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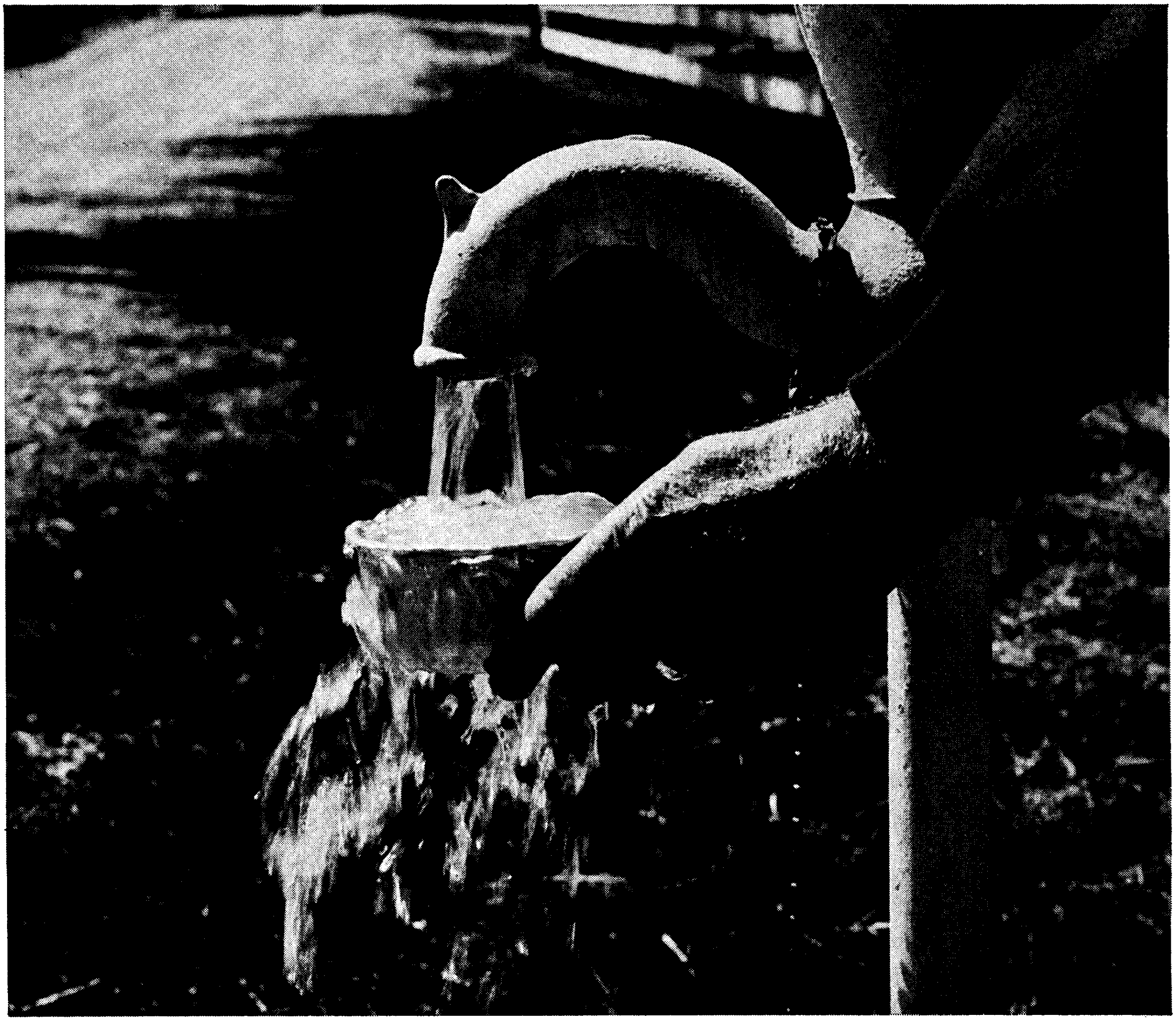

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Cover Photo—Wild Turkey in Upland Habitat,
Uvalde County, Texas.
Photo by Jack Stevens, Soil Conservation Service, Montell, Texas.

Social Welfare and Integrated Resource Management[1]

DILLARD H. GATES

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Highlight

Resource management decisions cannot be properly made based upon single use but must give full consideration to alternative uses or combinations of uses. The impact of uses upon resources must be evaluated. The soundness of management decisions must be evaluated on the basis of their impact upon human welfare. A philosophy of integrated resource management will reflect concern for both resources and people.

The dependence of man upon resources is legend.

The demands placed upon wildland resources by a growing, mobile, affluent and leisure-time oriented population is a legend in our time. Despite accelerating demands upon wildland resources, we do not understand the complex interactions between resources and man. We have limited knowledge and a partial understanding of the impact of various land management decisions upon resources. In many cases, decisions may have been made and forgotten without monitoring or evaluating either their direct or side effects. Only in comparatively recent times have we become particularly concerned about the full impact of man's actions upon resources. Concern for the lack of understanding of the impact of resources and resource use upon man is of even a more recent vintage. In fact, it is just emerging.

An increasing, but still limited, part of the population now realizes that wildland resources are limited. This realization alone has placed additional stress on an already stressed human environment. We now worry not only about how to acquire additional resources for human use but also about how our use of resources adds to their scarcity or contributes to their depletion. We (at least some of us) now realize that man must "make do" with what he now has and that what he now has is both limited (Planet Earth) and limiting insofar as human welfare is concerned.

Although resources are limited the seemingly limitless population growth makes increasing demands on resources. Therefore, it is imperative that land use decisions or schemes of management optimize production of goods and values from wildland resources over the long run. We can no longer afford expedient short-run economic optimization.

Goods and values derived from wildland resources are assumed to be necessary or desirable from the standpoint of the social welfare of man. A nation-wide policy of integrated resource management, embracing both public and private lands, is needed to achieve the goal of optimizing production of goods and values from wildland resources over the long run.

D. A. Smith[2] defined integrated resource management as, "The application of management strategies to achieve the maximum output from the optimized use of natural resources of a specific area for the benefit of a referent-group and its successors." This definition provides a framework within which to achieve the public goal for resource management.

Our representative form of government contains the mechanisms to translate public attitudes into goals as well as action to accomplish these goals. Individuals and groups set society's goals by articulating their desires and through the ballot box. Society's goals should provide the conceptual framework for planning, establishment of objectives and their implementation.

Some goals for resource use have been identified through legislation such as the Multiple Use, Environmental Protection and Environmental Quality Acts. Many individuals and/or groups may not fully support either the legislation or the goals. We assume these goals do reflect the attitude of the broad public today on matters of resource management and environmental quality.

Expressed goals, no matter how noble, are merely rhetoric until supported by objectives designed to accomplish the goals and implement objectives. For example: a goal set by society may be to enhance and protect the environmental quality of rangelands. To reach this goal, certain specific things must be done—that is, objectives must be set. An objective may be to restore vegetation to its natural state on specific areas. However, this objective is still meaningless unless implemented. This means planning, funds, and manpower. Thus, the planning process for integrated resource management must embrace setting of goals, establishment of objectives and implementation of actions necessary to accomplish the objectives. No plan is complete unless it includes methods for implementation.

The resource manager generally gets into the planning loop when objectives are established or the implementation of action to accomplish objectives that have been set by others. The proper point to insert resource management expertise into the planning process is a moot question. I feel it should be much sooner. However, significant resource manager inputs generally follow broad policy decisions or setting of goals. This procedure frequently places the resource manager in the difficult position of being asked—required—expected—or ordered to carry out or develop resource treatments or management

[1] Received for publication April 24, 1972.

[2] Master of Forestry thesis, University of British Columbia, 1969.

schemes not compatible with ecological characteristics of wildland resources. In other words, the resource manager may be committed to action as a result of decisions made by others who had less than the best possible knowledge and understanding of the problem.

We should recognize that resource managers do not always utilize fully all information available in their resource management decision-making processes. This is especially true when the decision maker is strongly single discipline-oriented or when through ignorance he fails to involve other legitimate disciplines into the decision-making process.

In most cases today, resource decisions cannot be based upon single disciplines or single use but must give full consideration to alternatives or combinations of use. In so doing, the impact of various uses or combination of uses upon both resources and resource users must be understood and evaluated. Results of these evaluations become a part of the decision-making processes.

Tragically, all the information now available sometimes has little impact upon the human characteristics of seeing only one side of a problem or presenting only one viewpoint. In fact, the great amount of information (not always facts) available to decision makers may actually ease the management decisions without fully exploring all facets of a problem.

Objectivity is still a rare commodity. However, it can be increased and strengthened by insisting that resource information is factual and by taking an interdisciplinary approach to integrated resource management. An interdisciplinary approach to problem solving will add not only credibility but acceptance to resource management decisions.

Accelerating demands on rangelands require an interdisciplinary approach to resource problems. Paradoxical, these very demands from an expanding and concerned society may force the interdisciplinary approach to integrated resource management. In the long run, rangeland resources may be "saved" by forces or activities which at first appeared to be, and in many cases probably were, destructive. What at first appeared to be our dilemma would be our salvation. *Silent Spring* and many so-called Doom's Day ecologists have caused us to look more closely at what we were doing with our resources and ourselves.

Integrated resource management has significant social implication when related to management and use of resources by and for man. Contrary to the viewpoint of the traditional conservationist or preservationist, resources are not managed for the sake of resources but for people. Thus, integrated resource management includes an increasingly important social dimension that may be difficult for some resource managers to recognize, appreciate, or deal with effectively.

In general, resource managers have been trained to manage resources. Management decisions were, or are, made primarily upon the basis of their impact upon resources. Traditionally the qualified resource manager had at least a working understanding of the response of rangeland resources to given specific treatments. He was little concerned about the social implications of resource management decisions. For too long, too many resource managers have operated under the false premise that both their authority and responsibility stopped at a given boundary.

These procedures are no longer acceptable. The resource manager today must make his decision with full consideration of its social implications. He must understand resources. He must understand the impact of people upon resources. Just as importantly, he must be sensitive to the impact of resources on people. The rangeland resource manager must recognize the social implications implicit in many biological phenomena. Most of us consider ourselves biologists. We must recognize that neither biology nor sociology is a separate and distinct science. Resource management decisions must be made only following a full evaluation of their impact on human welfare. (In fact, this is a good basis for evaluating most decisions.)

A multidisciplinary approach to resource decisions is required to assure adequate understanding and treatment of capabilities and limitations of resources, needs and desires of people, and the social environment in which the decision is made. The multidisciplinary approach involves more than a range man, a forester, and a wildlife man having a cup of coffee together. It involves all concerned disciplines really working together. Thus, if we are actually managing resources for man, can the social scientist be omitted? This may appear to be a cumbersome approach, but in the final analysis, it will provide a mechanism for expertise in all concerned disciplines to be appropriately applied to problems of resource management.

Summary

(1) We must understand the resource and people we are trying to manage.

(2) Resources are managed for people. Therefore, resource decisions must reflect a concern for human welfare.

(3) A multidisciplinary approach is required to provide understanding, credibility, and acceptance of management decisions.

(4) The concept of integrated resource management embraces the resources, the people, and their interactions.

The Environment—Where Do We Stand?

From the Vantage Point of Space[1]

R. KEITH ARNOLD

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Highlight

Remote sensing from satellite systems offers real potentials for data collection on rangeland problems, structure, and use. When techniques, now being tested at a number of locations, have been more fully developed, more information from remotely based sensors will be available for reducing the uncertainties surrounding daily policy and management decisions. Techniques under development are discussed.

A significant part of man's current concern about his environment can be traced to his reaction to the first, incredible, astronaut's-eye-view of this planet. The vision of "spaceship earth" drifting in lonely isolation has shocked millions of thoughtful citizens into a chilling awareness of the completely closed character of the life support system we live in. Casual acceptance of, or indifference to, the fact of our total dependence on a finite resource supply, and on a supporting environment of demonstrated yet unmeasured fragility, is now fairly generally recognized as a foolish and shortsighted posture. The "need to know" what is happening to our global environment—not just from one century to the next but almost from day-to-day—has become painfully evident.

Technical feasibility has been established, and launching of the first earth resources technical satellite (ERTS-A) is planned for later this year. Other more sophisticated projects, including Skylab and the space shuttle, will follow. What then are the potentials for these new intelligence systems?

First, let us discard the idea that one photograph or image will provide each of us the data we need for day to day management of the environment, for the seasonal or annual planning requirements, or for the major policy decisions faced at every level of government and corporate activity. Replacing the single highly skilled photo interpreter are teams of scientists studying sensor-signature codes, engineering teams perfecting an unlimited array of electromagnetic sensors, groups of data and image processing specialists looking for new ways to surface, automatically and routinely, the useful information which lies hidden in many forms and formats of imagery and electronic signals.

If we are past the show and tell stage, where are we? Modern remote sensing technology is unfolding opportunities which are staggering. Here are some of the opportunities:

The synoptic or big view.—From imagery taken 150 miles out in space we can view without distortion the entire State of Wyoming on 10 photographs.

Multistage sampling.—We now have the capability of extending useful sampling from the observation of a single blade of grass through larger samples to the limit of one face of the earth.

Repetitive imagery.—We can now repeat imagery at intervals which have air, soil, water or phenological significance.

Multiband imagery.—For most of man's existence on earth, we have had to limit our remote sensing to the 4/10's of a micrometer of the electromagnetic spectrum that the optic nerve responds to. Now we span most of the electromagnetic spectrum.

Image and signal enhancement.—We have just scratched the surface with a few developments in optical and electronic image and signal enhancement which allows maximum information retrieval for specific purposes and selective combinations of information from many sources.

Data handling and communications.—This technology is ahead of, or equal to, requirements that we in natural resources may place upon it. But as you develop a strategy for employing all of the above in concert, data handling may become limiting.

There is little new in the technology devices listed above. We can and have used them before the space age. Continuous use for many purposes over wide areas for practical application at reasonable cost is not possible without the space dimensions.

The most commonly invoked application of space information systems to rangeland problems is for the development of a complete inventory of our western wildlands. It is vitally important that we have an accurate, up-to-date knowledge of the structure, use, and condition of this immense area, but the job is of such magnitude, complexity, and cost that it has never been done.

But important as adequate rangeland inventories are, we must not fail to recognize the potential utility of a permanent or continuing space information system for documenting change. The capability to delineate on space photos major categories of land use has already been demonstrated. It presents an unparalleled opportunity for observing and evaluating, on a regional or even sub-continental scale, shifts in row-crop agriculture, irrigation, range grazing, new-town development, surface mining, and other similar activities. We can also expect to be able to detect the extent and severity of certain types of natural or man-caused environmental change, and to appraise its probable significance. The synoptic view will not give us a diagnosis of the causes of envi-

[1] Presented at the annual meeting of the Society for Range Management, Washington, D.C., February 8, 1972.

ronmental degradation, but when we have learned what to look for, it will provide an environmental "early warning system." It will help establish a base level from which to judge, measure, and evaluate change. It will help explain locally observable phenomena which, out of context of the total mosaic, are meaningless.

The limiting factor, or pacing element, in useful application to range and other natural resources problems, is research. Thanks to the momentum of the Nation's total space effort, and to the technological achievements of the aerospace and electronics industries, the hardware engineering aspects of producing data from remotely based sensors are well advanced. What is lagging far behind is knowledge of relationships among earth resources phenomena and sensor response. These phenomena change over space and over time at varying rates for different phenomena.

Let us return to data handling, briefly. This will be serious enough with the relatively limited output of the experimental ERTS-A. But when a continuing satellite system becomes operational, the sheer volume of data will utterly swamp all available staff and facilities if we do not know by then how to sort, reduce, and process data automatically to extract specific needed information. Ways of doing this have been under study by a number of skilled and imaginative people. The Purdue University remote sensing lab has made excellent progress in automatic discrimination of agricultural crops. The random and heterogeneous patterns of range soils and vegetation represents a more difficult challenge. Techniques of scanning aerial or space photos using an automatic recording microdensitometer, being studied by Forest Service researchers at Berkeley and Ft. Collins, show considerable promise.

The success of data interpretation depends on identification of energy patterns in different bands of the spectrum that are uniquely characteristic of whatever it is that is to be discriminated. To produce discrimination keys for consistent and reliable recognition of range ecosystems, for example, the distinctive spectral features or "signatures" of each must be established. It is also necessary to know at what season of the year the characteristics differences can best be detected, on which kind of film, and using what filters. The influence of climate, site quality, current grazing regime, and other variables must also be isolated. Our staff at Berkeley has been building a microdensity image data bank for forest and rangeland classes using Apollo 9 infrared color photos, and multiband simulated space imagery representing several seasonal conditions.

Other important related research deals with such problems as optical properties of vegetation, recognition and possible diagnosis of stress symptoms in plants, and design of multistage sampling techniques for quantifying timber volumes and forage production. The National Aeronautics and Space Administration is taking the lead in helping to plan, coordinate, and fund research. The Departments of Interior and Agriculture and a number of universities are actively participating.

In considering the practical outlook for satellite information systems, it is difficult to avoid extremes of either optimism or skepticism. But if we accept the potential of the foregoing applications, two critical questions still remain: Who will use the information, and how will they integrate it into current decision making and program planning? There is not time, nor for that matter the experience-based judgment, to examine these questions in the depth that they deserve. Raw data from ERTS-A will be recorded on magnetic tape at central receiving stations, processed, and distributed to trained interpreters in Federal and State establishments, universities, and other organizations. They will have the responsibility of working closely with the people who will put this information to practical use. Gradually, as raw data are converted into maps, statistical summaries, and electronic printouts showing patterns of selected phenomena, a wide variety of user groups will become directly involved in adaptation to specific resource problems. These will include livestock producers, land managers, water user associations, advisory and regulatory boards, State and regional land-use planners, Federal agencies, and legislative committees. Decisions involving allocation of funds, choice of management strategies, and the scheduling of action programs should be made with greater assurance of success.

In the final analysis, information derived from remotely based sensors offers one more opportunity for reducing the uncertainties surrounding decisions that must be made every day. Those of us who are decision makers and policy planners will have more accurate indicators of change and a more rapid feed-back on environmental conditions.

Relationships of Wildlife to Livestock on Some Developed Ranches on the Laikipia Plateau, Kenya

RICHARD N. DENNEY[1]

Forestry Officer, Wildlife, Kenya Range Management Project, Food and Agriculture Organization of the United Nations, Nairobi, Kenya.

Highlight

The status and relationships of wildlife with domestic livestock on 42 ranches in the relatively developed ranching area of the Laikipia Plateau in Kenya, East Africa, were surveyed during 1967 and 1968. The average ranch was 35,400 acres, with approximately 3,000 cattle. Conservative estimates indicate a wildlife population of at least 100,000 animals of Thomson's gazelle size or larger, with some data being obtained on a total of 64 species. Most of the ranchers were tolerant of wildlife, in reasonable numbers, and except for certain species. The three most important wildlife-related problems were disease transmission, forage competition, and damage. Ranch practices which influenced wildlife were fencing (particularly game-proof fences), bush control, and shooting. The average rancher is interested in the possibility of a biologically sound, controlled game utilization scheme under which game meat could be sold. The potentials of expanded sport hunting and game cropping can make wildlife a profitable asset to the ranchers. Unless some means of assuring the landowner of a substantial return on the wildlife on his ranch is provided, the generally tolerant attitude prevailing now will deteriorate, and with it the status of the wildlife.

The Laikipia Plateau has been the home of wildlife and Masai livestock since long before the arrival of the first European. It has become one of the most important livestock areas in Kenya today. It may also be one of the last areas in which considerable numbers and varieties of wildlife will be found in the not too distant future, other than in game reserves and national parks, depending on the attitude of the ranchers toward wildlife and the resultant policies adopted in ranch management. These ranchers may become more tolerant, even genuinely concerned about the welfare of wildlife, if it can be shown that game has an intrinsic value to them. To better understand the relationships between wildlife and livestock it was necessary to assess the factors of livestock husbandry of these relatively well-developed highland ranches which affect and are affected by wildlife. This survey represents a beginning in such an evaluation. Due to the increasing settlement in some of the rangelands of Kenya through stabilizing nomadic pastoral groups by land adjudication and grazing schemes, many of the principles evolved through almost 50 years of ranching experience in Laikipia can have immediate application.

Information and data concerning natural features, the type and extent of improvements, livestock data, management practices, and the attitude toward wildlife, as well as seasonal estimates of game numbers, wildlife-livestock disease relationships, competition, damage and wildlife utilization and values were obtained from 42 ranches in Laikipia.

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Location and Study Area Description

The Laikipia Plateau is an area in west central Kenya lying west and north of Mount Kenya, from just south of the equator to 0° 45′ north latitude and between 36° 15′ and 37° 10′ east longitude (Fig. 1). It is characterized by relatively low and erratic annual rainfall, which dictates a grazing or ranching economy. The area as a whole is comprised of 1,869,000 acres, of which approximately 92% is uncultivated meadows and pasture (Kenya M.E.P. and D., 1965). The greater part lies on the rolling plains drained by the Ewaso Nyiro and Ewaso Narok rivers and their tributaries. Altitudes vary from 4,500 feet in the lower Ewaso Nyiro to 7,500 feet in the foothills of the Aberdare Mountains, with the bulk of the plateau lying between 5,500 and 6,500 feet.

Climate

Although located practically on the equator, this area is characterized by moderate temperatures, relatively low humidity and a low, erratic annual precipitation. Daily temperatures have a maximum of 79 F and minimum of 45 F, with a mean annual temperature of 59 F.

The average annual rainfall ranges from 18 inches on the lower Ewaso Nyiro to 32 inches on the slopes of the mountains, with an overall average of 25 inches. Approximately 32% of the rainfall is received during the March through May period, 21% during July and August and 20% during October and November. The July–August rains, locally termed the "grass rains," are more pronounced toward the western side of the Laikipia Plateau.

Water is a limiting factor in the plateau, but the Ewaso Nyiro and the Ewaso Narok, with many of their tributaries draining the Mount Kenya and Aberdare Mountains watersheds, provide year-round water. Other drainages provide seasonal or temporary water, and natural springs occur in some areas, particularly at the northwest end of the plateau. Swamps and lowlands have been channelled to provide water, and reservoirs of various sizes, along with boreholes (wells) provide much of the water for livestock.

Vegetation

The rangeland comprising the Laikipia Plateau is mostly characterized by a semi-arid climate. The land is of marginal agricul-

FIG. 1. Location of the study area, the Laikipia Plateau, Kenya, East Africa.

tural potential with a natural vegetation of dry forms of woodland and savanna, primarily an *Acacia-Themeda* association. It is a potentially productive range, limited by the encroachment of bush; and, while sensitive to severe grazing, burning is usually part of its management. Usually less than 10 acres are required per stock unit.

Second is rangeland with an arid climate. Here only local limited areas are suited to agriculture, with shrubby-type woody vegetation dominating. Desirable perennial grasses can dominate, although highly susceptible to overgrazing. More than 10 acres are required per stock unit.

The vegetative types are basically grassland, bushed grassland, wooded grassland and woodland, the latter restricted to riverine conditions and higher elevations on the slopes of the mountains. Individual ranches varied considerably in the vegetative types represented, depending on local site features such as altitude, topography, soils and precipitation. Based on the acreages of the vegetative types on the ranches, 39% of the area is bush, 37% open grassland or plains, 14% savanna, 6% forest, riverine or steep slopes, and 4% heavy forest and bush mixed.

Normal Characteristics of the Developed Ranch

When the terms "owners" and "private land" are used in this paper they do not refer to freehold or titled land, but rather to land on leaseholds under which practically all the land in Kenya is held, usually on a 999-year lease. The ranches ranged from 8,000 to 128,000 acres, with an average size of 35,400 acres. Carrying capacities ranged from 6 to 24 acres per animal unit per year, with an average of 10.9 acres. Stocking rates varied from 6 to 20 acres, with a mean of 11.4 acres per head. Compared with the average carrying capacity it appears the plateau is generally within the indicated carrying capacity.

The ranching economy is basically beef production, with an average of 3,000 head, comprised of 65% Boran and 23% Boran crosses. Many ranchers have high-grade exotic bulls (*Bos taurus*), but some are turning to artificial insemination to produce controlled crosses. Although sheep were among the first livestock introduced in Laikipia by Europeans, they have never gained the prominence that cattle have. Seventy-seven per cent of the 62,500 sheep found on 25 ranches are the wool-producing Merino breed.

Management, production, and range improvement are directly proportional to development in most cases. Paddocking into units consistent with the size of the ranch and system of grazing, and with water available in each paddock, is the desired objective. Based on an arbitrary classification considering perimeter fencing and paddocking, as well as water development and the furthest that stock must travel to water, 60% of the 42 ranches are in stages of advanced development or are fully developed. The Ministry of Agriculture uses an estimate of 70 cents to $1.12 per acre for water development.

Three ranches have none of their perimeter fenced, and there are 1,395 miles of ring-fencing on the other 39 ranches. Thirty-three ranches have interior fencing, with a mean of 32 paddocks averaging 900 acres. Five strands of smooth wire are used for general fencing; however, new ideas have been tried on special fences in relation to wildlife. Some of these involve game-proofing, while others aim to allow game passage without fence damage. One rancher built inter-

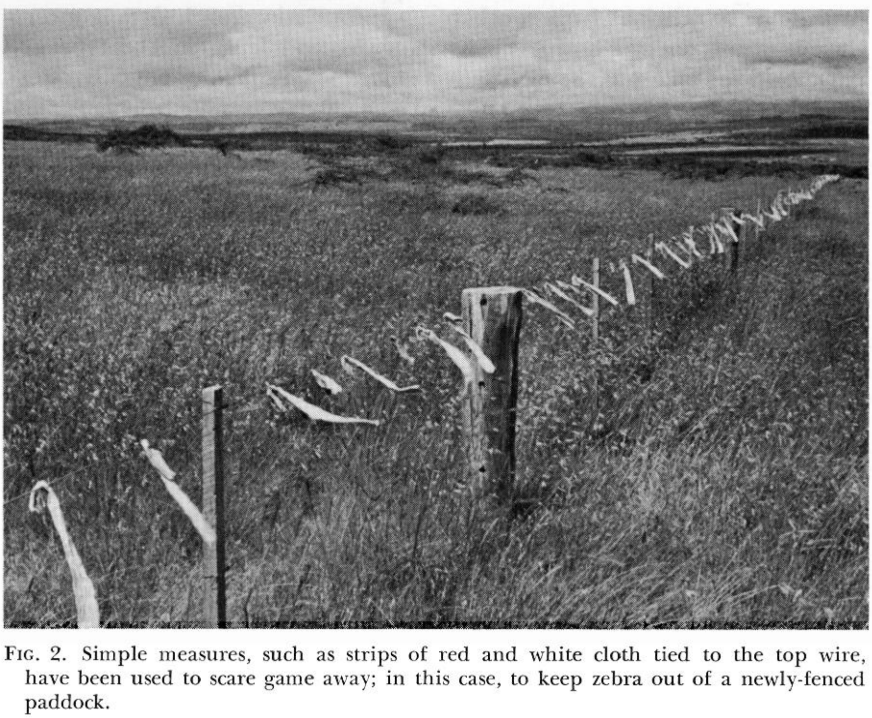

FIG. 2. Simple measures, such as strips of red and white cloth tied to the top wire, have been used to scare game away; in this case, to keep zebra out of a newly-fenced paddock.

nal fences after a two-year trial, consisting of three strands of smooth wire on posts 90 feet apart with four droppers. He has found that this effectively bars his mature cattle, while the flexibility allows large game to go through and the lowness allows them to jump over. Rather simple measures have been tried for short-term effect. When fencing a new paddock, one rancher hazed the zebra out before closing the last side, then tied strips of red and white cloth on the top wires for about three miles (Fig. 2). The material endured long enough to keep the zebra spooked out, but became faded and disintegrated in time. Buffalo and other forest wildlife grazed nightly on a ranch lying adjacent to the forest land at the north end of the Aberdares, causing destruction to existing fencing. A combination fence and ditch has been constructed along seven miles of ranch boundary adjacent to the forest to keep such wildlife out. The ditch is six feet deep, one foot wide at the bottom, seven feet wide at the top, and the dirt is piled three feet high on the ranch side of the ditch (Fig. 3). A four-strand smooth wire fence is built atop the dirt mound, with posts 30 feet apart with four droppers. Economically the rancher feels that the increase in forage adjacent to the forest will enable him to run more stock, which will compensate for the barrier cost of $1,120 per mile.

While such a structure adequately protects one ranch, and may be justified economically, it then behooves adjacent ranchers, farmers and settlements and/or the government to link such systems with other similar structures or adequate natural barriers to prevent the funnelling of the diverted wildlife onto neighboring enterprises which may be of lower economic potential but nevertheless essential, such as settlement schemes on a subsistence basis. Twenty miles of game moat exist in the Nyeri area, separating forest and the Aberdare National Park

FIG. 3. Game-proof ditch and fence under construction, showing the dirt piled on the ranch side. A four-foot fence will be erected on the dirt and the ditch covered with cut bush.

from adjacent settlement schemes. The government plans to link this moat with the one described at the north end of the Aberdares over the next four years at an estimated cost of $2,464 per mile, plus $280 per mile maintenance costs per year.

Various other styles of game-proof fencing without the moat have been tried with some success. The Timau area was not included in the survey, but three ranches there have been blocked into a unit within a common perimeter fence against buffalo and elephant, as well as vermin (hyena, wild dog, jackal). This highly successful fence has been up six years, and consists primarily of heavy gauge wire netting up to five feet, with angled bracing to the outside from the tops of the posts which are strung with barbed wire. The cost was $980 per mile, but the increased grass production in the pastures adjacent to the forest was felt to justify the cost.

Another type consists of chain-link or ring-lock wire, sometimes with part of the lower portion buried in the ground, with two or more strands of barbed wire on top, and may have one strand of barbed wire at ground level if the mesh is not buried. This type of fence is usually seven to eight feet high. However, one such fence enclosing approximately 23,000 acres to keep hyena and jackals out of sheep paddocks is about five feet high and heavy gauge wire netting was used at a construction cost of $1,000 per mile (Fig. 4).

Fences utilizing chain-link, woven wire, wire netting or similar tight mesh usually preclude the entrance of most predators and allow their strict control within the enclosure. They also effectively block the movement of ungulates, the species affected being dependent to some extent upon the total height of the fence. Therefore, the extensive uncoordinated use of such structures could have serious implications in regard to unprotected neighbors and certain wildlife populations.

The seasonal abundance of ticks makes it necessary to keep livestock as free of them as possible through the use of dips or sprays. There is an average of one tick control device per 15,000 acres. Toxaphene is the tick control compound used

FIG. 4. Five-foot high wire netting fence to keep hyena and jackal out of a 23,000 acre area.

on 83% of the ranches, and dipping or spraying is performed during the tick seasons by most ranches at least fortnightly at an average cost of 3.5 cents per head per treatment.

