applications.

Month of application	Rate and source of N	Yields 1969	1970	1971	Avg
Dec.	0	700c[1]	360c	320c	460c
	20 U*	740c	490b	370b	530b
	40 U*	830b	490b	370b	560b
	40 AN	1030a	580a	440a	680a
May	0	700c	430c	340c	490c
	20 U*	820b	580b	420b	600b
	40 U*	1030a	600b	500a	710a
	40 AN	890b	710a	400b	670ab
June	0	1000c	520c	370b	630c
	20 U*	1200b	660b	420b	760b
	40 U*	1090bc	670b	510a	760b
	40 AN*	1370a	830a	510a	910a
July	0	1020c	620bc	430b	690b
	20 U*	990c	710ab	500a	730b
	40 U*	1170b	560c	520a	750b
	40 AN*	1430a	770a	490a	900a

[1] Column means for each month of application by year of harvest or by 3-year average, when followed by the same letter, are not significantly different at the 5% level.

*Fertilizer foliar applied in aqueous solution.

yields, but not as much as the 40 lb of ammonium nitrate-N.

The foliar application of 20 lb of urea-N per acre applied in December or June significantly increased yields in 2 out of 3 years. When applied in May it increased yields all 3 years, and when applied in July it increased yields in only 1 out of 3 years. The 40 lb of foliar-applied urea-N applied in December or May increased yields all 3 years, but when applied in June or July it increased yields in only 2 out of 3 years. In contrast, the 40 lb of ammonium nitrate-N significantly increased yields every year, regardless of date of application and whether broadcast or as a foliar spray. When applied in December, the 40 lb of urea-N had no effect on average herbage yields in the first month of harvest, but when applied in May (Fig. 1) it increased yields in the first month of harvest. In the remaining harvests, the December application of 40 lb of urea-N increased average yields more than the 20 lb of urea-N, but less than the 40 lb of ammonium nitrate-N.

Foliar application of 40 lb of urea-N in May increased average herbage yields in June and July more than any other rate or N source. When the herbage was harvested in August, yields were about the same for the two N sources. At the September harvest the 40 lb of ammonium nitrate-N increased yields most.

Percent Protein

Except for the 20-lb rate of urea-N applied in December, both rates of foliar applied urea-N and both the dry and foliar applied ammonium nitrate-N significantly increased average protein content of herbage over the 3-year period of study regardless of date of application (Table 3). The 20 lb of urea-N increased average protein content of herbage progressively more with progressively later dates of application. December application increased average protein content 10%, June application increased average protein content by only 5%, May application increased average protein content 10%, June application 14%, and the July application 22%.

Table 3. Crude protein (%) of herbage in 1969, 1970, and 1971, and 3-year average from 0, 20, and 40 lb per acre of N as urea (U) and 40 lb per acre of N as ammonium nitrate (AN). Treatments applied in December, May, June, and July on separate plots and repeated each year. Percent crude protein averaged over 4 monthly harvests each year for December and May applications and over 3 monthly harvests for June and July applications.

Month of application	Rate and source of N	Crude protein 1969	1970	1971	Avg.
Dec.	0	6.9b[1]	7.1d	7.5c	7.2c
	20 U*	7.0b	7.7c	8.0c	7.6c
	40 U*	7.5b	9.2b	9.3b	8.7b
	40 AN	8.5a	9.8a	11.1a	9.8a
May	0	6.8b	7.0c	7.6c	7.1c
	20 U*	7.2b	7.3c	8.9b	7.8b
	40 U*	8.7a	9.0b	11.2a	9.6a
	40 AN	8.5a	9.9a	11.6a	10.0a
June	0	5.9b	6.5d	7.4d	6.6c
	20 U*	6.2b	7.5c	8.9c	7.5b
	40 U*	7.3a	8.6b	10.5b	8.8a
	40 AN*	7.3a	9.1a	11.3a	9.2a
July	0	6.1c	7.9c	7.8c	7.3c
	20 U*	7.7b	9.2b	9.9b	8.9b
	40 U*	8.1a	10.4a	11.7a	10.0a
	40 AN*	8.2a	10.6a	10.4b	9.7a

[1] Column means for each month of application by year of harvest or by 3-year average, when followed by the same letter, are not significantly different at the 5% level.

*Fertilizer foliar applied in aqueous solution.

Foliar application of 40 lb of urea-N resulted in the smallest increase—21%—when applied in December. Applications in May, June, and July increased average protein content by about 35%.

The 40 lb of ammonium nitrate-N was most effective in increasing average protein content when applied in May in dry form (41% increase) or in June as foliar application (39% increase).

Application of 20 lb of urea-N in December or in May significantly increased protein content of herbage in only 1 out of 3 years. Significant increases were obtained in 2 out of 3 years when application occurred in June, and in all 3 years when it took place in July. The 40 lb of urea-N increased protein content each year for all dates of application, except in the first year after December application. The 40 lb of ammonium nitrate-N consistently increased protein content each year for all dates of application.

Foliar application of 20 lb of urea-N had virtually no effect on average protein content of herbage (Fig. 2). When applied in May, 20 lb of urea-N increased average protein content only 1.3 percentage points.

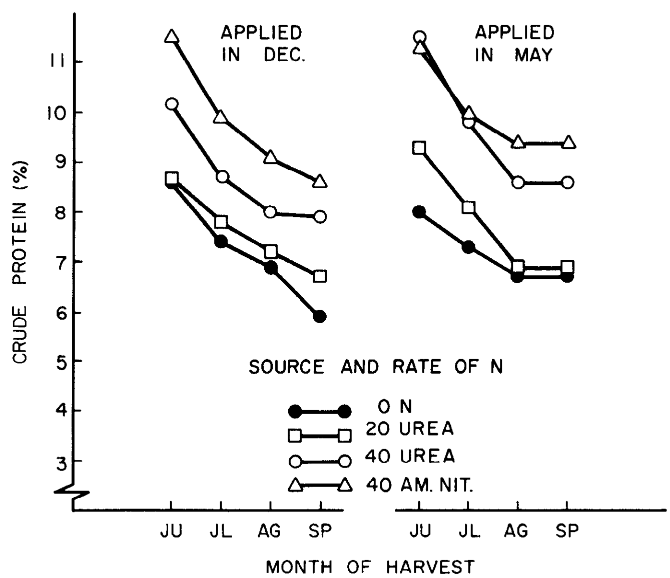

Fig. 2. *Average percent crude protein over 3 years (1969–71) by month of harvest at four N treatments and two dates of application.*

When applied in December, the dry application of 40 lb of ammonium nitrate-N increased protein content of herbage significantly more at all harvest dates than did foliar application of 40 lb of urea-N. However, when applied in May, 40 lb of ammonium nitrate-N increased protein content more than 40 lb of urea-N only during the last 2 months of harvest—August and September. When both sources of N were applied on the foliage in June or July, little effect on protein content was found for either source of N at any harvest date.

Protein Yield

All rates of urea-N and ammonium nitrate-N increased average protein yield (dry-matter yield times percent crude-protein) over the 3-year study, regardless of date or method of application (Fig. 3). The smallest average increase (22%) resulted from 20 lb of urea-N applied in December. The 40 lb of ammonium nitrate-N produced the greatest increases in protein yield of all treatments when applied in December,

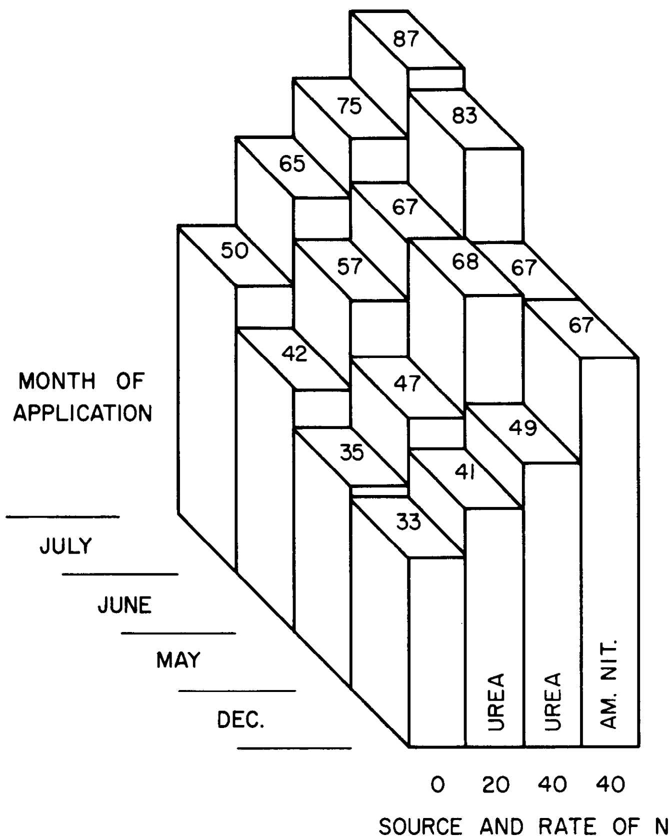

Fig. 3. *Average yield of crude protein (dry matter yield in lb per acre multiplied by percent crude protein) over 3 years (1969–71) at four N treatments and four dates of application.*

May, or June; the 40 lb of urea-N produced the greatest yield of protein of all N treatments when applied in May. Average increases in protein yield for the 40-lb rate of the two N sources ranged from 91 to 102%.

When applied in July, ammonium nitrate-N produced the greatest increase in average protein yields—74%. The 40 lb of urea-N produced a 49% average increase; 20 lb of urea-N produced an average increase of 30%.

Nitrate-N

The nitrate-N content of total herbage was not affected in 1969 or 1970 by method of application or source or rate of N from December applications (Table 4). In 1971, only the December application of N failed to increase the nitrate-N content of herbage. In 1971, all rates and sources of N increased nitrate-N levels when applied in May and harvested in June or applied in early July and harvested in late July. When applied in June and harvested in late July, only the high rates of both urea and ammonium nitrate increased nitrate-N. When applied in early July and harvested in late July, both rates of urea-N about doubled nitrate-N and 40 lb of ammonium nitrate-N increased nitrate-N ninefold.

Table 4. Nitrate-N (ppm) content of herbage in 1969, 1970, and 1971 from 0, 20, and 40 lb per acre of foliar applied N as urea (U) and 40 lb per acre of both dry and foliar applications of N as ammonium nitrate (AN). Treatments applied in December, May, June, and July on separate plots and repeated each year.

Month of application	Month of harvest	Nitrate-N			
		0	20 U	40 U	40 AN
Dec.	1969[1]	52a[2]	55a	51a	51a
Dec.	1970[1]	51a	50a	56a	62a
Dec.	June 1971	50a	60a	70a	70a
May	June 1971	40b	80a	80a	100a
June	July 1971	70b	90b	150a	180a
July	July 1971	90c	160b	200b	930a

[1] All plots were harvested in June, July, August, and September each year. Data are means over 4 months of harvest.
[2] Row means for individual months of application, when followed by the same letter, are not significantly different at the 5% level.

Species Composition

Abundance of only two species was significantly affected by the N treatments during the study (Table 5). Percentage frequency of both slimleaf goosefoot (*Chenopodium leptophyllum* Nutt.) and Russian thistle (*Salsola kali tenuifolia* Tausch) increased during the 3 years. The annual increases were greatest on the 40-lb ammonium nitrate-N treatment.

Table 5. Species composition by percent frequency of two annual forbs during 1969-70-71 from 0, 20, and 40 lb per acre of N as urea (U) and 40 lb per acre of N as ammonium nitrate (AN). N treatments repeated each year on same plots.

Species	Year	Composition			
		0	20 U	40 U	40 AN
Slimleaf goosefoot	1969	1c[1]	1c	1c	1c
	1970	2c	2c	6b	7ab
	1971	3c	7ab	7ab	10a
Russian thistle	1969	1d	1d	1d	1d
	1970	1d	1d	2cd	4bc
	1971	2cd	6ab	7a	7a

[1] Means for each species, when followed by the same letter, are not significantly different at the 5% level.

Discussion and Conclusions

Overall, the source of N was far more important for increasing herbage yields, crude-protein content of herbage, and total yield of protein than method of application. The most effective source of N was ammonium nitrate. The greatest advantage of ammonium nitrate over urea was from application in December. When applied in May, urea and ammonium nitrate-N at the 40-lb rate were about equally effective in increasing herbage yields, protein content, and protein yields. When applied in June or July, the ammonium nitrate-N was superior to urea-N for increasing both herbage and protein yields, but was not superior to urea-N for increasing crude protein content.

The reduced effectiveness of urea-N from the December application was no doubt due to gaseous losses of ammonia from urea-N after hydrolysis during the winter months. Occasional warm days that would promote hydrolysis are not infrequent during the winter. The reduced effectiveness of urea-N from application in June and July was probably related to losses of volatile ammonia-N caused by high temperatures and dry weather (Simpson, 1968).

The similarity of herbage responses from May application of the same rate of both sources of N suggested that gaseous losses from urea-N are negligible when applied at this date. For this date of application, the choice of nitrogen source for range fertilization is only a matter of economics.

The substantial increases in herbage yields, crude protein content, and protein yields from applications of N as late in the growing season as early July lengthen the period when the

N may be applied. However, the presence of adequate soil moisture or precipitation after application, which is needed for best response, is less common in July.

Although nearly all N treatments increased nitrate-N content of herbage in 1971, by far the greatest increase was from the ammonium nitrate fertilizer applied in early July and harvested in late July. However, even this large increase in 1971 did not reach the level of nitrate-N considered toxic to livestock (2,000 ppm [Bradley et al., 1940]).

The effect of nitrogen fertilizers on species composition may be both desirable and undesirable. The increased abundance of Russian thistle from N fertilization may be desirable, because Russian thistle is a fair to good forage plant. The increased abundance of slimleaf goosefoot may be undesirable. There is evidence that slimleaf goosefoot tends to concentrate nitrate-N under N fertilization (Houston et al., 1973). This could conceivably create nitrate-toxicity problems for livestock unless the species was controlled. Slimleaf goosefoot is easily controlled with atrazine herbicide (Houston and van der Sluijs, 1973).

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Growth Rate of Mixed Prairie in Response to Nitrogen and Phosphorus Fertilization

RUSSELL J. LORENZ AND GEORGE A. ROGLER

Highlight: *Earlier initiation of spring growth and increased dry matter production of mixed prairie are important to the livestock industry, particularly in the northern Plains where the winter feeding period is often prolonged. The effect of N and P levels on growth rate and production of mixed prairie was studied over an 8-year period at the Northern Great Plains Research Center near Mandan, North Dakota. Annual application of N had no effect on growth rate prior to May 1; however, during the May 1–May 15 period, and during each successive growth period, rate of growth increased as N level increased up to 160 lb elemental N/acre (160-N). By May 15, plots receiving 40-N produced more dry matter than did plots without N by June 1. As the season progressed, the production lag of the nonfertilized plots became greater. The yield level reached on June 15 by plots receiving 40-N was not attained by the 0-N plots until July 15. Yield levels reached by fertilized plots on July 1 were never attained by nonfertilized plots.*

Dry matter production can be increased by application of N or N + P fertilizer to mixed prairie in many areas of the northern plains of the United States and in the prairie provinces of Canada. The cool-season species found in the mixed prairie begin growth early in the spring, a time when low soil temperature restricts natural nitrification processes. Therefore, response to fertilizer N early in the growing season is sizeable, even on soils relatively high in total N. The significant interaction between N level and harvest date reported by Lorenz and Rogler (1973) indicates that spring growth can be stimulated by application of fertilizer N. Earlier initiation of spring growth and accelerated growth rate early in the season following application of N have been observed by others (Rogler and Lorenz, 1957 and 1965; Johnston et al., 1967).