Arable lands comprised only 0.3% of the area, being devoted to maize, lucerne and other fodder crops, but included 1,500 acres of wheat on one ranch. The bulk of the maize is for African labor.

Livestock can be grazed out throughout the year without supplemental feed. The paddocked ranches employ a flexible system of rotation similar to the decision deferment described by Hoffman et al. (1968), based on specific needs or situations, usually for an entire growing season or part of it when moisture conditions are best, and where systematic deferment cannot be applied economically. Some ranchers heavily graze a paddock and then rest it until it fully recovers. Some burning is still carried out, especially in the *Acacia-Themeda* zone, but not with any set frequency.

Slaughter animals are one of the main sources of income, and the study area ranch mean annual shipment was 468 steers, 108 heifers and 43 cull cows. The gross income per ranch from beef cattle and wool sheep averaged $67,236 per year, or $1.90 per acre.

Livestock Mortalities and Control

Death losses of livestock naturally decrease the productivity of a livestock enterprise, and necessary steps to alleviate such losses increase the operating costs. Disease losses on the 42 ranches ranged from 0 to 5%, averaging 1.8%, and with 40% of the ranches reporting less than 1%. Total annual mortality ranged from 0.8 to 8.0%, with an average of 3.2%.

Based on the 123,000 cattle reported on these ranches, there would be a total annual death loss of almost 4,000 head, of which approximately 2,200 would be attributable to disease. One rancher stated that 80% of the disease in his cattle was due to tick-borne diseases. Another said that 25% of his disease mortality was due to anaplasmosis, and several other ranchers felt that most of their losses were due to this tick-borne rickettsial disease alone. Tick-borne diseases (anaplasmosis, heartwater, sweating sickness, redwater and East Coast fever), which may be implicated with wildlife, are generally guarded against through tick control with toxaphene (83% of the ranches, of which 17% use an organo-phosphate in combination). Other diseases as well, attributed by the ranchers to wildlife, are ondiiritis, rinderpest, foot and mouth disease, anthrax, lymphangitis, contagious bovine pleuropneumonia, leptospirosis, biliary fever, African swine fever, haemorrhagic septicaemia and blackquarter. Annual expenditures for prophylaxis and treatment of diseases and parasites by Laikipia ranchers, apart from dipping and spraying costs, average approximately $958.

Livestock losses from accidents (broken legs, bloat, calving, etc.), plant poisoning and snakebite are of considerable magnitude (1.3%). Predation by "vermin" accounts for mortalities approximating 1.2%, and losses due to spearings and theft amount to 0.7%. Losses in the first and third of these categories can be minimized to some extent by paddocking, and if a ranch isn't sufficiently developed the herding practices can alleviate some of these losses. Control of losses from predation is effected by shooting, the use of gin (steel) traps and live-traps, poison baits and, to some extent, herding practices. Gun traps used to be employed, but the majority of ranches use carcasses or kills poisoned with strychnine or toxaphene nowadays. Dogs are used extensively by some ranchers to flush, trail, and "tree" or bag predators such as lion, leopard, cheetah, hyena, and sometimes jackal.

Wildlife

Rancher Attitude and Policy

The quantity and species of wildlife present on a ranch, either as resident or migrant populations, may have considerable influence on the administrative policies and operational management of that ranch. In spite of this, however, 90% of the ranchers indicated a tolerant attitude toward wildlife generally, but not without certain qualifications, such as being tolerant of reasonable numbers, and except certain species (variable, but including buffalo almost unanimously, and waterbuck, zebra, rhinoceros, eland, and lion). Of the 38 ranchers claiming tolerance, six proclaimed themselves essentially as protectionists. At the other extreme were two ranches with wildlife extermination policies, and two not quite so radical, but considered intolerant of wildlife. In four cases it was apparent that the attitude and administrative policy of the ranch ownership was not approved of or supported by the ranch manager.

Several ranchers remarked that ranching would be much easier and simpler if there was no wildlife, and in a few cases efforts to drastically reduce wildlife populations or exterminate them have been initiated. Fortunately, most of the ranchers who feel that their operation would be simplified without game still prefer to have them around for aesthetic or utility purposes.

Since the welfare of wildlife species depends so greatly on the attitudes of the ranchers toward them, and their resultant management policies, it is essential to maintain the tolerance of the ranchers who are tolerant, and to improve the attitudes of those who are not. In view of the expressed thoughts that wildlife adds to the general burden of ranch management, and to the costs incurred as discussed in the following sections, it would appear that wildlife must pay its own way to maintain tolerance or decrease antipathy. Therefore, it is clear that wildlife must contribute further to the economy of these developed ranches to insure proper game management.

Wildlife Species and Numbers

Sixty-eight species of wild animals were listed as occurring on the 42 ranches, some of which, however, are insignificant economically or are of such low densities as to occur on few ranches. The estimated populations, where applicable, are based entirely on guesstimates by the ranchers, although a

Table 1. Population data for important wildlife species on forty-two Laikipia Plateau ranches, 1967–68.

Species	Number of ranches on which present		Populations			
	Resident	Seasonal	Resident	Seasonal	Mean	Total
Baboon, yellow (*Papio cynocephalus*)	11	20			425	4,600
Buffalo, cape (*Syncerus caffer*)	22	34	108	133	120	3,330
Bushbuck (*Tragelaphus scriptus delamerei*)	21	30	58	70	64	1,310
Cheetah (*Acinonyx jubatus*)	22	30	11	14	12	300
Duiker (*Cephalus monticola, C. natalensis*)	19	32			71	1,360
Eland (*Taurotragus oryx pattersonianus*)	20	34	155	201	178	3,000
Elephant (*Loxodonta africana*)	5	32	81	136	109	200
Gazelle, Grant's (*Gazella granti raineyi*)	26	27	216	230	223	5,800
Gazelle, Thomson's (*Gazella thomsonii thomsonii*)	31	36	750	897	823	26,000
Giraffe, reticulated (*Giraffa reticulata*)	19	29	90	105	97	2,220
Hartebeest, Kenya Jackson's (*Alcelaphus buselaphus jacksoni*)	31	35	94	104	99	3,180
Hippopotamus (*Hippopotamus amphibius*)	11	12			21	200
Hyena, spotted (*Crocuta crocuta*)	20	34			25	430
Impala (*Aepyceros melampus*)	37	39	697	746	722	27,080
Leopard (*Panthera pardus*)	31	38			10	310
Lion (*Panthera leo*)	7	28	10	18	14	150
Oryx, beisa (*Oryx beisa annectens*)	20	22	110	132	121	2,560
Ostrich, Somali (*Struthio camelus*)	21	24	31	35	33	730
Reedbuck (*Redunca r. wardi, R. fulverufula chanleri*)	21	27			60	1,270
Rhinoceros, black (*Diceros bicornis*)	13	18	7	9	8	120
Steinbuck (*Raphicerus campestris*)	20	33			90	1,800
Warthog (*Phacochoerus aethiopicus*)	8	13			225	1,800
Waterbuck (*Kobus ellipsiprymnus, K. defassa*)	31	38	104	114	109	3,540
Zebra, common (*Equus burchelli*)	31	38	131	336	234	6,210
Zebra, Grevy's (*Equus grevyi grevyi*)		5	18	100	20	20

Game Department study on 27 of the ranches in the Rumuruti area indicated that these estimates are reasonably accurate (Hughes, 1968). Population data showing seasonal ranges (resident, and resident plus migratory animals) or means, the number of ranches on which they occur, and total estimated populations are presented in Table 1 for the most important species.

Taking the minimum species population data from the ranchers that made estimates of numbers, there is a minimum of 100,000 game animals of Thomson's gazelle-size and over, which would average out to at least 2,500 head per ranch, with Thomson's gazelle, impala, zebra, Grant's gazelle, warthog, eland, buffalo, oryx and waterbuck in decreasing numerical order. These represent the species which have the greatest economic potential.

An important class of wildlife, often overlooked or assigned secondary importance, are the avian species. While not dealt with comprehensively in this survey, some data were obtained which are pertinent. There is a large number of game birds present in Laikipia, but no attempt was made to determine numbers or actual distribution, although certain significant population factors were noted. The ranchers reported that the game bird populations were very much higher about ten years ago, particularly the helmeted guinea fowl (*Numida mitrata*), yellow-necked spurfowl (*Pternistis leucoscepus*), and crested and red-winged francolins (*Francolinus sephaena* and *F. levaillantia*). A severe reduction in numbers was thought to have been caused by a combination of factors, namely drought, flood, and diseases. Most of the ranchers felt that while the game bird populations are not anything like they were, they are in the process of gradually building up again. The slow build-up was attributed to predation and poaching on a small basic breeding population.

Disease Relationships

The greatest concern of the ranchers regarding wildlife is the fear of disease transmission to their livestock, particularly tick-borne diseases. In spite of this general feeling, however, five of the ranchers had none to negligible disease problems, which they attributed to careful sanitation, prophylaxis and treatment. There is evidence to indicate that many parasites and diseases did not originate with wildlife, but, on the contrary, were transmitted to them by domestic livestock, e.g. rinderpest. However, this does not change the fact that, whether susceptible to certain diseases or not, wildlife may be important reservoirs or carriers of them. Prevention of such diseases in livestock is difficult if prophylaxis does not exist or is not satisfactory, and, of course, treatment of wildlife is not feasible, if possible.

It appears that tick-borne diseases can be adequately controlled with proper tick control that new and modern acaricides can provide. Even if all the wildlife were removed from specified areas, certain soil-borne diseases, such as anthrax, tetanus, blackquarter, Salmonellosis, lymphadenitis, botulism and coccidiosis, would still be almost as prevalent in livestock. On the basis of those diseases attributed to wildlife by the ranchers, it would appear that the most serious threat to livestock is posed by buffalo, with waterbuck a close second, then zebra, eland, impala, Kenya hartebeest, warthog, giraffe, Thomson's gazelle, steinbuck and elephant in order of decreasing accusations.

In an effort to assign an economic value to the contributing costs of wildlife in relation to diseases and their control or treatment, let us assume that one-half the cost of tick control, and one-half the cost of annual veterinary expenditures, is due to wildlife. If we arbitrarily assume that the average ranch has 3,000 head of cattle, and dips fortnightly at an average cost of 3.5 cents per head per time, the annual cost of dipping is $2,800, half of which is $1,400. As determined in this study, the average annual veterinary costs are $958, half of which is $479. Therefore, wildlife *may* cost the average ranch $1,879 annually for disease control.

Forage Competition

Competition for forage constituted the second largest threat to livestock from wildlife. While the majority of ranchers have a tolerant attitude toward wildlife in reasonable numbers, seasonal influxes of migratory species were felt to be particularly competitive and/or damaging.

Forage competition was felt to be negligible by eight of the ranchers, one of whom qualified this by stating that this was normally the case with static wildlife populations. Ten ranchers felt that all wildlife species were competitive because the cattle and sheep browsed during the dry seasons, therefore competing with grazers or browsers year-round. Another said that all species were competitive on new grass, and that game took forage on his ranch that would support 150 more cattle at an average value of $62 each. Still another reported that the game went after the best stargrass. One rancher felt that all wildlife except giraffe, gerenuk and elephant were in competition with his stock, while another excluded elephant alone from a competitive role.

Zebra were reported by 21 ranchers as competing with livestock, with one stating that zebra eat one and a half times the amount that cattle do, and clean off the grass. Eight ranchers listed impala as being in competition with livestock, two of them limiting this to competition with sheep, and another stating impala competition existed only in certain paddocks. Thomson's gazelle were listed as competitive in eight cases, one with sheep, and two where the grass was short. Buffalo were considered to be in competition in six cases, one specifying that this was only near

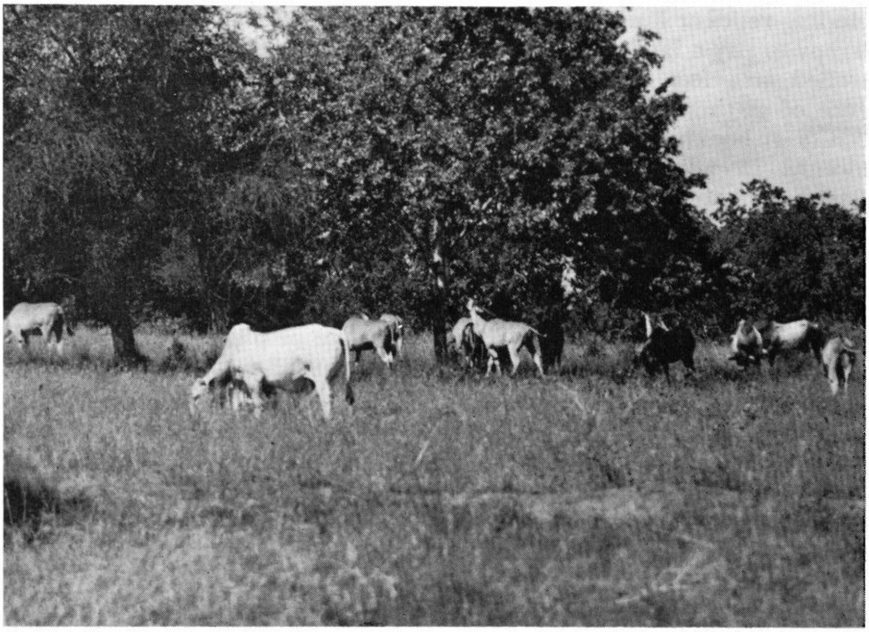

FIG. 5. Wild, free-ranging eland browsing on trees while cattle graze in close association, illustrating compatibility through differential forage preferances.

the forest. Four ranchers listed Kenya hartebeest as competing with livestock, while eland and waterbuck were considered as competition in three cases each, and oryx in two instances. Grant's gazelle and hippo were each listed as competitive in one case. Another rancher felt that all the antelopes were in competition with his cattle.

It is interesting to note that one of the ranchers observed that the lack of bush understory in his paddocks was due, he assumed, to the effect of giraffe. Another rancher was of the opinion that the bush would encroach rapidly into the grassland if all the game was eliminated (Fig. 5). There are minimal data available on the food habits of the various wildlife species, particularly as they differ seasonally, and from one habitat to another. Nevertheless, it may be assumed that the most direct competition is from the grazing ungulates, including those that feed on a mixture of grass and herbaceous dicotyledons, such as buffalo, hartebeest, waterbuck, reedbuck, oryx, Grant's and Thomson's gazelles, zebra, hippo and warthog. Some of the Laikipia species include grass, herbaceous dicots and browse in their diets, namely elephant, rhinoceros, impala, bushbuck and eland; others are principally browsers, such as giraffe and gerenuk. Therefore, it does not appear logical to state that all wildlife, or even all antelopes, are in direct competition with livestock.

Near the end of the rainy season competition should be at a minimum when there is a greater selection of species available and the game is not concentrated. Conversely, competition probably becomes intensified as the dry season progresses and the diversity and quantity of grasses become more limited. At any rate, forage competition may be significant on most ranches, at least seasonally, and from certain species such as zebra on early stages of regrowth.

It is difficult to assess the economic impact of wildlife competition on these ranches, but assuming that the rancher who stated that he could run 150 more steers if it were not for game competition was right, then it is costing him almost $2,800 per year (150 head at $62 prorated over three and a half years—the age at which steers are generally sold). This is probably an over-estimation, however, since he was already admittedly overstocked. The overall average annual cost of wildlife competition would probably be nearer $560.

Damage and Predation

The third liability of wildlife on the ranches concerns damage, both from the standpoint of physical damage to developments such as fences, waterpoints and crops, and losses through predation. Of these, predation caused the greatest economic losses.

Nine ranchers reported that fence damage was nil or negligible, while 15 reported fence damage to some extent, but not specified as to value. Eleven ranches had fence damage averaging $288. Elephant caused the most fence damage, followed by buffalo, giraffe, eland, zebra, hartebeest, ostrich, oryx and rhino. Wildlife were reported as responsible for an average of 30% of the annual fence maintenance costs, or $84.

The majority of the game, particularly resident populations, soon get used to the fences and learn about them, although when under stress, such as being chased by dogs when the labor is hunting, or when stampeded, cause some fence damage. There is no doubt that extensive fencing influences the seasonal movements of game, and contributes to the establishment of resident populations of some species which might otherwise move.

Damage to crops was mainly to maize and wheat, although elephants were reported as damaging fruit trees on one ranch. Baboons were the chief culprits in crop damage, with rhino, forest hogs, warthog, porcupine, Thomson's gazelle and squirrel reported specifically. No estimates of value were made pertaining to this type of damage. Baboons were reported to foul waterpoints and supplies by several ranchers.

In regard to predation, 13 ranches reported such losses, but values were not specified. However, predation on 18 other ranches averaged $1,075. The main predators and the number of ranches reporting losses to them were: hyena, 19; lion, 13; leopard, 13; wild dog, 5; cheetah, 4; and jackal, 4. Losses ranged from one to 100 cattle, and up to 130 sheep and goats annually. One ranch expends $1,400 per year on vermin control. The overall annual average predation loss is probably around $1,960.

Utilization

Most of the emphasis one hears about wildlife relationships on ranches pertains to detrimental effects, but the uses made of game are not usually evaluated. Here we will attempt to assess the various ways in which wildlife is used on these ranches, and assign some value to them. According to the Wild Animals Protection Ordinance the landowner has the right to control any wildlife necessary for the protection of his real property. Other than legal sale of hides through a permit from the Game Department the landowner seldom receives any monetary return from animals cropped or taken on control on his property. The meat, however, is generally consumed on the ranch by the staff, labor, and/or dogs.

Of the 42 ranches, 34 shoot for the pot, that is, for personal consumption. Twenty-eight shoot to supply meat to the labor, and 12 shoot to feed their dogs. Six ranches reported that they shoot primarily for control purposes, the use of the meat being secondary.

One significant source of wildlife income to 20 ranches is the fees and charges that professional hunters and their clients pay the landowners to hunt and camp on the ranches. These hunting privileges vary and are not specifically known, but usually include at least the equivalent of the controlled area fee for any animals shot. This is the sphere of activity which could be expanded considerably, depending on the temperament of the individual landowner, and could provide a relatively high value per animal at little or no cost to himself. Any sportsman, including resident hunters, would be happy to pay a landowner the controlled area fees for the convenience of getting away from the necessity of booking a hunting block months in advance in Nairobi. Based on known values, the estimated average annual income from this source is approximately $420.

One of the ranches, besides being an operating cattle enterprise, is the base of operation for one of Kenya's wild animal trappers. With the appropriate capture permits from the Game Department he not only captures animals on his own ranch, but catches such unique animals as reticulated giraffe, Grevy's zebra, and beisa oryx, as well as elephant and common zebra, on various ranches in Laikipia where they occur. The individual ranchers concerned receive an agreed upon fee for each animal captured on their property, and foreign exchange is earned from throughout the world by the sale of these animals to zoological gardens and parks. Captured animals are held in pens on the trapper's ranch for a period of at least two months to adapt them to captivity and a new diet.

When we consider that at least two-thirds of the ranchers shoot game for their labor meat supply, it is obvious that wildlife contributes significantly to the ranch economy; however, assigning a monetary value to this contribution is beset with difficulties. For example, some ranchers stated that the labor would not be supplied with meat if it were not for the game, other than livestock mortalities from accidents or natural causes. Nevertheless, the labor does get this contribution to the maintenance of health, energy and efficiency. This amounts to 638 kilograms of meat per year, worth approximately $294, which does not include the game meat eaten in considerable quantities by the ranchers and their families.

Sixteen of the ranches sell zebra hides regularly, receiving up to $8,400 annually at $84 per hide (this is conservative, as zebra hides are selling above this minimum price), and averaging $1,829. There is also a demand for Thomson's gazelle hides, as well as impala and Grant's gazelle, on which 12 ranches received an average annual income of $1,014.

Other Wildlife Values and Potentials

The wildlife values discussed here are those of psychological and aesthetic benefits, or those of such ambiguous criteria as to defy tangible economic description, as well as potentials which either have not been exploited, or in which the exploitation could be expanded.

The aesthetic value of just liking to see the wildlife around their ranches was expressed specifically by 17 ranchers. In addition, the shared pleasures of aesthetic values and comradeship through allowing their friends to come and hunt were reported by 26 ranchers. Seven of the ranchers had wildlife as pets or in captivity in a semi-domesticated state, which included buffalo, eland, ostrich, hyrax, oryx, and Thomson's gazelle.

There is a potential income to certain ranches in the aesthetic values of wildlife through game viewing. It is likely that many residents, as well as some tourists who could be contacted through tour agencies, would appreciate the leisurely wildlife observation away from the crowded and competitive-booking commerical game lodge atmosphere. One rancher has initiated such a plan by constructing three bandas (huts) near a reservoir on his ranch, where individuals or families can come to relax and observe his plains game. Another ranch has built a tree-house in the forested foothills near a natural salt lick where elephant, buffalo, bushbuck, and sometimes rhino can be observed. One rancher, a professional hunter himself, caters to people desiring wildlife photography, and allows no shooting on his own ranch. With a relatively small investment and efficient contacts, a good number of the ranchers could realize a considerable income from this aspect of wildlife alone.

It is conceivable that an intangible value accrues to a rancher from his wildlife populations in that poaching may take some of the pressure off his livestock, which might otherwise suffer more from stock theft and spearing.

A greater potential exists in hunting by sportsmen on the ranches than is now realized. As mentioned previously, some of the ranchers have already derived income from professional hunters and their clients, and this could probably be expanded considerably. As pointed out by Denney (1968), the Game Department kills more animals on control operations than are killed by licensed hunters in Kenya. With closer liaison with the ranchers, the Game Department could refer resident hunters to specific ranches with cropping or control problems on other than dangerous game. The rancher could collect the controlled area fees for such animals killed, and the Game Department would not have to spend the time and money on certain types of control operations, which undoubtedly cost more than the controlled area fees they would lose to the ranchers. While such a program would assist the Game Department and/or the rancher in game control operations, it is undoubtedly true that the control desired would not be attained. Such exploitation of the potential sport hunting business can be conducted under the framework of existing wildlife laws.

The logical assumption that sufficient effect would not be attained through sport hunting in cases requiring game control over an extensive area points directly to the fact that perhaps the greatest potential field of wildlife utilization, and at the same time good game management, lies in the sphere of controlled game cropping, particularly on private land. Protein malnutrition is one of the most important nutritional factors affecting the development of man and economy in Africa, and the fact that kwashiorkor is common in children in many parts of Kenya is mute testimony to the existence today of protein malnutrition (Mann, 1968). Wildlife undoubtedly provides, through poaching and subsistence hunting, much of the animal protein consumed in many parts of Kenya today, but a biologically sound program of wildlife utilization could supplement or provide the protein requirements of thousands of people until the developing rangeland and livestock schemes come to fruition.

Table 2. Wildlfe potential values on an average Laikipia ranch with current populations and assuming legalization of the sale of game meat.

Species	Mean population	Annual crop	Mean live weight (lb.)	Total carcass weight (lb.)	Mean hide value ($)	Total value ($)
Buffalo	120	12	1,000	6,000	4.20	890.40
Bushbuck	64	6	70	210	3.50	50.40
Duiker	71	7	20	70	1.40	19.60
Eland	178	18	600	5,400	3.50	817.60
Grant's	223	22	78	858	3.50	196.00
Hartebeest	99	9	200	900	4.20	165.20
Impala	722	72	80	2,880	3.50	649.60
Oryx	121	12	198	1,188	2.80	198.80
Reedbuck	60	6	50	150	2.10	33.60
Steinbuck	90	9	18	81	2.10	30.60
Thomson's	823	82	32	1,312	2.80	207.20
Warthog	225	22	88	986	1.40	165.20
Waterbuck	109	10	250	1,250	5.60	229.60
Zebra	234	23	330	3.795	42.00	1,498.00
Total	3,139	310		25,062		5,152.00

Although none have felt inclined to do so, it is within the discretionary powers of the Chief Game Warden under Kenya laws to authorize the sale of wildlife meat. Before any wildlife is cropped a large amount of biological and ecological data is required. These data would include a complete inventory of the wildlife in the proposed cropping area; determination of migrations and seasonal ranges within the ecological unit of which the cropping area is a part; the species productivity and annual recruitment, as well as natural mortality; the incidence of parasites and diseases; and such population dynamics factors as the sex and age ratios. Quotas established for the individual ranches would have to be prorated according to the area of the ranch in relation to the rest of the ecological unit, and the seasons or amount of time specified species used that ranch, which would insure that several ranchers did not take their "ten per cent" out of the same herd of animals. Such quotas would have to be set by the Game Department for each ranch within a cropping area.

Riney and Kettlitz (1964) reported the impressive potential of wildlife utilization in South Africa, where two to three thousand ranches crop game for an estimated $1,120,000 annually. Olafse (1970) found that an impala in Natal is worth $35 in terms of meat, hide and horns. If we take mean wildlife population data from Table 1, and only consider those which are of the most economic importance, we can project the potential value of game cropping on an average Laikipia ranch (Table 2). The annual cropping quota is taken as 10%, although such species as buffalo (Bindernagel, 1968), duiker, Grant's

Table 3. Wildlife related data on an average livestock ranch of 35,000 acres, derived from 42 Laikipia Plateau ranches, 1967–69.

Item	Costs ($)	Income ($)
Real or demonstrated values		
Diseases attributed to wildlife	980	
Tick control and veterinary costs	1,820	
Predation	1,288	
Forage competition	560	
Fence repair and maintenance	87	
Value of meat for labor		294
Fees from professional hunters and clients		420
Sales of hides under permit		2,822
Buffer value to stock theft and spearing		+
Bush control effect of browsing wildlife		+
Game viewing, wildlife photography, aesthetic values		+
Subtotal	4,735	3,536+
Potential values		
Game cropping costs	1,756	
Predator control (cyanide guns)	560	
Game cropping (25,062 lbs. carcass wt.)		5,152
Sport hunting		1,400
Intensive wildlife husbandry		+
Subtotal	2,316	6,552+
Total	7,051	10,088+

gazelle, hartebeest, impala, steinbuck, Thomson's gazelle (Hvidberg-Hansen, 1969), and warthog could probably stand a heavier cropping and still maintain a static population, depending on the ranch objectives. Carcass weights are considered as 50% of live weights, though Ledger (1968) demonstrated them to be higher, and the value per pound of carcass weight is calculated at 14 cents, though four Nairobi hotels said they would pay 28 to 60 cents per pound for Thomson's gazelle carcasses. It appears, therefore, that if the sale of wild meat was legal, and that veterinary requirements on sanitation and hygiene could be met, a very tangible income from wildlife could accrue to the ranchers.

Because of the environmental adaptations of game concerning heat stress, water conservation, forage selection and endemic disease resistance, many species can lend themselves well to game farming or game ranching, as demonstrated in the literature by Riney and Kettlitz (1964), Riney (1964), Treus and Kravchenko (1968) and Olafse (1970). The foregoing reports emphasize the possibility of domesticating several species of wildlife, which alone or as a complement to cattle and sheep, could utilize a broader spectrum of habitat conditions and vegetative associations to the benefit of the ranchers.

It would appear that not only can wildlife be compatible with a livestock operation in certain situations, but the potential exists to increase the ranching income through wise and efficient management of the domestic *and* the wild stock.

Conclusions

Table 3 represents an average ranch on the Laikipia Plateau, based on mean data extracted from 42 ranches, listing the costs attributed to and the income from wildlife. Certain costs or proportions of them have been chosen arbitrarily, and some data based on the few ranches for which those specific data occurred have been used. Therefore, the inclusion or exclusion of certain costs may be controversial. One half the livestock health cost of tick control and veterinary costs are arbitrarily attributed to wildlife because ranches with little or no appreciable game populations still must dip or spray, and not all of the diseases can be attributed to wildlife. Similarly, the costs due to disease mortality are considered as half, and the percentage is based on the proportion of disease mortality to overall livestock losses of 3.2%, inasmuch as several ranches had negligible disease mortality. Predation losses are likewise computed on the basis of the proportion of these losses in the overall death losses. It is felt that many of the wildlife liability factors are overstressed here, and possibly some of the benefits are conservative. In fact, many people would consider wildlife as a calculated risk or an act of nature, and therefore not chargeable for implied costs. It is apparent from the data used here that the real or demonstrated values attributed to wildlife do not balance the assumed costs; however, with the legalization of the sale of game meat the potential values can exceed the implied costs of wildlife. This is particularly true if predator control measures, such as cyanide guns, can obviate the inroads of predators. If the rancher did not perform the game cropping himself, he would get a flat fee per head for various species of wildlife without incurring any costs. It is equally obvious that certain species of wildlife, such as elephant, rhino, buffalo, lion, cheetah, leopard, and hyena, will not be tolerated in developed areas and when in conflict with man's immediate interests. The bulk of the data gained in this study has direct application to the more developed ranches; however, many of the principles are applicable to developing rangelands. Traditional social structure and local economic conditions, along with land use, condition and trend, must be carefully analyzed and understood before comprehensive wildlife management plans can be drafted and implemented for the developing ranch areas.

In view of the obvious importance of the Laikipia Plateau in Kenya's wildlife future, and the fact that under existing laws the landowner has the power of life or death over wildlife on his land, it is essential that a wildlife management program be drafted for this area specifically. Fundamental to the preparation of such a long range management plan are a complete ecological study of the Laikipia Plateau, including a wildlife survey and the determination of food habits, migrations and seasonal ranges, population dynamics and carrying capacities; basic research on diseases and parasites of livestock and wildlife, and the relationships between them; a pilot game cropping scheme should be initiated to develop the necessary techniques and methods required, and to evaluate the markets.

In addition, the Game Department should strive to improve its public image, particularly with the landowners, through a public relations drive to acquaint and encourage landowners with what they could do to make far more use of the sporting and tourist potentials, which would include a clear explanation of the relevant laws, guidance of fees they charge, and liaison with tourist and hunting agencies.

The Laikipia Plateau offers a location and the opportunity for a unique experiment to determine which wildlife species could be most successfully domesticated. Such a demonstration should be based on a relatively large number of the several species tested, in which newly-caught young would be hand-reared and husbanded in much the same manner as livestock, including herding and paddocking with standard fencing, dipping and inoculating when necessary, culling, castrating, selective breeding of the more tractable individuals, and precise measurements for growth rate and weight gains. Now is the time to initiate such a study, while a broad spectrum of species and numbers is still available. If successful, the ultimate application of such a study would be on unfilled niches of developed ranches and in marginal range areas where disease, parasites, terrain, bush and/or water are the limiting factors for livestock.

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Clipping Effects on Seeded Foothill Ranges in Utah[1]

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Highlight

Russian wildrye produced significantly more herbage than crested wheatgrass when clipped at intensities of 25, 50, and 75% under four clipping regimes of April, May, June, and both April and June. Thin stands of Russian wildrye were more productive than thick stands of either Russian wildrye or crested wheatgrass. Clipping in both April and June yielded the most herbage, but after five years of clipping, this treatment had the least vigorous plants. Early clipping (April) caused the least damage to plant vigor, but yielded less herbage. The heavier the intensity of clipping, the greater the amount of herbage presumably available for animal consumption, but also the lower the plant vigor. Optimum tradeoffs between herbage harvested and plant vigor appear to come from Russian wildrye or crested wheatgrass clipped 50% in April and May.

Crested wheatgrass (*Agropyron cristatum* (L.) Gaetrn.) has been widely recommended for seeding on Intermountain foothill ranges. Russian wildrye (*Elymus junceus* Fisch.) is also a promising species for seeding these ranges.

Russian wildrye has been recommended for seeding on sagebrush, mountain brush and juniper sites in the Intermountain area on soils which are too alkaline for fairway or crested wheatgrass and too dry for tall wheatgrass (Hull and Holmgren, 1964). In experimental seedings on 18 areas in the salt-desert shrub region of western Wyoming, Hull (1963) found Russian wildrye was the best of 14 species tried. In these studies crested wheatgrass was slightly inferior to Russian wildrye. However, Cook (1966), in an 8 year study in Utah, found Russian wildrye did not produce as much forage on good sites as did crested wheatgrass. Hull and Holmgren (1964) found the same relationship in Idaho on good sites.

Stelfox et al. (1934), conducted studies in Canada with Russian wildrye to determine the effect of (1) row spacing, (2) fertilizer treatment, (3) association with alfalfa, and (4) early spring burning on seed production. They found that row spacing was the most important factor. Optimum spacing varied from 2 to 4 feet, depending on moisture conditions and age of the stand. Increased width of row spacing generally increased seed and forage production by Russian wildrye (Lorenz and Rogler, 1959; Lorenz and Rogler, 1964). Cook et al. (1967), however, found herbage yield was similar under any row spacing or intensity of seeding after the plants became established.

Effect of clipping frequency on productivity and root development of Russian wildrye has been studied both in the greenhouse (Thaine and Heinrichs, 1951) and in the field (Thaine, 1954). Frequent clippings reduced yield in the greenhouse, but in the field three to five clippings per growing season produced greater herbage yield than one or two clippings. Root yield and root reserves were decreased with increased frequency of clipping.

The present study was designed to test the effects of season and intensity of clipping on thick and thin stands of Russian wildrye and crested wheatgrass on a foothill range in Utah.

Study Area and Methods

The study area was located 20 miles west of Snowville in Box Elder County, Utah. The site was on the edge of the Curlew Valley floor at 4,700 ft elevation.

The soils, described by Gates et al. (1956), range in pH from 7.8 to 8.5. Organic matter content is relatively low with surface texture varying from loam to silty clay loam.

Study plots were located in a big sagebrush community which in its native condition, was dominated by big sagebrush (*Artemisia tridentata* Nutt.), with squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith), Indian ricegrass (*Oryzopsis hymenoides* (Roem. and Schult.) Ricker), western wheatgrass (*Agropyron smithii* Rydb.), and other drought-tolerant species occupying interspaces between sagebrush plants. Because of a deteriorated condition, the area contained halogeton (*Halogeton glomeratus* (Bieb.) C. A. Meyer), cheatgrass (*Bromus tectorum* L.), Russian thistle (*Salsola kali* L.) and peppergrass (*Lepidium perfoliatum* L.) in interspaces between sagebrush plants.

Precipitation in the locality is low and erratic. Forty percent of the annual precipitation falls as snow, and 30% occurs in May and June as rain. Average annual precipitation from 1960–1970 was 24.4 cm. During the study, precipitation was above average in 1965, 1967, and 1968. Precipitation was below average in 1966 and 1969.

Temperatures in the area average 5 C in January and 23 C in July. The maximum recorded tem-

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Table 1. Dry matter produced (lb./acre) by crested wheatgrass and Russian wildrye in 1969 after 5 years of clipping.

Treatment	Species	
	Crested wheatgrass	Russian wildrye
Date of clipping		
Early	202 a[1]	573 a
Early & late	163 b	359 c
Mid	176 b	424 b
Late	182 b	356 c
Intensity of clipping		
25%	212 a	456 a
50%	181 b	469 a
75%	148 b	370 b
Stand density		
Thick	196 a	376 b
Thin	165 b	484 a

[1] Numbers within the same type of treatment in same column followed by the same letter are significantly different at the .05 level.

perature is 44 C, and the minimum is 3 C. The average length of growing season is 125 days, with the last killing frost usually occurring in the spring about May 25, and the first killing frost in autumn on about October 1.

The study was conducted in stands of Russian wildrye and crested wheatgrass in both thick and thin stand densities. The number of Russian wildrye and crested wheatgrass plants per 9.6 ft^2 plot from thick stands averaged 5.5 and 8.0, respectively; whereas, for thin stands they averaged 3.0 and 6.0, respectively.

Clippings were made to simulate grazing from 1964 to 1968. Five plants each of Russian wildrye and crested wheatgrass in both thick and thin stands were clipped at three intensities (25, 50, and 75% by weight) at 4 dates. The dates of clipping were early spring (April 17), mid spring (May 22), late spring (June 26) and early and late spring (April 17 and June 26). Each treatment was replicated four times. Clipped samples from individual plants were placed in individually numbered bags, air dried, and weighed to determine production. Control plants were not clipped, but production was taken by ocular estimate. Vigor measurements taken each year prior to clipping included plant height and number of seedheads.

Clipped plants were allowed to grow during 1969 before final vigor measurements were taken. Vigor measurements taken after a 1-year rest from clipping included plant height, number of seedheads, crown diameter, and crown cover rating. Crown cover ratings were based on percent live material in the crown of the plant as follows: 1–10% = 1, 11–20 = 2 . . . 91–100% = 10. All production data for 1969 were taken by ocular estimate on 9.6 ft^2 plots.

The data were summarized and analyzed by computer. Averages reported in Tables 1, 2, and 3 are overall averages, i.e. stand density averages are confounded with date and intensity of clipping.

Results

Species and Stand Density Differences

There were significant differences ($P < 0.05$) between species and densities of stand within species. Russian wildrye produced significantly ($P < 0.05$) more herbage than crested wheatgrass (Table 1). Production per acre was greater in thin stands of Russian wildrye than in thick stands of either species. However, production of crested wheatgrass was greater in the thick stand. Crown cover ratings and crown diameter were greater in thin stands than in thick stands. Crown diameters were significantly ($P < 0.05$) greater for Russian wildrye than for crested wheatgrass (Table 2).

Crown cover rating was con-

Table 2. Final vigor data taken in 1969 after a 1-year rest following 5 years of clipping on Curlew Valley seeding study. Crown diameter and plant height measurements are reported in centimeters.

Treatment	Crown diameter		Plant height		Crown cover rating[1]		Number of seedheads	
	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye
Date of clipping								
Early	22	36	16	31	5	6	4	21
Early and late	24	34	16	30	4	4	2	13
Mid	25	34	15	29	4	6	2	13
Late	20	34	16	30	3	5	2	17
Intensity of clipping								
25%	24	36	18	32	5	6	2	16
50%	22	40	16	30	4	6	2	18
75%	23	31	13	28	3	5	3	16
Stand density								
Thick	20	29	14	26	4	5	1	6
Thin	26	40	17	26	5	6	4	26

[1] Crown cover rating—1 = 10% live material in crown, 2 = 20%, . . . 10 = 100%.

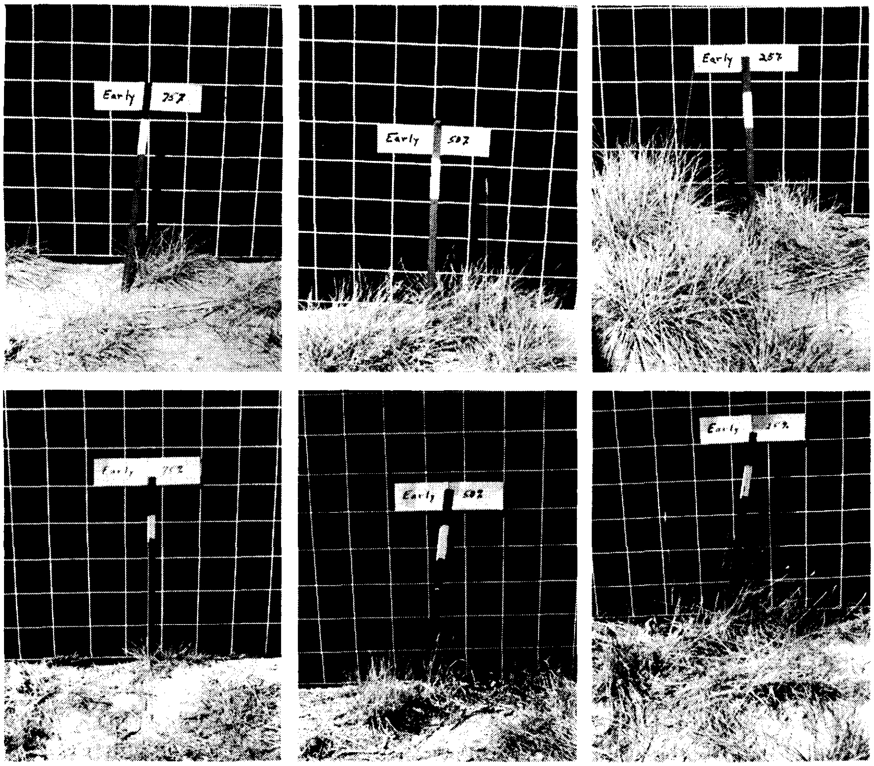

FIG. 1. Russian wildrye (upper row) and crested wheatgrass (bottow row) after five years (1964–1968) of clipping at three intensities at Snowville. Clipping percentages: left-75%; center-50%; and right-25%.

sidered the best measure of vigor. When all vigor measurements (plant height, crown diameter, etc.) were used as dependent variables (x's) and production was used as the independent variable (y), 82% of the variability in production was accounted for. Crown cover rating alone accounted for 80 percent of the variability.

Russian wildrye was more vigorous than crested wheatgrass under any clipping treatment (Table 2). Average crown diameter for Russian wildrye was 34 cm and for crested wheatgrass it was 22 cm. Average crown cover rating for Russian wildrye was 5, and for crested wheatgrass it was 4. Plant height and leaf length for Russian wildrye were significantly greater than for crested wheatgrass.

Effects of species and density of stand are clearly reflected in the number of seedheads produced (Table 2). At both stand densities Russian wildrye produced more seedheads than crested wheatgrass. Both species produced more seedheads in thin stands than in thick stands, but the difference is more pronounced from the thin to thick stands of Russian wildrye. Russian wildrye produced most seedheads in the thin stand when clipped early at 50%.

Season of Herbage Removal

To properly evaluate the effects of season of clipping on forage production, two factors must be considered: (1) amount of herbage removed at clipping and (2) effect of herbage removal on plant vigor. Clipping both early and late produced the most herbage (Table 3), but had the lowest vigor after 5 years of treatment (Table 2). However, plants clipped twice the same year produced less ($P < 0.05$) herbage during the last 2 years of study. Late clipping also decreased vigor and yield as treatment progressed through the years. Least forage was produced from early clipping

Table 3. Dry matter (g/plant) clipped from crested wheatgrass and Russian wildrye during 4 years at Snowville seeding.

Treatment	1965		1966		1967		1968	
	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye	Crested wheatgrass	Russian wildrye
Date of clipping								
Early	5.2	9.6	4.6	14.4	3.8	9.4	2.8	12.5
Early & late	9.1	20.8	8.8	27.1	10.5	21.0	5.3	16.2
Mid	9.0	19.9	7.7	22.9	5.6	11.9	4.0	16.7
Late	8.8	15.6	5.7	21.1	12.7	18.9	7.6	11.6
Intensity of clipping								
25%	5.5	10.0	5.4	15.1	7.1	10.8	4.7	10.9
50%	7.4	17.5	6.9	23.8	9.3	16.3	5.7	15.9
75%	11.2	21.9	7.9	25.1	7.9	18.7	4.5	15.9
Stand density								
Thick	4.9	8.9	3.1	9.9	3.9	7.4	2.9	7.0
Thin	11.1	23.9	10.4	32.9	12.4	23.2	6.9	21.4

but this clipping caused least reduction in plant health.

Effects of season of clipping upon vigor were most apparent in thick stands of both species in 1969. Crown cover ratings were lowest in both species due to clipping the same plant early and late. Plant vigor was reduced least by early clipping. There was a decline in crown cover rating from 1965 to 1969.

Crown diameters increased from 1965 to 1969 but the density of growth in the crown decreased. The greatest increase in crown diameter occurred in plants clipped early, and the least increase occurred in plants clipped late.

Intensity of Clipping

The heavier the intensity of clipping, the greater the amount of herbage available for animal consumption (Table 3), but plants clipped the heaviest were lowest in vigor (Table 2). There was a reduction in crown cover and an increase in crown diameter with increased intensity of harvesting. Changes were greatest on plants clipped most heavily. The effects of clipping intensity are shown readily in a series of photographs (Fig. 1).

Conclusion

The thin stand of Russian wildrye performed extremely well under all seasons and intensities of clipping. Under the harsh conditions of the big sagebrush site, it out-performed crested wheatgrass. Russian wildrye produced more forage and maintained vigor better under all defoliation treatments than did crested wheatgrass. Production of Russian wildrye was 3 to 4 times that of crested wheatgrass under all treatments. At the end of 5 years of clipping, the thin stand of Russian wildrye had at least 10% more live material per plant than the thin stand of crested wheatgrass. The thin stand of Russian wildrye produced 2 to 3 times more seedheads per unit area than crested wheatgrass.

If recommendations were to be made from these data, it appears that early and mid season clipping intensities were less detrimental to vigor of either species than late defoliation or harvesting twice, early and late. It also appears that lower rates of seeding (thin stands) are preferable on dry foothill sites. The optimum tradeoff between harvested herbage and plant vigor appears to come from herbage removal on Russian wildrye or crested wheatgrass during early or mid spring at a moderate intensity.

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Carbohydrate Reserves of Crested Wheatgrass and Russian Wildrye as Influenced by Development and Defoliation[1]

M. J. TRLICA, JR. AND C. WAYNE COOK

Research Assistant and Research Professor,[2] Utah State University, Logan, Utah.

Highlight

Carbohydrate reserves of crested wheatgrass (*Agropyron cristatum*) and Russian wildrye (*Elymus junceus*) were lowest after initial spring growth, but maximum levels were rapidly attained as plants approached maturity. Fall regrowth caused reductions in total available carbohydrate (TAC) stores. More TAC reserves were used to produce new growth if plants were defoliated during spring growth than if defoliated at maturity or quiescence. Autumn TAC storage levels in both crested wheatgrass and Russian wildrye were reduced by all previous defoliations. Autumn reserve storage was directly related to the amount of new growth produced after defoliation. Results indicate that both crested wheatgrass and Russian wildrye are adapted for either fall or early spring grazing and under some circumstances for spring-fall use. Defoliation when plants are rapidly replenishing reserves or before maturity reduces subsequent new growth and carbohydrate reserve stores in the autumn.

Two introduced grasses, crested wheatgrass (*Agropyron cristatum*) and Russian wildrye (*Elymus junceus*) are important seeded rangeland species of the western United States and Canada. These two species are presently being utilized for grazing, erosion control and roadside revegetation. Information about (1) seeding methods (Cook, 1958; Cook, 1966; Cook et al., 1967; Cook et al., 1970), (2) growth responses after grazing or foliage removal (Cook and Stoddart, 1953; Cook et al., 1958; Frischknecht, 1968; Currie and Smith, 1970), (3) nutritive values (Cook and Harris, 1952; Cook and Harris, 1968), and (4) competitive relationships with other species (Cook and Lewis, 1963; Cook, 1965; Drawe, 1971) are available for these two species. Little information is available, however, on the physiological effects of defoliation for crested wheatgrass and Russian wildrye. This study was therefore conducted from 1967 to 1969 to determine carbohydrate reserve stores for these two grasses as influenced by phenological development and several defoliation treatments.

Experimental Area and Procedure

The study areas were located in central and northwestern Utah. The climate is semiarid with warm, dry summers and cold winters. Average yearly precipitation was slightly greater than the 10-year average of 28 cm during 1967 and 1968, and slightly less than average in 1969. The spring and early summer of 1968 were dry, but about three times the normal amount of precipitation fell in August. Precipitation was below average throughout most of 1969. Site descriptions of these foothill ranges were given by Frischknecht (1968) and Drawe et al. (1972).

Both crested wheatgrass and Russian wildrye were seeded in the autumn of 1958 and 1960 following sagebrush (*Artemisia tridentata*) removal and summer fallow treatments. Plots containing both species were fenced to eliminate livestock grazing. Pure stands of each species on adjacent similar sites were selected for study.

Defoliation treatments of both species were made by clipping 90% of the plant's current photosynthetic tissue. Defoliations were made during early fall (September) of 1967 and 1968 when plants were mature. These were single defoliations in both cases. Because of late summer rains, both grasses had produced two new leaves per tiller before defoliation. The second single defoliation treatment for plants of both species was made after "killing" frosts in November of 1967 and 1968 when the plants were quiescent. Green leaf and stem bases were still present, however. Another single defoliation treatment was made during early growth (April) of 1968 and 1969 when both grasses had produced about 20% of their anticipated annual growth based on weight. Both species were in the second or third leaf stage of growth. A fourth single defoliation treatment was applied during early June of 1968 and 1969. Both grasses were at anthesis and had produced about 75% of their anticipated annual growth at this time. In all cases, different plants were defoliated each year. Data were therefore available for 2 years for each of the 4 single clipping treatments at 4 phenological stages of development.

In addition to the 4 single defoliation treatments, a fifth treatment was carried out by defoliating plants during quiescence (November) of one year and subsequently harvesting the same plants again in early growth (April) the following year in both 1967 and 1968. A sixth treatment involved defoliating plants at anthesis (June) in 1968 and clipping the same plants again in September at maturity. Because of dry conditions in 1969, little regrowth was made by plants clipped in late spring during anthesis; therefore, these plants were not clipped twice as in 1968.

In all cases, total available carbohydrates (TAC) from root and crown samples of defoliated plants were determined when plants had produced new growth equal to ap-

[1] This was a cooperative project between Utah State University and the Bureau of Land Management. Utah Agriculture Experiment Station journal paper 1221. Received November 20, 1971.

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proximately 20% of mature size. These determinations were compared with TAC concentrations of unclipped plants to determine the carbohydrate stores used for respiration and production of new growth. Root and crown samples from all defoliation treatments and control plants of crested wheatgrass and Russian wildrye also were collected during the autumn of each year for TAC analysis. Plants that had been defoliated during quiescence in 1967 and 1968 were not sampled until the following autumn of 1968 and 1969, respectively. Thus, a range of 2 months to a full year may have elapsed between various defoliation treatments and autumn sample collections. Unclipped plants of both species were sampled periodically throughout the autumn of 1967 and the growing season of 1968 to determine carbohydrate reserve fluctuations in roots and crowns throughout the annual growth cycle.

A separate experiment was conducted in the late summer and fall of 1967 and 1968 to determine the influence of additional soil water on plant regrowth and TAC storage. Both crested wheatgrass and Russian wildrye plants were clipped at maturity in early September and small earthen dikes were constructed at the base of the treated plants. Equal numbers of control plants of both species were selected in the same proximity and dikes were constructed around their bases. These plants were irrigated to provide additional soil water throughout the remainder of the growing season. Sixteen to 32 liters of water (equal to approximately 10 cm of precipitation) were supplied at 1 to 2-week intervals to each diked plant in an effort to stimulate fall regrowth. These plants were excavated in the fall, along with those plants not receiving additional water, to determine if soil water regime had a significant effect upon herbage regrowth and carbohydrate reserve storage.

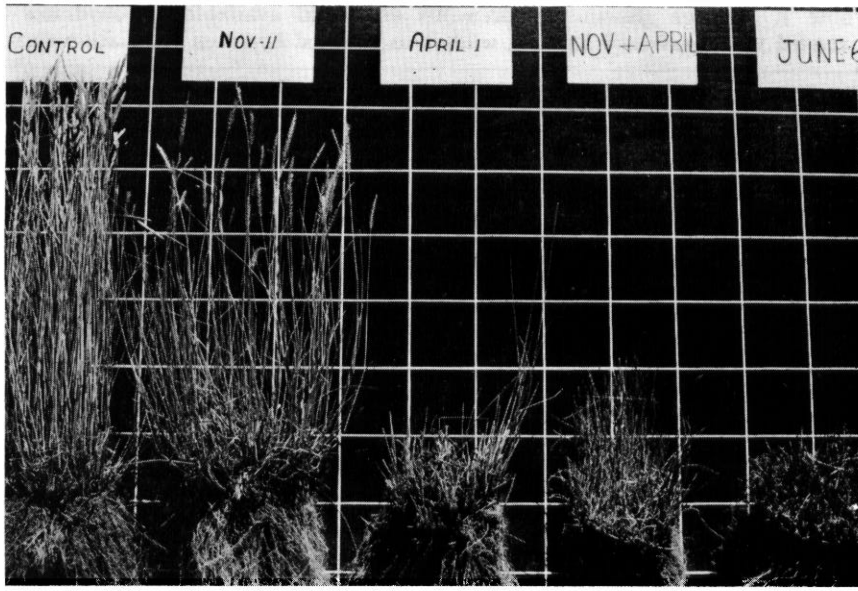

FIG. 1. Crested wheatgrass plants in the autumn from control, quiescence (Nov. 11), early growth (April 1), both quiescence and early growth (November and April) and anthesis (June 6) defoliation treatments.

Roots were separated from crowns in the field and washed with water. Grass root systems were collected to a 30 cm depth. The lower 4 to 5 cm of the culms, rhizomes, and tillers were designated as crown tissue. No attempt was made to separate live tissue from dead unless decay was obvious. These samples were placed in pint jars and covered with 95% ethanol to reduce enzyme activity. Samples were taken to the laboratory, lids were removed from the jars, and the jars placed in a forced-draft dryer at 70 C. Approximately 1 week was required to evaporate the ethanol and an additional week to dry the samples.

After drying, the samples were ground to pass through a 40-mesh screen. Laboratory analyses were conducted to determine TAC as milligrams of available carbohydrates per gram of dry plant matter. Weinmann (1947) and Smith et al. (1964) defined TAC to include sugars, dextrins, starches, and fructosans. Structural carbohydrates such as pentosans, hemicellulose, and cellulose were not included in the TAC fraction. No allowance was made for water of hydrolysis from polysaccharides in the calculations (Grotelueschen and Smith, 1967).

Extraction of TAC from 0.5 g samples of plant material was accomplished by using 0.2 N sulfuric acid as described by Smith et al. (1964). These extracts were analyzed on a glucose equivalent basis by using an iodometric titration developed by Heinze and Murneck (1940) with modifications of reagents as suggested by the Association of Official Agricultural Chemists (1965). Standard curves were determined for each stock solution.

Results and Discussion

Differences in growing conditions during the 3 years of this study caused yearly differences in growth of crested wheatgrass and Russian wildrye. Precipitation during 1968 was above normal and plant growth was greater. Plants clipped later in their yearly growth cycle produced less new growth by fall (Fig. 1). Both species followed similar trends in production of new growth following defoliations. Plants clipped at quiescence (November) or during early growth (April) produced more new growth by the following autumn than

Table 1. Average growth measurements and total available carbohydrates (TAC) in the autumn of two years for crested wheatgrass and Russian wildrye as affected by seven defoliation treatments.

Phenological stage of defoliation	Crested wheatgrass: Current year's growth (cm)	Seedstalk length[1/] (cm)	% growth attained as compared with control	TAC[2/] (mg/g) Roots	TAC[2/] (mg/g) Crowns	Russian wildrye: Current year's growth (cm)	Seedstalk length[1/] (cm)	% growth attained as compared with control	TAC[2/] (mg/g) Roots	TAC[2/] (mg/g) Crowns	Average TAC[2/] (mg/g)
Control	32	50	100	128a	113	30	75	100	137a	84a	116
Quiescence	26	48	73	115ab	96a	28	58	83	112bc	75ab	100a
Early growth	26	44	66	108b	89ab	26	55	75	124ab	78ab	100a
Quiescence and early growth	23	42	54	118ab	97a	23	58	74	115bc	77ab	102a
Anthesis	8	0	20	83	78b	19	0	30	113bc	65b	85b
Maturity	3	0	10	102b	79b	4	0	15	100c	78ab	90ab
Anthesis and maturity[3/]	3	0	8	59	55	4	0	15	103c	66b	71b

[1/] Plants clipped at or after anthesis did not produce seedstalks.

[2/] Treatment means in a column followed by a similar letter are not significantly different from each other at the .05 level of probability.

[3/] Only data for 1968 were available for plants clipped at anthesis and again at maturity. Error variance for all treatments for the two year's data were used to test all seven treatments. This assumes that one year's data for the anthesis and maturity defoliation did not influence the magnitude of the error mean square term.

plants defoliated at anthesis (June) or at maturity (September). Plants defoliated at quiescence and again during early spring growth produced about as much new growth as plants clipped only once during early spring growth. When crested wheatgrass and Russian wildrye were clipped at anthesis and again at maturity, they produced about as much new growth by late autumn as when defoliated only once at maturity. Trends in seedstalk height after defoliation were similar to that of new growth production (Table 1).

Drawe et al. (1972) found Russian wildrye to be more productive than crested wheatgrass on similar sites under any intensity or season of defoliation. Clipping both species at light and moderate intensities during early or mid-spring growth was less detrimental to plant vigor than clipping after anthesis or clipping during early growth and again after anthesis. Similar trends in growth and production of these two grasses were found in the present study (Table 1).

Cycling of Carbohydrate Reserves

Seasonal trends in carbohydrate reserve depletion during initial growth and the subsequent replenishment of reserves have been well documented for several range species (Sampson and McCarty, 1930; Troughton, 1957; Weinmann, 1961; and Coyne and Cook, 1970). Hyder and Sneva (1959) described the growing season trends in total available carbohydrates of roots and stem bases of crested wheatgrass. However, the carbohydrate reserve cycles throughout a year for both crested wheatgrass and Russian wildrye growing on similar sites have not been compared.

Total available carbohydrates (TAC) in roots and crowns of crested wheatgrass and Russian wildrye followed somewhat similar patterns (Fig. 2 and 3). Carbohydrate reserves were high in the fall and decreased to a low level during initial spring growth. The lowest TAC level was found during early growth (April) when approximately 20% growth had been produced by both species. Approximately 50 to 60% of the reserves stored the previous summer and fall were used in respiration and initial growth the following spring. Crested wheatgrass and Russian wildrye were at the second to third leaf stage during the period of low reserve concentrations. Thereafter carbohydrate reserves in both roots and crowns rapidly accumulated until maxi-

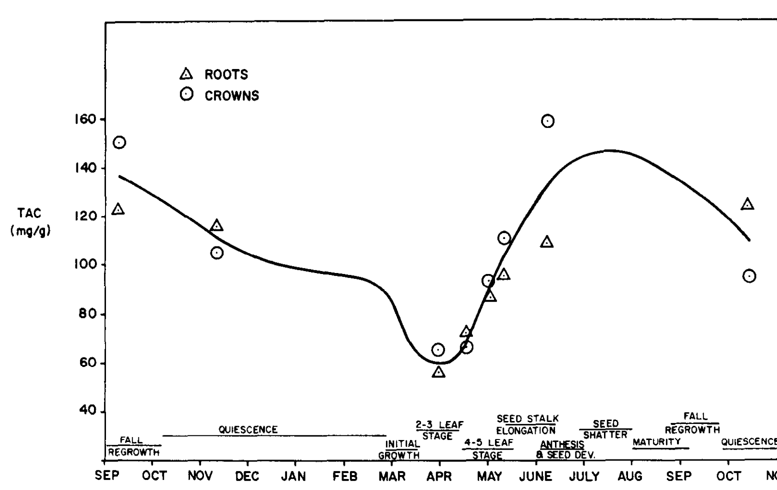

FIG. 2. Total available carbohydrates (TAC) in roots and crowns of crested wheatgrass (1967–1968) as related to stage of phenological development. Theoretical TAC cycle is indicated by the line in this graph.

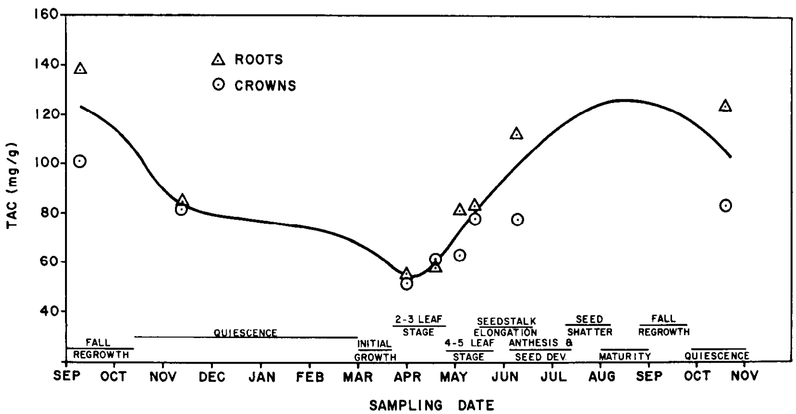

FIG. 3. Total available carbohydrates (TAC) in roots and crowns of Russian wildrye (1967–1968) as related to stage of phenological development. Theoretical TAC cycle is indicated by the line in this graph.

mum levels were attained as plants neared maturity (Fig. 2 and 3).

The decline of reserve levels in crowns of crested wheatgrass and roots of Russian wildrye in the fall of 1967 may be attributed largely to fall regrowth (Fig. 2 and 3). Russian wildrye produced about 5 to 10% more regrowth than crested wheatgrass, which may account for greater reductions in autumn TAC storage levels in Russian wildrye.

The growing season trend in TAC concentrations for both species was similar to that reported for crested wheatgrass by Hyder and Sneva (1959). They attributed the rapid increase of reserve storage levels after initial growth to abundant leafiness and a delay in stem elongation. This was probably true for both crested wheatgrass and Russian wildrye in the present study. Since both grasses had similar phenological development, both had similar reserve depletion and restoration patterns. Reserve replenishment during vegetative growth was more rapid however for crested wheatgrass than for Russian wildrye (Fig. 2 and 3).