The relative growth rate of above-ground portions of the plant, particularly early in the season, is of considerable importance to total dry matter accumulation for the season. Livestock are often allowed to graze mixed prairie early in the spring before the plants have made enough growth to provide both photosynthetic tissue for continued optimum plant growth and forage for grazing livestock. Therefore, any practice capable of increasing early spring growth rate will be important. This study was initiated at the Northern Great Plans Research Center, Mandan, N. Dak., to evaluate the influence of N and N + P fertility level on spring growth rate, and to determine the proportion of the growth above and below a 1-inch height of harvest.

Study Area and Procedure

The study area was selected for uniformity of topography, slope, and vegetative cover on a nearly level site located on the Missouri Plateau west of the Missouri River near Mandan, N. Dak. The soil series is Temvik. The vegetation is mixed prairie with western wheatgrass (*Agropyron smithii* Rydb.) and needleandthread (*Stipa comata* Trin. & Rupr.) the dominant cool-season midgrass species and blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) the dominant warm-season shortgrass. Threadleaf sedge (*Carex filifolia* Nutt.), sun sedge (*Carex heliophila* Mack.) and prairie junegrass (*Koeleria cristata* (L.) Pers.) are also important cool-season species.

The 1915–1971 average annual precipitation at the Northern Great Plains Research Center is 15.88 inches; the average annual growing season (April to August) precipitation is 11.21 inches.

The change in growth rate of mixed praire following fertilization was evaluated by comparing dry matter yields obtained by harvesting seven sets of plots, one each on each of seven consecutive dates each year for 8 years (1958-1965).

The authors are research agronomists, Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture, U.S. Northern Great Plains Research Center, Mandan, North Dakota.

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Table 1. Dry matter yield (lb/acre) of mixed prairie on successive harvest dates when cut at 1-inch height in each of 8 years, and the increase in dry matter (lb/acre) on each successive harvest date.

Harvest date	Yield[1]									Average increase/period	
	1958	1959	1960	1961	1962	1963	1964	1965	Avg	Amount	Percent
May 1	98	16	15	[2]	[2]	63	[2]	[2]	24	–	–
May 15	174	69	52	38	241	167	207	167	139	115	479
June 1	425	104	284	142	529	515	285	424	338	199	143
June 15	802	233	536	170	1379	745	348	882	637	299	88
July 1	1227	490	1213	306	2222	1566	987	1537	1194	557	87
July 15	1598	521	1856	333	3416	1391	1834	1914	1608	414	35
August 1	1496	479	1621	416	4157	1356	1838	2180	1693	85	5
LSD 0.05	103	53	140	32	224	80	108	127	70		
0.01	136	70	185	42	297	106	143	168	93		

[1] Each value is the average of six fertilizer treatments replicated three times.
[2] Not enough growth for harvest on May 1.

Harvest dates were the first and 15th of each month, beginning with May 1 and concluding with August 1. Fertilizer treatments included in each set of plots were 0, 40, 80, and 160 lb elemental N/acre (0-N, 40-N, 80-N, and 160-N) without P, and 0-N and 80-N each with 18 lb elemental P/acre (0-18 and 80-18). Fertilizer was applied on November 3, 1957, and in October each year thereafter through 1964. Ammonium nitrate was the source of N and treble superphosphate was the source of P.

The experimental design was a randomized block replicated three times. Plot size was 6 x 20 ft; a 3- x 20-ft swath was cut from each plot at a height of 1 inch. In addition to the mower harvest, three 1- x 2-ft areas were clipped at the soil surface in an unmowed area of each plot. A record of these surface-harvest areas was maintained to prevent use of the same area more than once in either the 1958-60 period or in the 1963-65 period. Harvest at the soil surface was omitted in 1961 and 1962 to allow a longer period between repeated use of the surface-harvest areas.

All dry matter produced above the 1-inch height can be assumed to be available for management in a grazing system. Total dry matter production as measured by harvest at the soil surface can be used in considering treatment effects on plant growth.

Results and Discussion

Production varied considerably from year to year, primarily in response to precipitation. Yields were extremely low in 1959 and 1961, 2 years in which precipitation was nearly 4 inches below the 1915-1971 average. Unusually high yields in 1962 and 1965 reflect timely May and June rains in 1962 and above average precipitation in 1965. Yields reported herein were obtained during an 8-year period in which precipitation ranged from 3.9 inches below to 7.5 inches above the long-time average. In 3 of the 8 years, precipitation was within ± 1 inch of the long-time average.

During the 8-year period, yields from harvest at 1-inch height were lowest in 1961 and highest in 1962, the 2 years in which harvest at the soil surface was omitted. Thus, the 6-year averages for the surface harvest data lack the effects of these 2 years. In summarizing any data in which surface and 1-inch harvest yields are compared, 1961 and 1962 have been omitted from the 1-inch harvest data.

Seasonal Growth Pattern

The yields obtained on each harvest date when cut 1 inch above the soil surface and the average increase in dry matter since the previous harvest date are shown in Table 1. The values for each of the 8 years are the average of all fertilizer treatments on each date. In 4 out of the 8 years, there was not enough growth on May 1 to permit harvest. By May 15, yields averaged 139 lb/acre, 5.8 times the May 1 yield. May 1 to May 15 was the period of greatest yield increase on a percentage basis, but the actual yield increase was only 115 lb/acre. Percentage increase in dry matter decreased for each successive growth period, but the increase in weight was larger for each successive period through the June 15-July 1 period.

Average of all fertilizer treatment yields obtained on each

Table 2. Dry matter yield (lb/acre) of mixed prairie on successive harvest dates when cut at the soil surface in each of 6 years, the average increase in dry matter (lb/acre) on each successive harvest date, and the average dry matter production (lb/acre) below 1 inch.

Harvest date	Yield[1]							Average increase/period		Production below 1 inch[3]	
	1958	1959	1960	1963	1964	1965	Avg	Amount	Percent	Amount	Percent
May 1	863	663	665	722	[2]	[2]	486	–	–	454	93
May 15	764	925	874	961	1156	1117	966	480	99	827	86
June 1	1345	957	1313	1684	1382	1400	1347	381	39	1007	75
June 15	1616	1492	1592	1933	1489	2023	1691	344	26	1100	65
July 1	2072	1855	2472	3266	2597	2927	2532	841	50	1362	54
July 15	2299	1706	3101	2866	3132	3234	2723	191	8	1204	44
August 1	2404	1503	2675	2637	3089	3440	2625	–98	–4	1130	43
LSD 0.05	187	117	179	170	184	190	103				
0.01	248	155	238	224	245	253	137				

[1] Each value is the average of six fertilizer treatments replicated three times.
[2] Not enough growth for harvest on May 1.
[3] Based on 1-inch harvest yields without the 1961 and 1962 data.

date of harvest in each of 6 years and the average increase in dry matter since the previous harvest date for the surface harvest data are shown in Table 2. In most years, highly significant yield increases occurred between each successive date of first harvest through July 15. Total yield obtained by harvest at the soil surface increased rapidly in May and June, and the maximum yield was obtained in July or August of each year, followed by a significant dry matter loss in 3 out of the 6 years. The period of most rapid growth was between June 15 and July 1 in 5 of the 6 years. The increase in dry matter for this period averaged 841 lb/acre, and ranged from 363 lb/acre in 1959 to 1333 lb/acre in 1963. During this period, climatic factors are favorable for growth of both the cool-season and warm-season species.

The increase in dry matter weight for each period up to July 1 was much larger for the yields obtained by harvest at the soil surface (Table 2) than it was for the yield above 1 inch (Table 1), but the percentage increase was always greatest for the production above 1 inch. Excluding 1961 and 1962, the average dry matter yields above 1 inch become 32, 139, 340, 591, 1170, 1519, and 1495 lb/acre for the seven harvest dates, respectively. New growth below 1 inch for each of the seven growth periods is then 373, 180, 93, 262, -158, and -74 lb/acre, respectively. As would be expected, most new growth is below 1 inch early in May. The reduction in weight of dry matter (negative values for new growth) below 1 inch after July 1 can be attributed to dropping of the lower leaves and to physiological factors not measured in this study.

Fertilizer and Growth Rate

The effect of the fertilizer treatments on the 6-year average forage production as measured by harvest at the soil surface is shown in Figure 1. Differences between treatments were very small on May 1. The increase in rate of growth due to N fertilization was evident by May 15. As N level increased through the 80-N level, the magnitude of the increase became greater. A period of rapid dry matter increase occurred between June 15 and July 1, in which the 80-0 treatment produced a greater yield increase than did the 40-0 treatment. This was also true for the July 1 to July 15 period. This reduced growth rate indicates that the 40-N level was not adequate for maintaining optimum growth throughout the season. Plots receiving the 80-18 treatment produced significantly more than did those receiving the 80-0 treatment for all periods after June 1. There was no significant difference between the 0-0 and the 0-18 treatment yields, and often the differences between the 80-0 and 160-0 treatment yields were not significant. However, application of 18-P with 80-N produced a highly significant yield increase over the 160-0

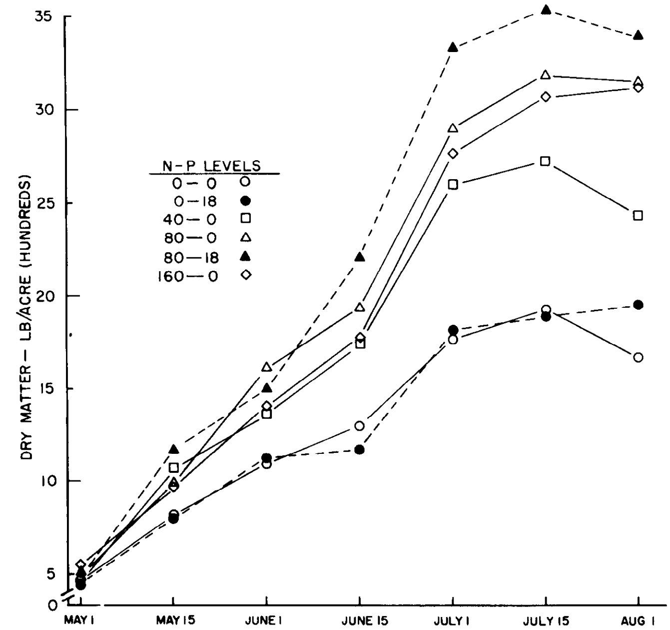

Fig. 1. *Effect of fertility level on 6-year average dry matter production of mixed prairie when cut at the soil surface on successive dates during the growing season.*

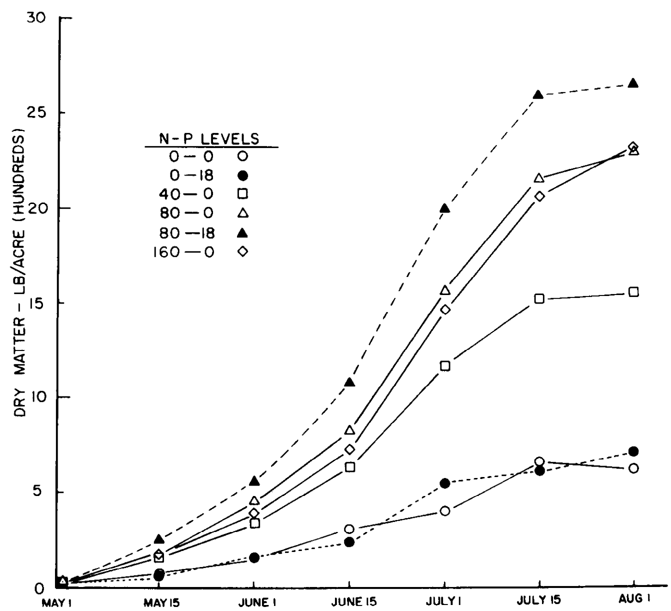

Fig. 2. *Effect of fertility level on 8-year average dry matter production of mixed prairie when cut at 1-inch height on successive dates during the growing season.*

Table 3. Six-year average daily increase in dry matter (lb/acre) produced by mixed prairie when fertilized with various levels of N and P.

	Average daily increase or decrease in dry matter											
	Total production						Production above 1 inch					
Growth period	0–0	0–18	40–0	80–0	80–18	160–0	0–0	0–18	40–0	80–0	80–18	160–0
May 1–May 15	24	22	41	32	45	28	2	2	8	8	13	10
May 15–June 1	18	22	19	42	22	29	6	7	12	19	20	17
June 1–June 15	14	3	27	21	48	24	10	5	17	21	28	18
June 15–July 1	32	43	56	65	75	66	6	20	37	54	62	52
July 1–July 15	10	5	8	19	14	20	17	3	18	30	36	36
July 15–August 1	–17	5	–19	–2	–9	4	0	3	–5	3	–20	5
May 1–August 1	13	16	21	29	32	28	6	7	14	22	23	22

treatment, indicating that inadequate P was limiting growth at the high N level.

The 8-year average dry matter yields for each fertilizer treatment on each harvest date when cut at the 1-inch height are shown in Figure 2. There was no yield increase from fertilizer application for the May 1 harvest,but for each harvest after May 1, response to N and to P at the 80-N level was sizeable and highly significant. The effect of N on growth was evident by May 15 of each year. In only 2 out of 8 years did May 15 yield above 1 inch exceed 100 lb/acre for the 0-N plots, while yields from plots receiving N exceeded 100 lb/acre on this date in all but 2 years, and averaged 181 lb/acre over the 8-year period. The 40-0 treatment yields averaged 91, 182, 332, 770, 862, and 925 lb/acre more than did those of the 0-0 treatment on the six harvest dates, May 15 through August 1, respectively. The increase in manageable forage (above 1 inch) ranged from 108 to 193%. Thus, 40-N more than doubled dry matter above 1 inch on each harvest date during the season and almost tripled it by July 15. Plots receiving 80-0 produced 98, 304, 519, 1,179, 1,490, and 1,678 lb/acre more on these six harvest dates, respectively, than did plots receiving no fertilizer. The increases ranged from 163 to 295%. Plots receiving 160-0 produced 108, 237, 416, 1,070, 1,399, and 1,696 lb/acre more on the six harvest dates, respectively, than did plots receiving no fertilizer. These yield increases were not significantly different from those of the plots receiving 80-0, consequently the percent increase over the check on each harvest date was about the same for the 160-0 and 80-0 treatments.

Of particular interest is the fact that yield above the 1-inch height from plots receiving 40-N averaged 150 lb/acre on May 15, while it was not until June 1 that plots without N reached this yield level. As the season progressed, the production lag of the nonfertilized plots became greater. The yield level reached on June 15 by plots receiving 40-N was not attained by the 0-N plots until July 15. Yield levels reached by fertilized plots on July 1 were never attained by nonfertilized plots.

Fertilizer and Daily Dry Matter Increase

The rate of increase in total dry matter is indicative of plant vigor. Large increases on a daily basis reflect rapid increase in leaf area, which enables the plant to maintain a satisfactory growth rate in spite of partial defoliation by grazing. The daily increase in dry matter, combined with other management considerations, provides a guide to grazing capacity of mixed prairie during each portion of the growing season. Application of N increased total daily dry matter production for each period between May 1 and July 15 (Table 3). After July 15, total dry matter often decreased. The increase was highly variable between treatments and from year to year.

The effect of N on daily increase in dry matter above the 1-inch height is also shown in Table 3. During May, daily increase in dry matter was from 2 to 6.5 times greater with N than without. During June and July the relative increase was somewhat less, but the actual weight of the increase was considerably larger than it was in May.