Both root and crown storage concentrations of crested wheatgrass and Russian wildrye followed somewhat similar trends. Root reserves were, however, greater ($p < .01$) than crown reserve concentrations at fall quiescence (Fig. 2 and 3). Trlica and Cook (1971) found autumn crown reserve concentrations to be greater than root reserve concentrations for Indian ricegrass (*Oryzopsis hymenoides*) and needle-andthread (*Stipa comata*).

Effects of Additional Water on Regrowth and Carbohydrate Storage

Additional soil water that was supplied during the late summer and fall of 1967 and 1968 to control plants and plants that had been defoliated at maturity caused both crested wheatgrass and Russian wildrye to resume growth. Watered plants produced an average of one more leaf per tiller and 10 to 20% more regrowth than did unwatered plants. This additional growth caused a significant reduction ($p < .05$) in autumn TAC storage levels of both species. The TAC level in roots and crowns of plants that received additional water were about 15% lower than reserve levels in unwatered plants.

A significant interaction ($p < .05$) between plant parts and years was probably caused by greater increases in root TAC storage than crown storage in 1968. More favorable growing conditions during 1968 may have caused greater root storage levels at quiescence during that year.

Carbohydrate Reserve Stores as Affected by Defoliation Treatments

Both crested wheatgrass and Russian wildrye used similar amounts of TAC to produce 20% new growth after defoliation. No differential utilization of reserves from roots or crowns was observed. However, significant differences ($p < .05$) were found in the amount of TAC utilized among plants from various defoliation treatments to produce 20% new growth. Both grasses used more reserves to produce 20% new growth when clipped during early growth than when clipped at maturity or quiescence. Higher temperatures and respiration rates during the late spring and summer regrowth period may have contributed to greater reductions in TAC reserves for plants defoliated during early growth.

The amount of new growth produced by defoliated plants was directly related to the time remaining in the growing season (Fig. 1). As would be expected, plants defoliated the previous autumn at quiescence or during early spring growth produced more new growth than plants clipped at anthesis or maturity. Differences in growing conditions during the 3 years caused significant differences ($p < .05$) in length of current year's growth and seedstalk lengths among years; however, significant differences in autumn reserve levels among years were not present.

Autumn carbohydrate reserves were similar for crested wheatgrass and Russian wildrye. Comparable phenological development and responses to growing conditions may account for the similarity in fall reserve stores of these two grasses.

Clipping significantly reduced fall reserve levels of both grasses as compared to unclipped plants (Table 1). However, only small reductions in autumn TAC storage occurred when plants were defoliated during quiescence the previous year or during early growth the same year. Trlica and Cook (1971) earlier reported similar results for desert range species. Crested wheatgrass and Russian wildrye plants that were clipped at either anthesis or maturity, or clipped at anthesis and again at maturity, had substantial reductions in TAC stores in the autumn (Table 1). Plants from these 3 treatments had little chance for regrowth before autumn frosts and consequently had little photosynthetic tissue for carbon dioxide assimilation and carbohydrate storage during the normal storage period. Thaine (1954) reported that carbohydrate reserves of Russian wildrye diminished with increased clipping frequency during the growing season. The present study indicated however, that clipping crested wheatgrass or Russian wildrye at quiescence and again during early growth was no more detrimental to TAC storage than clipping them once at the later stage of phenological development.

Root TAC reserves were reduced more by defoliations than were crown reserves (Table 1). A highly significant interaction ($p < .01$) between root and crown TAC levels and species was caused by larger differences between TAC levels of roots and crowns of Russian wildrye as compared with roots and crowns of crested wheatgrass. The roots of Russian wildrye from any defoliation treatment were considerably higher in TAC than the crowns.

Although autumn carbohydrate reserves were directly related to the amount of photosynthetic tissue present during normal storage periods, regression analysis indicated that variability in TAC levels (Y's) could not be accounted for by differences in percentage of new growth attained compared to controls, length of current year's growth, and seedstalk heights (X's). Measurements of these independent variables could only account for as much as 34% of the variability in autumn TAC stores of crested wheatgrass and Russian wildrye. If other measures of plant vigor at quiescence were utilized, such as leaf area, weight, and crown cover, then plant carbohydrate reserve status might be predicted with greater accuracy. McKendrick and Sharp (1970) found that herbage production of crested wheatgrass was highly correlated with organic reserve index, basal area per plant, and number of tillers per unit surface area.

Results from this study suggest that both crested wheatgrass and Russian wildrye are physiologically adapted for fall or early spring grazing and possibly for spring-fall grazing as suggested by Hyder and Sneva (1963). Grazing when plants are rapidly replenishing reserves during late spring or before fall quiescence however, may cause serious reductions in plant TAC reserves and new growth. Carbohydrate reserve data support the findings of Drawe et al. (1972) that clipping during the latter part of the growing season or combined early and late spring clipping are detrimental to vigor of crested wheatgrass and Russian wildrye.

Summary and Conclusions

A study was conducted from 1967 to 1969 in central and northwestern Utah to determine seasonal carbohydrate reserve cycles and how various defoliation treatments affected utilization and storage of carbohydrate reserve in crested wheatgrass and Russian wildrye. Phenological development and autumn carbohydrate levels were similar for both grasses. Root and crown reserve levels were lowest after initial spring growth; however, reserves were rapidly accumulated and maximum levels were attained as plants approached maturity.

Fall regrowth stimulated either by natural rainfall or irrigation caused reductions in total available carbohydrates (TAC) stores during this period. Irrigated plants produced 10 to 20% more regrowth and reserve levels were about 15% lower than plants which did not receive additional water. Carbohydrate reserves of plants which produced fall regrowth were not replenished before fall quiescence.

Both crested wheatgrass and Russian wildrye used similar amounts of TAC to produce new growth following defoliation. More reserves were utilized to produce 20% new growth if plants were defoliated during early growth than if defoliated during maturity or quiescence.

Autumn reserve levels in both crested wheatgrass and Russian wildrye were reduced if plants had been defoliated as compared to unclipped plants. Plants defoliated at either anthesis or maturity had less autumn TAC stores than plants defoliated at quiescence the previous fall or during early spring growth. Defoliations at quiescence and again during early growth were usually no more detrimental to TAC storage in these grasses than a single defoliation, when the single defoliation was carried out at the later phenological stage of development. Autumn reserve stores were directly related to the amount of new growth produced after being defoliated. However, percentage new growth attained compared to controls, length of current year's growth, and seedstalk heights could only account for 34% of the variation in autumn TAC storage levels.

Results from this study indicate that both crested wheatgrass and Russian wildrye are physiologically adapted for fall or early spring grazing and possibly for spring-fall range. However, grazing when plants are rapidly replenishing reserves or before fall quiescence may be detrimental to plant welfare.

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Herbage Response to Precommercial Thinning in Direct-Seeded Slash Pine[1]

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Highlight

Direct-seeded slash pines (*Pinus elliottii* Engelm. var *elliottii*) were thinned at age 3 years to densities ranging from 500 to 5,300 trees/acre. At stand age 12 years, herbage yields were inversely related to tree basal area, varying from 560 lb./acre under tree basal areas of 125 ft² to 2,230 lb. under 54 ft². Where timber stand densities were equal, yield did not vary between plots that had been thinned selectively and those on which continuous opening had been created by removing trees in strips.

An appreciable forage resource can be maintained in well-spaced slash pine plantations if proper grazing and judicious burning are practiced. When pines are regenerated by direct seeding, however, they are often so dense that they reduce forage yields drastically, even with frequent burning. Since over-dense stands also produce less than optimum amounts of timber, some land managers thin when the trees are in late seedling or early sapling stages.

In the study reported here, herbage yields at stand age 12 years were evaluated in direct-seeded slash pines that had been thinned at age 3 to densities ranging from 500 to several thousand trees/acre. Some of the thinnings were achieved by removing all trees from strips 6.6 or 9.9 ft in width, and on some plots a checkerboard pattern was created by running strips at right angles to each other. An opportunity was therefore afforded to compare herbage yields under such patterns of stocking

[1] Received December 31, 1971.

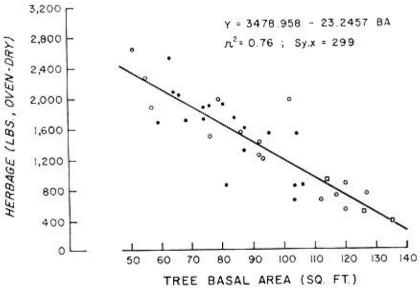

FIG. 1. Herbage yield and tree basal area/acre. Circles indicate selectively thinned plots, squares are unthinned check plots, and solid dots represent strip-thinned plots.

with yields on areas without large continuous openings.

Study Area and Methods

Slash pine seed was sown in March 1959 on 40 acres of the Palustris Experimental Forest in central Louisiana. Since the aim was to create an over-dense stand for experimental purposes, 2 lb. of seed were sown per acre—about twice the recommended rate. The catch was good, and in early 1961 stocking averaged 5,600 trees/acre. In the summer of 1961, 11 thinning treatments, plus a check, were established in three completely randomized replications on 0.4-acre plots:

Five selective thinnings, in which plots were thinned by hand to 4,200, 2,800, 1,400, 750, or 500 of the tallest, well-spaced healthy trees/acre.

Four strip thinnings, in which trees were cleared from strips 6.6 ft wide, leaving swaths of trees 6.6 ft wide. Three of these thinnings were made by hand and one by disking. Disking left 3,000 trees/acre; hand clearing 2,800. Timbered strips of two hand-cleared treatments were additionally hand-thinned to 1,400 trees/acre, one immediately after initial clearing, the other at age 5.

1) Checkerboard: hand-cleared strips run at right angles to each other, creating 6.6-ft square blocks averaging 1,400 trees/acre.
2) 3.3-ft strips: trees removed by hand from strips 9.9 ft wide, leaving 3.3-ft swaths containing 1,400 trees/acre.

FIG. 2. Unthinned check plots, which averaged 3,737 trees/acre and 125 ft²/acre of basal area, produced 559 lb./acre herbage.

FIG. 3. Plots with 500 trees/acre averaged 54 ft² of basal area and 2,233 lb./acre oven-dry herbage.

Soils are of the Bowie and Beauregard series; surface and internal drainage are conducive to timber and herbage growth. Prescribed fires for hazard reduction were applied at ages 6, 7, 9, and 11 years. The quantity of herbage was apparently enhanced by the frequent burning, which controlled hardwood sprouts and prevented smothering of forage plants by accumulated pine straw.

Trees and herbage were measured at age 12 on 0.1-acre subplots. In each subplot herbage samples were clipped to ground level on 17 systematically spaced quadrats 1.55 ft on edge.

Results

Herbage yields at age 12 years were least on plots with highest timber densities (Table 1). Unthinned check plots, with 125 ft² of basal area and 3,737 trees/acre, produced 559 lb./acre oven-dry herbage. Plots thinned to 500 trees/acre had 54 ft²/acre of basal area and over a ton of herbage/acre. Yields were intermediate at timber densities between these two extremes.

The significant regression (Fig. 1) indicates that tree basal area provided a general index to herbage yield regardless of the thinning method.

Table 1. Herbage yields (lb./acre, oven-dry) as related to density and basal area (ft²/acre) of slash pine stands.

Treatment and number of trees left after thinning[1]	Trees per acre, age 12 years	Basal area per acre	Herbage yield[2]
Check—5,600	3,737	125	559 a
Selective—4,200	3,463	120	619 a
6.6 strip-disk—3,000	2,943	105	1,040 ab
Selective—2,800	2,607	113	1,154 ab
Selective—1,400	1,337	92	1,266 abc
6.6 strip—2,800	1,920	89	1,319 abc
Checkerboard—1,400	1,047	71	1,518 bcd
6.6 strip + selective—1,400	1,247	81	1,585 bcd
6.6 strip + deferred selective—1,400	1,333	83	1,694 bcd
Selective—750	710	81	1,699 bcd
3.3 strip—1,400	983	63	2,049 cd
Selective—500	467	54	2,233 d

[1] Treatments are arranged in order of increasing herbage yield.
[2] Values with no common letter are significantly different at the 5-percent level (Duncan's multiple range test).

Pinehill bluestem (*Andropogon divergens*), generally a principal plant on cutover range, comprised 43 to 85% of the herbage. Percentage was greatest on heavily thinned plots with high herbage yields and least on densely timbered plots with low yields. Other bluestem grasses, including slender bluestem (*A. tener*), which usually shares dominance with pinehill bluestem on cutover sites (Duvall, 1962), accounted for less than 10% of the herbage on most plots.

Panicums and other grasses comprised less than 20%. The principal grasses in this group were switchgrass (*Panicum virgatum*), spreading panicum (*P. rhizomatum*), narrowleaf panicum (*P. angustifolium*), and pineywoods dropseed (*Sporobolus junceus*).

Forbs averaged up to 40% of the herbage on the densely timbered check and selectively thinned plots, but elsewhere made up 10 to 25%. Principal forbs were southern bracken (*Pteridium aquilinum* var. *pseudocaudatum*), swamp sunflower (*Helianthus angustifolius*), poor-joe (*Diodia teres*), fragrant goldenrod (*Solidago odora*), littleleaf tickclover (*Desmodum ciliare*), and weak tephrosia (*Tephrosia onobrychoides*). These species are found also on treeless range, and all but southern bracken, which is poisonous to cattle (Kingsbury, 1964), have forage value.

Figures 2 and 3 illustrate herbage yields under the heaviest and lightest timber stocking.

Discussion

Herbage yield was related to timber density, whether trees were uniformly distributed or crowded into strips or blocks. Though plots thinned in strips had larger continuous openings, they produced no more herbage than selectively thinned plots of comparable density. Yield differences between cleared and timbered strips within plots were not measured, but variation in herbage density appeared negligible. At 12 years, the tree canopy was fairly uniform on most plots, possibly cancelling effects of strips.

Herbage yields in these direct-seeded slash pine stands equalled or exceeded those in planted slash pine stands of comparable densities[2]. In fact, plots with 500 trees/acre equalled the production previously reported on similar sites with no trees (Grelen and Epps, 1967). The high yields may have been related to the prescribed fires, which were applied more frequently than is common in timber management.

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THESIS: TEXAS TECH UNIVERSITY

Effect of Redberry Juniper Control on Understory Vegetation, by Robbie G. Graves. M.S., Range Management. 1971.

The quality and yield of herbage in redberry juniper stands (*Juniperus penchoti*) were determined during 1970, one and two years after juniper had been controlled with chemicals. Herbage production between trees on two sites where juniper had been controlled was 88% higher than where juniper had not been controlled. Herbage beneath dead trees was more than twice as high as beneath live trees. The number of grass species increased following juniper control on both deep hardland and very shallow sites. The species composition did not change radically where junipers were controlled.

Crude protein production on both sites was dependent upon dry matter herbage production, therefore, protein yields nearly doubled where junipers had been controlled. Nutrient composition of herbage was very similar between controlled and uncontrolled plots and between sites. On all sampling dates, soil moisture was significantly greater on areas where juniper had been controlled and was dead than on plots where juniper was alive.

In converting the additional forage production to pounds of beef produced, an additional 8.1 lbs. of beef could be produced where juniper was controlled. If calf return produced 30 cents per lb., the increase in beef production would add $2.43 per acre in gross annual income.

Soil Properties and Nutrient Availability in Tarweed Communities of Central Washington[1]

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Highlight

Comparison of soil nutrient levels and certain soil physical properties between tarweed communities and adjacent stable, productive needlegrass communities indicated a lower nutrient capital of N, S, and exchangeable Mn and poorer physical condition in the tarweed communities. Pot studies with mountain brome and orchard grass revealed low availability of N, S, and P in soils from tarweed communities and suggest a need to amend native soil nutrients with these elements.

High elevation grasslands on basalt-capped plateaus dominated by Columbia needlegrass (*Stipa columbiana* Macoun.) are important summer range for livestock and wildlife in north central Washington. These plateaus are also vital sources of water.

A prevalent problem on many of these areas is a series of abrupt breaks in the grassland vegetation, resulting in a mosaic of barren areas dominated by cluster tarweed (*Madia glomerata* Hook.) (Fig. 1). These breaks are characterized by a 15- to 20-cm lower soil surface, a high percentage of bare soil, an abrupt ecotone from a community dominated by perennial grasses and forbs to one dominated by annual forbs and active frost heaving. Topography of this nature is referred to locally as biscuit-scab or biscuit-swale.

According to Kaatz (1959), patterned ground of the type described covers hundreds of square miles of central Washington and appears to have resulted from intensive frost action associated with a periglacial climate. Daubenmire (1970) describes abrupt vegetation discontinuities which coincide with loessial-lithosolic soil contacts. However, he could find no consistent differences in soil characteristics that would explain the vegetation discontinuities.

Revegetation studies have shown that competition for moisture by cluster tarweed and frost heaving of new grass seedlings are the primary obstacles to revegetation of barren areas (Stevenson, 1950; Hull and Cox, 1968). These authors concluded that cultivation and seeding in the spring resulted in the best grass stands. However, Hull and Cox found that this procedure was impractical on heavy soils and alternatively advised spraying annual weeds with 2,4-D in the spring, drilling grass seed in the fall, and respraying weeds the following spring. Although Hull and Cox tested various fertilizer treatments, they apparently did not test them in conjunction with the weed control and drilling schedules, and none were judged successful.

The abrupt drop in soil surface between needlegrass and tarweed communities indicates that much of the topsoil is either missing or has never developed. Because of this, there is a possibility that soil nutrients are a limiting factor in the tarweed community. To insure successful revegetation of these tarweed communities with perennial grasses, it is necessary to acquire a knowledge of the native nutrient capital and nutrient availability of the soils of the tarweed communities.

Using characteristics of the soil from needlegrass communities as a reference, this study evaluates the nutrient capital and nutrient availability of soils from adjacent tarweed communities. At the same time, comparison of physical and chemical soil properties of the two communities will be used to indicate the favorability of the tarweed community for germination and establishment of seeded perennial grasses and forbs.

The Study Area

Table Mountain, a basalt-capped plateau at an elevation of 1,850 m near Ellensburg, Washington, was the study area. The mosaic pattern of tarweed communities with islands of needlegrass communities is prominent in this area, occurring as open parks among stands of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.).

Vegetation of the needlegrass communities consists primarily of perennial grasses, sedges, and forbs such as Columbia needlegrass, tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), Idaho fescue (*Festuca idahoensis* Elmer), Raynolds sedge (*Carex raynoldsi* Dewey), mountain dandelion (*Agoseris glauca* (T. and G.) Jeps.), lambstongue groundsel (*Senecio integerrimus* (Greenm.) Cronq.), butterweed groundsel (*S. serra* Hook.), and aster (*Aster foliaceus* (D. C. Eat.) Gray). In the tarweed communities, annual plants such as cluster tarweed, Sawatch knotweed (*Polygonum sawatchense* Small), Kellogg knotweed (*P. kelloggi* Greene), woodlandstar (*Lithophragma bulbifera* Rydb.), collinsia (*Collinsia parviflora* (Pursh.) Piper), and cryptantha (*Cryptantha torreyana* (Gray) Greene) are prominent. Three common perennial species in the tarweed community are bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith), lupine (*Lupinus wyethi* Wats.), and phacelia (*Phacelia hastata* (Torr.) Cronq.).

The soil, developed from basalt parent material, is a loam of the Anatone series.[4] Anatone soils have a reddish-

[1] Received October 15, 1971.

[2] The assistance of Tom D. Anderson, project chemist, in the collection of field and greenhouse data and analysis of soils is gratefully acknowledged by the author.

[3] Central headquarters located in Portland, Oregon.

[4] Unpublished soil survey report for Chelan County, Washington, U.S. Dep. Agr. Soil Cons. Serv.

FIG. 1. Mosaic of needlegrass and tarweed communities on Table Mountain.

brown, extremely stony A1 horizon and a reddish-brown, very gravelly, and cobbly silt loam B horizon. Depth ranges from 25 to 50 cm. These soils are well drained with moderate permeability and medium to rapid runoff.

Total annual precipitation is about 90 cm, occurring mostly as snow, and mean annual temperature is approximately 2 C (Berndt and Fowler, 1969).

Methods

Two separate areas were selected for study. The first, referred to as the upland area, is on a gently sloping, southeast-facing hillside near the top of a ridge. The other, designated the lowland area, is 400 m away at the foot of a slope facing generally southwest. Three separate and distinct needlegrass and tarweed communities in each area were selected for sampling. Soil cores and loose samples of soil were collected at depths of 0 to 7.5 cm and 7.5 to 15 cm at three random locations in each community.

Properties measured included: bulk density, soil texture, pH, organic matter, and total P (Black et al., 1965a and 1965b); total N (Keeney and Bremner, 1967); total K (Belt, 1967); total S (Tiedemann and Anderson, 1971); cation exchange capacity (Chapman and Pratt, 1961; Ballentine and Gregg, 1947); and exchangeable Ca, Mg, Mn, Na, and K by atomic absorption spectroscopy (Robinson, 1966). All determinations were made in duplicate. Data were evaluated using analyses of variance of a split-plot design with areas and communities as factors of the whole plot units and depths as a split-plot factor. Whole plot units are arranged completely at random.

To evaluate the availability of N, P, K, and S in soil from the two communities, a pot test was conducted using orchard grass (*Dactylis glomerata* L.) and mountain brome (*Bromus carinatus* Hook. and Arn.).

Soil was collected from each community at each area to a depth of 15 cm, screened in the field through a ½-cm screen, brought to the laboratory, and air-dried.

Plants of the two species were grown from seed in separate pots containing 1,000 g of soil to which the following nutrient treatments were added:

(1)	$N_0P_0K_0S_0$	Check
(2)	NPKS	Full nutrient treatment
(3)	N_0PKS	No nitrogen
(4)	NP_0KS	No phosphorus
(5)	NPK_0S	No potassium
(6)	$NPKS_0$	No sulphur

Nutrients were applied at rates equivalent to 224 kg/ha of N as ammonium nitrate (44.6 mg/kg = 100 kg/ha), 336 kg/ha of P_2O_5 as monosodium phosphate, 112 kg/ha of K as potassium chloride, and 112 kg/ha of S as calcium sulphate. Plants were grown in a greenhouse under 12-hour photoperiod and night and day temperatures of 18 and and 24 C, respectively. Distilled water was added to the pots to replace evapotranspiration losses.

All foliar material was harvested after 16 weeks, oven-dried, and weighed. Relative yield was used as an indication of the availability of each nutrient tested. The relative yield of a nutrient is an expression of the capacity of a soil to supply that nutrient under the experimental conditions employed (Jenny et al., 1950; Klemmedson and Jenny, 1965). It is the ratio of the yield without the nutrient to the yield with the full nutrient treatment. For example, the relative yield for

$$\text{N (RYN)} = \frac{\text{yield in grams with } N_0PKS}{\text{yield in grams with NPKS}} \times 100$$

The higher the relative yield, the greater the availability of a particular nutrient to a given plant species.

Data from the pot test were not analyzed statistically because field replication was not carried through to the greenhouse.

Results

Soil Tests

Of the physical and chemical properties measured, only bulk density, organic matter, total N, total S, and exchangeable Mn displayed significant departures between needlegrass and tarweed soils (Table 1). However, these properties indicated that soil from tarweed communities had a less favorable physical condition and a lower nutrient capital than needlegrass soil, and that the upland area was more fertile than the lowland area.

Average bulk density in needlegrass soil was 0.87 g/cm³ compared with 1.06 g/cm³ in tarweed soil—a highly significant difference. Although no significant difference between depths was observed, there was a significant depths × communities interaction. In the tarweed communities, bulk density decreased from 1.11 to 1.02 g/cm³ between the 0- to 7.5-cm and 7.5- to 15-cm depths, whereas in the needlegrass communities bulk density increased between those depths from 0.85 to 0.88 g/cm³ (Table 2).

Average organic matter content in soil from the needlegrass communities was more than twice as great as in tarweed communities (6.7% compared with 3.1%). This difference is highly significant. Areas did not differ significantly in their content of organic matter; but the areas × communities interaction was significant, reflecting a difference in organic matter content of 4.8% between communities at the upland area compared with a differ-

Table 1. Physical and chemical soil properties of needlegrass and tarweed communities at two areas. Values are the average of the 0- to 7.5- and 7.5- to 15.0-cm depths.

Property	Upland		Lowland		F-test areas	F-test communities
	Needlegrass	Tarweed	Needlegrass	Tarweed		
pH	5.4	5.6	5.7	5.7	NS	NS
Bulk density[1] (g/cm^3)	0.84	1.08	0.88	1.04	NS	**
Sand (%)	34.0	40.0	37.0	41.0	NS	NS
Silt (%)	42.0	43.0	40.0	39.0	NS	NS
Clay (%)	24.0	17.0	23.0	20.0	NS	NS
Organic matter (%)	7.7	2.9	5.7	3.3	NS	**
Total N (%)	0.40	0.16	0.28	0.18	*	**
Total P (%)	0.12	0.12	0.15	0.13	*	NS
Total K (%)	0.64	0.51	0.66	0.64	NS	NS
Total S (%)	0.042	0.019	0.031	0.024	NS	**
Cation exchange capacity (me/100 g)	41.9	40.7	41.6	34.6	NS	NS
Exchangeable K (me/100 g)	1.92	0.91	1.30	0.79	NS	NS
Exchangeable Mn (me/100 g)	0.094	0.042	0.076	0.051	NS	**
Exchangeable Na (me/100 g)	0.19	0.17	0.20	0.20	NS	NS
Exchangeable Mg (me/100 g)	1.91	2.54	2.09	3.24	NS	NS
Exchangeable Ca (me/100 g)	11.93	13.43	11.44	11.43	NS	NS

[1] Gravel percentage was not taken into account.
* Significant at the 5% level.
** Significant at the 1% level.
NS = Not significant.

ence of only 2.4% at the lowland area. Organic matter declined significantly (P = 0.01) between depths, but most of the difference occurred in the needlegrass communities—a response signalled by a highly significant depths × communities interaction. In the needlegrass communities, organic matter decreased from 7.5 to 5.9% between the 0- to 7.5- and 7.5- to 15-cm depths, whereas in the tarweed communities it decreased only from 3.2 to 3.0%.

Total N, total S, and exchangeable Mn were the only soil nutrients that differed significantly be-

Table 2. Comparison of physical and chemical properties between the 0- to 7.5- and 7.5- to 15.0-cm depths in needlegrass and tarweed communities. Values are the average of the upland and lowland areas.

Property	Needlegrass		Tarweed		F-test depths
	0 to 7.5 cm	7.5 to 15.0 cm	0 to 7.5 cm	7.5 to 15.0 cm	
pH	5.5	5.6	5.7	5.6	NS
Bulk density[1] (g/cm^3)	0.85	0.88	1.11	1.02	NS
Sand (%)	36.0[1]	35.0	40.0	41.0	NS
Silt (%)	41.0	40.0	42.0	40.0	NS
Clay (%)	23.0	25.0	18.0	19.0	NS
Organic matter (%)	7.5	5.9	3.2	3.0	**
Total N (%)	0.36	0.32	0.18	0.17	*
Total P (%)	0.13	0.14	0.12	0.13	NS
Total K (%)	0.65	0.65	0.58	0.57	NS
Total S (%)	0.041	0.038	0.023	0.023	NS
Cation exchange capacity (me/100 g)	41.8	41.8	38.2	37.1	NS
Exchangeable K (me/100 g)	1.68	1.54	0.88	0.82	NS
Exchangeable Mn (me/100 g)	0.112	0.057	0.057	0.036	**
Exchangeable Na (me/100 g)	0.19	0.20	0.18	0.18	NS
Exchangeable Mg (me/100 g)	2.00	2.00	2.46	2.41	NS
Exchangeable Ca (me/100 g)	11.50	11.88	12.46	12.40	NS

[1] Gravel percentage was not taken into account.
* Significant at the 5% level.
** Significant at the 1% level.
NS = Not significant.

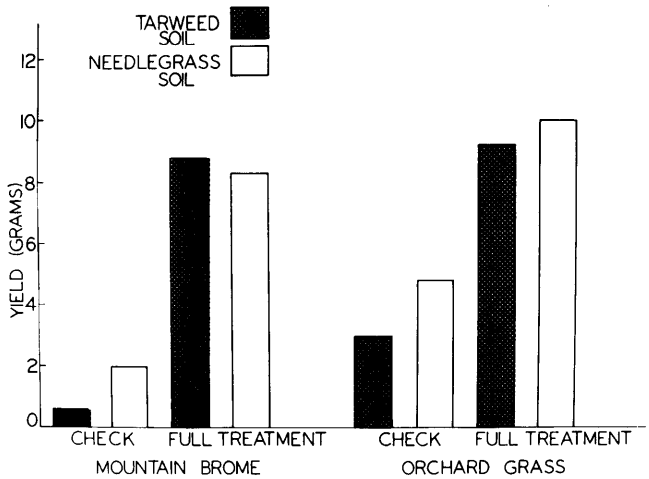

FIG. 2. Yield of mountain brome and orchard grass with the check and full nutrient treatments.

Table 3. Relative yields (%) of four nutrients in soil from needlegrass and tarweed communities with orchard grass and mountain brome.

	Upland area		Lowland area	
Nutrient	Needlegrass	Tarweed	Needlegrass	Tarweed
Orchard grass				
N	56	39	66	34
P	48	60	77	73
K	93	96	100	93
S	61	54	74	53
Mountain brome				
N	56	8	22	15
P	47	62	60	29
K	115	103	105	106
S	66	51	57	29

tween needlegrass and tarweed communities. Average total N was twice as great in needlegrass soil (0.34%) as in tarweed soil (0.17%). This difference is highly significant. Also, total N was significantly higher ($P = 0.01$) at the upland than lowland area, and the areas × communities interaction was highly significant. Total N declined significantly between the 0- to 7.5- and 7.5- to 15-cm depths, but most of the difference between depths was confined to the needlegrass communities.

Soil from the needlegrass communities contained significantly more total S than soil from tarweed communities (0.036% compared with 0.022%). However, in contrast to total N, there was no significant difference in total S between areas, the areas × communities interaction was not significant, and there was no change with depth.

Exchangeable Mn was nearly twice as great in needlegrass soil (0.085 me/100 g) as in tarweed soil (0.046 me/100 g). Exchangeable Mn declined significantly with depth ($P = 0.01$), and the depths × communities interaction was highly significant.

Pot Tests

Absolute yields of mountain brome and orchard grass supported results of soil tests, indicating that soils from needlegrass communities were more fertile than soils from tarweed communities and that the upland area had a higher nutrient capital than the lowland area. Total yield of both test species was higher in needlegrass soil than tarweed and higher at the upland area than lowland.

Yield of both species with the check treatment was greater in needlegrass soil than in tarweed soil (Fig. 2), but there was no difference between soils for full nutrient treatment yields. Mountain brome yield in tarweed soil with the full nutrient treatment was 14 times greater than check yield. In the needlegrass soil, the full nutrient treatment yield was four times greater than the check yield. With orchard grass the increase between the check and full treatment yield was three times in tarweed soil and two times in needlegrass soil.

Relative yields showed that N, S, and P were the nutrients primarily responsible for differences in check yields between needlegrass and tarweed soils (Table 3). Potassium was 100% available in soils from both communities.

Mountain brome appeared to be the more sensitive of the two species as an indicator of nutrient availability. At the upland area the relative yield of N for mountain brome was 56% in soil from the needlegrass community compared with 8% in soil from the tarweed community. Thus, N was seven times more available in needlegrass than in tarweed soil. Sulphur was only slightly more available in needlegrass soil (66%) than in tarweed soil (51%). Phosphorus, in contrast, was more available in tarweed soil. At the lowland area, the difference in availability of N for mountain brome narrowed between needlegrass soil and tarweed soil—22% and 15%, respectively. At the same time, the difference in relative yields for P and S between communities increased so that P and S were twice as available in needlegrass soil as in tarweed soil.

Relative yield differences between needlegrass and tarweed soils for orchard grass were not as pronounced as those for mountain brome. Nor did the test indicate a deficiency of P in the lowland tarweed community as observed with mountain brome. Nitrogen was about two-thirds and one-half respectively, as available in tarweed soil as in needlegrass soil at upland and lowland areas. Availability of S was only slightly different in the two soils at the upland area but about two-thirds as available in tarweed soil as in needlegrass soil at the lowland area.

Discussion and Conclusions

Establishment of the needlegrass community as a base for judging favorability of soil of the tarweed community for germination and establishment of seeded species appears justified on the basis of soil nutrient levels.

According to Jenny's guidelines (1930), the average level of total N in the needlegrass soil of 0.34% is at an upper limit for this site. Total phosphorus is also at the upper limit of the range observed in the northwest United States (0.09 to 0.13%), but total K is below the range reported for most soils of the western United States of 1.7 to 2.5% (Parker et al., 1946). Sulphur is in the middle of the range reported by Burns (1968) for most soils (0.01 to 0.06%).

From the calculated C:N:S ratio of 114:9:1 in needlegrass soil, it appears that N is optimally available and that the S level is high enough that N would be utilized efficiently (Black, 1968; Burns, 1968).

Despite the apparent favorability of the nutrient regime of needlegrass soil, relative yields of the four nutrients showed that only K was 100% available—and it was the only nutrient below the commonly observed level.

The contrasting availability of nutrients to mountain brome and orchard grass is probably a result of differential nutrient requirements of the two species, and an indication of the ability of each species to utilize the native nutrient capital of the soil. Orchard grass appears to have a lower nutrient requirement and greater ability to utilize the existing soil nutrients than mountain brome.

However, relative yields with mountain brome were a better reflection of differences in actual nutrient levels between needlegrass and tarweed communities and between upland and lowland areas than orchard grass. Moreover, the response of mountain brome suggests that a comparison of actual soil nutrient levels is not a true indication of nutrient availability. There were no apparent differences in the level of soil P between communities, and yet P was two times more available to mountain brome in needlegrass soil than in tarweed soil at the lowland area. For N, the disparity between nutrient level differences and nutrient availability was even more pronounced. Total N was more than two times greater in needlegrass soil than in tarweed soil at the upland area—and seven times more available for mountain brome. Also, the relative yield of 22% in needlegrass soil for mountain brome was a reflection of the lower level of N at the lowland area.

The results indicate that there are severe deficiencies and low nutrient availability of N and S in tarweed communities of this area. In addition to the recommended procedures of Hull and Cox (1968), revegetation efforts should include a fertilizer program to amend soil N at the upland area and N, P, and S at the lowland area.

Because of the differences in relative yields of N, P, and S between orchard grass and mountain brome in tarweed soil, and the fact that only K was 100% available in needlegrass soil, there appears to be a need to establish relative yield criteria for these nutrients in wildland soils using individual species to be seeded. Jenny et al. (1950) established such criteria for N and P using lettuce on agricultural soils of California. According to these workers, a relative yield of N of 30% or less in a pot test indicates a soil low in N which will give a field response for added N. A relative yield above 50% indicates a high N supply with little chance for a field response. For P, these relative yield levels are 20% and 30%.

Since relative yields of the four nutrients with mountain brome and orchard grass were similar in needlegrass soil at the upland area, perhaps these values can be established as an upper limit for these two species in soil from stable, productive high elevation grasslands. Confirmation of this would require field tests to determine if a significant response to added nutrients would occur in needlegrass soil at the upland area.

Although the effect of higher bulk density and lower organic matter content on the microenvironment of tarweed soils was not measured, these two characteristics probably contribute to rapid heat exchange between the soil and atmosphere, rapid heat transfer within the soil, reduced infiltration, and rapid drying of the soil surface. All of these factors would likely have an adverse effect on seedling establishment in the late spring.

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Controlling Red Threeawn on Abandoned Cropland with Ammonium Nitrate[1]

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Highlight

In our experience, red threeawn is more sensitive to N fertilizer than any other species. This sensitivity is fortunate because a low rate (20 lb./acre) of N fertilization controlled red threeawn, improved botanical composition, and increased herbage yield on an abandoned plowed field on the Central Great Plains. This work suggests the need for additional research to determine whether 20 lb. N/acre may cause succession to bypass the static *Aristida* stage and change botanical composition more quickly to desirable forage species.

This paper presents a case of nitrogen-induced plant mortality and secondary succession on an abandoned cropland on shortgrass plains in Colorado. The subject is primarily a technical matter at the present time. Nevertheless, sensitivity of red threeawn (*Aristida longiseta* Steud.) to ammonium nitrate suggests practical value. We have about 5 million acres of abandoned cropland in the Central Great Plains. Many of the plowed fields were abandoned 40 years ago, but remain in the *Aristida* stage (Costello, 1944) of secondary succession because blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) has little capacity to reestablish by seed on shortgrass plains (Hyder et al., 1971). A simple treatment that would reduce red threeawn and increase forage production on the abandoned croplands could be valuable.

The objective was to study degrees of tolerance among species to nitrogen fertilizer. If some species have low requirements and tolerances for nitrogen while others have high requirements, we can manipulate botanical composition and redirect secondary succession by applying nitrogen fertilizer.

Methods

This experiment included an untreated check, 5 rates of nitrogen (N) and 1 rate of phosphorus (P) in 4 randomized blocks; but the treatments were combined in a 6N by 2P factorial experiment. The N rates were 20, 40, 60, 100, and 200 lb./acre, and the P rate was 20 lb./acre. Treble super-phosphate and ammonium nitrate were applied surface broadcast annually in the fall of 1963, 1964, and 1965. Herbage yields and botanical composition by weight were sampled in August each year following fertilization (1964, 1965, 1966) and in 3 additional years (1967, 1968, 1969). Oven dry weights and composition percentages are reported. The plots were established on McGrew sandy loam at the Central Plains Experimental Range near Nunn, Colorado.

Results

Control of Red Threeawn

Within 2 years, fertilization at all rates of N reduced the yield of red threeawn below that on unfertilized plots (Table 1). Red

[1] Cooperative investigations of the Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Colorado Agricultural Experiment Station, Fort Collins. Scientific Series Paper No. 1691, Colorado Agricultural Experiment Station. Received October 14, 1971.

Table 1. Percentage change (relative to unfertilized plots) in the yield of red threeawn due to fall fertilization at 5 rates of N (lb./acre) in 1963, 1964, and 1965.

	Rate of N applied				
Year	20	40	60	100	200
1964	+ 6	− 1	− 5	− 30	− 20
1965	−26	−30	− 9	− 35	− 86
1966	−52	−82	− 88	−100	−100
1967[1]	−69	−90	−100	−100	−100
1968[1]	−35	−41	− 66	− 80	−100
1969[1]	− 9	−24	− 66	− 83	−100

[1] Residual effects of N were obtained in the last 3 years.

threeawn continued to decrease in the third year of fertilization and in the first year of residual effects (1967), when fertilization rates of 20 and 40 lb. N/acre had reduced red threeawn 69 and 90%, respectively. Reductions of 100% resulted from 60 or more lb. N/acre applied in 3 consecutive years. Red threeawn recovered rapidly in the second and third years (1968 and 1969) of residual effects where the rate of fertilization had been

Table 2. Mean annual herbage yield (lb./acre) and annual precipitation (inches).

Year	Mean herbage yield[1]	Precipitation[2]
1964	473 a	4.3
1965	2052 d	14.8
1966	1545 c	11.0
1967[3]	2730 e	22.9
1968[3]	911 b	13.1
1969[3]	622 a	16.4
Mean	1889	13.8

[1] Amounts followed by the same letter are not different at 95% probability. Yields by individual rates of N fertilizer are shown in Fig. 2. These mean yields are averaged over all rates of N, which were applied in the fall preceding each of the first 3 years.

[2] The mean annual precipitation over the past 30 years was 12.2 inches. The lowest amount on record was 4.3 inches in 1964 and the highest amount was 22.9 inches in 1967.

[3] Residual effects of N were measured in the last 3 years.

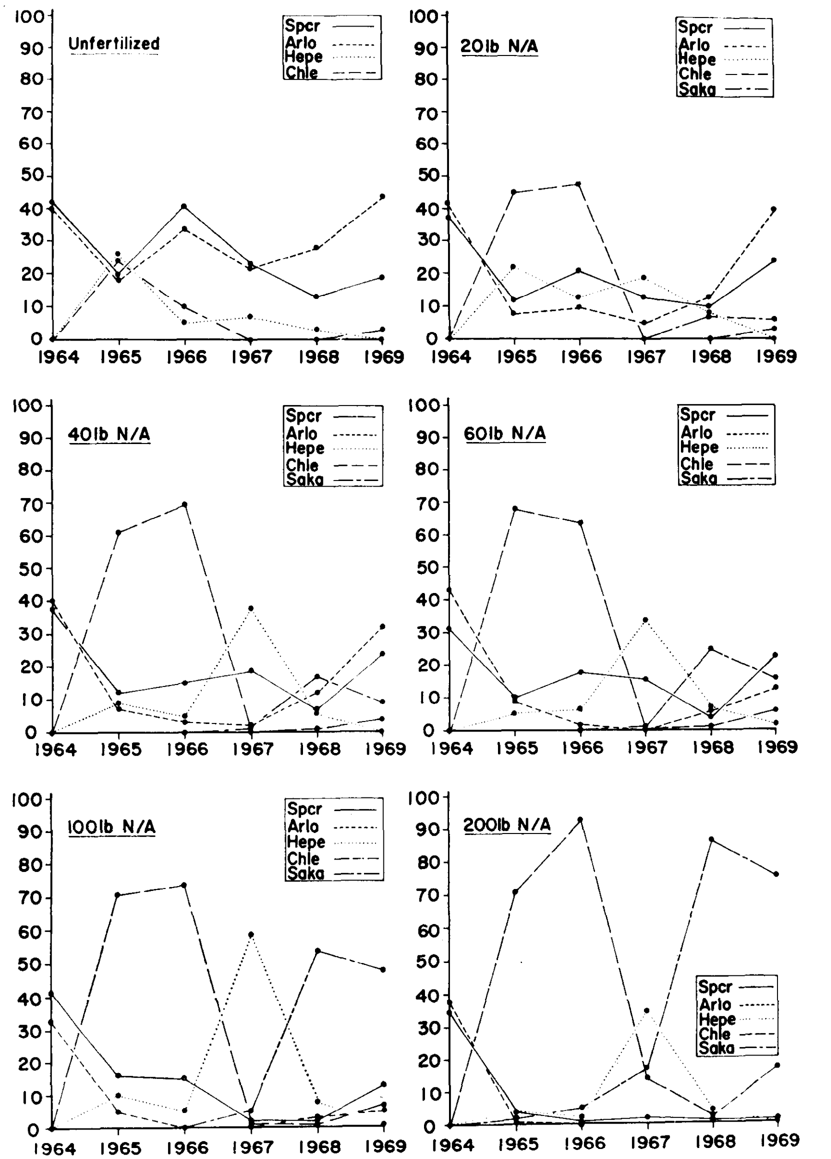

FIG. 1. Botanical composition (% by oven dry weight) of 5 species (Spcr = sand dropseed, Arlo = red threeawn, Hepe = prairie sunflower, Chle = slimleaf goosefoot, and Saka = Russianthistle) on abandoned cropland fertilized with ammonium nitrate in the fall 1963, 1964, and 1965.

20 and 40 lb. N/acre. Thus, continuous fertilization at a low rate of N would be needed to maintain control.

Botanical Composition

Five species accounted for 60% or more of herbage dry matter yields. Two were perennial pioneer grasses [red threeawn and sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray)] and three were annual forbs [slimleaf goosefoot (*Chenopodium leptophyllum* Nutt.), prairie sunflower (*Helianthus petiolaris* Nutt.), and Russianthistle (*Salsola kali tenuifolia* Tausch.)]. Of these 5 species, red threeawn and slimleaf goosefoot are least desirable as forage for cattle.

Percentage contributions of these 5 species to total herbage yields are shown in Figure 1 by years and N rates. Severe drouth in 1964 (the first year after fall fertilization) prevented growth of annual species and killed some perennial pioneer grasses. Thus, in 1965, the

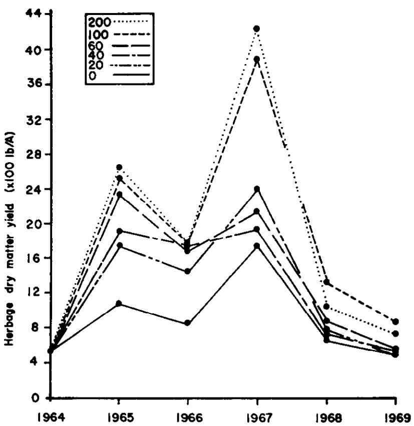

FIG. 2. Herbage yields on abandoned cropland fertilized with ammonium nitrate at the rates shown in the legend, in the fall 1963, 1964, and 1965. Residual responses were obtained in the last three years.

herbage contained a large proportion of annual species, even on unfertilized plots. Perennial pioneer grasses recovered from drouth in subsequent years, but their contribution to composition varied with precipitation and the amount of N applied in 3 consecutive years.

Nitrogen fertilization reduced perennial pioneer grasses and increased annual forbs. Red threeawn was more susceptible to N than sand dropseed, but both species were nearly eliminated by 60 lb. or more of N per acre. By 1969, the third year of residual effects, these grasses were coming back on all plots except those fertilized at 200 lb. of N/acre.

Secondary succession after fertilization was stopped proceeded from slimleaf goosefoot to prairie sunflower, to Russianthistle, to pioneer perennial grasses. At all rates of N, slimleaf goosefoot became dominant by replacing perennial pioneer grasses in the second and third years (1965 and 1966). Prairie sunflower replaced slimleaf goosefoot as dominant species in 1967. The degree of dominance attained by prairie sunflower increased with increase in rate of N up to 100 lb./acre. Perennial pioneer grasses regained dominance in 1968 and 1969 where the rate of N had been 20 or 40 lb./acre. However, at 60 lb. N/acre, Russianthistle followed prairie sunflower as dominant in 1968 and remained as codominant with perennial pioneer grasses in 1969. At 100 and 200 lb. N/acre, Russianthistle attained dominance in both 1968 and 1969, but its stands were so thick in 1969 that plant height seldom exceeded 5 inches.

Herbage Dry Matter Yields

Nitrogen rates, years of harvest, and N by year interaction were sources of highly significant (99%) variation in herbage dry matter yields. Phosphorus failed to change the overall yield or botanical composition.

Herbage yields were low in the "dry" season of 1964 (Table 2). In subsequent years, including the last 3 years of residual responses, N increased herbage yields (Fig 2). The largest increase due to N occurred in 1967, which was the first year of residual responses and also was the wettest year on record at that station. Over all years and treatments, the yields varied about 10 fold—from about 400 to 4000 lb./acre on an oven dry basis. These yields from abandoned cropland were greater, even without fertilization, than those on adjacent unplowed blue grama range.

Over all 6 years, the mean annual increase in herbage yield due to N varied from 336 to 943 lb./acre for N rates of 20 and 200, respectively. These increases in herbage yield account for a total 6-year return (N efficiency) of 33.6 to 9.4 lb. of herbage per lb. of N for N rates of 20 and 200, respectively (Table 3).

Table 3. Mean annual increase in herbage yield (lb./acre) due to N and N efficiency (lb. herbage/lb. N applied).

Nitrogen rate[1] (lb./acre)	Mean increase in yield[2]	Mean N efficiency[2]
20	336	33.6
40	339	17.0
60	449	15.0
100	900	18.0
200	943	9.4

[1] Nitrogen fertilizer was applied in 3 consecutive years.

[2] Herbage yields were taken in 6 consecutive years. Mean increases are those amounts in excess of the mean yield on unfertilized plots averaged over the 6 years.

Discussion

On these abandoned plowed fields, a decrease in red threeawn is desirable, provided that it can be obtained without excessive losses of sand dropseed or excessive increases of slimleaf goosefoot. When evaluated for grazing by livestock, the most beneficial of N-induced changes resulted from repeated applications of 20 lb. N/acre. However, to initiate a fast decrease in red threeawn, one could apply 60 lb. N/acre in the first year and continue fertilization at 20 lb. N/acre in subsequent years. The economic value and practical feasibility of this proposed fertilization program should be determined by grazing trials.

Plant mortality and secondary succession after fertilization for 3 years reveal differences among species in tolerance to N. The secondary succession of annual species induced by 100 and 200 lb. N/acre is similar to that observed on freshly plowed areas, except that slimleaf goosefoot is essentially lacking on plowed soil. Succession on freshly plowed areas begins with prairie sunflower the first year and goes to Russianthistle the second year. Thereafter, succession proceeds to red threeawn and sand dropseed in different ways and at various rates. At the *Aristida* stage of secondary succession, red threeawn generally is dominant in a relatively static community that is quite undesirable for pasture. Red threeawn apparently closes the community and slows down further succession to terminal dominant and sub-dominant perennials such as scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.), western wheatgrass (*Agropyron smithii* Rydb.), needleandthread (*Stipa co-*

mata Trin. and Rupr.), sun sedge (*Carex heliophila* Mackenz.), and blue grama. An earlier than *Aristida* stage of succession in which sand dropseed, Russianthistle, and prairie sunflower dominate (as induced by nitrogen fertilization) should provide better pasture for cattle in the short run. This work suggests the need for additional research to determine whether continuous fertilization at 20 lb. N/acre may cause succession to bypass the static *Aristida* stage and change botanical composition more quickly to terminal dominant and subdominant perennials. Long term grazing trials are needed to answer questions about economic advantages and successional trends under continuous fertilization at a low rate of nitrogen.

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Forage Yield in Two Forest Zones of New Brunswick and Nova Scotia[1]

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Highlight

A reconnaissance was made of the forage yield in a series of forest types in New Brunswick and Nova Scotia. Forage yields per acre were comparable to values reported from many studies in western North America, but plant composition differed. Grasslike species constituted a small proportion of total weight in most forest cover types, while ferns provided a high proportion. Correlation of yield with density characteristics of the tree stand was poor.

Considerable literature exists on weight yields of browse and herbage serving as forage for big game and livestock in western and southern North America (Doell and Smith, 1965). Less attention has been given to the food supply, on a weight basis, of herbivores in the wildlands of northeastern America. I conducted a preliminary survey of browse and herbage yield of forest-cover types in northern New Brunswick in July and August 1966, and in southwestern Nova Scotia in 1967.[3]

Study Areas and Methods

Rowe (1959) and Loucks (1962) have discussed physiography and vegetation in New Brunswick and Nova Scotia and Roland (1945) has described the flora of Nova Scotia in detail. Local climate and vegetation are strongly influenced by bodies of salt water and the low, but abruptly rising hill masses. Lowlands cover most of Nova Scotia and eastern New Brunswick and are the most extensive land type in these provinces. Uplands comprise the other prominent land type. They form dissected plateaus from 500 to over 2,000 feet in elevation.

An upland area of northwestern New Brunswick was sampled in or near the Canadian Forestry Service's Research Block No. 3 which has been described by Hughes (1964) at the Green River Field Research Station, and lowlands in southwestern Nova Scotia were sampled on and near the Tobeatic Wildlife Management Area. Sampling in the Green River area was conducted in Loucks' (1962) "sugar maple-yellow birch-fir zone." In the Tobeatic area sampling was in the "red spruce-hemlock-pine zone."

The Green River area displayed a recurring pattern of deciduous stands on ridges, mixed forest on middle slopes, dense coniferous stands on lower slopes and flats. Swamps dominated by northern white cedar (*Thuja occidentalis*)[4] occurred along creek beds and lake shores. Principal deciduous trees were sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), white birch (*Betula papyrifera*) and yellow birch (*Betula alleganiensis*). Conifers were white spruce (*Picea glauca*), black spruce (*Picea mariana*), northern white cedar and balsam fir (*Abies balsamea*).

At Tobeatic, areas of impeded drainage form muskegs or swamps. Low ridges carry conifers or mixed forest, and some small pure deciduous stands. Deciduous species were red maple (*Acer rubrum*), aspens (*Populus* spp.), red oak (*Quercus rubra*) and white birch. Conifers were red spruce (*Picea rubens*), black spruce, balsam fir, eastern hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*).

Sample plots were located randomly in forest stands on maps of Canadian Forestry Service research blocks for the Green River survey, and on provincial forest inventory maps for the Tobeatic survey.

Clusters of three plots were established in the field by measuring

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[3] The author acknowledges the assistance of G. Baskerville, Canadian Forestry Service; L. Holt, Bowaters Mersey Paper Company; and field assistants J. Maxwell, R. MacLennan, W. Bauman and W. Prescott.

[4] Tree nomenclature follows Hosie (1969) and nomenclature of other plants follows Roland (1945).

Table 1. Forage yield (lb./acre) by categories in 10 cover types of two forest zones in New Brunswick and Nova Scotia. Height range of 0 to 7.5 ft. Year of study stated for each forest zone.

Zones and cover types	Evergreen Twigs	Evergreen Leaves	Deciduous Twigs	Deciduous Leaves	Herbage Forbs	Herbage Grass-like plants	Herbage Ferns[1]
Sugar maple—yellow birch—fir zone (1966)							
Mature hardwood	2	10	41	169	56	T[2]	111
Pole-size softwood	2	6	8	14	41	—	19
Cedar Swamp	25	99	41	294	44	23	10
Red spruce—hemlock—pine zone (1967)							
Dense softwood	6	31	11	14	10	T	68
Open softwood	27	122	48	302	122	3	446
Dense mixedwood	24	194	12	43	33	13	210
Open mixedwood	6	26	177	445	77	23	371
Dense hardwood	17	77	42	207	104	171	180
Saplings[3]	5	22	44	282	71	106	283
Brushland[4]	—	—	124	723	146	—	168

[1] Polypodiaceae and Osmundaceae, mostly *Dryopteris* spp. and *Pteridium* spp.
[2] Trace, less than 1 lb./acre.
[3] Young, regenerating stands on clear or partially cut areas, burns or blowdowns.
[4] Deciduous shrub communities occupying rock barrens or severely burned areas.

FIG. 1. Dense, mature hardwood forest in New Brunswick composed mainly of sugar maple.

direction with a hand compass and distance with a steel tape from a topographical feature. Plots were centered 15 feet from the cluster center thus established on magnetic bearings of 0, 120 and 240 degrees.

Yield of the current year at Green River was determined by clipping all herbaceous plants, terminal twig growth and leaves from 3.1 × 3.1 ft. square quadrats. At Tobeatic double sampling (Wilm et al., 1944) was employed, using quadrats of the same size. Green weights of forbs, grass-like plants, the terminal growth of twigs, and leaves of the current year were estimated. One of each six quadrats was also clipped. Clipped material from both study areas was oven dried in a convection oven for 48 hours at 70 C. For the Tobeatic material regressions of actual oven dry weight on estimated green weight were made for leaves, twig terminal growth, grass-like plants, ferns and forbs, by the "ratio-of-means" method described by Blair (1958).

At each plot a point count was taken using a 10-factor wedge prism (Bell and Alexander, 1957). Results were used to estimate basal area and number of trees per acre for stems over 1.5 inch diameter. Mean percentage of crown cover was calculated for each plot from 10 measurements made with a

Table 2. Total forage, winter browse and herbage yields (lb./acre) in 10 forest cover types in New Brunswick and Nova Scotia. Height range 0–7.5 ft. Year of study stated for each forest zone.

Zones and cover types	Mean winter browse[1]	Mean herbage[2]	Mean total forage [3]	St'd. error
Sugar maple—yellow birch—fir zone (1966)				
Mature hardwood	53	167	220	61
Pole-size softwood	16	60	90	16
Cedar swamp	165	77	536	157
Red spruce—hemlock—pine zone (1967)				
Dense softwood	48	78	140	37
Open softwood	197	571	1070	207
Dense mixedwood	230	256	529	156
Open mixedwood	209	471	1125	525
Dense hardwood	136	455	798	137
Saplings[4]	71	460	813	275
Brushland[4]	124	314	1161	181

[1] Deciduous twigs, coniferous twigs and leaves.
[2] Ferns, grass-like plants and forbs.
[3] Including leaves of deciduous woody species.
[4] See type description under Table 1.

FIG. 2. Dense softwood forest in New Brunswick typical of stands sampled in both zones during the present study, composed of red and black spruce and balsam fir.

Fig. 3. Open softwood forest in Nova Scotia. Scattered white pine and red spruce with a dense understory of ferns, and softwood seedlings and saplings.

"moosehorn" instrument (Garrison, 1949). Mean stand height was estimated from clinometer measurements and mean age from annual ring counts of several codominant trees at each plot cluster.

Results and Discussion

Forage yields in Nova Scotia and New Brunswick (Tables 1 and 2) fall into the same range as yields in western North American forests (Eddleman and McLean, 1969; Young et al., 1967; Pase and Hurd, 1958). However, composition differs: grasses and grass-like species were less prominent in the New Brunswick and Nova Scotia forest types than in western areas; the weight of ferns was greater than other classes of herbage in most forest types. Principal forb species in terms of biomass in the Green River area were wood sorrel (*Oxalis montana*), Sasparilla (*Aralia nudacaulis*), clintonia (*Clintonia borealis*), wild lily-of-the-valley (*Maianthemum canadense*) and bunchberry (*Cornus canadensis*). With exception of wood sorrel the same species were important in the Tobeatic area. Other species also important in the latter area were goldenrod (*Solidago* spp.), asters (*Aster* spp.), goldthread (*Coptis groenlandica*) and boxberry (*Gaultheria procumbens*). Grass-like species were mostly sedges (*Carex* spp.), but were not classified by species. Bracken (*Pteridium aquilinum*) contributed an important part of the fern biomass, as did species of the genus *Dryopteris*, principally *D. noveboracensis*.

Shrubs, and seedlings and saplings of arboreal species in order

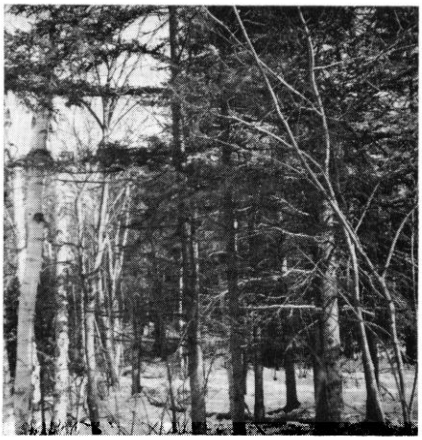

Fig. 4. Dense mixedwood forest in Nova Scotia composed of red spruce, balsam fir, white birch and red maple.

of weight of browse produced at Green River were: balsam fir, white cedar, alder (*Alnus* spp.), spruces, sugar maple, beech, mountain maple (*Acer spicatum*), hobble bush (*Viburnum alnifolium*) and hazel (*Corylus cornuta*). The principal woody species at Tobeatic in order of weight, were: spruce, balsam fir, huckleberry (*Gaylusaccia baccata*), sheep laurel (*Kalmia* spp.), alder, hemlock, red maple, white pine and blueberry (*Vaccinium* spp.). In both areas a number of other shrubs were present in very small amounts.

Winter browse yield in the Maritimes was high compared to that reported in the west (Pase and Hurd, 1958; Young et al., 1967)

Table 3. Characteristics of the tree overstory (stem over 1.5 inches in diameter at breast height) in stands sampled during forage field reconnaissance in New Brunswick and Nova Scotia.

Zones and cover type	Coniferous basal area (ft² acre)	Deciduous basal area (ft² acre)	Mean crown cover (%)	Mean stand height (ft)	Mean stand age (yr)	Estimated percentage of study area
Sugar maple—yellow birch—fir zone (1966):						[1]
Mature hardwood	10	80	88	55	97	8
Pole-size softwood	136	19	90	47	56	58
Cedar swamp	143	3	68	53	154	8
Red spruce—hemlock—pine zone (1967):						[2]
Dense softwood	134	14	75	42	64	3
Open softwood	60	6	44	49	87	30
Dense mixedwood	71	46	73	40	67	4
Open mixedwood	40	33	61	64	62	17
Dense hardwood	8	75	54	36	52	1
Saplings[3]	39	9	29	21	28	10
Brushland[3]	2	0	—	—	—	11

[1] Areas calculated for Research Block No. 3 from Hughes 1964:20.
[2] Areas calculated from 1956 Provincial Forest Inventory Data supplied by the Nova Scotia Department of Lands and Forests (R. M. Bulmer, personal communication, March 15, 1967).
[3] See type description under Table 1.

Fig. 5. Sapling stand on an old burn in Nova Scotia composed of red spruce, balsam fir, white birch and red maple.

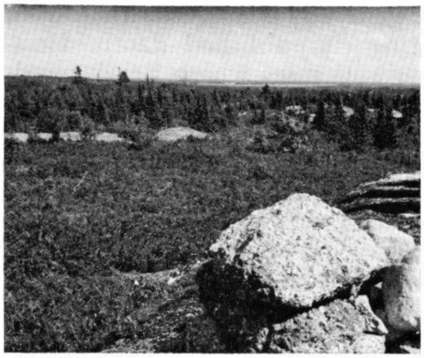

FIG. 6. Brushland community in foreground composed mostly of huckleberry, with an open softwood stand in the background. Nova Scotia.

but it is difficult to compare these data because height ranges and definitions of browse differ.