Fertilizer and Production Below 1 Inch

Whether grazing intensity is regulated by height of remaining stubble or by percent of the total production remaining, the amount of photosynthetic tissue at any given time will determine plant vigor under specific growing conditions. The data presented allow calculation of the percent of the production below 1 inch on specific dates. On the average, the percentage of the total dry matter below 1 inch decreased steadily throughout the season, beginning with 93% on May 1 and ending with 43% on August 1 (Table 2). A summary of the data for each fertility level on each date of harvest is shown in Table 4. On May 1 the percent dry matter below 1 inch was about the same for all fertilizer levels; all were 95% or more. By May 15, the range was from 81% for the high fertility levels to 92% for the nonfertilized treatment. As the season advanced, the percent dry matter below 1 inch decreased, but the difference between fertilizer levels increased. In all cases, the percent below 1 inch was lowest for the 80-0, 80-18 and 160-0 treatments and the highest for the 0-0 and 0-18 treatments. Removal of forage to a given height would therefore remove a far greater percentage of the total above-ground portion of the plant when fertilizer was used than it would when no fertilizer was used.

Table 4. Percent of the forage yield of mixed prairie vegetation found below 1 inch on each harvest date when fertilized with various levels of N and P. Values are 6-year averages.

Harvest date	Dry matter below 1 inch					
	0–0	0–18	40–0	80–0	80–18	160–0
May 1	97	97	96	95	95	96
May 15	92	93	86	85	81	81
June 1	87	86	77	74	64	70
June 15	77	80	68	62	58	62
July 1	77	70	57	47	44	47
July 15	67	69	50	38	34	37
August 1	68	71	46	38	40	36

Two factors account for most of the change in proportion of the dry matter below 1 inch with increase in fertility level: (1) increased height of individual plants in response to fertilizer, and (2) reduction of basal cover of the shortgrass, blue grama, while the single-stemmed midgrass, western wheatgrass increased per unit area as N level increased (Lorenz and Rogler, 1972). Guidelines for grazing intensity based on either stubble height or percent of total production will have to take into account the effect of fertilizer on plant response if vigor and sustained production are to be maintained. Change in growth habit of the plants must be considered in evaluating the effects of grazing pressure on fertilized mixed prairie. The combination of cool-season and warm-season species provides more nutritious forage for season-long grazing than does either type alone. Therefore, management practices which will allow use of fertilizer to increase production without the loss of blue grama must be developed.

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Factors Affecting Mesquite Control with Tordon 225 Mixture

RONALD E. SOSEBEE, B. E. DAHL, AND JOHN P. GOEN

Highlight: *The influence of various site characteristics was studied for Tordon 225 Mixture effectiveness in honey mesquite control in the Rolling Plains of Texas. Tordon 225 Mixture was commercially applied in 1970 at 0.5 lb a.e./acre under an experimental label for Texas. Generally, soil temperature (18-inch depth) above 75°F, relatively low soil water content (0 to 6-inch depth), and tree height (less than 8 ft) were most influential in the root mortalities obtained in this study.*

Chemical control of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) often results in erratic success. It has long been established, however, that mesquite kills from herbicides are greatest on upland and sandy sites and kills are consistently less on bottomland or deep hardland sites (Fisher et al., 1959). Recently Dahl et al. (1971) and B. E. Dahl, Ronald E. Sosebee, and John P. Goen (unpublished data) found soil temperature between the 12-and 24-inch depth to be the most important environmental factor influencing mesquite mortality from 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T). Hence, the objective of this study was to determine the influence of various environmental conditions and stage of growth on honey mesquite mortality from Tordon 225 Mixture[1] herbicide (picloram plus 2,4,5-T).

Procedures

In the summer of 1970, 15 sites (locations) were selected on four ranches in the Rolling Plains from Kalgary to Water Valley, Texas. On each site, 25 trees were permanently marked for individual study. The sites varied in exposure, topography, soil type and densities of mesquite. At the time of herbicide application, the following environmental parameters were measured: soil temperature, soil water content, relative humidity, air temperature, depth to $CaCO_3$ effervescence with 10% HCl, and the time of day. Height, basal diameter, stage of phenological development, and abundance of flowers were noted for each tree at the time of herbicide application.

For soil temperature determination, a 3/8-inch steel rod was driven into the ground to 6, 12, 18, and 24-inch depths. A glass laboratory thermometer was carefully lowered into each hole. It was left in the hole at least 10 minutes, which allowed it to equilibrate with the temperature of the soil. When removed from the hole, the thermometer was immediately read and the temperature recorded. Average soil temperature for the site was determined from three replications at each depth.

Soil water content was determined from gravimetric samples taken in 6-inch increments to a depth of 24 inches. The average percent water for each site was determined from two replications.

The sites were aerially sprayed between June 9 and June 25, 1970, either by airplane or by helicopter as part of a commercial application of Tordon 225 Mixture, which was applied under an experimental label for Texas. Tordon 225 Mixture is the triethylamine salt formulation of picloram and 2,4,5-T in combination (1 lb a.e. each/gal). Each chemical in the mixture was applied at 0.25 lb a.e./acre in a total volume of 4 gal/acre. The commercial herbicide mixture was composed of a diesel: water emulsion (1:3). Triad[1] (a surfactant) was included in the mixture at a rate of approximately 1 oz/acre.

Root kills for each marked tree were determined in October, 1971, following the second growing season after herbicide application. Trees were considered dead if no evidence of sprouts or live tissue could be found.

Results

Environmental factors affecting mesquite mortality from 2,4,5-T (Dahl et al, 1971) also affected mesquite mortality from Tordon 225 Mixture. Root mortalities as high as 92% were observed on sites with soil temperature above 75°F at a

The authors are assistant professor, associate professor and research associate, Department of Range and Wildlife Management, Texas Tech University, Lubbock. (College of Agricultural Sciences Publication Number T-10-108. Texas Tech University.)

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[1] Use of trade names is for the convenience of readers and does not constitute endorsement by the authors or Texas Tech University.

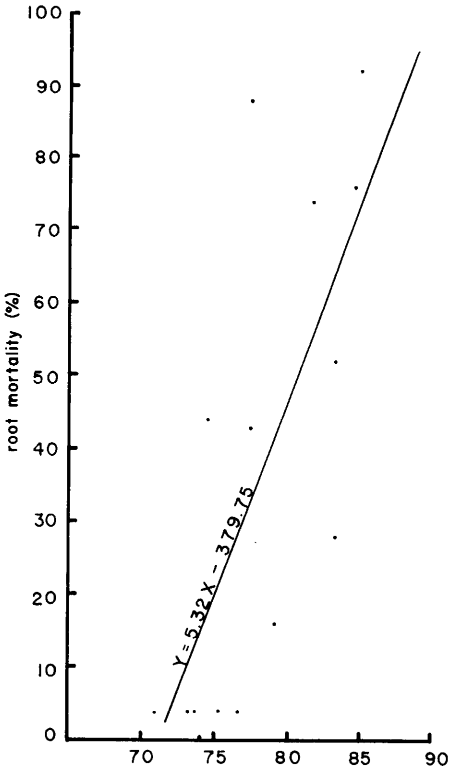

Fig. 1. *Relationship of average soil temperature at the 18-inch depth to average mesquite mortality from Tordon 225 Mixture applied in 1970. Average based on 25 trees on 15 sites (except one, which is the average of 23 trees). Mortality was determined following the second growing season after herbicide application.*

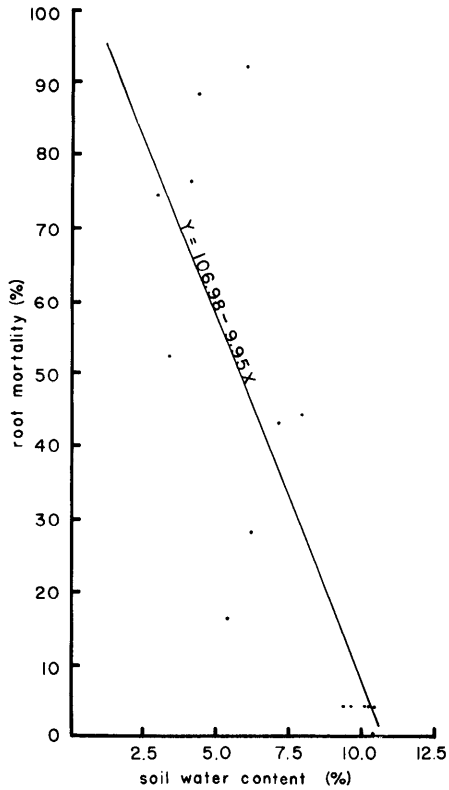

Fig. 2. *Relationship of average surface (0–6 inches) soil water content to average mesquite mortality from Tordon 225 Mixture applied in 1970. Average is based on 25 trees on 15 sites (except one, which is the average of 23 trees). Mortality was determined following the second growing season after herbicide application.*

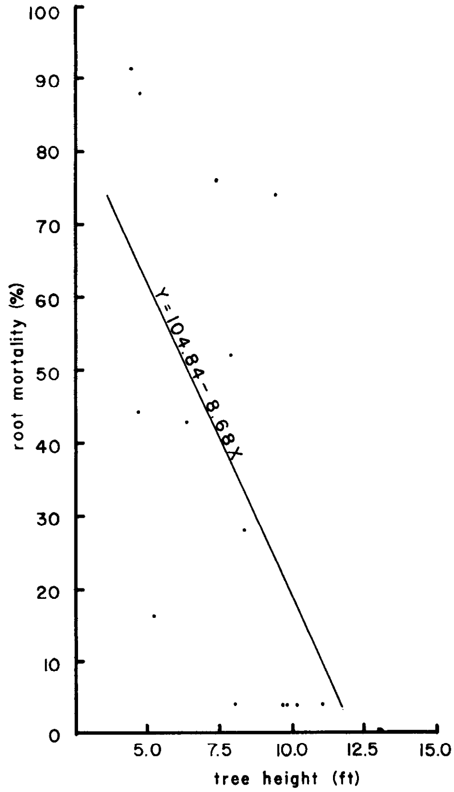

Fig. 3. *Relationship of average tree height of average mesquite mortality from Tordon 225 Mixture applied in 1970. Average is based on 25 trees on 15 sites (except one, which is the average of 23 trees). Mortality was determined following the second growing season after herbicide application.*

depth of 18 inches (Fig. 1). However, on some sites with soil temperature (18-inch depth) above 75°F, low percentages of root mortality were obtained; apparently because of the physiological processes occurring in the trees independent of soil temperature at the time of herbicide application. Root kill was characteristically low for sites with cool soils.

Soil water content to 24-inch depths was important in influencing mesquite mortality, although the relationship was negative. Limited amounts of soil water in the surface soil (0 to 6 inches) was most highly correlated with root kills (Fig. 2). With two factor multiple regression analysis, water content in the surface soil and the soil temperature at 18 inches accounted for 67% of the variability in the root mortality.

Trees taller than 8 ft were difficult to kill with aerial applications of Tordon 225 Mixture (Fig. 3). Large trees growing in dense stands shaded the soil, resulting in cooler soils and higher percentages of soil water. Tree height and soil temperature at 18 inches accounted for 65% of the variability in root kill and tree height and water content of the upper 6 inches of soil accounted for 67% of the variability.

Other measured environmental factors, stage of phenological development, and abundance of flowers did not significantly affect root mortality from Tordon 225 Mixture. No difference in mesquite mortality was detected between those sites sprayed either by airplane or by helicopter.

Discussion and Conclusion

All trees included in this study were sprayed at least 60 days after the leaves emerged from the bud. Although this is the only criteria commonly used for determining optimum spraying date, other criteria should also be evaluated. Physiological activities of plants are very well attuned to the environmental conditions that prevail over their native habitat. Therefore, all environmental conditions and phenological development should be considered when determining optimum conditions for spraying.

Honey mesquite control with Tordon 225 Mixture was closely correlated to the environmental conditions. Generally, mesquite mortality was greater when soil water content was low and soil temperature was above 75° F. Recent studies of site characteristics influencing mesquite kill with 2,4,5-T revealed that soil temperature is the most important environmental parameter. Root kills never exceeded 12% on sites with soil temperature less than 75° F at 12- to 24-inch depths (Dahl et al., 1971; B. E. Dahl, Ronald E. Sosebee, and John P. Goen, unpublished data). Therefore, for best results, it has been recommended that 2,4,5-T be applied when the soil temperature 12- to 14-inches deep exceeds 74° F.

Table 1. Summary for the 15 sites sprayed with Tordon 225 Mixture in 1970. Root mortalities were determined following the second growing season after herbicide application.

Site number	Site description	Form of aerial application	Soil temperature at 18-inches (°F)	Root mortality (%)
1	Deep hardland	Airplane	75	44
2	Bottomland	Airplane	74	4
3	Sandy upland	Airplane	77	88
4	Shallow upland	Helicopter	79	16
5	Bottomland	Helicopter	73	4
6	Bottomland	Helicopter	71	4
7	Shallow upland	Helicopter	85	76
8	Upland	Helicopter	77	43[1]
9	Deep hardland	Helicopter	75	4
10	Upland	Helicopter	85	92
11	Upland	Helicopter	82	74[1]
12	Deep hardland	Airplane	77	4
13	Shallow upland	Airplane	83	52
14	Bottomland	Airplane	74	0
15	Deep hardland	Airplane	83	28

[1] Average was determined from 23 trees. Two trees on each site had been destroyed.

When each site is viewed with respect to its soil temperature at 18 inches using Dahl's (1971) criteria, we could have anticipated the results obtained in this study with few exceptions (Table 1). However, the correlation of mesquite root kills from Tordon 225 Mixture to soil temperature was not as high as it was when 2,4,5-T was applied alone. We believe this is due to confounding of the effects of soil temperature with stage of mesquite growth. It is generally accepted that no root kills are obtained when growth-regulating herbicides are applied during periods when stored carbohydrates are being depleted, such as at the time of spring bud burst and leaf enlargement (Crafts, 1953; Fisher et al., 1959; Crafts and Crisp, 1971). Apparently herbicides are not moved to the roots in quantities sufficient to effect root kill during periods when stored carbohydrates are being depleted, regardless of soil temperature. Fisher et al. (1959) and Wilson and Dahl (1971) found that carbohydrates were fully restored to mesquite roots within 3 to 4 weeks after the time of maximum depletion. When the carbohydrate level of roots is fully restored, the basal region cannot act as a carbohydrate sink; consequently, neither carbohydrates nor herbicides move from the leaves to the root storage area (Crafts and Crisp, 1971). Wilson and Dahl's study also showed that the carbohydrate level in the roots of trees with many reproductive organs was more slowly restored than in the roots of trees with few or no flowers or pods. Therefore, we postulate that translocation to the roots either slows down or stops during reproduction, rendering applied herbicides ineffective as root killers.

Herbicide applications during this study were made when the carbohydrate level in the roots, particularly of those trees with few flowers and pods, should have been fully restored. Apparently, on sites with optimum soil temperatures trees that were not killed had reached the stage in their seasonal growth when carbohydrate translocation to the roots had ceased. For example, the 16% root kill obtained from site 4 was much lower than expected, using soil temperature as a guide. However, delaying application until later in the season gives sites ordinarily too cold for good herbicide control of mesquite time to warm up to a desired temperature (e.g. site 15). If no confounding results from lack of carbohydrate translocation later in the season, then it would be advantageous to wait until cooler sites have had sufficient time to warm up. However, by the time the soils of many of the colder sites have had time to warm up to a desirable temperature, the plants growing on warmer sites no longer are in the phenological stage most responsive to herbicides.

Soil temperature also depends upon the water content of the soil. Soils with a lower water content warm up sooner than those with a higher water content; hence, the negative relationship between soil water content and mortality rates.

Another important factor influencing root mortality in this study was tree height. Trees taller than 8 ft had lower mortality rates than did trees under 8 ft tall. With one exception (site 11) the taller trees occurred on the bottomland and deep hardland sites in very dense stands (more than 700 trees/acre). The soil temperature of most of these sites ranged from 71° to 77° F, marginal at best for optimum spraying conditions. Shading undoubtedly prevented higher soil temperatures, since in very dense stands of mesquite only sun flecs penetrated the canopy and reached the soil surface.

Possibly, tree height was also correlated with herbicide coverage. The leaves of the lower branches may not have received adequate coverage of the herbicide, especially in very dense stands. Each branch and stem is served primarily by its own vascular system to the basal bud zone and roots (R. B. Wadley, unpublished data). Therefore, those parts of the tree served by a particular branch or stem not receiving any herbicide would remain alive. The tree would, therefore, easily sprout from the basal bud zone or the stems and continue to live.

The effectiveness of Tordon 225 Mixture is directly related to the environmental conditions and stage of phenological development existing at the time of herbicide application. However, studies over a more extended period are needed to determine the optimum time for spraying with Tordon 225 Mixture.

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Estimating Food Intake by Observing Mastications by Tractable Deer

HEWLETTE S. CRAWFORD AND JAMES B. WHELAN

Highlight: *Six confined deer were fed weighed parts of different plant species collected in southwestern Virginia and the number of mastications required to consume the material was determined. Mastications to consume a gram of plant material differed significantly by plants and by animals, and there was a significant interaction. In general, succulent plant parts required fewer mastications than did fibrous plant parts. Nineteen samples would estimate to within 20% of the mean number of mastications per gram at the 95% confidence level for the animal and plant exhibiting the greatest variation during winter. More samples would be required during spring for sampling fibrous plant parts and fewer for sampling succulent plant parts.*

Efforts to determine the relationships between white-tailed deer (*Odocoileus virginianus*) forage in the environment and the nutritional requirements and habitat carrying capacity of deer herds have been limited by an inability to identify and quantify plant material ingested by deer.

Forage consumption by deer is influenced mainly by three factors: forage availability, palatability, and voluntary intake. Preference ratings for forages are directly related to voluntary intake of the plants. Voluntary intake of forages by ruminant animals appears to be regulated not only by the quality or digestibility of the forages but especially by the bulk caloric density of the plant materials. Working with sheep, Clancy et al. (1972) found that the animals limited their dry matter and digestible energy intakes of a diet with the highest energy concentration (bulk caloric density) in relation to their physiological need rather than gut fill.

In field studies, forage availability can be measured and palatability can be estimated, but it has been impracticable to measure voluntary intake. The developing use of tractable leashed or unleashed "lead deer" makes it possible to observe directly the intake of forage plants selected voluntarily by deer. The use of tractable deer for food utilization studies in the field has been summarized by Wallmo and Neff (1970). The major advantages of the techniques are: identification of species, parts or phenological stages of ingested plants; relationship of selection or rejection to plant availability; facilitation of control in experimental design; and the large quantities of data that can be collected. The major disadvantage is being unable to accurately quantify plant intake. The best method to determine intake may be via an esophageal fistula (Crawford, 1970; Veteto et al., 1972), and this procedure is being investigated. However, fistulating and maintaining enough deer to adequately sample different environments seem beyond the realm of immediate applicability, and an alternate method should be developed to use along with a limited number of fistulated animals.

The forage intake of live animals has been estimated primarily by measuring the time lapse between picking up a plant and swallowing it (Watts, 1964; Healy, 1967) or by counting the number of bites—a bite being the act of breaking off or picking up a plant part (Wallmo, 1951; Wallmo and Neff, 1970; Neff, 1967a).

Neither method yields a quantitative estimate of the amount eaten. Deer do not consume equal weights of different plant parts in equal periods of time. For instance, it may take considerably longer to consume a 3-gram piece of hardened woody stem with fibrous bark than to consume a leaf weighing 3 grams. One bite may consist of the tip of a dried leaf weighing less than a gram or a shoot complete with several leaves and weighing 5 to 10 grams.

Neff (1967b) estimated weight ingested by hand plucking representative "bites" and determining a mean weight per species. Frels and Veteto (1966) attempted a similar procedure and found it unworkable. The success of this technique may depend upon the species and plant part being ingested.

Bite counts have been used to evaluate feeding by livestock, but different workers have used various definitions of bites (Bjugstad et al., 1970). Sheppard (1921) equated bites with "jaw-wags" per mouthful of forage.

The objective of this study was to determine if there is a quantitative relationship between the number of mastications by tractable deer and the weight of plant materials consumed.

Development of a technique which would provide a quantitative estimate of dry matter intake, coupled with chemical analysis of a representative sample of the dry matter, would give an estimate of the intake of nutrients and calories. Knowing (1) the animals' requirements, (2) daily intake of nutrients and calories, (3) the quantity of food in the environment, (4) the nutritional and caloric content of foods, and (5) the digestibility of food, it becomes possible to measure the theoretical potential carrying capacity for the various structures of deer populations, provided range components other than food are adequate. Under future levels of more intensive wildlife management, carrying capacity information will be used in habitat management; under today's low intensity wildlife management, information relevant to potential carrying capacity is needed to evaluate the effects of various land management practices on deer habitat.

Methods

Plant species and parts were selected for study based on observation of plants chosen by two tractable deer over a 2-week period during midwinter and three deer over a 3-week period in early spring. For the winter sample, red maple (*Acer*

Authors are principal ecologist, Southeastern Forest Experiment Station, U.S. Department of Agriculture, Forest Service, Blacksburg, Virginia, and assistant unit leader, Virginia Cooperative Wildlife Research unit, U.S. Department of Interior, Bureau of Sport Fisheries and Wildlife, Blacksburg, Va.

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rubrum)[1] twigs were selected to represent hardened woody stems, goldenrod (*Solidago* spp.) and aster (*Aster* spp.) to represent cured forbs, wintergreen (*Gaultheria procumbens*) to represent small evergreen plants, laurel (*Kalmia latifolia*) to represent evergreen leaves of shrubs, and leaves of scarlet oak (*Quercus coccinea*) to represent deciduous leaves in the diet. During spring, red maple and yellow poplar (*Liriodendron tulipifera*) were selected to represent the past season's growth of deciduous leaves, violet (*Viola* spp.) and anemone (*Anemone* spp.) to represent newly grown forbs, goldenrod to represent forbs with green overwintering basal leaves, and laurel to represent evergreen leaves in the diet. The amounts of plant material fed are shown below.

Plant species	Part	Green wt
	Winter	
Red maple	5 hardened woody twigs	3-6g
Aster and goldenrod	5-6 cured stalks	1-2g
Wintergreen	10-20 plants	4-12g
Laurel	10 leaf bunches with small stem	12-25g
Scarlet oak	10 leaves	4-6g
	Spring	
Red maple	10 leaves	2-3g
Yellow poplar	10 leaves	4-11g
Anemone	10 leaves	5-11g
Violet	10 plants	6-12g
Goldenrod	20+ basal leaves	4-8g
Laurel	10-20 leaves	6-9g

The quantity of material presented at one time to the animals was pretested to limit bias in the number of mastications required to consume a gram. Presentation of only one leaf caused bias because the animal took more mastications per gram than when more than three leaves were presented. The quantities of plant material presented should decrease this bias and represent what might be available at a given spot in the field. The amount of experimental material fed represented approximately 5 to 10% of the animals' daily intake.

Plants were collected from the forest each morning and taken to the laboratory, where surface moisture was removed by shaking the plants in paper bags. Each species was weighed, separated for feeding to each animal, and placed in separate bags. Samples were fed early in the afternoon. Any material not eaten was weighed. The animals' normal ration was fed after the sampling period.

A subsample of each species was oven-dried at 70°C for 48 hours. Oven-dry weights were computed for each plant species each day of the study.

Before study measurements were started, two observers fed the selected plant species to six deer each day for 1 week. After this familiarization period, the same observers fed the samples once a day for 8 consecutive days. Plants were either handheld or placed on the floor of the pen (Fig. 1). Each observer independently counted the mastications and compared counts. Vertical jaw movements made when taking the material into the mouth were not counted as mastications. A mastication was a sideward rotating motion of the jaws. Mastications could be seen from the front, back, or sides. At times an animal would ingest a plant while it masticated another plant; however, the rotating mastication motion could still be distinguished from a vertical motion made by ingestion. Rotation could best be distinguished by observing the junction point of the upper and lower mandibles.

Three male and three female deer were used in this study. One female was the smallest, weighing about 50 lb, one male weighed about 90 lb; the other animals ranged from 54 to 86 lb. All were born the previous spring and had been reared in the deer enclosure at Virginia Polytechnic Institute and State University.

Results

Data collected during the winter sampling period were expressed as mastications per gram of fresh weight and oven-dry weight and were subjected to an analysis of variance with a factorial design. The number of mastications required to consume a gram of plant material differed significantly ($P<0.01$) by animals and species of plants. There was also a significant ($P<0.01$) interaction between plants and animals.

During winter the oven-dry weight data were less variable than fresh weight data for all plants except laurel. Ice and snow covered the vegetation collected on some days, making it difficult to remove the excess moisture and obtain an accurate fresh weight. Variation was greatest for hardened woody stems of red maple and cured stems of aster and goldenrod. Average sampling errors (95% half confidence interval as a percent of the mean) were approximately 24% (Table 1) for oven-dried weights or 4% to 6% less than those for fresh weights. Only oven-dry data will be discussed for the winter sample.

Fig. 1. *Plant material was either handheld, as with the cured forbs (above), or spread on the floor of the pen, as with the dried leaves in the lower photo.*

[1] Common and scientific names follow Gleason (1968).

Table 1. Average sampling error[1] for six deer.

Species	Fresh weight	OD[2] weight
Winter		
Red maple stems	27.5	23.7
Aster stems	29.8	24.2
Wintergreen whole plants	15.3	13.5
Laurel leaves and stems	10.5	13.5
Scarlet oak leaves	16.8	13.7
Spring		
Red maple leaves	26.1	27.5
Yellow poplar leaves	44.1	41.2
Violet whole plants	16.3	18.2
Anemone leaves	16.5	16.8
Goldenrod leaves	18.6	30.4
Laurel leaves	11.1	11.1

[1] Sampling error is the 95% half confidence interval expressed as a percent of the mean mastications per gram.
[2] Oven-dry weight.

Table 2. Mastications per gram and 95% half confidence interval (oven-dry basis) during winter.

	Animal					
Plant	01	84	89	290	281	1331
Red maple	95±27	51±16	36±6	60±17	47±9	51±9
Aster and goldenrod	198±68	111±30	108±30	148±27	94±18	115±23
Wintergreen	44±7	27±2	20±2	27±2	20±5	23±4
Laurel	33±5	18±2	12±2	16±2	12±1	13±2
Scarlet oak	52±7	49±8	27±5	29±3	32±5	25±2

The cured stalks and flowering stems of aster and goldenrod required significantly more mastications per gram than the other plants by all animals (Table 2). Hardened woody stems required the next greatest number of mastications per gram, followed by oak leaves, which varied considerably by animal. The difference in mastications per gram between woody twigs and oak leaves was significant for some animals but not for others. Mastications to consume a gram dry weight of wintergreen leaves were significantly fewer than those for oak leaves for some animals. For all animals, the mean number of mastications for wintergreen was significantly less than the mean for red maple. The mastications per gram for laurel were significantly fewer than those for all other plant species for all animals.

The smallest animal—a doe—consistently took more mastications per gram for all plant species. Two medium-size animals, a buck and a doe, often took the fewest mastications per gram. For all plant species, significant differences in the number of mastications per gram were detected between animals.

Variation during the spring sampling period was approximately the same for fresh weight data and oven-dry data except for goldenrod. Oven-dry data for goldenrod were considerably more variable than fresh weight data, probably because of differences in moisture content of the selected subsamples. Yellow poplar and red maple leaves had fresh weight sampling errors in excess of 20%, but all other species showed less variation. Fresh weights were used to analyze the spring sample.

Many more mastications per gram were required by all animals when eating dried leaves of red maple and yellow poplar than when eating succulent herbaceous plants in spring (Table 3). The smallest animal averaged considerably more mastications per gram than the others. Significant differences in mastications per gram between red maple and yellow poplar leaves were not detected for any of the animals.

Mastications required to consume equal weights of herbaceous growth differed by plant species. Violet required the fewest, anemone the next greatest number, followed by goldenrod basal leaves of new and old growth and the overwintering green leaves of laurel. The increase in mastications from one species to the next was significant for only some animals. The mastications per gram required to eat violet and anemone differed significantly for three deer. Differences in mastications per gram for green basal leaves of goldenrod and green leaves of laurel were not detected for five experimental animals.

Significant differences in mastications per gram between animals were not detected for yellow poplar or violet. For all other plant species, significant differences were detected between some animals.

Discussion and Conclusions

We conclude that the number of mastications to consume equal amounts of vegetation differs between species of plants and individual tractable deer or between some plant species and some deer.

Within animal and within plant variation give a basis to compute iteratively the number of samples required to estimate the relation of number of mastications to dry matter intake of plant species within a specified sampling error for individual animals. Considering the animal and plant which exhibited the greatest variation during winter, approximately 17 observations were needed to estimate intake to within 20% of the mean at the 95% confidence level for red maple twigs, and 19 observations were needed to obtain the same level of accuracy for cured aster and goldenrod stalks when using the oven-dry data. We could have used fresh weights and taken 23 samples for red maple twigs and 26 samples for cured aster and goldenrod stalks and achieved the same level of accuracy for the same animal. If we wished to decrease the sampling error to 10% of the mean, it would require over 3½ times as many

Table 3. Mastications per gram and 95% half confidence interval (fresh weight) during spring.

	Animal					
Plant	01	84	89	279	280	1331
Red maple	95.1±67.5[1]	32.3±3.8	49.0[2]	24.1±3.1	22.8±2.4	22.4±4.7
Yellow poplar	73.4±63.5	29.7±9.4	43.0±24.4	27.3±11.8	18.3±4.0	20.9±5.2
Violet	4.8±1.2	3.5±0.5	3.7±0.7	3.6±0.5	3.2±0.5	3.2±0.5
Anemone	6.4±1.4	4.9±0.9	4.3±0.7	5.4±0.9	4.4±0.5	4.8±0.5
Goldenrod	7.9±0.9	6.5±1.7	7.0±1.9	6.0±0.9	6.4±0.7	6.4±1.2
Laurel	12.1±1.9	8.4±0.7	7.6±0.5	7.3±0.9	7.5±0.7	7.2±0.7

[1] Values are reported to the nearest one-tenth, so half-confidence values will agree with computed percentage values and rounding error will be eliminated.
[2] Only one sample taken.

observations as did the 20% sampling error level.

Animal number 01 exhibited more variation when eating dried plant material during the spring trials than during the winter trials. During the spring the animal did not eat dry leaves with any relish, and on one day would not eat any dried leaves. Approximately 70 samples would be required for red maple leaves and 86 for yellow poplar leaves to estimate mastication-intake relationships of these species to within 20% of the mean with 95% confidence. Two other animals exhibited reluctance to eat dried leaves. The next most variable animal would require only 9 samples of red maple leaves, but 31 samples would be needed for dried yellow poplar leaves.

Dried scarlet oak leaves did not present any sampling problem during winter. The eight samples gave sampling errors ranging from 8% to 17% for the six animals. Dried leaves are readily eaten during winter, but use decreases when new growth begins. Plants selected by deer in the spring feeding period were taken during the transition period from winter to spring. However, we did not conduct the experimental pen feeding until over a month later. The animals' desire for dried leaves changed during this period and probably increased the variation in the mastications required to consume a gram. At times the animals would masticate a leaf for a short time and then drop it. The mastications were not always definitive and observer counting errors could have contributed to sampling variation.