In some studies high forage yield has been found to be correlated with open stand conditions (Pase and Hurd, 1967); Eddleman and McLean, 1969; Halls and Schuster, 1965). In this study, average values for forest types show the same general trend (Tables 2 and 3) but regressions of individual plot yields against measures of stand density gave poor correlations. Poor correlation between basal area per acre and browse yield was also found in Virginia (Whelan, 1962). Regressions of forage yield on stand density (Pase and Hurd, 1967; Halls and Schuster, 1965) resemble curves of solar radiation reaching forest understories under varying crown closures (Vézina and Péch, 1964). Miller (1965) stated that transmission of solar radiation through forest canopies depends on the biomass of foliage and branches and the way the biomass is distributed in the space occupied by the crown. Crown biomass and arrangement may have been exceptionally variable in the mixed forests sampled in this study, creating different radiant energy environments and possibly differing yields of understory vegetation in stands of similar density. These differences probably account for much of the standard error within cover types (Table 2).

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An Alternate-Furrow System for Seeding Northern Colorado Rangeland[1]

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Highlight

The most successful method for seeding cool-season grasses on northern Colorado rangelands has been to plant with a drill in the spring on a smooth, fallowed seedbed. However, wind erosion may destroy a level-drilled seeding. Planting in deep furrows has resulted in poorer stands, but the deep-furrows appear to be necessary for control of wind erosion. A system is proposed for alternating deep-furrow drilling with level-drilling on the beds between the furrows in order to combine the erosion control benefits on the deep-furrows with the better stand establishment characteristics of the level-drilled planting.

When several range seeding methods were evaluated in northern Colorado, drill-planting on fallowed soil consistently produced the best stands (Bement et al., 1965). During the past 15 years, I have planted more than 75 experiments in north-central Colorado, and have observed many others. In general, the most consistent success has resulted from using the following planting procedures:

1. Fallow the area to be seeded and prepare a firm seedbed.
2. Plant before or early in the period of highest precipitation (April and May).
3. Control wind and water erosion with cultural treatments and strip planting.

Furrows of various sizes and shapes are commonly used to control erosion on exposed soil. Planting in the bottom of a furrow (deep-furrow seeding) is an accepted way of combining erosion control with the seeding operation, and deep-furrow seeding is the usual method of planting small grains in the fall in northern Colorado. In central Utah, deep furrows produced better stands of crested wheatgrass than did drill-planting (McGinnies, 1959), but in northern Utah there was no difference between furrows and level planting (Hull, 1970).

When I have seeded range grasses in northern Colorado in the spring, stands obtained from level drill-planting have generally been better than from deep-furrow planting (unpublished data). However, there were several cases where heavy winds destroyed the level-drilled seeding before the seedlings became established.

To prevent wind erosion in small-plot studies and retain the advantages of level seeding, furrows have been cut between the seeded rows in most small-plot studies I have planted since 1963. These small furrows (3 to 4 inches deep) have effectively prevented wind "blow-outs" and appeared to reduce water erosion. The use of furrows between rows requires that the seeded rows be at least 18, and preferably 24 inches apart; this is a wider row spacing than is generally desirable for most range seeding. The distance between rows in the seeded stand could be reduced if grass could be established both in the furrows and on the level beds between the furrows. The following study reports an evaluation of level drilling and alternating level and deep-furrow rows.

Methods

Plantings were made 1967 through 1970 at Fort Collins Experimental Range, 10 miles north of Fort Collins, Colorado; and 1968 through 1970 at Central Plains Experimental Range (CPER), 12 miles northeast of Nunn, Colorado. Precipitation at the Fort Collins site is approximately 15 inches and the soil is a Larimer gravelly loam; at CPER, precipitation averages 12 inches and the soil is a Vona sandy loam. The plot areas were plowed in the summer of the year before planting. In early spring, the plots were smoothed and cultipacked. Individual plots measured 11 by 25 feet. Two plantings were made at each seeding date at each location. Crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) and Russian wildrye (*Elymus junceus* Fisch.) were planted on the dates shown in Table 1.

The two planting treatments were (1) level-drilled and, (2) alternating rows level-drilled and deep-furrow drilled (this treatment is called "alternate-furrow" in this paper). In the level-drilled (control) plots, drill-rows were planted 12 inches apart. In the alternate furrow treatment, rows were first level-drilled with rows 24 inches apart. Then, deep-furrow rows, with furrows approximately 3 inches deep, were planted midway between the level-drilled rows, and seed was planted in the bottom of the furrow. Thus, the final configuration was an alternation of deep-furrow rows and level-drilled rows on the beds between the deep-furrow rows; the final row spacing was 12 inches. All seeding was done with a hand-pushed cone-type seeder at a ¾-inch planting depth and at a seeding rate of 25 seeds per foot of row (6 lb./acre).

The plots were kept relatively free of weeds with selective herbicides and by occasional hand-weeding. Rabbits and large herbivores were excluded, but small rodents were sometimes found in the plot area.

Seedlings were counted in early September of the year seeded. Seedling counts represent establishment, rather than just emergence, because previous studies indicated that there is almost no loss of plants between September and the following spring.

[1] A contribution of Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Colorado Agricultural Experiment Station. Published with the approval of the Director of the Colorado Agricultural Experiment Station as Scientific Series Paper No. 1702. Received for publication December 31, 1971.

Table 1. Number of seedlings per foot of seeded row counted in September of the year of seeding.

Location, species and seeding date	Treatment			
		Alternate furrow		
	Level-drill (control)	Level rows	Deep-furrow rows	Average
Fort Collins				
Crested wheatgrass				
April 7, 1967	4.7	5.3	2.6	4.0
April 10, 1968	3.0	3.7	2.4	3.0
May 2, 1968	6.2	6.3	3.6	5.0
April 18, 1969	7.0	6.8	3.9	5.4
April 13, 1970	6.2	5.8	5.7	5.8
Russian wildrye				
April 18, 1969	9.2	8.5	5.5	7.0
April 13, 1970	7.1	6.6	5.6	6.1
CPER[1]				
Crested wheatgrass				
April 15, 1968	6.9	6.8	3.0	4.9
April 30, 1968	7.2	8.1	4.0	6.0
April 28, 1969	8.6	11.2	5.6	8.4
April 16, 1970	4.7	3.7	1.3	2.5
May 12, 1970	6.7	8.1	5.7	6.9
Russian wildrye				
April 28, 1969	4.3	3.6	1.2	2.4
April 16, 1970	2.8	2.6	.6	1.6
May 12, 1970	4.0	3.6	2.8	3.2
Average	5.9	6.0	3.6	4.8

[1] Central Plains Experimental Range, Nunn, Colorado.

Results

The average number of seedlings per foot of row in the level-drilled control plots did not differ significantly from the average number of seedlings per foot in the level-drilled rows in the alternate-furrow plots (Table 1). However, the number of seedlings per foot of row in the deep-furrows was significantly lower than the number in the level-drilled rows between the furrows or in the level-drilled plots. The average number of seedlings in the alternate-furrow plots (the average of numbers of seedlings in deep-furrow and level-drilled rows) was 4.8 seedlings/ft^2 and was significantly less than the average of 5.9 seedlings in the level-drilled plots.

During the period covered by this study, no planting was seriously damaged by wind or water erosion. The small size of the planted areas probably prevented the wind getting a sufficient "sweep" at the plots to blow out any of the non-furrowed plots. However, the furrows were always partially or, more commonly, completely filled with soil by the end of the season; this resulted from movement of soil by both wind and water. When wind or rain storms occurred soon after planting, soil was deposited in the furrows, and the seed in the deep-furrows was sometimes buried to a total depth of 1½ to 2 inches. Other studies I conducted concurrently (unpublished) indicated that there was a substantial reduction in seedling numbers when seed is 1½ to 2 inches deep as compared to seed planted ½ to 1 inch deep. Thus, it is to be expected that the number of seedlings per foot of row is lower in the furrows than in the alternating beds.

The reduction of seedling numbers in the furrows was greater at CPER (50% fewer) than at Fort Collins (32% fewer) because the sandy soil at CPER filled the furrows more quickly than did the loam soil at Fort Collins. The distribution of seedlings in the level-drilled rows on the beds was generally more uniform than in the furrows; this is at least partly attributable to the less precise seed placement in deep-furrow planting and to the uneven deposition of eroded material in the furrows.

Discussion

Deep-furrow planting is successful with small grains because their large seed size and high seedling vigor permit them to emerge when planted several inches deep in moist soil. Most range grasses have small seeds and cannot emerge if covered as deeply as the small grains. Furrows that are deep enough to provide adequate erosion control and improved soil moisture relations will also permit the seed to be covered too deeply for optimum establishment. However, fair to good establishment has been obtained from furrows about 3 inches deep. Based on this study and on observations in other plantings, the furrows probably do not need to be spaced closer than 24 inches to give adequate erosion control on a well-prepared and firmed seedbed. Stands of grass from seed level-drilled on the beds between the furrows have been consistently good to excellent. Thus, it should be possible to obtain better overall stands by using the alternate deep-furrow and level seeding system than might be obtained with deep-furrow planting alone, and at the same time, keep erosion to a minimum.

Another method of planting has been suggested for northern Colorado wherein the ground is plowed, immediately formed into ridges by a specially-built heavy roller, and the furrows seeded (Hyder and Bement, 1969). No plowing is attempted until the soil has been wet, but no provision is made for a fallow period. Reported results range from less than 1 to more than 3 plants of crested wheatgrass per foot of row in the furrows when field-scale equipment was used (Hyder, et al., 1971). However, there was no non-ridged (level) planting and no planting on fallowed ground with which to compare these results.

The alternate-furrow seeding system has not been tried on field scale plantings. At present, a seeder is being assembled to make larger seedings. These seedings will be made at Fort Collins and CPER on fallowed, tilled, cultipacked seedbeds. It is hoped that by publishing this paper, others will be encouraged to try this technique in order that it may receive a thorough trial. This system does not require expensive or specialized equipment; at present, it is believed that an alternate-furrow seeding can be made with minor modifications to ordinary seeding equipment. The machinery needed for fallowing and packing the seedbed are the same farm implements commonly used for these purposes. However, it is suggested that the planting be confined to strips (Bement et al., 1965) to minimize any serious wind erosion hazard and that alternate-furrow planting not be used for seeding sandhills sites where a protective stubble is required.

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Response of a Seeded Mixture of Warm-season Prairie Grasses to Fertilization[1]

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Highlight

A seeded mixture of warm-season prairie grasses containing big bluestem (*Andropogon gerardi,* Vitman), switchgrass (*Panicum virgatum* L.), Indiangrass (*Sorghastrum nutans,* L.), and sideoats grama (*Bouteloua curtipendula,* L.) was fertilized over a four-year period with N, P, K, S and Zn. Yields were increased by N and combinations of N and P, but not by K, S, or Zn. Fertilization did not alter indexes of quality (% protein and % digestible dry matter) in the mature tissue. After four years, the percentage of each species in the mixture had not been altered by fertilizer treatment. Encroachment by cool-season species and weeds was not encouraged by fertilization which was largely attributed to the fact that fertilizers were applied after May 15 of each year.

Perennial warm-season prairie grasses are an important part of the total forage resources which provide summer grazing in the Plains states. There are many management factors which influence the production of these grasses. Proper fertilization is but one important practice.

Fertilizer studies employing both pure and mixed stands of several prairie grasses, both seeded and natural have been reported in the literature. These reports, however, have been conflicting. A Wyoming study by Rauzi et al. (1968) demonstrated that production from warm-season grasses in native pastures was not increased by N fertilization. However, in a British Columbia study, applied N was effective in increasing forage production on some, but not all, native ranges (Hubbard and Mason, 1967). In their study, residual effects of fertilizer application produced yield increases six years after initial usage. Residual effects of range fertilization were found to be beneficial in research reported by Read (1969).

Rogler and Lorenz (1957) reported that N increased the production of Northern Great Plains rangelands. Similar responses have been reported by Goetz (1969) and Johnston et al. (1968). In Montana, Black (1968) found that combinations of N and P produced forage yields significantly greater than yields from the use of N alone. The responses were greatest in the year of fertilization, but residual effects on forage yield were significant one to two years later. In Nebraska, Warnes and Newell (1969) and Warnes et al. (1971) studied the effects of N and P on stand establishment and yield of five warm-season grasses. They reported that proper timing of annual fertilizer N applications after the year of establishment maintained superior stands and increased forage yields.

There has, however, been some hesitancy to recommend N for warm-season prairie grasses due to reported encroachment by cool-sea-

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son species (Huffine and Elder, 1960) and some weeds (Owensby et al., 1970) in the fertilized stands of the desired warm-season species.

Realizing the inconsistency of reports in the literature and the need for further work with additional nutrients, this study was designed to measure the response of a seeded mixture of warm-season prairie grasses to the application of N, P, K, S and Zn.

Experimental Procedure

This study was initiated in 1967 on an established stand of warm-season prairie grasses seeded in 1965. A mixture of big bluestem (*Andropogon gerardi*, Vitman), switchgrass (*Panicum virgatum*, L.), Indiangrass (*Sorghastrum nutans*, L.), and sideoats grama (*Bouteloua curtipendula* L.) had been seeded at 1.6, 0.5, 1.0 and 1.0 lb. of pure live seed per acre respectively.

The soil was classified as a Crofton silt loam, a Typic Usthorthent by the 7th approximation classification system. This soil, formed under grass vegetation, occurs on moderate to steep slopes of 5 to 40% and is well drained. It is a highly eroded soil with a low organic matter content. Rapid to moderate surface runoff occurs with most rainfall intensities. Thickness of the solum ranges from 6 to 15 inches while the depth to free lime varies from 0 to 8 inches. This soil is highly calcareous (pH 7.0 to 8.0+), has a high exchangeable K content (325 ppm) but is low in available P (1.5 ppm) as measured by the Bray procedure.

Nitrogen as 33-0-0 was surface applied each year while P as 0-46-0, K as 0-0-60, S as "Sol-U-Sul," and Zn as an NTA chelate were broadcast on alternate years. All nutrients were applied after May 15. Treatments were replicated 4 times in a randomized complete block design.

Forage yields, expressed on a dry matter basis, were recorded in early to mid-August each year from a 3 ft × 20 ft harvested area. Plant samples were collected for analysis in 1967, 1968, and 1970. The protein content of the plant tissue, as measured by the Kjeldahl procedure described by Bremner (1965) was recorded in 1967, 1968, and 1970. The samples collected in 1970 were also analyzed for P, K, Ca, Mg, Zn, Cu, Fe and Mn (Knudsen and Hassan, 1969) and the percentage of digestible dry matter (Tilley and Terry, 1963). In 1971, the botanical composition of the mixture was measured according to the method described by Burzlaff (1966).

Table 1. The influence of N, P, K, S and Zn (lb./acre) on the yield (ton/acre) of a seeded mixture of warm-season prairie grasses.

Treatment					Year				
N	P	K	S	Zn	1967	1968	1969	1970	4-year total
—	—	—	—	—	.23 a[1]	.43 a	1.53 a	.64 a	2.83 a
40	—	—	—	—	.42 b	.38 a	1.96 b	1.04 b	3.80 b
80	—	—	—	—	.56 c	.44 a	2.59 c	1.32 bc	4.87 c
80	20	—	—	—	.88 d	.49 a	3.31 d	1.48 cd	6.13 d
80	40	—	—	—	.90 d	.59 a	3.17 d	1.81 d	6.44 d
80	20	20	—	—	.84 d	.52 a	3.48 d	1.46 cd	6.32 d
80	20	20	40	—	.85 d	.53 a	3.26 d	1.58 cd	6.23 d
80	20	20	40	10	.91 d	.54 a	3.44 d	1.59 cd	6.42 d

[1] Treatment means within any one column having the same letter are not significantly different at the 95% confidence level.

Results

Forage Yields

Forage yields were increased by fertilization in three of the four years of the study (Table 1). Applied treatment had no effect on yields in 1968 when precipitation during the growing season was below normal. In 1967, forage production was increased by the use of both 40 and 80 lb. N/acre. The largest increase resulted from the first 40 lb. increment. The addition of 20 lb. P/acre to 80 lb. N/acre produced an additional increase in yield, but raising the P rate to 40 lb./acre had no effect.

With favorable moisture, largest forage yields were recorded in 1969 with yield trends similar to those observed in 1967. The 1970 yields were less consistent than those recorded in 1967 and 1969, but production trends were similar. There was a clear response to the addition of 40 lb. N/acre with yield responses varying among the other treatments. The lack of other distinct treatment effects may have been due, in part, to the shortage of rainfall during the 1970 growing season. The addition of K, S and Zn did not increase yields at any time.

The four-year yield totals also show the beneficial effect of the combination of N and P on forage production of the warm-season prairie grass mixture. Yields were increased approximately one ton/acre by each 40 lb. increment of N without added P. The use of P combined with the N produced an additional yield response. These data show that the combination of N and P is needed for maximum forage production. These four-year yield totals also show that K, S and Zn had no measurable influence on forage yields.

Analysis of Plant Tissue

The nutrient content of the mature forage collected in 1970 was not altered by fertilizer treatment. Differences were due to random variation.

The tissue sampled in 1968 was considerably higher in protein than tissue collected in 1967 or 1970 (Table 2); but considering the low

Table 2. The effect of fertilizer treatment (lb./acre) on the protein content (%) of and protein produced (lb./acre) by a seeded mixture of warm-season prairie grasses.

Treatment					Protein content			Protein produced		
N	P	K	S	Zn	1967	1968	1970	1967	1968	1970
—	—	—	—	—	4.64 a[1]	8.12 a	4.30 a	21 a	71 a	54 a
40	—	—	—	—	5.26 a	10.09 b	4.66 a	44 b	78 a	96 a
80	—	—	—	—	5.19 a	10.05 b	5.99 a	58 b	91 a	157 b
80	20	—	—	—	4.69 a	10.16 b	5.20 a	82 c	105 a	153 b
80	40	—	—	—	4.64 a	10.44 b	5.48 a	83 c	119 a	197 b
80	20	20	—	—	4.70 a	9.38 ab	5.42 a	79 c	96 a	159 b
80	20	20	40	—	4.73 a	9.12 ab	5.39 a	81 c	97 a	168 b
80	20	20	40	10	4.64 a	9.87 b	5.60 a	84 c	107 a	178 b

[1] Treatment means within any one column having the same letter are not significantly different at the 95% confidence level.

yields in 1968, this observation may be explained, in part, by plant dilution. In general, fertilizer treatment had no consistent effect on the protein content of the mature tissue.

Except for 1968, fertilization increased protein production. In 1967, the use of both N and a combination of N and P increased the protein yield. During this year, the two N rates were equally effective in their influence on the amount of protein produced. In 1970, protein production from the application of 40 lb. N/acre was not different from that produced by the check treatment. Protein production was, however, increased by the application of 80 lb. N/acre. The use of P produced no further increases. The application of K, S, and Zn had no effect on protein production throughout the study.

In order to obtain another measure of forage quality, the tissue from the 1970 harvest was analyzed for digestible dry matter. Utilizing these percentages as well as the yield data, the amount of digestible dry matter produced per acre was determined (Table 3). This data showed that fertilizer usage had no influence on the percentage of digestible dry matter in the mature tissue. The production of in vitro digestible dry matter was increased, however, by the use of both N and the combination of N and P.

Botanical Composition

One of the chief criticisms of fertilizing warm-season prairie grasses has been that this practice stimulates the growth of cool-season species and weeds. Although the seeded mixture included big bluestem, switchgrass, Indiangrass and sideoats grama, the predominant species after four years were big bluestem and sideoats grama (Table 4). No Indiangrass could be detected in any of the treatments.[2]

The percentage of big bluestem and sideoats grama in the mixture was not altered by fertilizer treatment. Percentages of switchgrass, cool-season species, weeds and bare ground were quite variable. The largest percentage of bare ground occurred in the check treatment (4.6%) where forage growth was much shorter and less dense.

The weed content was fairly uniform across all treatments. These data show that there were no large increases in the weed population with fertilization while the amount of cool-season species varied among treatments. There was, however, no large increase in the amount of these species resulting from fertilization.

[2] The authors wish to thank Mr. Dewey Teel, Holt County Agricultural Extension Agent, for his excellent assistance in determining the vegetation inventory.

Discussion

Previous work in Nebraska by Warnes and Newell (1969), Warnes et al. (1971), and Burzlaff et al. (1968), had shown that warm-season prairie grasses would respond to the use of N. The data from this study support these earlier findings. In addition, there was a marked response to the use of 20 lb. P/acre, illustrating the importance of the combination of N and P on soils with low or very low levels of available P.

There was no indication of a response to K, S or Zn throughout the study. Apparently, the K content of the soil (325 ppm) was sufficient to supply the K requirements of the forage produced in

Table 3. The effect of N, P, K, S and Zn treatments (lb./acre) on the percentage (%) and the amount of digestible dry matter produced (lb./acre) by warm season prairie grasses.

Treatment					Digestible dry matter	Digestible dry matter produced
N	P	K	S	Zn		
—	—	—	—	—	53.9 a[1]	690 a
40	—	—	—	—	56.2 a	1167 b
80	—	—	—	—	57.9 a	1529 bc
80	20	—	—	—	55.8 a	1653 c
80	40	—	—	—	58.8 a	2114 d
80	20	20	—	—	57.5 a	1679 c
80	20	20	40	—	54.8 a	1722 c
80	20	20	40	10	56.1 a	1776 cd

[1] Treatment means within any one column having the same letter are not significantly different at the 95% confidence level.

Table 4. The effect of fertilizer treatment (lb./acre) on the vegetative composition (%) of a mixture of warm-season prairie grasses.

Treatment					Composition				
N	P	K	S	Zn	Big bluestem	Sideoats grama	Switch-grass	Cool season grasses	Weeds
—	—	—	—	—	63.4 a[1]	29.2 a	.4	0.0	0.0
40	—	—	—	—	62.5 a	36.7 a	0.0	0.0	.4
80	—	—	—	—	47.9 a	49.2 a	.4	.4	.8
80	20	—	—	—	65.8 a	31.3 a	2.1	.4	.4
80	40	—	—	—	69.2 a	32.5 a	0.0	.4	.4
80	20	20	—	—	64.6 a	32.5 a	1.7	1.3	0.0
80	20	20	40	—	61.7 a	37.1 a	.9	0.0	.4
80	20	20	40	10	69.6 a	25.8 a	3.8	.4	.4

[1] Treatment means within any one column having the same letter are not significantly different at the 95% confidence level.

this study. Because of the low organic matter content and the calcareous nature of the soil, it was thought that the grasses might respond to the use of S and Zn. The data show, however, that neither nutrient increased forage yields.

The fertilizer applied over the four-year period at the rates shown did not change the soil level of N, P and K as measured by standard laboratory procedures (data not shown). In addition, there was very little, if any, downward movement of N and P. Calculations of nutrient recoveries show that only small amounts of the added fertilizer were recovered in the plant tissue. Either higher rates will have to be applied to bring about changes in soil nutrient levels or different laboratory procedures will be needed to detect the small changes that may take place.

In addition to yield, these nutrients were evaluated with respect to their effect on forage quality. In this study, fertilization had no effect on the protein content of the forage tissue. These data are not in agreement with reported work with bluestem range by Moser and Anderson (1964) or native Northern Plains rangeland by Rogler and Lorenz (1957). It should be pointed out here that protein determinations were made on mature tissue collected at harvest. It is highly possible that differences in protein content could have been detected if samples had been collected at earlier stages of maturity.

The fact that the percentage of digestible dry matter in the tissue was not altered by fertilization would agree with conclusions reached by Blaser (1964) who, after reviewing the literature, reported that stage of maturity rather than fertilization had a greater influence on the digestible dry matter in forage tissue.

After four years of fertilization the primary grasses of the mixture were big bluestem and sideoats grama and the percentage of each was not altered by fertilization. No Indiangrass could be detected and the percentage of switchgrass was rather small in all treatments. It appears that factors other than fertilization were responsible for the failure of these two grasses to become established.

Fertilization did not increase encroachment by cool-season grasses or weeds. Researchers from other states, however, have reported that fertilization of established stands of warm-season grasses has increased growth of cool-season species (Owensby et al., 1970) and weeds (Huffine and Elder, 1960). In this study, the lack of encroachment by the undesirable plants may be due, in part, to the fact that fertilization was delayed until after May 15th of each year. It was thought that by delaying application, the nutrients would be more readily used during the period of active growth of the warm-season species. Studies are now in progress to determine the effect of timing of fertilizer applications on the yield and quality of the warm-season prairie species.

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Nitrogen and Phosphorus Availability in a Fertilized Rangeland Ecosystem of the Northern Great Plains[1]

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Highlight

Factorial combinations of ammonium nitrate at rates of 0, 100, 300, and 900 lb. N/acre and concentrated superphosphate at rates of 0, 100, and 200 lb. P/acre were broadcast on a native range site (a *Bouteloua-Carex-*[*Stipa*] faciation of a mixed prairie association) near Sidney, Montana. In 2 years, the addition of a high rate of N and P fertilizer increased total forage production 3.3-fold, total crude protein 6.7-fold, and plant N and P percentages about 2.0-fold. High rates of N applied alone had no marked effect on plant P percentage the year of application, but plant P percentage was reduced nearly 2.0-fold the second year by all rates of N. Nitrate-nitrogen was concentrated in the upper 3 feet of soil in 1969 and in the upper 5 feet of soil in 1970. Nearly all of the P fertilizer applied was concentrated in the upper 3 inches of soil in 1969 and in the upper 6 inches of soil in 1970. The high rate of N applied alone decreased soil pH from about 6.9 to 6.1 in the 0- to 6-inch soil depth in 1969 and from 6.9 to 6.5 in 1970 even though the soil was strongly calcareous.

Forage production on rangeland is governed by plant-soil-climate relationships. Nutrient content of forage, within individual plant species, is dependent on soil fertility and the rate of release of soil nutrients. In the northern Great Plains, cycling and availability of nutrients to plants are controlled largely by climatic factors—primarily soil temperature and available soil water. The effects of high fertilization and other range management techniques on nutrient cycling and availability, and their interaction with climatic factors, have not been fully determined.

The significance of N and P fertilizer interactions on availability of soil N and P, and subsequent plant growth and nutrient uptake, becomes increasingly important when fertilizer materials are applied at high rates. The objectives of this paper are to consider these interactions in relation to the N and P content of range plants.

Materials and Methods

Details of the study site, experimental design, fertilizer treatments, and harvest methods are given in a preceding paper by Wight and Black (1972). In brief, the experiment was a randomized block, split-plot design with P fertilizer rates of 0, 112, and 224 kg/ha (0, 100, and 200 lb./acre) as main plots and N fertilizer rates of 0, 112, 336, and 1008 kg/ha (0, 100, 300, and 900 lb./acre) as subplots. The respective sources of N and P were ammonium nitrate and concentrated superphosphate.

Plant samples were obtained by hand clipping one 0.25- by 4-m (0.8- by 13.1-foot) quadrat per plot at ground level. Harvested plants were separated by species, ovendried at 65 C, and ground for chemical analysis. For discussion purposes in this paper, plant species were grouped into two categories: Grasses—western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), prairie junegrass (*Koeleria cristata*), and needleandthread (*Stipa comata*); and nongrasses—threadleaf sedge (*Carex filifolia*) and other sedges, goatsbeard (*Tragopogon dubius*) and other forbs, and fringed sagebrush (*Artemisia frigida*) and other shrubs.

Plant N was determined by the Kjeldahl method, modified to exclude plant nitrates (Jackson, 1958); and crude protein was calculated (% N $\times$ 6.25 = % crude protein). Plant P was determined colorimetrically (Barton, 1948) following wet oxidation of plant tissues. All significant differences in plant N and P content discussed are at the P = .05 level, unless otherwise indicated.

Before initial fertilization in the spring of 1969, soil samples were obtained by genetic horizons and various chemical and physical soil

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properties were determined. In the fall of 1969 and 1970, soil samples were also taken from selected fertilizer plots at the following depth increments: 0 to 7.5, 7.5 to 15, 15 to 30 cm, and by 30-cm-depth increments to 244 cm (8 ft). Available P was estimated by the $NaHCO_3$ method (Olsen et al., 1954). Organic matter percentage was determined by the Walkley-Black procedure; pH, by glass-calomel electrodes in 1:1 soil-to-water pastes; NO_3-N, by the phenoldisulfonic acid procedure; and total soil N, by the Kjeldahl procedure (Jackson, 1958). Percentages of sand, silt, and clay were determined by the hydrometer method.

Table 1. Some chemical properties of Sprole loam range site.

Horizon	Soil depth (cm)	Texture*	pH	Organic matter (%)	Total N (%)	NO_3-N (ppm)	$NaHCO_3$-soluble P (ppm)
A1	0– 11	SL	6.8	2.50	.133	7.9	1.8
B2	11– 25	SClL	6.9	1.67	.104	0.8	0.3
B3ca	25– 36	ClL	8.1	2.27	.143	1.3	0.4
C1ca	36– 46	ClL	8.3	1.60	.098	1.3	0.2
C2ca	46– 76	L	8.5	0.94	.059	0.8	0.5
C3	76– 91	L	8.6	0.60	.035	1.3	0.5
C4	91–119	SL	8.8	0.47	.029	0.8	1.7
C5	119–132	SL	8.4	0.50	.024	0.8	1.2

* SL = Sandy Loam; SClL = Sandy Clay Loam; L = Loam.

Results and Discussion

Results of soil analysis of the samples obtained by genetic horizon prior to fertilization are shown in Table 1. From the B horizons downward, the glacial till soil increases in soil particle size, with the quantity of small and large gravel increasing progressively with depth. Organic matter and total N percentages decreased sharply with profile depth below 46 cm (18 inches). Soil pH increased sharply in the 25- to 36-cm (10- to 14-inch) soil depth which coincided with the beginning of the zone of high lime content. In general, the soil profile is highly calcareous and deficient in available N and P. Soil NO_3-N and $NaHCO_3$-soluble P decreased to an extremely low level below the first 11 cm (4.5 inches). Available P increased slightly in the 91- to 132-cm (36- to 52-inch) depth.

At the end of the first and second growing seasons, soil NO_3-N, pH, and $NaHCO_3$-soluble P were determined by selected increments to a depth of 244 cm in selected fertilizer plots. Soil NO_3-N was determined in plots receiving 0, 112, 336, and 1008 kg/ha of N applied alone. Profile distribution and total soil NO_3-N for these fertilizer plots are shown in Table 2. Check plots in the fall of 1969 and 1970 had very low levels of soil NO_3-N, totaling 29 and 27 kg/ha (26 and 24 lb./acre), respectively. Total soil NO_3-N increased about 55 kg/ha (50 lb./acre) for each 112 kg/ha (100 lb./acre) of N applied, and the amount present was about the same at the end of both growing seasons. Since one-half of the N applied was in ammonium form, it had to undergo nitrification before it could be measured in nitrate form. In either year, only 50 to 70% of the added N was measured as nitrate. In 1969, considerable quantities of added N (30 to 50%) were probably immobilized in the organic phase or present in other forms of N. Added N may have stimulated N mineralization from organic sources in this severely N-deficient soil by the second year, which may explain why soil NO_3-N was higher in the fall of 1970 than in the fall of 1969, despite plant N uptake for two seasons.