Sampling variation for cured aster and goldenrod stems during winter might be explained the same way since pen feeding trials followed field observations by over a month. Aster and goldenrod were relished highly during early winter. During the feeding trials in late winter, several animals fed hesitantly on these plants. Variation in mastications was increased for several animals when we changed one observer for one day. On this day, red maple twigs and the cured herbaceous plants were the first items fed. The number of mastications increased substantially for these plants. We assume the animals became accustomed to the observer by the time they were fed the third species because variation in mastications did not increase for the last three plants.

Samples of the winter evergreen plants, wintergreen and laurel, were less variable. Eight samples fed to one animal had a sampling error of 23%, which was corrected to 20% by taking 10 samples. Eight samples gave errors below 20% for the remaining test animals. Twelve samples taken during the spring would estimate mastications per gram of the most variable succulent plant to 20% of the mean with 95% confidence.

We believe that the variation associated with relating weight of vegetation consumed to mastications may be less when using lead deer in field trials where the animals are not subjected to unusual disturbance. Several times during the pen experiment, the animals were disturbed by uninvited observers and consequently altered their normal mastication process. Experienced lead deer with experienced observers ate relatively uniformly under controlled field conditions. When disturbed in the field, our animals stopped all movement including mastication. After the disturbance was identified, they continued masticating in a normal manner. When disturbed in their pens, the same animals often continued to eat but appeared nervous and masticated faster with less definition between mastications.

Some animals may ingest several plants before they masticate and swallow. This may increase the difficulty of relating the number of mastications to a plant species. One out of three of our most dependable lead deer ate rapidly and occasionally would masticate two or three plant species in one mouthful. This was not a problem in the field when desirable plants were few and scattered, but it was a problem during the lush spring growth. No problems of this nature were encountered with the other animals.

We attempted to use a stop watch to relate weight consumed to seconds masticated. The results in the controlled pen situation were not better than counting mastications. As noted by Neff (1966), using a stop watch in field work with leashed deer is difficult in that one hand is constantly busy. Additionally, the animals chew intermittently when they are alarmed or cautious, making it difficult to determine when timing should start and stop.

Relating mastications to plant intake holds promise for quantifying plant intake with relatively small samples only by calibrating individual animals for different plant species or groups of species. The technique may be especially appropriate when using several lead deer in conjunction with one or two esophageally fistulated deer. Plant material collected from a fistulated animal could provide a check on the accuracy of relating mastications to plant weight consumed. Field study with additional animals in other areas is needed to determine the practicality of the technique.

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TECHNICAL NOTES

A Method for the Collection and Transport of Native Grasses from the Field to the Glasshouse

R. D. B. WHALLEY AND RAY W. BROWN

Highlight: *A simple method for transplanting native grasses from field to glasshouse with negligible mortality is suggested. The method has been used successfully in both Australia and in the United States and was far superior to other transplanting techniques. The method has also been used successfully with forbs and shrubs.*

In recent years interest in the eco-physiology of native grasses, forbs, and shrubs has increased. Quite often the study of these plants under controlled laboratory or glasshouse conditions requires that they be removed from their native environment. Since these species are often quite sensitive to root disturbances and rapid changes in environmental conditions, they are difficult to transport from the field to the glasshouse without experiencing heavy mortality. The authors have found a simple, satisfactory method for transplanting a wide range of native grass and grass-like species with negligible mortality. This method can be summarized as follows:

1) The entire plant is carefully removed from the soil with a shovel or similar tool, including a relatively undisturbed ball of soil around the roots.

The authors are senior lecturer, Department of Botany, University of New England, Armidale, N.S.W. 2351, Australia; and plant physiologist, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Logan, Utah.

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Table 1. Plants successfully collected and transported into the glasshouse.

Species	Location and elevation (ft)		Number of plants	
			Collected	Survived
Australia				
Wallaby grass				
(*Danthonia* sp.)	N.S.W.	3,500	24	24
Kangaroo grass				
(*Themeda australis*)	S.A.	100	5	5
	Qld.	1,100	5	4
Nigger heads				
(*Enneapogon nigricans*)	N.S.W.	3,500	3	3
Swamp foxtail				
(*Pennisetum alopecuroides*)	N.S.W.	3,500	3	3
Windmill grass				
(*Chloris truncata*)	N.S.W.	3,500	3	3
Slender rat's tail				
(*Sporobolus elongatus*)	N.S.W.	3,500	3	3
Mat grass				
(*Hermarthria uncinata*)	N.S.W.	3,500	3	3
United States				
Spikefescue				
(*Hesperochloa kingii*)	Utah	9,800	12	12
Spike trisetum				
(*Trisetum spicatum*)	Montana	10,400	12	12
Red three-awn				
(*Aristida longiseta*)	Utah	4,500	8	8
Bluebunch wheatgrass				
(*Agropyron spicatum*)	Idaho	6,200	8	8
Idaho fescue				
(*Festuca idahoensis*)	Idaho	6,200	6	6
Sedge				
(*Carex* spp.)	Idaho	6,200	6	5
Sheep fescue				
(*Festuca ovina*)	Montana	10,400	6	6
Alpine bluegrass				
(*Poa alpina*)	Montana	10,400	6	6
Prairie junegrass				
(*Koeleria cristata*)	Utah	9,800	6	6
Green needlegrass				
(*Stipa viridula*)	Idaho	6,200	6	6
Sandberg bluegrass				
(*Poa secunda*)	Utah	8,000	4	4

Fig. 1. (Left) *The plants are placed in a plastic bag, and the leaves and culms clipped.* (Center) *A small quantity of water is added to dampen the soil.* (Right) *The plastic bag is sealed and labeled.*

2) The entire plant is immediately placed in a large plastic bag, and the leaves and culms clipped to about 10% of their original height (Figure 1, left).
3) A small quantity of water is added to dampen (but not saturate) the soil (Figure 1, center), and the plastic bag is sealed and labeled (Figure 1, right).
4) The plants are shaded as much as possible from direct solar radiation during transport. In the glasshouse, the plants are placed in pots, adding a soil mix if necessary, and then watered.

A number of different species from a variety of ecological types have been successfully collected by this method in both Australia and the United States (Table 1). These plants were collected successfully at different times during the growing season, including periods of active growth. The method described was far superior to other techniques, including direct potting in the field. Plants have been stored in plastic bags for several days in a vehicle without suffering severe damage or mortality. Apparently the soil water status is not critical at the time of collection, but root disturbances are reduced if the soil is moist.

In addition to grasses and sedges, this method has been used successfully to collect many different species of forbs and shrubs (e.g. western yarrow (*Achillea millefolium*), dwarf clover (*Trifolium nanum*), alpine pussytoes (*Antennaria alpina*), yucca (*Yucca glauca*), big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*). However, severe clipping of the aerial shoots was not necessary.

The above procedure should be strictly followed to insure success. For instance, some mortality can be expected if the plastic bags are not sealed, or if the leaves are not clipped.

Development, Testing, and Evaluation of the Deep Furrow Drill Arm Assembly for the Rangeland Drill

JERRY E. ASHER AND RICHARD E. ECKERT, JR.

Highlight: *A deep-furrow drill-arm assembly for a Rangeland drill was developed, tested, and evaluated. Horizontal disk angle was the single most important factor affecting construction of an adequate furrow. This angle varied among sites and was influenced by vegetative cover and soil conditions. The final design was an assembly with an adjustable disk angle. Seedling stands in deep furrows were equal to or superior to those in standard furrows.*

Many workers have shown the value of deep-furrow planting for seedling establishment and survival in varied rangeland environments (McGinnies, 1959; Eckert and Evans, 1967; Evans et al., 1967, 1970; Hull, 1970; Klomp and Hull, 1972; and Eckert et al., 1973). In these studies, furrows were constructed with hand tools or with shovel-type openers not adapted to rough, rocky rangeland conditions.

A cooperative effort was initiated in 1968 to design, test, and evaluate a drillarm assembly for the Rangeland drill to make furrows with the desired microclimate characteristics and one also adapted to large-scale operations.

The authors are natural resource specialist, Bureau of Land Management, U.S. Department of the Interior, Albuquerque, New Mexico, and range scientist, Agricultural Research Service, U.S. Department of Agriculture, Renewable Resource Center, University of Nevada, Reno. The senior author was formerly with the BLM, Elko District, Nevada.

The work represents cooperative investigation of the Bureau of Land Management, U.S. Department of the Interior, the Agricultural Research Service, U.S. Department of Agriculture, and the Agricultural Experiment Station, University of Nevada, Reno, Nevada (Journal Series Number 241).

Manuscript received January 15, 1973.

Development and Testing

In 1968, we modified one Rangeland drill by replacing the 20-inch disks with 24-inch disks. Four of the ten arm assemblies were removed, and the arms were reversed so that the disks cast to the outside. This arrangement resulted in row spacing of about 20 inches. With 100 lb weight on each arm, this equipment made good furrows in sandy and cultivated soils. In uncultivated, loamy soils, these arms could not support the additional weight of 400 lb required to cut an adequate furrow.

In 1969; the U.S. Forest Service Equipment Development Center fabricated two "heavy-weight" drill arms with 24-inch disks and capable of supporting 400 lb of "add-on" weight. These arms were tested on 350 acres, including a fire rehabiliation, a sagebrush spray-drill operation, and an atrazine fallow. On loam and clay-loam soils with rocks 5 to 15 inches in diameter, these arms with 400 lb of weight made furrows that averaged 3 inches deep and 4 inches wide at the top. The standard drill with standard weight (20 to 40 lb) made a furrow only 1 inch deep and 1 inch wide in moist soil and barely scratched the surface of dry soil.

Mechanical problems associated with weight additions were corrected, and six arm assemblies with 24-inch disks and various horizontal and vertical angles were tested in 1970. The horizontal angle is the pivot of the disk viewed from above. The vertical angle is the tilt of the

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Fig. 1. *Drill arm assembly, showing adjustment for horizontal and vertical angles.*

disk viewed from above. No significant mechanical problems were encountered on 900 acres of extremely rough, rocky terrain on four sites. However, one very important fact became apparent. Small differences in disk angle drastically changed the weight requirement. For example, a disk at one angle with 80 lb cut a better furrow than a disk at another angle with 320 lb of "add-on" weight.

Construction of an adequate furrow was influenced by at least ten variables, the most important of which was the horizontal disk angle. Too much horizontal angle results in wide, shallow furrow and creates maintenance or breakage problems because the disk tends to dig at rocks and vegetation rather than roll over them. Conversely, with too little horizontal angle, the disk merely scratches the surface, and no furrow is cut. The disk angle required varies from site to site. Therefore, we recommended the manufacture of two adjustable disk-arm assemblies (Fig. 1).

The horizontal angle adjusts from 55 to 75° in 2.5° increments; the vertical angle adjusts from 4 to 18° in 2° increments. Adjustments on one arm can be made in 3 to 5 minutes. Conditions of vegetative cover and soil texture, moisture, or freezing, encountered indicated that adjustment once or twice a week was sufficient.

The new arms were tested on 1,300 acres in Nevada and Oregon in 1971. One 700-acre site was a mixture of rock-free and moderately rocky ground. On another site of 600 acres, 12- to 36-inch diameter rocks were encountered constantly. The adjustable arms could carry 200 lb of weight, yet only 100 lb were needed. Vertical angles used ranged from 4 to 6°; horizontal angles ranged from 60 to 67.5°. In all tests, the new arms made deep furrows with one-half the weight needed on fixed-angle arms.

So far only two minor disadvantages of deep furrowing have been noted. A drill-row spacing of 20 inches instead of 12 inches decreases plant density and perhaps reduces the soil-stabilization effect of the seeding. On many sites, however, this is the only effective seeding method, so there is really no comparison with the standard drill. More emphasis must also be placed on contour seeding because of furrow size.

Stand Evaluation

Seedling stands and stand establishment were compared in standard and deep furrows under different situations. Stands in deep furrows were equal to or superior to those in standard furrows. Stands were always superior in deep furrows under the more difficult seeding conditions. Superiority in deep furrows was indicated by larger, more vigorous plants; greater plant density and frequency; more seedlings headed; and greater survival. All these characteristics were not found in each comparison, but varied from site to site.

On a fire rehabilitation, frequency of crested wheatgrass (*Agropyron desertorum*) per ft of row was 20% in standard furrows, compared to 46% in deep furrows. Rhizomatous grasses and Sandberg bluegrass (*Poa secunda*) formed a dense sod. This sod was cut and lifted by the 20-inch disk on the standard drill, but after seeding, the sod dropped back to its original position covering the seed. The deep-furrow drill threw strips of sod completely out of the furrow.

On a 1,000-acre sagebrush spray-drill operation, the frequency and height of crested wheatgrass seedlings were 60% and 6 inches, respectively, in the deep furrow. Stand characteristics were 41% and 3 inches on areas seeded with disk assemblies that did not make adequate furrows. These disks, weighted with 200 lb, rolled over the top of the understory vegetation.

On four atrazine-fallow projects ranging from 80 to 1,200 acres, crested-wheatgrass seedlings were from 2.2 to 3.3 inches taller, survival was 13% greater, and 13% more of the seedlings produced reproductive culms in deep furrows than in standard furrows. Seedling densities of intermediate wheatgrass (*Agropyron intermedium*) and pubescent wheatgrass (*A. trichophorum*) were three to eight times more, height 0.5 to 2.4 inches greater, and frequency 43 to 51% higher in deep furrows than in standard furrows.

Summary and Recommendations

Since 1968, 2,300 acres on ten sites in four Bureau of Land Management districts in two states have been seeded with the deep-furrow technique. A standard Rangeland drill was the basis for comparison in most instances. Most testing was done under extreme operational conditions with no significant mechanical problems.

Seedling stands and stand establishment were generally much better in deep furrows. The standard drill was adequate on some sites; however, in uncultivated medium or heavy-textured soil, under rocky conditions, or where the understory was a sod of bluegrass, cheatgrass (*Bromus tectorum*), or rhizomatous grasses, the deep-furrow arm assembly was required to make an adequate furrow.

The U.S. Forest Service Equipment Development Center, San Dimas, California, has completed specifications for an adjustable, drillarm assembly capable of making the desired type of furrow under a wide range of vegetation and soil conditions.

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Chemical Fertilization of Fourwing Saltbush

STEPHEN E. WILLIAMS AND GEORGE A. O'CONNOR

Highlight: *Fourwing saltbush is an important member of arid and semiarid rangeland communities, supplying high quality forage for herbivores as well as serving as an erosion deterrent. Methods of saltbush establishment, however, have met with only limited success. Results of a greenhouse study show that small additions of balanced fertilizer can greatly increase saltbush growth and hence likely increase the probability of saltbush establishment. The results appear to warrant further study in the form of field tests to evaluate the practicality of large scale fertilization of saltbush plantings.*

Fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) has long been recognized as an important member of arid and semiarid rangeland communities. It provides high quality forage for herbivores and serves as an important erosion deterrent. Among the most palatable of Southwestern shrubs, fourwing saltbush is cropped by all classes of livestock (Judd, 1962), while wildlife utilize it for cover, roosting sites, and food (Van Dersal, 1938). It has high nutritional value, which is maintained during the winter months (Cook et al., 1959).

Mature fourwing saltbush plants are commonly 1 to 2 m tall, with stems freely branching above the ground surface. The extensive root system of fourwing saltbush may penetrate 5 to 15 m into alluvial soils, making the plant very drought resistant and well suited to erosion control (Van Dersal, 1938). Establishment of fourwing saltbush on overgrazed or otherwise abused rangeland may, therefore, have the duel economic function of restoring rangeland for livestock and wildlife utilization as well as providing limited erosion control.

Direct seeding of saltbush has generally resulted in very poor establishment. In part this has been due to low seedling emergence and poor survival of seedlings in the field (Springfield, 1970; and Cable, 1972). Field plants have been established using greenhouse stock, but transplanting of stock from a natural stand failed (Cable, 1972). Springfield (1970) increased seedling survival through the use of mulches and also increased transplant survival by germinating and growing plants in soil taken from under mature saltbush growing in the field. Williams (1972) showed that this increased survival was in part due to beneficial endomycorrhizal fungi present in the soil.

The purpose of this investigation was to determine what effect small additions of a balanced 12-12-12 fertilizer had on the growth of fourwing saltbush.

Materials and Methods

Three soils were used in this study. The names *under, between*, and *garden* will be used hereafter to refer to these soils. The *under* sample was collected from immediately under the fourwing saltbush canopy, whereas the *between* soil was collected between the saltbush plants at least 6 feet away from the nearest plant. A distinction was made between soil collected from under the saltbush and soil collected between plants because of a suspected mycorrhizal fungi infestation of soil immediately under the plants. Mycorrhizal populations have been shown to increase nutrient availability for some plants. *Garden* soil was collected from a private garden in the Albuquerque area and had been heavily fertilized for a number of years.

The *garden* soil was classified as the calcareous Gila clay loam, which is a member of the coarse-loamy, mixed, thermic family of Typic Torrifluvents. Bulk samples of the soil were collected 3.2 km west and 16 km south of the Federal Building in Albuquerque. The *between* and *under* soils were classified as the Las Lucas loam and were members of the fine-silty, mixed mesic family of Ustollic Camborthids. Samples were collected 3.2 km south of La Ventana, N. M., and 2.4 km due east of San Luis, N. M., just east of state highway 44 at the old Civilian Conservation Corps camp.

Approximately 180 kg of each soil type was collected from the top 15 cm of the profile. The soils were air dried and stored in metal garbage cans at room temperature. The soils were mechanically ground and larger chunks of organic material, soil aggregates, and rocks were removed.

The effect of small additions of fertilizer on the growth of saltbush was studied under greenhouse conditions. Thirty-six pots (diameter 23 cm and height 18.5 cm) were divided into three groups of 12 pots. Each group was filled with one of the three soils (about 7.2 kg of soil/pot). One gram of 12-12-12 fertilizer, equivalent to 22.8 kg N/ha, 10 kg P/ha, and 18.75 kg K/ha, was added to each of six pots from each group. The remaining six pots in each group constituted the control (no fertilizer) treatment. Seeds (100 per pot) were planted in a ring 3 cm from the outside of the pot and 1 cm below the soil surface. The fertilizer was banded about 2 to 2.5 cm immediately below the seeds.

The pots were randomly oriented in the greenhouse and watered 26 times with a total of 12.1 cm of water during the 97-day growth period, resulting in a favorable moisture regime for the seedlings. The locations of the 36 pots were randomly changed 20 times during the growth period to minimize temperature and light differences within the greenhouse.

Twenty-three days after emergence, all plants were thinned to nine plants per pot. Plants were thinned again at the end of another 43 days to maintain a population of nine plants per pot (only plants which had germinated since the first thinning were removed).

At the end of 97 days, plants were harvested, dried at 75°C for 14 days, and weighed.

Results and Discussion

The average dry weights of plants were not significantly ($P = 0.05$) different for saltbush grown on any soil when all soils were fertilized (Table 1). However, plants grown on the unfertilized *under* and *between* soils yielded significantly ($P = 0.05$) less than plants grown on the unfertilized *garden* soil. The addition of fertilizer to either the *between* or *under* soil resulted in significantly ($P = 0.05$) greater yields when compared to the

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The authors are former graduate student and assistant professor, Department of Agronomy, Box 30, New Mexico State University, Las Cruces.

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Table 1. Average yield (mg) of plants per pot grown on *under, between,* and *garden* soils. Weights are for the aboveground portions of the plants only.

Treatment	Soil[1] Between	Under	Garden
Fertilized	174.8 a	149.3 a	135.2 a
Unfertilized	72.5 b	85.8 b	138.6 a

[1]Yield values followed by the same letter in any column or row were not significantly different (P = 0.05). Significance was determined using the student t test.

unfertilized soils, whereas the *garden* soil was unaffected by fertilizer application. The *garden* soil was reported to have been heavily fertilized in the past and was, therefore, not expected to respond to small additions of fertilizer. Small additions of fertilizer to the *between* and *under* soils resulted in yields that were not significantly different from the yields obtained on the heavily fertilized *garden* soil. Crusting observed in the clay loam *garden* soil (but not in the *between* or *under* soils) may have affected the yield of saltbush in these pots.

There was no difference in yield between the unfertilized *between* and *under* soils, indicating that any mycorrhizal effect on nutrient availability in the *under* soil was negligible. The additions of fertilizer had a much more pronounced effect on yield on either the *between* or *under* soil than did the mycorrhiza found to be present in the *under* soil.

Yields from the fertilized *between* and *under* treatments were pooled and were found to be significantly (P = 0.001) different from the pooled yields for unfertilized *between* and *under* treatments. Yields due to fertilizer were about 100% greater than yields for unfertilized pots indicating the potential for increasing saltbush growth and hence the probability of establishment with the use of fertilizer.

Conclusions

The experiments described herein were conducted in the greenhouse under favorable moisture and temperature conditions, and hence probably maximized the fertilizer effect. Anderson (1972), for example, observed no significant response in mean leader growth of saltbush to the application of 252.5 kg N/ha in the field. Variation within treatments was large, however, and effective moisture was only 55% of normal during the year of Anderson's work, which would probably reduce any fertilizer effect. No phosphorus or potassium was applied with the urea used in Anderson's study and only leader growth was measured rather than total plant weights.

The large yield increases observed in this study appear to warrant continued study into the effects of fertilizer on saltbush establishment. Field studies in which different rates and types of fertilizer are applied should provide more conclusive evidence as to the practicality of facilitating large scale saltbush establishment with fertilization.

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Ungulate Diets in the Lower Grand Canyon

R. M. HANSEN AND P. S. MARTIN

Highlight: *Plant fragments were identified and quantified by a microscopic examination of the dung of the burro, cattle, and bighorn in the western end of the Grand Canyon, Arizona. Genera of plants common to the diets of all three ungulates were:* Sphaeralcea, Bromus, Tridens, Muhlenbergia, Acacia, Ephedra, Opuntia *and* Tidestromia. *Wherever free ranging large herbivores occur, as in the Lake Mead National Recreation Area, it is possible to study their diets by analysis of their dung. The diet of modern large herbivores can be compared with the unique Pleistocene record of ground sloth and extinct mountain goat dung preserved for over 11,000 years in adjacent caves.*

Many innovative methods of determining diets in wild and domestic herbivores have been used in recent years. One such

Authors are professors, Department of Range Science, Colorado State University, Fort Collins, and Department of Geosciences, University of Arizona, Tucson.

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this study appear to warrant continued study into the effects of fertilizer on saltbush establishment. Field studies in which different rates and types of fertilizer are applied should provide more conclusive evidence as to the practicality of facilitating large scale saltbush establishment with fertilization.

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Many innovative methods of determining diets in wild and domestic herbivores have been used in recent years. One such method is based on microscopic counts of cutinized epidermal fragments and lignified cell walls remaining after digestion (Ward, 1969; Free et al., 1970; Stewart and Stewart, 1970; Hansen, 1972). If the quantification method of Sparks and Malechek (1967) is used, the percentage of relative density of plant fragments discerned in the dung of herbivores is considered to be similar to the percentage of dry weights for the ingested plants. Even if the discernibility of plant fragments is changed by digestion, the magnitude is not generally great enough to destroy the identifying characteristics.

In spite of several centuries of livestock grazing in desert shrub ranges in the southwest, there is little specific knowledge of the quantities of plants eaten or shared among ungulates living together. We wish to appraise the diets of large ungulates on undisturbed open range at the eastern edge of the Mojave Desert just inside the Grand Wash Cliffs of the Grand Canyon.

The modern dung samples for comparison with those of extinct ground sloths (*Nothrotherium shastense*) and mountain goats (*Oreamnos harringtoni*) were collected near Rampart and Muav Caves. A qualitative appraisal of ancient dry dung of the Shasta ground sloth from the caves revealed abundant fragments of desert shrubs, especially *Ephedra, Sphaeralcea,* and *Atriplex* (Laudermilk and Munz, 1937).

We are sincerely grateful to Sarah R. Woodmansee for her expertise in the microscopic analyses of these samples.

Procedures and Methods

Four composite samples of dung were obtained in the Lake Mead National Recreation Area in late March, 1972. Cow dung appearing to be "fresh" to several years old was collected on the south side of the Colorado River between Rampart Cave and Columbine Falls. About 3 grams from each of about 40 different locations were combined in a composite sample of about 140 grams. Cattle were not seen in the area.

Bighorn sheep pellets were obtained from beneath an overhang of Muav limestone within 1 km of Rampart Cave. Most pellets were light brown and very few appeared to be recent droppings.

On the north side of the Colorado River, opposite Muav Cave, burro dung occurs abundantly on the exposed flats of an earlier delta of Lake Mead. About 12 grams of fresh burro dung (March diet) were collected from four locations where recent deposits had been made. Burros were seen or heard daily. Burro dung believed to represent various seasons and perhaps greater than 1 year in age was obtained from 50 random locations (annual diet). About 1 gram was collected

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at each location. High temperatures and infrequent precipitation in the area insure long preservation of organic litter on the soil surface.

Twenty microscope slides were made from each of the four composite samples for each species of animal according to the technique of Sparks and Malechek (1967). Twenty systematic random microscope fields were examined for each microscope slide preparation. When a fragment was discerned that matched similar-appearing plant fragments of reference slides of identified plant species, the fragment in the dung was then assumed to be from the species of reference plant. Relative percent density of discerned plant fragments was calculated as described by Sparks and Malechek (1967). Analyses were based on comparisons with 105 species of vascular plants from the vicinity of Rampart Cave. These represent all the dominant plants and "likely" forage species and most of the more uncommon plants found by Martin during five trips to the cave at all seasons.

Table 1. Percent relative density of plant fragments discerned in burro, cattle, and bighorn dung from near Lake Mead, Grand Canyon, Arizona, 1972.

Names of plants	Cattle annual diet	Burro annual diet	Burro March diet	Bighorn annual diet
Tridens sp.	26.8	13.8	4.9	10.5
Ephedra nevadensis	15.3	0.1	0.2	9.4
Muhlenbergia porteri	15.0	24.9	15.3	11.9
Sphaeralcea sp.	5.1	4.1	3.1	52.2
Bromus rubens	3.4	7.3	43.8	1.1
Tidestromia oblongifolia	0.1	1.1	0.1	2.6
Phragmites communis	0.1	7.6	0.8	
Acacia constricta	21.1	4.1		3.0
Hilaria rigida	2.5	0.1		
Opuntia sp.	0.6	4.7		0.1
Prosopis juliflora	5.4			0.1
Seed	0.1			0.1
Stipa speciosa	1.5		0.3	
Agave palmeri	0.6		0.4	
Krameria parvifolia	1.5			
Yucca newberryi	0.5			
Astragalus-Oxytropis	0.1			
Lichen	0.1			
Aristida wrightii		14.7	4.1	7.2
Tamarisk pentandra		9.1	3.3	
Forb (*Nolina ?*)		4.7	1.6	
Peucephyllum schottii		0.1	0.9	
Eriogonum sp.		2.7		1.2
Phoradendron californicum		0.2		0.1
Artemisia sp.		0.4		
Carex sp.		0.2		
Lycium sp.		0.1		
Crossosoma bigelovii		0.1		
Agropyron sp.			10.7	
Plantago insularis			5.3	
Forb (*Oenothera ?*)			4.0	
Franseria dumosa			1.8	
Lappula sp.			0.8	
Fraxinus anomala				0.6
Aster biglovii				0.1

Results and Observations

The four most important plants in the annual diets of cattle were *Tridens*, *Acacia*, *Ephedra*, and *Muhlenbergia*, which together made up 78% of the diet (Table 1). Five plants, *Muhlenbergia*, *Aristida*, *Tridens*, *Tamarisk*, and *Phragmites*, made up 70% of the annual diet of the burro; *Bromus*, *Muhlenbergia*, and *Agropyron* made up 70% of the diet in March. The most common five plants eaten by bighorns were *Sphaeralcea*, *Muhlenbergia*, *Tridens*, *Ephedra*, and *Aristida*, which made up 90% of the diet.

It has been reported that bighorn sheep on desert shrub ranges are often in serious competition with the burro and cattle for food plants and until the vegetation recovers in some localities, the bighorn population cannot increase (Russo, 1965). Cattle and bighorn diets overlap strongly for *Tridens*, *Muhlenbergia*, and *Ephedra*; but cattle diets contain only 5% *Sphaeralcea*, which was the principal component of the bighorns' diet. *Sphaeralcea* is not common on the flats and slopes used by cattle, but it is one of the most common plants on slopes used only by bighorns.

Burros and bighorns occurred on opposite sides of the Colorado River where we obtained the samples; but since most of the principal plants in both ungulates' diets were eaten by both, intense food competition could possibly develop wherever they were forced to live together. McMichael (1964) reported 50% to 58% of the plants in the diets of burros and bighorns are shared.

The March diet of the burro reflects, in part, the availability of green, growing plants. *Bromus*, *Muhlenbergia*, and *Agropyron* were in green growth stages at the time the sample was obtained, and as soon as these plants reach maturity we would expect them to become of minor importance in the diet of the burro.

It appears that grass remains are much more abundant in the dung of cattle, burro, and mountain sheep than in the dung of the extinct Shasta ground sloth. As Martin et al. (1961) concluded, the browsing niche occupied by the extinct Shasta ground sloth in the Pleistocene remains unfilled.

Competitiveness among ungulates for plant species might be underestimated when only the annual diets are compared, and the amount of competitiveness between given ungulate species within each range type could vary. The seasonal availability of preferred plants and the responses of plants to grazing are important factors that need to be studied before the magnitude of ungulate competition for forage plants can be understood.

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MANAGEMENT NOTES

Spot Treatment for Gambel Oak Control

JOHN F. VALLENTINE AND DEWAYNE SCHWENDIMAN

Highlight: *Gambel oak can be effectively eliminated in localized, small scale projects by (1) foliage spraying with picloram-silvex at a 1:2 lb a.e./acre rate, (2) basal stem spraying with silvex, 2,4,5-T, or picloram, (3) soil application of picloram granules at 4 lb a.e./acre, or (4) complete top removal followed by root raking.*

Gambel oak (*Quercus gambelii* Nutt.) occurs naturally on several million acres of land in Utah, Colorado, New Mexico, and Arizona. It is found principally from 5,000 to 9,000 ft elevation in areas receiving 14 to 20 inches of average annual precipitation. Stand density varies from very dense thickets to open stands intermixed with serviceberry (*Amelanchier alnifolia*), mountainmahogany (*Cercocarpus montanus* and *C. ledifolius*), chokecherry (*Prunus virginiana*), maple (*Acer glabrum* and *A. grandidentatum*), cliffrose (*Cowania stanisburiana*), and snowberry (*Symphoricarpos* spp.). Sites dominated by Gambel oak frequently alternate with pinyon-juniper, sagebrush-grass, and ponderosa pine sites.