Soil NO_3-N was distributed throughout the profile to a depth of 244 cm with the two highest rates of N. However, most of the NO_3-N was concentrated in the upper 91 cm (3 ft) in 1969 and in the upper 152 cm (5 ft) in 1970. Above-average April–May precipitation in 1970 caused soil NO_3-N to move deeper into the profile than ordinarily would be expected on rangeland in the northern Great Plains.

Soil pH was determined in check

Table 2. Profile distribution and total soil nitrates (ppm) at the end of the 1969 and 1970 growing season as influenced by high N fertilization (kg/ha).

Soil depth (cm)	Nitrogen added: 0		112		336		1008	
	1969	1970	1969	1970	1969	1970	1969	1970
0– 7.5	1.3	1.4	1.3	1.5	8.8	7.5	57.0	17.2
7.5– 15	1.2	1.1	1.2	1.3	5.4	8.1	50.5	27.2
15– 30	1.1	1.0	1.9	1.3	10.2	5.2	25.7	11.6
30– 61	1.0	1.0	1.9	1.6	19.4	12.3	62.5	20.0
61– 91	1.0	0.8	2.0	4.5	6.6	15.1	13.8	12.2
91–122	0.9	1.0	1.7	5.0	5.8	12.5	5.0	52.0
122–152	0.9	0.5	1.4	1.8	2.5	8.1	1.9	20.9
152–183	0.5	0.5	1.4	1.7	2.1	2.4	1.4	8.0
183–213	0.5	0.5	1.0	1.0	1.5	1.6	1.0	1.4
213–244	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0
Total NO_3-N (kg/ha)	29	27	52	78	210	283	566	594

Table 3. Soil pH in 1969 and 1970 and $NaHCO_3$-soluble P (ppm) in 1969 in the profile as influenced by high N and P fertilization.

Soil depth (cm)	Soil pH				$NaHCO_3$-soluble P		
	1969		1970		1969		
	0–0*	1008–0	0–0	1008–0	0–0	1008–0	1008–224
0– 7.5	6.8	6.2	6.9	6.5	1.5	2.6	44.8
7.5– 15	6.9	6.0	7.0	6.8	0.5	1.0	16.0
15– 30	8.1	7.8	7.9	7.8	0.3	0.4	2.1
30– 61	8.3	8.1	8.1	8.0	0.3	0.3	1.0
61– 91	8.5	8.4	8.5	8.4	0.5	0.5	0.6
91–122	8.8	8.7	8.8	8.7	1.5	1.4	1.2
122–152	8.5	8.5	8.6	8.6	1.4	1.3	1.4
152–183	8.5	8.5	8.4	8.3	0.2	0.3	0.3
183–213	8.3	8.4	8.3	8.4	0.3	0.2	0.2
213–244	8.4	8.4	8.4	8.4	0.3	0.3	0.3

* kg/ha of N and P applied, respectively.

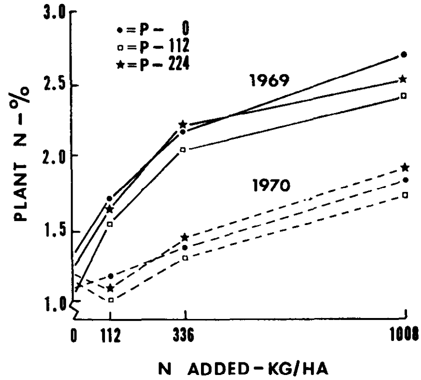

FIG. 1. Average plant N percentage of grasses as influenced by high fertilization.

and high-N plots in the fall of 1969 and 1970 (Table 3). In both years, pH was reduced considerably in the 0- to 7.5- and 7.5- to 15-cm (0- to 3- and 3- to 6-inch) depths by N applied at the high rate. Although not shown in Table 3, the 336-kg/ha (300-lb./acre) rate of N caused a proportionate one-third of the decrease shown for the high N rate. Inasmuch as the zone of high lime accumulation began at about the 30-cm (12-inch) depth, changes in pH below this depth were minimal. Soil pH increased in the zones above 30 cm (12 inches) between 1969 and 1970 on the high-N plot as would be expected because of the relatively high buffering capacity of calcareous soils. The first-year change in pH from the high rate of N fertilization in this study was similar to that reported by Smika et al. (1961) for nine annual applications of N at a rate of 101 kg of N/ha (90 lb. of N/acre).

Soluble P was increased severalfold by P fertilization, but the increase was limited primarily to the top 15 cm of the soil profile (Table 3). Small increases in soluble P were detected in the 15- to 30- and 30- to 61-cm (6- to 12- and 12- to 24-inch) depths. High application rates of P resulted in some movement of P into deeper soil layers making it more readily available to plants under semiarid conditions. In the upper 15 cm, soluble P in the high-N plot without P added was slightly higher than the check. The increase in soil pH associated with the high rate of N applied alone would be expected to increase soil P availability because the solubility of inorganic P sources in calcareous soils increases when soil pH decreases. However, the $NaHCO_3$ method failed to detect much of an increase in soluble P levels as a result of the high-N rate in the fall of 1969; yet plant P content and total P uptake increased nearly 2-fold.

Plant N Percentage

Since the influence of fertilizer treatments on plant N percentage was similar for individual species, data were averaged by years for grasses and nongrasses and are shown in Figures 1 and 2, respectively. In 1969, N applied at rates of 112, 336, and 1008 kg/ha increased N percentage of grasses 1.2-, 1.7-, and 2.0-fold, respectively, and 0-, 1.4-, and 1.7-fold, in 1970 (Fig. 1). Similar increases in plant N percentages were obtained for nongrasses (Fig. 2). Phosphorus applied alone or in combination with N had no influence on plant N percentages of grasses or nongrasses in either year.

In 1969 and 1970, total forage production increased about 1.7-, 2.8-, and 4.0-fold with applications of 112, 336, and 1008 kg/ha of N. These increases in total dry matter production, when combined with progressive increases in percent plant N, resulted in a 2.7-, 5.4-, and 6.7-fold increase in total production of crude protein. Over the 2-year period, the check plot produced only 177 kg/ha (158 lb./acre) of crude protein, compared with 736 kg/ha (657 lb./acre) produced with an application of 1008 kg/ha of N alone or 1190 kg/ha (1062 lb./acre) produced with the same rate of N applied in combination with P. Crude protein was not significantly influenced by P applied alone. When compared within the same level of added N, P increased total crude protein production about 30%.

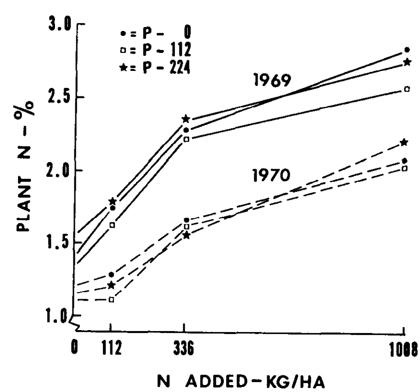

FIG. 2. Average plant N percentage of nongrasses as influenced by high fertilization.

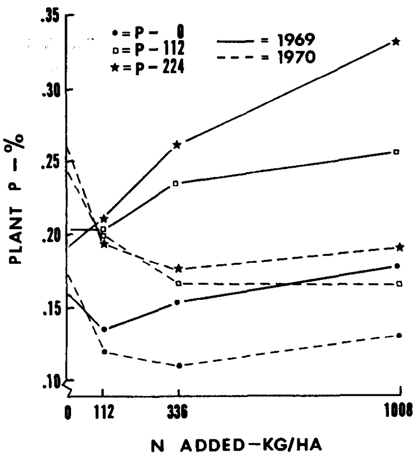

FIG. 3. Average plant P percentage of grasses as influenced by high fertilization.

Dee and Box (1967) found a positive effect of P fertilizer within N treatments on the crude protein level of several mixed prairie grasses. In this study, grasses alone accounted for only 25% of the total crude protein produced without fertilization in 1969 and 1970. With high N-P fertilization, grasses produced 50% of the total protein in 1969 and 80% in 1970.

Percent recovery of N applied at rates of 112, 336, and 1008 kg/ha was 42, 37, and 16% with P added, and 30, 22, and 9% without P, respectively. Although efficiency of N recovery decreased with increasing rate of N applied and N recovery percentages were low, similar results have been reported by other research workers in the northern Great Plains (Rogler and Lorenz, 1957; Smika, Haas, and Rogler, 1960; Smoliak, 1965; Cosper, Thomas, and Alsayegh, 1967; Black, 1968; and Johnston et al., 1968). These researchers have also observed the positive effect of P fertilization on the efficiency of N recovery.

Plant P Percentage

Average plant P percentage of grasses for 1969 and 1970 is shown in Fig. 3; nongrasses, in Fig. 4. In 1969, N applied alone at a rate of 112 kg/ha depressed P percentages of grasses and nongrasses, 336 kg/ha had no effect on P percentages, and 1008 kg/ha increased plant P percentages, compared with the unfertilized plot. The increase in plant P obtained the first year with the high-N rate is in contrast with other research (Smika et al., 1960; Cosper et al., 1967; and Black, 1968), where traditionally N applied alone has reduced percent plant P. The first-year decrease in pH may have increased the availability of soil P from native sources. However, the second year following application, all rates of N applied alone significantly reduced (P = .01) plant P percentage in both grasses and nongrasses. Without the addition of P fertilizer, plant P percentages in grasses and nongrasses fertilized with N alone were below the level of 0.17% P set by the National Research Council (1958) for a maintenance ration. With P added at either rate, plant P percentage was adequate in the grasses and more than adequate in nongrasses. In general, added P increased percent P proportionately more in nongrasses than in grasses.

High rates of N applied alone increased total forage P uptake 2-fold (data not shown); and when combined with either rate of P, high rates of N increased total P uptake 5- to 6-fold. In the presence of added N, about 10% of the fertilizer P applied was recovered in the aboveground plant material over the 2-year period. Phosphated plots should effectively increase plant P content for several years as reported previously by Black (1968) and Smoliak (1965).

In just 2 years, the addition of a high rate of N and P fertilizer increased total forage production 3.3-fold, total crude protein 6.7-fold, and plant N and P contents about 2-fold. Therefore, not only total forage production increased, but the quality of forage as well. Plant-soil systems of rangeland have a large proportion of the soil N and P required for plant growth tied up in the organic phase in relatively unavailable forms. This is

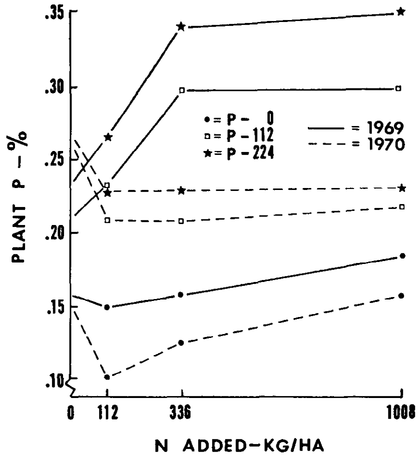

FIG. 4. Average plant P percentage of nongrasses as influenced by high fertilization.

corroborated by the low yield and low quality of unfertilized range plants in this study. The authors recognize that maximum forage yields may not be the most economical or desirable target. Nevertheless, at least 336 kg/ha of N and 112 kg/ha of P were required to obtain maximum forage yields and improve quality to adequate standards, while at the same time supplying the quantities of N and P needed to satisfy the nutrient-starved initial organic cycle and maintain an active final organic cycle.

In this study, plants growing on the high N-P fertilizer plots began growth earlier and grew faster in the spring of both years than plants growing on unfertilized soils. Power et al. (1963) have shown that high soil P levels reduced the sensitivity of plants to cool soil temperature. Nitrogen availability is equally important in stimulating early plant growth. Timely nutrient availability is an extremely important growth aspect in relation to efficient plant utilization of stored soil water and growing season precipitation in a relatively cool, semiarid climate.

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Paraquat Kills Geyer Larkspur[1]

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Highlight

Geyer larkspur, a poisonous, perennial forb, is highly susceptible to paraquat applied when flowering stems are slightly above ground. At 1/2 lb./acre, paraquat killed 90 to 95% of geyer larkspur, but was less effective when the treatment was preceded with 2,4-D at 2 lb./acre. Textile onion and most annual species were susceptible to paraquat, while all other perennial species were resistant. There was some reduction in herbage yields in the year of treatment. Although paraquat is not registered for controlling geyer larkspur, it could be considered for that purpose.

Geyer larkspur (*Delphinium geyeri* Greene) is a poisonous perennial plant of open plains and mountain slopes below 8,000 feet elevation in Colorado, Wyoming and Utah (Fig. 1). Although ranchers can avoid death losses by keeping cattle away from areas infested with geyer larkspur from about mid-April through July, many of them either lack alternate sources of forage or must constantly defer grazing of larkspur pastures, which forces overgrazing and declining productivity on other range areas. Either way the economic losses are serious. Unfortunately, ranchers cannot solve these problems satisfactorily without an effective and profitable way of either controlling the plants or suppressing the poison in the animals.

Geyer larkspur plants generally recover from an application of (2,4-dichlorophenoxy)acetic acid (2,4-D) by initiating shoot and root growth, the year after spraying, from previously dormant buds on vertical rootstocks (Hyder, 1971; Hyder and Sabatka, 1972). Therefore, it may be possible to increase plant mortality by breaking dormancy of rootstock buds and thus improve the movement of 2,4-D. Since defoliation often promotes activity in dormant buds, 1,1′-dimethyl-4,4′bipyridium ion (paraquat) might be used to increase the effect of 2,4-D. Paraquat is essentially a non-selective contact herbicide that desiccates and defoliates all plants. After entering tissues of green plants, paraquat is metabolically broken down and this process generates hydrogen peroxide, which destroys plant cells (Calderbank, 1968). Upon contact with soil, paraquat is quickly inactivated by adsorption to clay particles (Calderbank, 1968).

On rangeland, paraquat usually kills annual plants; whereas, most perennials grow back after treatment (Evans et al., 1967; Kay, 1964, 1968, 1970; Sneva, 1967; Wallace et al., 1966).

This paper reports the effects of spraying geyer larkspur and many other plant species with 2,4-D and paraquat at various rates and times. Mechanical defoliation treatments were included to determine

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FIG. 1. Geyer larkspur begins growth in April (left) and flowers in July (right). It is poisonous to cattle throughout the growing season.

whether the lethal effects of paraquat should be attributed to a natural susceptibility of geyer larkspur to defoliation or to a translocated phytotoxic effect.

Methods

Paraquat and 2,4-D in 1969

A 2 × 2 × 2 factorial experiment, in 3 randomized blocks, included 2 dates of spraying (April 28 and May 12, 1969), 2 rates of 2,4-D (none and 2 lb./acre), and 2 rates of paraquat (none and ¼ lb./acre), which was applied 2 days after the 2,4-D. However, since the ¼ lb./acre rate of paraquat applied April 30 incompletely desiccated geyer larkspur, the rate was increased to ½ lb./acre on May 14.

Experiments in 1970

Rate of paraquat.—Paraquat at none, ¼, ½, and ¾ lb./acre was applied on May 6, 1970. The experiment included 6 replications in a completely random design.

Date of paraquat.—Paraquat was applied at ½ lb./acre on May 6, May 18, May 25, and June 2, 1970. The experiment included 6 replications in a completely random design.

Mechanical defoliation.—All herbage was clipped to ground level by hand on May 8, May 15, May 22, May 29, or June 5, 1970. The experiment included 4 replications in a completely random design. Individual plots, located to include high larkspur densities, were 14 inches wide by 10 feet long. Geyer larkspur plants were counted on May 8, 1970, and May 1, 1971.

Treatment and Sampling Methods

Paraquat and 2,4-D were diluted in water containing 0.1% (v/v) of alkyarylpolyoxyethylene glycol and applied broadcast with a boom-type plot sprayer at a total spray volume of 20 gpa. Individual plots prepared for spraying experiments were 12 by 45 feet.

Treatment effects on geyer larkspur were evaluated by counting the number of plants on 100 square feet of each plot in May the year of spraying and in May one year later, in some cases also two years later. Treatment effects on other species were evaluated by frequency of occurrence involving 50 placements of a 16 by 16-inch quadrat on each plot one year after treatment. Frequency percentages were transformed to apparent density by the equation $d = -\log_e (q/100)$, where d is apparent density and q is the complement of frequency percentage, to estimate mortality percentages (Hyder, 1971).

Herbage samples were cut with a rotary lawnmower leaving 1½ inches or about 300 lb./acre of uncut stubble in 1970, and with a rotary mower of our design leaving about ¼ inch or about 50 lb./acre of stubble in 1971. Since yields between years are not compared to determine treatment effects, the amounts of uncut stubble are not added to yield values. Herbage samples were oven dried at 70 C.

All plots were located on mixed-grass prairie about 5 miles south of Cheyenne, Wyoming.

Results

Susceptibility of Geyer Larkspur to Paraquat

Paraquat and 2,4-D in 1969.—Desiccating geyer larkspur with paraquat after spraying with 2,4-D failed to increase the effect of 2,4-D (Table 1). However, paraquat alone, at either ¼ or ½ lb./acre, was more effective than 2,4-D at 2 lb./acre. Paraquat at ½ lb./acre applied May 14, when the flowering stems were slightly above ground, killed 90% of the plants. On the same plots 2 years after spraying (in 1971), the reduction in geyer larkspur amounted to 77%, but all treatments, including unsprayed check, allowed a little increase in number of geyer larkspur in 1971. Paraquat at ½ lb./acre desiccated all species within 1 week. Geyer larkspur and most annual species failed to grow back after treatment, but essentially all other perennial species grew back quickly.

Since paraquat alone applied in 1969 killed geyer larkspur, additional trials were planned to verify and expand the results. Subsequent

Table 1. Changes (%) in the counts of geyer larkspur one year after spraying in 1969.[1]

Date of treatment	Rate of paraquat (lb./acre)	Rate of 2,4-D	
		0	2 lb./acre
April 28[2]	0	− 4 a	−42 bc
	¼	−57 cd	−62 cd
May 12[2]	0	+ 8 a	−33 b
	½	−90 e	−75 de

[1] Percentage values followed by the same letter are not different at the 95% level of probability.

[2] Sprays containing 2,4-D were applied on the dates given, and paraquat was applied 2 days later.

Table 3. Changes (%) in apparent densities of species that were significantly affected by paraquat applied at 1/2 lb./acre on four dates in 1970.[1]

Species	Treatment date			
	May 6	May 18	May 25	June 2
Scarlet globemallow	− 8	+159*	+69	+ 68
Needleandthread	+36	+ 77	+31	+169*
Sandberg bluegrass	−79*	− 68*	−96*	− 62*
Textile onion	−90*	− 85*	−90*	− 85*
White biscuitroot	−32	− 66*	−37	− 34
Geyer larkspur (by frequency)	−83*	− 94*	−82*	− 72*
Geyer larkspur (by counting)	−89*	− 95*	−89*	− 71*

[1] Changes are based on differences between treated and untreated plots. All plots were sampled for the frequency of occurrence of species in 16 by 16-inch quadrats in May 1971. Frequency percentages were transformed to apparent densities for analysis of variance and the calculation of percentage changes due to treatment.

* Values are significantly different from zero (95% level of probability).

experiments included various rates and times of treatment with paraquat to determine best treatments. Mechanical defoliation, also, was included to determine whether the lethal effects of paraquat should be attributed to a natural susceptibility of geyer larkspur to defoliation or to some translocated phytotoxic effects.

Date of paraquat.—Paraquat applied at ½ lb./acre on May 6, May 18, May 25, and June 2, 1970, killed 89, 95, 89, and 71% of geyer larkspur plants, respectively. The smallest significant range (95% level of probability) for comparing two consecutive means is 6%. Thus, the greatest mortality (95%) was obtained in mid-May when the flowering stems of geyer larkspur were slightly above ground. Spraying at an earlier time allowed regrowth of some of the large plants, while spraying on or after May 18 prevented regrowth of geyer larkspur. Paraquat effectiveness dropped off rapidly after May 25.

Root systems excavated at different times after treatment exhibited a darkening of root tissue, which appeared first in dormant buds, in 3 to 4 weeks. This observation suggested that paraquat produced a translocated phytotoxic effect on geyer larkspur.

Rate of paraquat.—The changes in geyer larkspur counts amounted to −3, −75, −89, and −89% for paraquat rates of 0, ¼, ½, and ¾ lb./acre. The smallest significant range for comparing two consecutive means is 7% for the 95% level of probability. Thus, rates of ½ and ¾ lb./acre were more effective than ¼ lb./acre.

Clipping experiment.—Clipping after mid-May, when the flower stems of large plants were above ground, prevented regrowth and flowering the year of treatment. However, in 1971 there was no significant reduction in either the number of plants or plant vigor by any time of previous clipping. Since mechanical defoliation failed to kill plants, paraquat must have produced a translocated phytotoxic effect on this species.

Table 2. Changes (%) in apparent densities of species that were significantly affected by paraquat applied in 1969.[1]

Species	Rate of paraquat (lb./acre)	
	¼	½
Slimleaf goosefoot	+111*	+219*
Greenflower pepperweed	+ 46	+485*
Geyer larkspur[2]	− 57*	− 90*
Textile onion	− 81*	−100*
White biscuitroot	− 52*	− 59*

[1] Changes are based on differences between treated and untreated plots. All plots were sampled for the frequency of occurrence of species in 16 by 16-inch quadrats in May 1970. Frequency percentages were transformed to apparent densities for analysis of variance and the calculation of percentage changes due to treatment.

[2] Changes for geyer larkspur were determined by counting the plants on 100 square feet per plot before and one year after spraying.

* Changes in apparent density were significant at the 95% level of probability.

Susceptibilities of Other Species

Two perennial species, in addition to geyer larkspur, decreased significantly the year after treatment with paraquat in 1969 (Table 2). Textile onion (*Allium textile* Nels. & Macbr.) was essentially eliminated by ½ lb./acre of paraquat, and white biscuitroot (*Cymopterus acaulis* (Pursh) Raf.) was moderately susceptible. On the other hand, slimleaf goosefoot (*Chenopodium leptophyllum* Nutt.) and greenflower pepperweed (*Lepidium densiflorum* Schrad.), both annual forbs, increased significantly (95% probability) one year after treatment with paraquat.

Five perennial species in addition to geyer larkspur changed significantly after being treated with paraquat in 1970 (Table 3). As in 1969, textile onion and white biscuitroot decreased significantly. Sandberg bluegrass (*Poa secunda* Presl.), which appeared resistant in 1969, was susceptible in 1970. Both scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.) and needleandthread (*Stipa comata* Trin. and Rupr.) increased significantly after one date of spraying. Table 3 includes percentage changes of geyer larkspur as determined by frequency sampling and by counting plants. The two methods of evaluating changes in geyer larkspur gave nearly identical results.

Since very few perennial species were susceptible to paraquat, a list of those documented as resistant is given in Table 4. Other perennial species were too rare to indicate resistance or susceptibility to paraquat.

Table 4. Important perennial species documented as resistant to paraquat applied in 1969 and 1970.

Species name	Year observed	
Sandberg bluegrass (*Poa secunda* Presl)	1969	[a]
Needleandthread (*Stipa comata* Trin. and Rupr.)	1969	[a]
Scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.)	1969	[a]
Bladderpod (*Lesquerella macrocarpa* A. Nels.)	1969	[b]
Plains pricklypear (*Opuntia polyacantha* Haw.)	1969	[b]
Veiny dock (*Rumex venosus* Pursh)	1969	[b]
Western wheatgrass (*Agropyron smithii* Rydb.)	1969 &	1970
Blue grama (*Bouteloua gracilis* (H.B.K.) Lag.)	1969 &	1970
Sun sedge (*Carex heliophila* Mackenz.)	1969 &	1970
Junegrass (*Koeleria cristata* (L.) Pers.)	1969 &	1970
Fringed sagebrush (*Artemisia frigida* Willd.)	1969 &	1970
Bluebells (*Mertensia lanceolata* (Pursh) A. DC.)	1969 &	1970
Woody buckwheat (*Eriogonum effusum* Nutt.)	1969 &	1970
Common starlily (*Leucocrinum montanum* Nutt.)	1969 &	1970
Drummond milkvetch (*Astragalus drummondii* Dougl.)	1969 &	1970
Scarlet gaura (*Gaura coccinea* Nutt. ex Pursh)	1969 &	1970
Showy peavine (*Lathyrus polymorphus* Nutt.)	[b]	1970
Eveningprimrose (*Oenothera coronopifolia* (Torr. & Gray)	[b]	1970

[a] See text for changes in 1970.
[b] Frequency was too small to justify evaluation.

Herbage Yields

Treatment of mixed-grass prairie with 2,4-D generally increased herbage yields the year after treatment (Hyder, 1971). Paraquat, however, should decrease yields at least in the year of treatment. Thus, yields were taken July 20, 1970, after paraquat treatments on May 6, May 18, May 25, and June 2, 1970. Yields amounted to 362, 380, 311, and 296 lb./acre, respectively by dates of treatment; whereas, the yield on untreated plots averaged 364 lb./acre. Although these differences were not significant at 95%, treatments in late May and early June apparently decreased the yield about 15% not counting the uncut stubble. Regrowth herbage remained green later in the season and was greatly preferred by cattle in August.

In the year after treatment with paraquat in 1969 and 1970, herbage yields were the same as on untreated plots.

Discussion

Both geyer larkspur and textile onion were highly susceptible to paraquat. White biscuitroot was moderately susceptible. Most grasses and sedges appeared to tiller less profusely after treatment, even when their frequency of occurrence remained unchanged. Sandberg bluegrass was most susceptible, but all grasses and sedges probably were damaged temporarily, as shown by small reduction in herbage yield the year of treatment. Some, but not all, of the apparent decrease in sandberg bluegrass and increase in needleandthread could have been due to incorrect identification of these species at the early stage of vegetative development.

Paraquat at ½ lb./acre desiccated all species, most of which began regrowth in 2 weeks after treatment. If the paraquat was applied after the flower stems of geyer larkspur were above ground, there was no regrowth by the larkspur. Consequently, an area would be safe for cattle grazing in about 3 weeks after treatment with paraquat, as far as geyer larkspur is concerned. That would be about 6 weeks earlier than natural maturing and drying of geyer larkspur.

A 90–95% reduction in number of geyer larkspur plants the year after treatment is considered excellent kill. However, even this degree of control may not be enough to prevent cattle poisoning. Geyer larkspur densities run over 4 plants per square foot in some places. Thus, a 95% mortality could leave a density of 1 plant per 5 square feet. Thick stands might need to be retreated. Furthermore, new plants arising from seed could gradually increase the hazard. In any event, repeated treatments may be necessary.

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Sand Shinnery Oak Response to Silvex Sprays of Varying Characteristics[1]

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Highlight

Silvex at 0.5 lb./acre applied in diesel oil, diesel oil:water emulsion, water, or water plus surfactant controlled sand shinnery oak in the Rolling Plains of Texas. Decreasing the silvex rate from 0.5 lb./acre progressively decreased sand shinnery oak control. Addition of 0.25 or 0.5 lb./acre ammonium thiocyanate did not enhance the effectiveness of 0.5 lb./acre silvex on sand shinnery oak.

Sand shinnery oak (*Quercus havardii* Rydb.) infests about 1.5 million acres of rangeland in the High and Rolling Plains of Texas (Rechenthin and Smith, 1967). Dense infestations with stems 2 to 4 ft tall completely dominate many sites with deep sand or where sand is underlain by a shallow clay layer. Forage production may be reduced by more than 60% in such infestations (Robison and Fisher, 1968). Aerial applications of 2,4,5-T are most commonly used for control of sand shinnery oak. However, repeated applications are required for effective control and 2,4,5-T is less effective than 2-(2,4,5-trichlorophenoxy) propionic acid (silvex).

A diesel oil:water (1:4) emulsion is used by most ranch managers in northwest Texas for standard application of herbicides to woody plants. Total spray solution usually does not exceed 5 gal/acre. The emulsion is more effective than water for foliar sprays to honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) (Fisher et al., 1959). However, the emulsion does not enhance the effectiveness of silvex on small soapweed (*Yucca glauca* Nutt.) (Robison, 1968). No data were available to substantiate the need for diesel oil when spraying sand shinnery oak. Diesel oil represents only $0.09 to $0.16 of the usual $2.75 to $3.25 application cost for 0.5 lb./acre 2,4,5-T or silvex but a reduction in hauling and dispensing equipment would be realized without diesel oil.

Ammonium thiocyanate disrupts carbohydrate metabolism and photosynthesis (Wu and Basler, 1969) and evidently enhances translocation of 2,4,5-T in some woody species (Basler et al., 1967). The possibility of enhancing the phytotoxicity of 2,4,5-T to honey mesquite with ammonium thiocyanate was indicated by Robison (1965). Elwell (1968) showed that ammonium thiocyanate increased the effectiveness of 2,4,5-T on winged elm (*Ulmus alata* Michx.). However, no data were available as to the performance of silvex in the presence of ammonium thiocyanate.

The objectives of this study were to a) compare the reaction of sand shinnery oak to varying rates of silvex, b) compare the phytotoxicity of silvex in diesel oil:water emulsions with diesel oil only, water only and water plus surfactant and c) evaluate the influence of ammonium thiocyanate on the phytotoxicity of silvex to sand shinnery oak.

Material and Methods

The study site is located in the Rolling Red Plains physiographic province of northwest Texas. The soil grades from deep sand in the lowlands to sand underlain by a clay layer on hillsides. The soil is slightly acid and low in organic matter. Vegetation is dominated by sand shinnery oak and little bluestem (*Andropogon scoparius* Michx.) with scattered small soapweed, sand sagebrush (*Artemisia filifolia* Torr.) and plains pricklypear (*Opuntia polyacantha* Haw.).

In all cases, experiments were designed as randomized complete blocks with 17 by 75 ft plots replicated four times. Silvex was always applied in 21 gal/acre carrier with a truck-mounted sprayer.

Silvex at 0, 0.125, 0.25 and 0.5 lb./acre was applied in May, 1969 and the study was duplicated in 1970. Herbicide was applied in diesel oil:water (1:4) emulsion.

In another study, plots were treated with silvex at 0.5 lb./acre in a diesel oil:water emulsion, diesel oil only, water only, or water plus 0.5% (v/v) nonionic surfactant. Controls included untreated plots and plots sprayed with diesel oil not containing herbicide.

In a third study, 0.25 or 0.5 lb./acre of ammonium thiocyanate was combined with 0.5 lb./acre of silvex and compared to 0.5 lb./acre silvex alone and ammonium thio-

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Table 1. Sand shinnery oak stem densities (thousands/acre) and estimated canopy reduction (%) 1 and 2 years after treatment with various rates (lb./acre) of silvex in a diesel oil:water (1:4) emulsion.