Growth form of Gambel oak varies at maturity from shrubby growth 3 to 10 ft high to clumps of trees up to 30 ft high on deep soils. Gambel oak produces rather unpalatable forage, prevents access of grazing animals, and is a high water user. Although it does provide some cover, browse, and mast for wildlife and is valuable for watershed protection on steep, erosive sites, its high water use and reduction of more desirable forage species often makes its partial or complete elimination desirable on productive sites and special use areas.

The authors are professor of range science and graduate student, Department of Botany and Range Science, Brigham Young University, Provo, Utah.

Gambel oak typically grows in mottes characterized by many stems, a dense, connecting, underground root system, and extensive vegetative reproduction. Because of prolific sprouting from buds on the roots and stem bases following top removal whether by fire, mechanical means, or contact herbicides, the eradication or intensive control of Gambel oak is difficult and costly. Seedbed preparation techniques in widespread use on big sagebrush (*Artemisia tridentata*) such as disk plowing, chaining, and burning, are ineffective on Gambel oak and often increase its density. Effective broadcast control techniques are still being developed but generally require chemical treatment.

Local Treatment

However, there are several effective treatments that can be used to eliminate Gambel oak on small, localized sites, where higher control costs per acre are easily justified. Such sites include land being cleared for cultivation, roadways, residential areas, golf courses, and industrial sites. On farms and ranches local removal may be needed on sites for buildings, corrals, dams, fences, and trails. Eliminating Gambel oak and other woody vegetation in the vicinity of springs and seeps can also materially increase effective yield of stockwater. The best control method will depend upon density and size of Gambel oak plants, equipment

Table 1. Herbicidal control of Gambel oak in spot treatment at Spanish Fork, Utah, 1968-72.[1]

Herbicide	Application method	Application rate	Results
Picloram	Foliage spray	1 lb a.e./acre	25% top kill, 5–15% plant kill
2,4-D	Foliage spray	2 lb a.e./acre	25–50% top kill, 5–15% plant kill, sprouting prolific
Silvex	Foliage spray	2 lb a.e./acre	40–70% top kill, 20–40% plant kill, moderate sprouting
Silvex	Foliage spray	2 lb a.e./acre (repeated following year)	60–90% top kill, 50–75% plant kill, low sprouting
Silvex-picloram	Foliage spray	2:1 lb a.e./acre	85–100% top kill, 75–95% plant kill, minimum sprouting
2,4,5-T	Basal stem spray	16 lb a.e.h.g. (diesel carrier)	Nearly complete kill, minimum sprouting
Silvex	Basal stem spray	16 lb a.e.h.g. (diesel carrier)	Nearly complete kill, minimum sprouting
Bromacil	Basal stem spray	12 lb a.e.h.g.	Nearly complete kill, gradual killing
Picloram	Basal stem spray	8 lb a.e.h.g.	Kill complete, no sprouting, slow action
AMS	Basal stem spray	90% concentration	50% top kill, 25% plant kill
Picloram	Soil application	2 lb a.e./acre	80% plant kill, minimum sprouting
Picloram	Soil application	4 lb a.e./acre	100% plant kill, no sprouting

[1] With the application methods and rates reported here, perennial grasses were not materially affected except around the stems basally sprayed with bromacil.

availability, and purpose of oak clearing.

Chemical Control

Several herbicides utilizing foliage spray and basal stem and soil application provide practical means of eliminating Gambel oak in spot treatment. Herbicidal control trials reported in Table 1 were carried out since 1968 on Brigham Young University Farm near Spanish Fork, Utah. The study site containing Gambel oak in mottes comprised a west slope with silt loam soil receiving 15 inches average annual precipitation.

The 1 lb picloram-2 lb of silvex (or 2,4,5-T) was the only single-application foliage spray that gave effective control of mature Gambel oak. This apparent synergic effect was in contrast with picloram or silvex applied separately, neither of which adequately controlled the Gambel oak. Application of two pounds of silvex per acre in each of 2 successive years gave up to 90% top kill but only 50 to 75% plant kill. Although picloram-2,4,5-T mixtures were not applied to mature plants, use at 1:2 lb/acre ratio in related studies with oak sprouts and saplings suggested it would probably be as effective as the picloram-silvex mixture at equivalent rates. Some maintenance control in subsequent years following foliage application of herbicides may be required.

When applied as a basal stem spray to stems up to 6 inches in diameter, 2,4,5-T, silvex, and picloram were all very effective, but AMS was ineffective. Plants basally sprayed with bromacil went through a series of leaf drops; but after three growing seasons, most stems in the mottes treated were apparently dead. In the basal stem application, an attempt was made to saturate the lower 15 inches of each stem. Apparently, silvex, picloram, and bromacil applied basally was readily translocated through roots of Gambel oak, since stems located in excess of ten feet on the uphill side of study plots were killed. This plus the evidence that most stems in a Gambel oak motte underground root system, indicates it may not be necessary to treat all stems in mottes with marked boundaries.

Temporary soil sterilization with picloram granules at 4 lb a.e./acre provided another effective means of killing Gambel oak by spot treatment. However, this method requires adequate rainfall to carry the herbicide into the soil. When applied in late spring prior to a drought year, apparent herbicidal effects were delayed up to 15 months.

Mechanical Control

Gambel oak on deep soil sites can also be eliminated by intensive mechanical methods. Bulldozing followed by root raking to remove underground plant parts capable of sprouting is an effective approach. Mashing and burning followed by root raking can also be used. Where shallow or rocky soils prevent roots being combed from the soil, herbicidal treatment following top removal will generally be required. Since Gambel oak commonly occurs on heterogenous soils of varying soil depth and rockiness, plowing with a sweep-blade rootplow is seldom practical.

Musk Thistle *(Carduus nutans)*: An Undesirable Range Plant

A. C. HULL, JR., AND JOHN O. EVANS

Highlight: *Musk thistle, a spiny, unpalatable biennial plant native to Europe and Asia, is becoming widely established on western ranges. It is a vigorous grower and prolific seed producer and is spreading rapidly to uncultivated areas and wild lands used for ranges and watersheds. Though musk thistle spreads faster and is more vigorous where there is little plant competition, it is also spreading and growing well in good native and seeded ranges and in irrigated pastures and meadows. It is relatively easy to control with herbicides. It should be controlled before it spreads to larger acreages.*

Musk or nodding thistle (*Carduus nutans* L.), a plant native to Europe and Asia, is now widely established on western ranges. This thistle was introduced over 75 years ago into the eastern United States, where it apparently is not a serious problem. Though this plant has been sparingly established on midwestern and western ranges for a long time, only recently has it increased, become a problem, and been declared a noxious weed (Higgins, 1966; Furrer and McCarty, 1966; Nilson, 1969; Alley and Lee, 1969; Holmgren and Andersen, 1970; Jensen, 1970).

Description and Growth Characteristics

Musk thistle is a vigorous, aggressive plant with large, showy, purple flowers. Terminal heads are born singly on a relatively leaf-free stem and are usually at right angles to the stem. Lower down, the stem has clasping, spiny leaves. The stout, spiny, spreading involucre distinguishes this plant from other thistles. Plants are normally about 36 inches tall and have 10 to 100 seedheads, but they vary greatly in size with site and growing conditions. In southeastern Idaho, plants growing in a good stand of native vegetation varied from 8 to 40 inches (20 to 102 cm) in height and had from 1 to 40 or more heads. A single thistle was growing a few feet away on the edge of a wheat field with little plant competition. It was 6 feet (1.8 m) tall and widely branched and had 643 seedheads (Fig. 1).

Fig. 1. *A robust musk thistle along the fence line in a dry-land grain area north of Soda Springs, Ida., is 6 feet (1.8 m) tall and has 643 heads.*

Musk thistle is a biennial or winter annual in that it forms a rosette in spring, late summer, or fall and then develops flowers and seeds the next year (McCarty and Scifres, 1966). Flowers and seeds are produced over a long period. Seed production begins with the maturing of the first flowers in June and continues as later flowers mature until after fall frost (Fig. 2). The seeds or achenes are attached to plumes or plume bristles and can be carried long distances, primarily by wind and to a lesser extent by water, animals, machinery, and vehicles (Fig. 3).

Musk thistle is an abundant seed producer. Ten large terminal seedheads from plants in southern Idaho, northern Utah, and western Wyoming had an average of

The authors are range scientist, Agricultural Research Service, U.S. Department of Agriculture; and assistant professor, Department of Plant Science, Utah State University, Logan.

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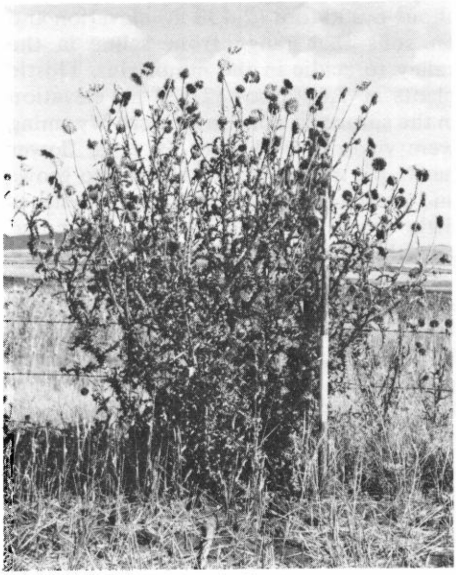

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535 seeds; one large head had 752. Ten smaller heads midway up the stem averaged 298 seeds. Assuming 40 heads per plant and 400 seeds per head, this is 16,000 seeds per plant. Seeds collected in Idaho, Utah, and Wyoming in September 1972 averaged 81% germination when placed in moist sand in the greenhouse. Most seeds germinate readily, but some remain dormant in the soil for 4 or more years (Higgins, 1966).

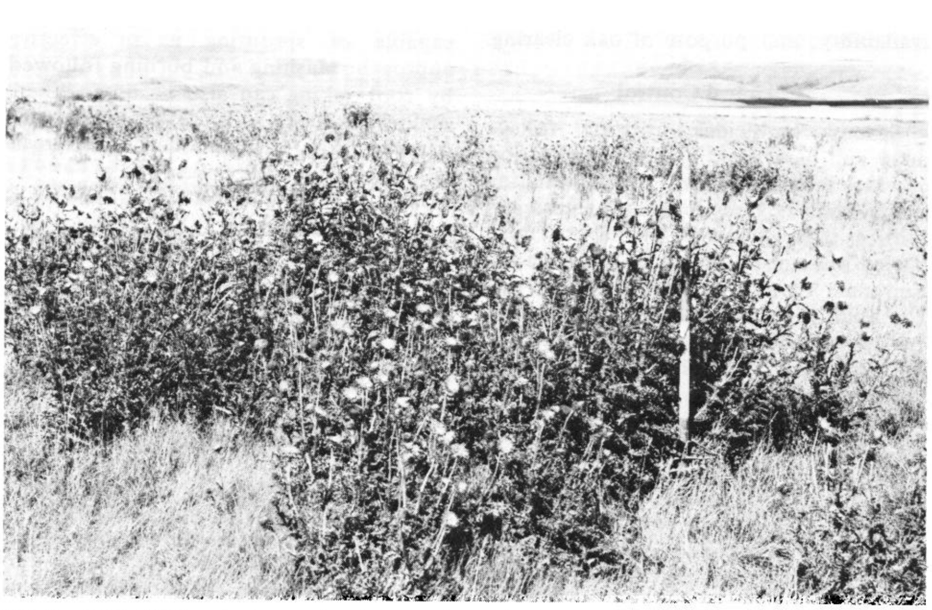

Fig. 4. *Musk thistle plants growing in a good stand of native vegetation on rangeland north of Soda Springs, Ida.*

Adaptation

Musk thistle has a wide range of adaptation. It grows from sea level to about 8,000-foot (2,438 m) elevation and on soils that range from saline in the valley to acidic in the mountains. Thistle plants at 7,000-foot (2,134 m) elevation in the spruce-fir zone in western Wyoming were vigorous with over 50 large flower heads per plant. Musk thistle also grows and produces viable seed in areas with as little as 10 inches (25 cm) of annual rainfall.

Because musk thistle is a biennial and does not resprout, plants may be easily killed by cultivation and also controlled by mowing; hence, it is not a major problem on either dry or irrigated cropland. It is spreading fastest and is most abundant along roadsides, fencelines, and areas with poor stands of vegetation. Though musk thistle plants are larger and more vigorous where there is little plant competition, musk thistle plants are also spreading and growing well in good native and seeded ranges, irrigated pastures, and in wet meadows with dense stands of grasses, rushes, and sedges (Fig. 4).

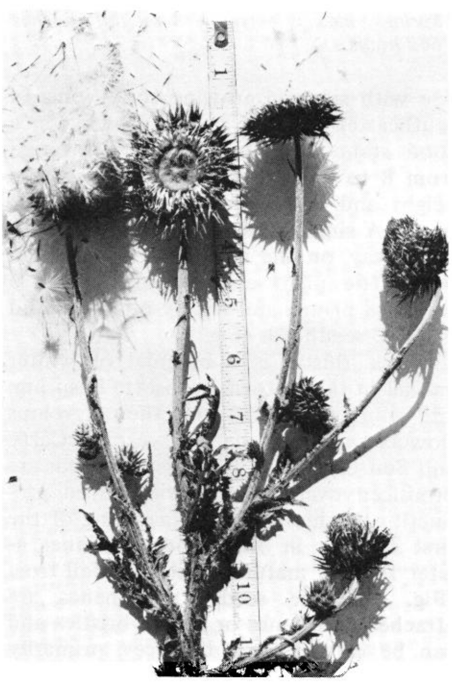

Fig. 2. *Flower heads on a branch of a musk thistle plant range from small seedheads in bud on the lower stems to seedheads at the top where the seed has long since disseminated.*

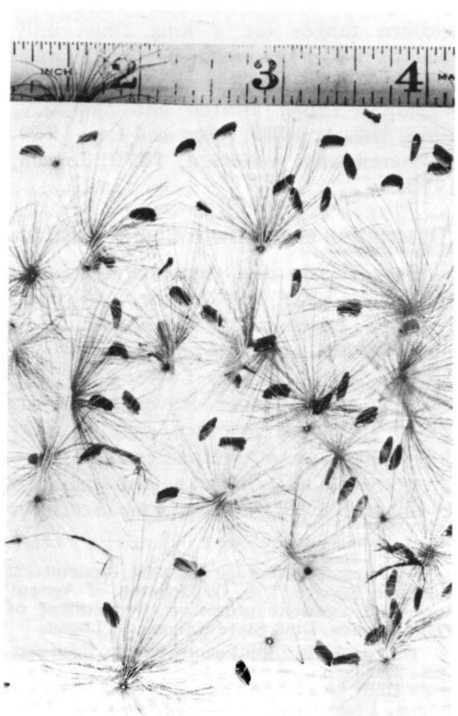

Fig. 3. *Seeds of musk thistle showing plumes capable of carrying the seeds long distances on the wind.*

Control Methods

Musk thistle is relatively easy to control with herbicides. One pound of 2,4-D (2,4-dichlorophenoxyacetic acid) mixed with 1/2 pound of dicamba (3,6-dicholoro-*o*-anisic acid) in 30 gal of water per acre gives excellent control. Although not registered, a mixture of 2,4-D and picloram (4-amino-3, 5,6-trichloropicolinic acid), mixed as above, is also effective in controlling musk thistle (Jensen, 1970).[1] Picloram beads are easy to use and are effective on small patches or isolated plants. Herbicide treatments may be applied in spring or fall when plants are in the rosette stage and most certainly before the flower heads begin to form.

Individual plants may be cut below the crown at any time. If cut plants have flower heads, these should be burned or otherwise destroyed so that the seeds will not mature. The possibility of biological control with insects is being investigated, and hopefully this method will have promise.

Is Control Feasible and Desirable?

A survey was made of the western states and some midwestern states where musk thistle poses a problem. In addition, 30 counties in Idaho, Utah, and Wyoming were asked to survey their musk thistle infestations. All of the county extension workers who replied, most state workers, and published reports indicate that musk thistle is a problem and that control should be undertaken immediately while infestations are small (Furrer and McCarty, 1966; Higgins, 1966; Nilson,

[1] Dicamba and 2,4-D are registered with the Environmental Protection Agency for use on rangelands, pastures, noncrop lands, fence rows, and similar areas. Picloram is registered for use only on rights-of-way, roadsides, and other areas that will not be cropped or grazed. All chemicals should be applied in accordance with directions on the manufacturer's label.

1969; Alley and Lee, 1969; and Jensen, 1970). To let musk thistle grow in waste places and on watershed lands will furnish seeds to infest pastures, meadows, and rangelands where it reduces the amount of forage available and hinders the movement of grazing animals. Also, most people do not like its sharp spines on picnic and camping areas.

The best way to prevent or reduce the amount of musk thistle is to deny it a suitable habitat. Therefore, areas that are susceptible to invasion by musk thistle or from which musk thistle has been eradicated should be treated or managed so that they will grow good stands of vegetation that will prevent or at least slow down reinvasion of this and other undesirable plants.

After an area has been treated and all thistle plants have apparently been killed and the land has been revegetated, control methods must be continued for plants that were missed, plants from seeds that were in the soil, and reinvading plants from seed from adjacent areas. Successful weed control is not a once-over treatment. It can be achieved only with follow-up to prevent reinfestation. Because this plant is a prolific seed producer and the seeds can be carried long distances, control should be simultaneous on all lands, both public and private.

Some Utah ranchers with large infestations of musk thistle on rangelands have been able to control the plant. However, because their lands have recurrent infestations from adjacent lands, they practice recontrol on a continuing basis.

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VIEWPOINT

Grazing Systems: A Least Cost Alternative to Proper Management of the Public Lands

Is economics research in range resources effectively meeting the needs of the public land administrator in decision making? I contend it is not, and I hope my comments will stimulate some of my fellow economists to expand their views and efforts in research in this field.

I start with an hypothesis that has not been empirically tested. We who support the hypothesis do so only on the basis of visual analyses and gut feelings that we are right. Our hypothesis is that properly designed grazing systems on public rangelands suitable for livestock use are the least cost alternative of meeting many of the major objectives and responsibilities of public land management agencies.

In this day of the environmental movement we hear many criticisms of the economist, his economic tools, and the concept of progress and profit at the alluded-to degradation of the environment and the quality of life. A recent New Yorker cartoon had this caption, "I guess we have to pay for the higher standard of living by a lower quality of life."

It is common to hear such statements as: "On a purely cost-benefit basis it just wouldn't pay to save planet Earth" (Maurice Strong); "The Planet is perishing on prescriptions written only to serve the cash register" (Russel Train); and "Economic success may result in social, environmental, and ecological collapse" (Barkley and Leakler).

One economist, in all seriousness, once asked me, "Why worry about erosion? If it doesn't pay to stop it, let it erode." I think there is much in this response that points up the problem. Economists are invariably trained in economic analysis developed to guide decisions in the private sector of the economy. They have effective tools to evaluate costs and returns to the businessman or rancher as long as values can easily be put in dollar terms. However, too often they fail to consider long-range social costs or consequences of man's activities, and they give only lip service to those non-market benefits and disbenefits that might result.

For decision making in management of public resources we must abandon exclusive reliance on economic tools designed primarily for the private sector. Instead we must utilize tools capable of guiding public decisions aimed at achieving multiple objectives, some of which will be subjective in nature.

A major responsibility of public land management agencies is to carry out the intent of Congress as indicated in enacted legislation. For example, major overall umbrella type objectives of the Bureau of Land Management are spelled out in such legislation as the Taylor Grazing Act and the Classification and Multiple Use Act which, though no longer in force, is still followed. Some of these responsibilities are: Stop injury to the public grazing land; provide for the orderly use, improvement, and development of the public lands; stabilize the livestock industry dependent upon the public lands; and manage the public lands to best meet present and future needs of the American people. It is stated in the Multiple Use Act that in determining values the greatest dollar return or the greatest unit output is not necessarily the major consideration.

There is no doubt Congress intended that agencies should carry out these responsibilities in an efficient and effective manner. I believe the intent of Congress can best be met by determining the least cost methods of meeting these objectives. However, most people who have been doing research on the economics of range resources have had improperly designed studies to be of much value to decision making for the public land administrator. Range economics research to date has essentially been *farm management research* geared to profit maximization for the rancher. Almost exclusively the researchers have attempted to measure the benefit of range improvement through development or management in terms of increased AUMs of forage or increased pounds of beef or lamb. They sometimes give lip service to intangible values but essentially they measure only the values easily converted to dollar terms. This same reasoning has carried over into studies on the economic evaluation of grazing systems.

A major objective of grazing systems in public land management is to maintain or improve range condition. Good range condition is the key to assuring most renewable multiple uses of the resource and sustained yields of resource values. Realistic dollar values cannot be placed on range condition per se. Therefore, economists have concentrated on evaluating only one of the products of the grazing system, increased forage production for livestock, which to the public land manager may not even be the most important product. For example, some grazing systems have been designed to increase browse species for critical winter range. These systems allow livestock to heavily utilize the grass species in the spring and then the livestock are taken off before they start to make significant use of browse. Increased forage production for livestock is not the goal. In fact, if needed, livestock use would be reduced to increase browse production on these critical big game ranges. Narrowly oriented evaluation systems using conventional benefit-cost analysis would probably show this as a questionable economic practice. But why would it be questionable? Because profit-motiviated tools and accountable dollar values are the only methods used for evaluation. Rather than worry about benefit-cost evaluations that are often arbitrary and dubious at best, wouldn't it be much more useful to try to determine if the grazing system is the least-cost method of obtaining the mix of multiple use values desired?

Today, with the public becoming ever more aware of the environment, the role of proper livestock management as a constructive tool in proper resource management is increasingly misunderstood. Many of the special interest groups regard livestock grazing as the principal problem in the destruction of wildlife habitat, erosion of the watershed, siltation of rivers and reservoirs, fouling of recreation sites, and destruction of scenic landscapes. They may be right if it is uncontrolled, season-long livestock grazing. However, we know from experience that livestock grazing is about the only factor of range resource management that can be effectively controlled to produce beneficial results. Good vegetative cover is the base for many of the uses of the range resource. Food and cover for wildlife, protective cover on the watershed, forage for livestock, and to some extent, scenic landscapes are all dependent upon the quality and quantity of vegetation. Livestock grazing management can be and is being used to manipulate the vegetation to serve these varieties of use. Properly managed grazing through grazing systems provides a most effective and efficient means for developing and perpetrating the range condition that is so important to this variety of resource values.

The economist, however, in the very narrow vein of benefit-cost analysis where increased forage is used as the key and often only benefit, can provide a misleading picture and additional ammunition to groups that are fighting livestock grazing on public lands. The final analysis usually shows that it costs "x" amount for each additional AUM and that the cost exceeds the benefits of the AUM as livestock feed; therefore, they state unless you can impute that other intangible values are at least equal to the cost difference, then it is a questionable economic practice.

Unfortunately, in such results the computed benefit-cost ratio is usually the only figure remembered or quoted and it adds fuel to the fire of some of the environmental groups who contend the taxpayer's money is being spent to subsidize grazing. Also, such ratios make it increasingly difficult to obtain adequate appropriations for range management. In my opinion such research is more of a disservice than a benefit to public land management, and such research should be more properly confined to private lands where profit is the major objective.

Another major problem with current economic studies of grazing systems is that the researchers use a "before and after" rather than a "with and without" evaluation. For example, their studies show the situation before initiation of a grazing system, which is compared to the condition after the grazing system has been established. Such an analysis assumes that had the system not been initiated, conditions would have remained static and there would have been no change. Therefore, they conclude the benefits are only the increased AUMs or pounds of beef and lamb produced and they compare the costs to increased production. They fail to take into consideration what actually would have happened had there been no grazing system initiated. For example, in a group allotment on public lands in Idaho, if there had been no change in livestock management, it would have required about a 54% reduction in livestock use. However, by entering into a grazing system, in this case a rest-rotation system, 30-some permittees were allowed to continue with no reduction because it was believed the area had the potential to carry the livestock use if properly managed. This proved to be the case, and the condition of the range has greatly improved to the point where additional livestock use may be allowed in the future. Current methods of "before and after" evaluation based on increased AUMs only would show little benefit for the money spent and would fail to show the true value of the grazing system in meeting one of BLM's responsibilities—stabilization of the livestock industry.

Economists are not unaware of the problems and possible deficiencies in their research on grazing systems. They state, and rightly so, that is is often impossible to determine what would have happened had the system not been initiated. They don't have the convenient homogenous types of test plots of the physical researcher that they can check results against. Grazing systems, usually large scale and nonduplicative, are not well designed for precise research evaluation.

Since the economist is hung up on the benefit-cost approach, he is faced with the difficult, if not impossible, task of quantifying and placing values on the nonlivestock grazing benfits. Usually, from evaluation of the literature, we find the economist assumes this problem away by making such statements as "However, the problem of quantifying changes in nongrazing benefits can be circumvented by the concentrating on the measurement of changes in livestock AUMs." Or he can get into philosophical discussions of whether the BLM is a proprietary agent of the Federal Government or an agent of the sovereign, which allows him to state: "As a proprietary agent managing an enterprise owned by the Federal Government, the BLM can count as increased benefits from grazing systems only those which result in additional revenues." Or another approach might be used, such as: "Only measurable returns and costs have been included in [our] equations. This is not to deny the existence or importance of nonmeasurable or difficult returns to measure ... [but]. Rather than attempt to measure these returns directly, the approach taken in this study is to impute values to these external benefits....(for example) if the present value of the net returns computed according to [our] equation is negative the absolute value of this negative amount would indicate the imputed worth of all external benefits." They would then go on to explain that if the negative amount isn't in fact their value, it is at least the amount society would have to pay to obtain them. If the amount in the equation is positive rather than negative, then all unmeasureable benefits are merely ignored because now it is assumed that public investment can be justified because it has been proven profitable in terms of returns to the single user group, the ranchers. These and similar statements and approaches can be found throughout the various studies.

I have no doubt belabored the point but I hope I have been able to get across to you the relative unusable nature of the results of such research to the public land administrator in carrying out his agency's responsibilities. I hope you can understand the frustration caused because more useful economic measures for decisions in public resource management have not been developed.

The public land manager, then, is faced with the problem of carrying out his agency's goals, objectives, and responsibilities. The basic overall responsibilities are spelled out in legislation. The specific objectives and means of meeting these responsibilities are detailed in the agency's action plans; in the case of BLM, the Management Framework Plans. In the past we have often looked to mechanical means of resolving problems or avoiding difficult management decisions by using such practices as range reseeding, chaining, contour furrowing, ripping, pitting, spraying, etc. Some of these practices have been successful; many have not. Certainly the effectiveness of a number of these projects in meeting agency responsibilities is open to question.

There is no doubt some past land treatment projects have been valuable, and various of these practices will, under certain circumstances, continue to be needed in the future. However, turning to grazing systems, we find that with using only properly located water developments and fencing, coupled with properly managed livestock, we can, in many, many cases, produce more effective results than through mechanical land treatment. The examples are many under a great variation of topographic and climatic conditions.

In closing, then, I return to my initial hypothesis—that properly designed grazing systems developed in conjunction with the agency's overall action plans for an area, are the least cost alternative of meeting the major objectives and responsibilities of government agencies in managing public rangeland resources.

My challenge to the research community is to develop research proposals designed to carry out evaluations that will either accept or reject this hypothesis. It will not be just a problem for the economists. Physical scientists will also be needed for the major job of determining and quantifying the physical effects, both beneficial and nonbeneficial, of grazing systems.—*Glen D. Fulcher,* Bureau of Land Management, Denver, Colorado.

BOOK REVIEWS

Natural Ecosystems. By W. B. Clapham, Jr. The Macmillan Co., 866 Third Avenue, New York 10022. 248 p., 1973 $3.95 paperback.

This is an age of environmental awareness. The dialogue between the watchdogs and the villains—between protectors of environmental quality and those accused of violating it—is peppered with popularised ecological phrases, prejudices, and misconceptions. There is a pressing need for hard evidence on what constitutes "acceptable levels of environmental degradation," for comprehensive data on which to confidently base environmental impact statements, and for equitable and enforceable legislation controlling human impact on our ecosystems. All this has come a little too soon for the comfort of ecologists, who are, after all, exploring a relatively young science of extreme complexity and must often rely on intelligent guesses rather than direct experimental data to answer pertinent questions on pollution, predator control, destructive recreation, etc.

The upwelling of public interest in ecology is being matched by a flood of general ecology texts, whose contents must fill the need for variety of approach and treatment to satisfy particular interests and backgrounds. Many of these books are designed as introductions to ecosystem biology, and most aim at the college student market. Clapham's *Natural Ecosystems* is one of a pair of such texts. The second, in preparation, is concerned with human intervention in ecosystem dynamics.

Arrangement of material in *Natural Ecosystems* is in step with conventional approaches, being grouped into abiotic components, energy flow and nutrient cycle, populations dynamics, niche structure and communities, aquatic ecosystems, terrestrial ecosystems, and a concluding chapter on environmental perturbations, which whets the appetite for the promised sequel text.

Presupposing a minimal "feel" for biology, the book provides a description of ecosystems and principles of ecosystem processes for both the student and extracurricular enquirer, with little emphasis on human impact. It is worth noting that Clapham's review of terrestrial ecosystems is balanced by his coverage of aquatic systems and that his discussion of climatic influences and transfer of energy and matter is well-rounded and eminently digestible for the untrained scientist.

The major thrust of the text is intentionally descriptive, concentrating on the properties of components in ecosystems with less emphasis on interactions between components and minimal discussion of the experimental dimension of ecological knowledge. This approach is satisfactory for a reader already interested in ecology, but for the "unconverted" it offers little challenge to proceed with the more pedestrian material in the latter portions of the book. Stimulation of one's curiosity should be a feature of introductory texts, particularly when dealing with a subject of such fascinating complexity and so pertinent to the future welfare of mankind. Though Clapham has presented ecology in a straightforward and readable manner, he has sacrificed a good deal of the excitement in current ecological research. These demerits are relevant when reviewing a text that is entering a highly competitive paperback market.

There are occasional points in the book over which ecologists may quibble, such as the statement that "without members of the grazing food chain such as deer, nitrogen bacteria would have no nitrogenous wastes to feed upon." There are also aspects which ecologists may find frustrating, such as the failure to identify species in several photographs, the limited treatment of quantitative relationships, and the frequent use of generalizations unsupported by examples from published research. On the whole, however, *Natural Ecosystems* succeeds as an excellent introduction to concepts and components in the natural world with which we live.—*B. E. Norton,* Utah State University, Logan.

ALSO WORTH NOTING

Two 1973 releases by the Tall Timbers Research Station of Tallahassee, Florida: **Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management** (Tallahassee, February 24-25, 1972). There are 16 papers, dealing primarily with invertebrates as pests; 244 p. **Proceedings, Annual Tall Timbers Fire Ecology Conference** (No. 12), held in Lubbock, Texas, June 8-9, 1972. Meets their usual high standards of presentation, illustrations, and printing. There were three sessions: grasslands, wildlife, and national parks; 27 papers in a total of 492 pages.—*R. S. Campbell,* Quincy, Illinois.