Rate	Density[1] 1 year	Density[1] 2 years	Canopy reduction 1 year	Canopy reduction 2 years
0	64.3 a	64.7 a	0	0
0.125	60.1 a	52.6 a	25	22
0.25	48.6 b	36.4 ab	62	43
0.5	20.2 c	24.3 b	93	82

[1] Means within a column followed by the same letter are not significantly different at the 5% level.

cyanate alone. Silvex-ammonium thiocyanate combinations were applied in the diesel oil:water (1:4) emulsion.

Total canopy damage from the sprays was estimated 30 days and 1 year after treatment. Approximately 1 year after 1970 treatments and 2 years after 1969 treatments, density of live sand shinnery oak stems was recorded from two, 1 m quadrats in all plots.

Results and Discussion

One year after treatment, reduction in density of live sand shinnery oak stems was related in a linear fashion to silvex application rates of 0.5 lb./acre or less (Table 1). If linearity in response had included higher rates, an estimated 0.7 lb./acre would be required for complete control. However, past research has shown that control with 1 lb./acre silvex is usually no better than with 0.5 lb./acre (Robison and Fisher, 1968). On that basis, rates higher than 0.5 lb./acre were not studied.

Densities of sand shinnery oak stems after application of silvex at 0.125 lb./acre were not significantly different from untreated areas (Table 1). The low silvex rate reduced the canopy by about 25% at 30 days after treatment. Canopy reduction did not change 1 and 2 years after application of 0.125 lb./acre. The canopy was reduced by about 60% the year of treatment with 0.25 lb./acre silvex but foliar area began to recover after 2 years.

Silvex at 0.5 lb./acre was the most effective rate for reduction of sand shinnery oak canopy and stem density (Table 1). Application of 0.5 lb./acre in a diesel oil:water (1:4) emulsion reduced the canopy by over 90% at 30 days and 1 year after treatment. Over 80% reduction was evident 2 years after herbicide application. Reduction in density of live stems ranged from 70% after 1 year to 75% at 2 years.

No silvex rate reduced sand shinnery oak regrowth from rhizome tissue. New shoots comprised about 5% of the density of untreated areas and about 25% of density in treated plots 2 years after application of 0.5 lb./acre silvex.

Carriers studied did not alter the effectiveness

Table 2. Sand shinnery oak stem densities (thousands/acre) after 1 and 2 years and estimated canopy reduction (%) 30 days and 2 years after treatment with 0.5 lb./acre silvex in various carriers at 21 gal/acre.

Carrier	Density after treatment[1] 1 year	Density after treatment[1] 2 years	Canopy reduction after treatment 30 days	Canopy reduction after treatment 2 years
Untreated check	80.9 a	68.8 a	0	0
Diesel oil check[2]	80.9 a	68.6 a	5	5
Diesel oil	28.3 b	21.4 b	97	73
Water	24.3 b	24.6 b	95	75
Diesel oil:water (1:4) emulsion	20.6 b	24.3 b	89	75
Water + 0.5% surfactant	24.3 b	24.8 b	99	75

[1] Means within a column followed by the same letter are not significantly different at the 5% level. First year reaction is average of two studies.

[2] Applied without silvex at 21 gal/acre.

of silvex on sand shinnery oak (Table 2). Initial canopy reduction ranged from 80 to 90% and was reduced to about 75% 2 years after treatment regardless of carrier. Diesel oil is considered phytotoxic but caused only minor foliar damage when applied without silvex. Addition of diesel oil or surfactant apparently did not increase retention or foliar absorption of silvex.

Addition of 0.25 or 0.5 lb./acre ammonium thiocyanate did not improve control of sand shinnery oak with 0.5 lb./acre silvex. Both materials dispersed readily in the carrier emulsion and were well agitated during application. Ammonium thiocyanate alone at 0.25 or 0.5 lb./acre was not phytotoxic to sand shinnery oak.

These data indicate that at least 0.5 lb./acre silvex is required for effective sand shinnery oak control into the second growing season. Use of a diesel oil:water emulsion as carrier was not advantageous since aqueous silvex sprays provided effective control.

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Voles Can Improve Sagebrush Rangelands[1]

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Highlight

During cyclic population peaks, voles kill and damage sagebrush and other shrub species over large areas. Damage is greatest when a dense, ungrazed herbaceous understory exists and when the snowpack persists throughout the winter. If peaks in population could be predicted, grazing should be managed to leave all possible herbaceous cover on areas where killing of brush is desired; conversely, grazing by cattle should be heavy where perpetuation of shrubs is preferred.

In the spring of 1969, we observed that voles had killed and damaged big sagebrush (*Artemisia tridentata* Nutt.) over sizable areas in Utah and Nevada during the previous winter. Phillips (1970) reported extensive damage by voles to big sagebrush in southern Idaho during the same period. Earlier, Mueggler (1967) observed a similar situation in Montana.

In this paper, we report results of sampling eight areas in southeastern Tooele County, Utah, in July 1969, to determine the amount of brush killed and the species of vole present. Range managers might take advantage of peak vole populations to improve ranges infested with big sagebrush, and precautions may be taken to deter damage where shrubs are desired.

Areas sampled ranged from 6,500 to 7,500 feet elevation; little damage was noted below 6,500 feet elevation. Average annual precipitation is estimated to range from 15 to 20 inches and about 60% falls as snow on the study areas. Study areas were in five different drainages that were snow-covered throughout the winter. By spring, many sagebrush stems had been girdled as high as the snow was deep—up to 20 inches on some areas. Brush plants were counted on a transect of 10 plots per area and judged as to whether they were undamaged or completely or partly killed by voles or by other factors. Plots were circular, 100 square feet in size, and spaced 30 yards apart. Species of rodents present on the study areas were determined by one night's trapping with two snap traps placed on each of the 80 plots.

Twenty-three longtailed voles (*Microtus longicaudus latus* Hall) and 20 deer mice (*Peromyscus maniculatus sonoriensis* Le Conte) were captured in 160 trap nights. Deer mice were uniformly distributed among the samples, but voles, which were present on all areas, were caught more commonly in samples from higher elevations. Although trapping followed the heavy brush kill, we are certain that the longtailed vole was the principal species involved in girdling of brush; deer mice are not known to eat bark.

Voles eat the cambium layer of sagebrush; in so doing they strip bark from plants and girdle stems and branches. Overall, an average of 59% of the big sagebrush plants were completely killed by voles and an additional 28% showed some damage (Table 1). Greatest kill of sagebrush was in draws and low places that had a dense cover of grass. These areas receive extra moisture, especially in the form of snow. Where present, tall cheatgrass brome (*Bromus tectorum* L.) was particularly favorable microtine habitat. The most prominent perennial grasses were thickspike wheatgrass [*Agropyron dasystachyum* (Hook.) Scribn.] and bluebunch wheatgrass [*A. spicatum* (Pursh) Scribn. and Smith].

Mueggler (1967) also observed that the greatest damage to sagebrush occurred in lush, productive spots where snowfall had been continuous throughout the winter. Phillips (1970) reported that toe slopes and canyon rims showed greater damage than canyon slopes and ridgetops.

Apparently a good herbaceous cover is conducive to buildup of high populations of voles, inasmuch as they form their runways through the litter on top of the ground. The second feature related to extensive brush kill is a snow cover that persists through the winter of a high vole density.

Of particular interest were two sizable areas, each several hundred acres in size, that were ungrazed by livestock in 1968. One area was private range, purchased and fenced by Wolf Brothers of Goshen, Utah, in the spring of

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[2] Stationed in Provo, Utah, Office, which is maintained in cooperation with Brigham Young University.

Table 1. Damage (%) to big sagebrush on areas of various brush densities following an irruption of longtailed voles, Tooele County, Utah.

Area	Brush density[1]	Brush girdled by voles		Brush previously killed[2]	Undamaged brush
		Dead	Damaged		
Vernon Canyon					
Slope 1	14.4	36	35	12	17
Slope 2	7.5	57	31	11	1
Bottom 1	4.4	64	23	13	0
Bottom 2	6.5	65	20	15	0
Harker Canyon	4.6	63	24	11	2
Bennion Canyon	3.7	73	27	0	0
Snow Hollow	7.2	60	35	17	3
Little Valley	5.4	56	26	12	6

[1] Number/100 ft^2.
[2] Causes not known.

1968. Owners were highly elated the following year because voles had killed most of the big sagebrush, thereby boosting yields of herbaceous species (Fig. 1). Longtailed voles appeared to select plants that also showed evidence of insect damage in the form of twig galls. However, this was a general observation and we have no specific information on this point.

The other area was part of a cattle allotment, protected from grazing by the Wasatch National Forest in connection with a juniper [*Juniperus osteosperma* (Torr.) Little] chaining and seeding project. Much sagebrush on the untreated slopes was killed by voles. This saved a considerable sum of money that was to have been used in a spraying project to kill brush.

Although big sagebrush was most seriously affected, girdling was also observed on associated rubber rabbitbrush [*Chrysothamnus nauseosus* (Pall.) Britton] and yellowbrush [*C. viscidiflorus* (Hook.) Nutt.]. Rubber rabbitbrush occurred only in the canyon bottoms; yellowbrush was more ubiquitous. In Vernon Canyon bottoms, there were approximately as many rabbitbrush plants as sagebrush. Up to one-half of the rabbitbrush plants were killed completely and most of those surviving showed evidence of vole damage. An average of three yellowbrush plants per 100 ft^2 were distributed over the study area. Few yellowbrush plants were completely killed and about one-half of them showed no damage whatsoever.

In some draws on north slopes where sagebrush was limited, voles girdled little snowberry (*Symphoricarpos oreophilus* A. Gray), Saskatoon serviceberry (*Amelanchier alnifolia* Nutt.) and western chokecherry [*Prunus melanocarpa* (A. Nels.) Rydb.]. Since these species were not on our transects, no attempt was made to determine the extent of damage on them, but many stems of all three species were killed. We observed no permanent damage to herbaceous plants.

In addition to the 1968 irruption of longtailed voles, Phillips (1970) reported that irruptions in 1958 and 1963 caused extensive damage to bitterbrush [*Purshia tridentata* (Pursh) DC.] in southern Idaho. The 1963 irruption in southern Idaho coincided with both the irruption reported by Mueggler (1967) in Montana and that reported by Smith (1969) in the Wasatch Mountains of Utah in the winter of 1963–64. The latter irruption caused heavy damage to red elderberry (*Sambucus racemosa* L.) between 7,500 and 9,000 feet elevation.

Since microtine population numbers are known to be cyclic, high points in cycles probably could be predicted by frequent small mam-

FIG. 1. Dense herbaceous understory prevails where sagebrush was killed by voles the previous winter.

mal censuses. In our study, however, the noticeable irruption occurred during the growing season immediately preceding the heavy damage to brush in the winter of 1968–69. Trapping during the previous 2 years in the same general area did not reflect a gradual buildup in microtine numbers (Black and Frischknecht, 1971). In addition to censusing, a better understanding of the factor or factors that trigger irruptions would be highly valuable.

Predictions of irruptions would be of great importance to grazing management programs. During an irruption, microtine populations can be expected to be highest in areas where considerable grass is left on the ground. Other things being equal, such areas are likely to be ungrazed or lightly grazed as under a rest-rotation system of management. Preliminary evidence suggests that the peaks in microtine population cycles are 4 or 5 years apart. Range managers should be aware that population peaks could coincide with a grazing cycle that rests a given unit from grazing every 4 or 5 years. Grazing could be manipulated so that areas on which brush control is needed are not grazed in years of vole irruptions to allow buildup of herbaceous cover for voles. On the other hand, areas on which shrubs are desired should be grazed well in those years to reduce herbaceous cover. This study demonstrates the complexities of range ecosystems and the need for understanding interactions of the components.

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Estimation of Herbage Intake from Jackrabbit Feces[1]

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Highlight

The rate of dry weight intake of blacktailed jackrabbits (*Lepus californicus*) in northeastern Colorado was calculated from records for the rate that fecal pellets were deposited on permanent plots. The indigestibility of the native sandhill range forage was estimated from values in the literature (Arnold and Reynolds, 1943). It was estimated that if the range forage removed by jackrabbits had been eaten by yearling steers the value of the beef might have amounted to $9.35 per hectare per year (or $3.70/acre/year).

Most methods studied for estimating herbage intake of leaf-eating herbivores have been concerned with the potential use of indicators found in the solid excreta. These methods require precise knowledge about the indicator (substance or substances) in the food eaten and in the feces. The quantity of leafy material consumed on rangeland can be estimated from fecal output if the indigestibility of the forage consumed and the quantity of feces produced per unit of time per unit of area are known. Total fecal collections from livestock have been obtained by means of animals trained to "harnesses" with fecal collection bags. Wild herbivores, such as jackrabbits, cannot withstand such stress. The difficulties in obtaining total collection estimates of fecal output in livestock may be circumvented for jackrabbits by using permanent plots from which the rabbit fecal pellets are harvested at regular intervals. In essence, appropriately sized permanent plots, of sufficient number, distributed and spaced in a regular-random pattern might serve as sub-sample units for predicting total fecal production.

The purpose of this manuscript is to describe the seasonal trends in the numbers and oven dry weights of fecal pellets voided by blacktailed jackrabbits (*Lepus californicus*) at the Eastern Colorado Range Station in the years 1968 to 1970.

Methods and Materials

This study was conducted on the Eastern Colorado Range Station approximately 27 kilometers north of Akron in Washington County, Colorado. The diet and forage preferences of blacktailed jackrabbits were studied here by Sparks (1968) and he has described the study areas.

Twenty-four sampling sites, each about 0.2 hectares (one-half acre), were used for this study. Twelve sampling sites grazed by cattle were paired in the same pasture with twelve "exclosures" to cattle and the paired sites were both on the same soil types. They were located in a linear north-south direction in a restricted random arrangement.

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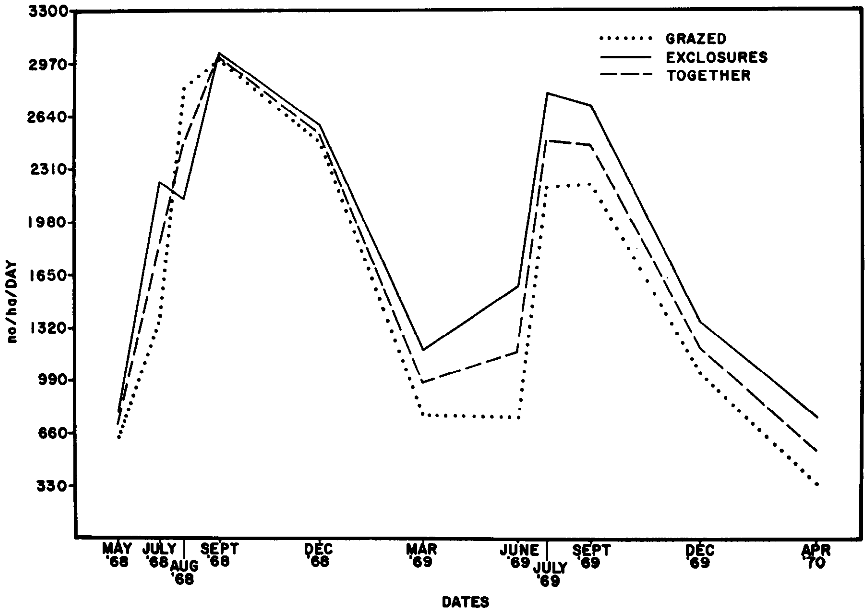

FIG. 1. The calculated numbers of blacktailed jackrabbit pellets voided per day in northeastern Colorado native sandhill rangeland for cattle grazed pastures and exclosures to cattle within pastures.

The distances between paired sampling sites averaged .7 km. The exclosures to cattle had been established for 6 or more years and they did not exclude rodents, rabbits or other small animals.

Fecal pellets of rabbits were collected from 20 permanently marked locations within each site grazed by cattle and each exclosure. A 30 cm by 50 cm quadrat was placed on the ground at each of the locations and all pellets within the quadrat were counted, collected,

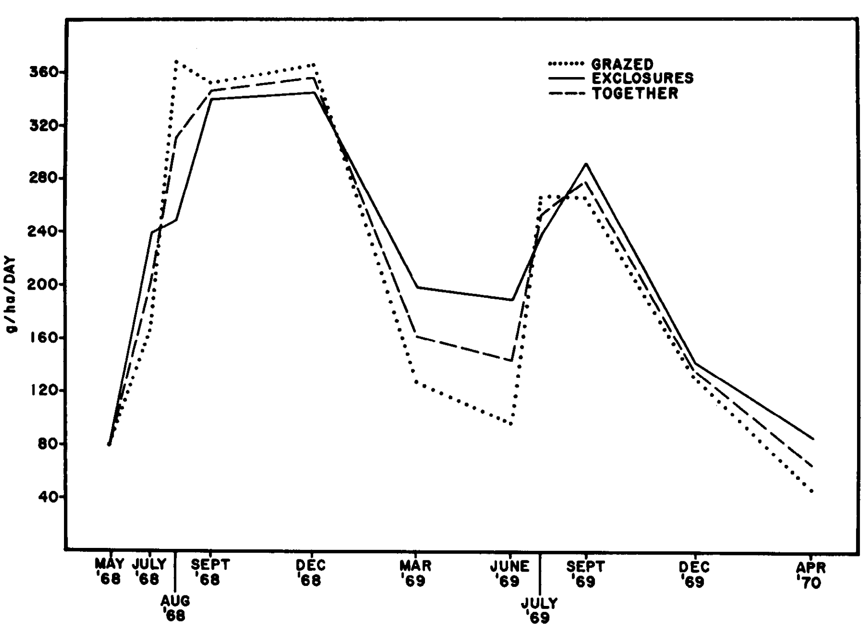

FIG. 2. The calculated weight of blacktailed jackrabbit pellets voided per day in northeastern Colorado native sandhill rangeland for cattle grazed pastures and exclosures to cattle within pastures.

oven dried and weighed. Pellets near the quadrat boundary but on the outside were removed and discarded. All pellets were counted and removed one month prior to the first collection period (May, 1968). The fecal pellets of rabbits were counted and collected eleven times, at about 3 month intervals, from May 1968 until April 1970. Counts of pellets have been used as a method of estimating jackrabbit densities (Taylor et al., 1935; Phillips, 1936; Arnold and Reynolds, 1943).

Results

There was no detectable relationship between jackrabbit pellet production and cattle grazing intensity or soil type, in the study area. When the overall harvest for number and dry weights of jackrabbit pellets was compared for the "paired" cattle grazed and ungrazed sites there was a small but highly significant difference (Figure 1). In August 1968 the mean numbers of pellets produced per day was greater on the grazed (2859/ha/da) than on ungrazed sites (2153/ha/da) but the difference was not statistically significant. For the April 1970 collection there was significantly more jackrabbit pellets being voided on the ungrazed sites (782/ha/da) than on the grazed sites (365/ha/da).

The ungrazed sites produced jackrabbit pellets whose mean dry weight was 0.01 g less than those on the grazed sites. However, within any one collection date the difference in the mean weight of a pellet was not statistically different between the grazed and ungrazed sites.

The number of fecal pellets voided and dry weight of pellets voided was significantly less in the summer of 1969 than in 1968 (Table 1 and Fig. 2). The aboveground herbage and plant composition on the study pastures was not significantly different between 1968 and 1969 (unpublished data). The maximum forage availability was in June and the minimum in

April. The maximum jackrabbit defecation rate lags 3 months behind the season of maximum plant biomass but the minimum defecation rate appears to occur with the season for minimum plant biomass.

Table 1. The average dry weight (grams) of rabbit pellets, the calculated dry weight (grams) of rabbit feces voided, and the calculated number of pellets defecated per hectare per day for samples collected from northeastern Colorado 1968–70.

Date of collection	Mean dry weight of pellet	Estimated mean dry weight/ha/da	Estimated mean number of pellets/ha/da
April 15, 1968	0.14		
May 29, 1968	0.11	80	727
July 10, 1968	0.11	203	1819
Aug. 5, 1968	0.12	311	2506
Sept. 9, 1968	0.11	349	3064
Dec. 17, 1968	0.14	359	2582
March 25, 1969	0.16	164	992
June 25, 1969	0.12	145	1189
July 23, 1969	0.10	256	2531
Sept. 3, 1969	0.11	282	2503
Dec. 18, 1969	0.11	139	1220
April 11, 1970	0.12	69	574
Overall mean	0.12	214	1792

Discussion

A technique was developed for estimating the relative abundance of various plants in the diets of leaf-eating herbivores (Sparks and Malechek, 1968; Hansen and Ueckert, 1970). To convert these data to absolute quantities, total daily intake of dry matter is needed. The attempts generally used in estimating dry matter intake by freely grazing time herbivores are: (1) pasture production assessments; (2) consumption—defecation ratios; (3) non-digestible indicators; and (4) fecal nitrogen.

The average daily consumption of range-type forage fed penned blacktailed jackrabbits, expressed as a percentage (dry matter intake/live body weight), was about 6.6% (Arnold, 1942). The average apparent digestion of dry matter for penned blacktailed jackrabbits fed range type forage was 45% (Arnold and Reynolds, 1943). This is about the same average dry matter digestion that is reported for livestock under winter range conditions (Cook and Harris, 1968). The dry matter digestion for livestock fed (summer) growing plants as northeastern Colorado averaged 69% and only 44% when they were fed (winter) quiescent range plants (Wallace and Denham, 1970). I believe the dry matter digestion of native range forage when selected under natural conditions by jackrabbits may be similar to that of livestock.

Directly measured values for digestion of dry matter by jackrabbits are not available from northeastern Colorado but if we assume the jackrabbit values measured in Arizona by Arnold (1942) and Arnold and Reynolds (1943) are approximately correct for northeastern Colorado, the dry weight of forage consumed by jackrabbits can be calculated for the study area.

$$\text{Forage removed} = \frac{\text{dry weight of feces produced}}{1 - \text{digestion index}} \times \text{time}$$

or

$$\text{Forage removed} = \frac{214 \text{ g/ha/da}}{1 - .45} = 389 \text{ g/ha/day}$$

If 389 grams of forage eaten equals 6.6% of the live jackrabbit biomass, and if the jackrabbits averaged 2.1 kg in live weight, there was an average of about 3 jackrabbits per hectare during the study. If we estimate the mean rabbit density for the study area based on 545 ± 42 pellets per jackrabbit per day (Arnold and Reynolds, 1943) there was also about 3 jackrabbits per hectare.

The digestibility of range forage by "adult-sized" jackrabbits appears to affect mean pellet weight (Arnold and Reynolds, 1943). In Arizona, blacktailed jackrabbits whose mean dry matter digestion index was 45% voided pellets whose mean dry weight was 0.12 g (*loc. cit.*). When jackrabbits ate a diet with a dry matter digestion index of 60% their pellets average 0.10 g and when the digestion index was 32% the rabbits lost body weight and voided pellets that averaged 0.14 g (*loc. cit.*). The overall mean weight of jackrabbit pellets in my study was 0.12. In summer when the body size of jackrabbits would average smaller (because of young jackrabbits) than in winter and forage is likely to be more digestible than in winter the pellets tended to be lightest in weight (Table 1). In winter when all jackrabbits on the study area are adult-size and are most likely to be forced to eat low quality dry forage, the mean pellet weight tended to be highest.

The impact of jackrabbits on rangeland can be demonstrated by considering herbage as a source of energy for the production of "carcass meat" (Cook, 1971). A reasonable assumption is that yearling cattle on the study area gain about 1 kg in body weight for each 10 kg of herbage consumed. Practically all plants eaten by jackrabbits are consumed by cattle when they are available to cattle. Let us assume that each 10 kg of herbage eaten by jackrabbits is worth a kg of beef. If beef is worth about 66 cents per kg the value is about \$9.35 per hectare per year (about \$3.70/acre/year). There are about 2×10^6 acres of range classified as "deep sand" and "sandy plains" in eastern Colorado. Therefore, the loss of forage to jackrabbits might have been worth 7.4 million dollars for the years 1968–1970 had yearling steers been used to harvest the forage instead of jackrabbits. The value that jackrabbits contribute to esthetics and hunting recreation should be subtracted to obtain a net value of the jackrabbits' worth to Colorado.

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Evaluating Animal Forage Preference[1]

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Highlight

Four relative preference indices were used to rank sheep preference for twelve plant species in a tall-forb community of a summer range in southwestern Montana. Ranking of preference values for the plant species was different by all four indices. Frequency measurements of plant species both in the diet and on the range were found useful in interpreting forage preference. Diet frequency values measure consistency of intake while range frequency values measure plant distribution within a community. These values when incorporated into a relative preference index increase its sensitivity, but do not substitute for measurements of diet composition or forage availability on the rangeland studied.

Numerous factors influence preference of grazing animals for individual plant species. Preference for any plant varies according to season of use, ecotypic differences, animal function, changes in plant community structure, and many other plant and animal modifiers. While the interactions of these preference modifying factors are important in determining which plant species a grazing animal will consume, most of them are not suitable for inclusion as part of a relative preference index. Interpretation of preference index values should integrate numerical values with other influential factors not incorporated into the index. Absolute preference index values for a particular plant species may indicate whether that plant is preferred or rejected, but the primary value of preference indices is to rank various plants with regard to their palatability under a specified set of circumstances.

Bartlett (1958) rated palatability by the difference between utilization of a plant and average utilization of all plants on the range. Recognizing the influence of availability on forage preference, he computed the palatability index for high, medium, and low availability classes, which were examined independently. Van Dyne and Heady (1965) developed a relative preference index (RPI) which allowed all availability classes to be considered simultaneously. Their index was a ratio of the percent of a plant in the diet to the percent availability of the plant. Chamrad and Box (1968) modified Van Dyne and Heady's index to include frequency of occurrence of a plant in the diet.

Diet frequency measurements can be important in determining relative preference of animals for specific plants because the index then includes not only the quantity of a plant the animals eat but also the consistency with which they select the plant. However, consistency of selection may be influenced by plant distribution, i.e., uniformly distributed plants might be more frequent in the diet than plants with irregular distribution. Allowance can be made for this by using frequency of the plant on the

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Table 1. Average RPI and relationship of frequency components for twelve plants studied.

Species	RPI_1[1]	RPI_2[2]	RPI_3[3]	RPI_4[4]	% frequency in diet / % frequency on range
Thickleaf groundsel (*Senecio crassulus*)	47.85	6.08	5.93	48.12	2.79
Spike trisetum (*Trisetum spicatum*)	12.71	11.50	7.45	20.16	.96
Mountain sorrel (*Rumex paucifolius*)	10.90	3.24	3.07	11.41	3.00
Yampa (*Perideridia gairdneri*)	8.39	3.46	1.68	17.21	1.36
Alpine leafybract aster (*Aster foliaceus*)	4.42	3.13	3.13	4.42	1.39
Mountain brome (*Bromus marginatus*)	3.93	3.66	3.66	3.93	1.07
Pale agoseris (*Agoseris glauca*)	3.46	2.53	2.13	4.14	1.33
Alpine timothy (*Phleum alpinum*)	2.74	2.30	2.15	2.92	1.21
Western valerian (*Valeriana occidentalis*)	1.95	1.51	1.11	2.70	1.10
Northwest cinquefoil (*Potentilla gracilis*)	1.29	1.39	1.25	1.34	.94
Mountain knotweed (*Polygonum montanum*)	.57	.78	.57	.78	.65
Sticky geranium (*Geranium viscossisimum*)	.006	.012	.006	.012	.51

[1] $RPI_1 = \dfrac{\%\text{ diet frequency} \times \%\text{ diet composition}}{\%\text{ range frequency} \times \%\text{ range composition}}$

[2] $RPI_2 = \dfrac{\%\text{ diet composition}}{\%\text{ range composition}}$

[3] $RPI_3 = \dfrac{\%\text{ diet frequency} \times \%\text{ diet composition}}{\%\text{ range composition} \times 100}$

[4] $RPI_4 = \dfrac{\%\text{ diet composition} \times 100}{\%\text{ range frequency} \times \%\text{ range composition}}$

range as a part of the availability factor.

Methods

The study was conducted on the U.S. Sheep Experiment Station[2] summer range in southwestern Montana within a tall-forb vegetation type. Two esophageally fistulated sheep per pasture were grazed in two separate 0.5 acre pastures. The fistulated sheep were used to collect forage samples for approximately one hour shortly after sunrise for five days during the early summer of 1968.

The fistula samples were analyzed by the microscopic point method under 15× magnification (Van Dyne and Heady, 1965). Plants that could not be identified at this low power were mounted on slides with Hoyer's solution and identified with a compound microscope at 125× magnification (Ward, 1970). One hundred points were examined for each sample to yield percent diet composition. The fistula collection from each sheep on each day was considered as one sample. Frequency in the diet for each plant species was determined as the percent of samples in which the species occurred.

Plant species within 30 4.8 ft² plots per pasture were clipped and weighed to give an estimate of the available green weight production. The weight of each plant species present in each pasture was divided by the total weight of forage produced in the pasture to yield percent range composition. Percent frequency on the range was computed for each plant species as the percentage of plots in which the species occurred.

Relative preferences for 12 plant species representative of varying levels of dietary composition were determined with four different indices.

$$RPI_1 = \frac{fd \times D}{fr \times R}$$

$$RPI_2 = \frac{D}{R}$$

$$RPI_3 = \frac{fd \times D}{R \times 100}$$

$$RPI_4 = \frac{D \times 100}{fr \times R}$$

where:

fd = % frequency in diet
D = % diet composition
fr = % frequency on range
R = % range composition

All of the relative preference indices included the ratio of percent diet composition to percent range composition for each plant species. RPI_1 included, in addition, the ratio of frequency in the diet to frequency on the range. No frequency measurements were used in RPI_2. Both RPI_3 and RPI_4 included only one measure of frequency. RPI_3 was a ratio of diet composition to range composition modified by frequency of the plant species in the diet, thus it accounted for the effects of consistency of selection but not for effects of plant species distribution within the community. RPI_4 included the ratio of diet composition to range composition modified by percent frequency on the range so it accounted for effects of plant species distribution but not consistency of selection. RPI_3 and RPI_4 both included constants in order to

[2] Cooperation by the Intermountain Forest and Range Experiment Station of the Forest Service, the Animal Husbandry Research Division of the Agricultural Research Service, U.S. Department of Agriculture, and the Idaho Agricultural Experiment Station is acknowledged.

maintain the computed values of all four indices in the same order of magnitude.

The relative preference index values were computed for each sheep each day. Preference rankings for the plants were determined from overall average values. Each index was correlated with RPI_1 to determine the linear relationship.

Results

The sheep in this study showed varying degrees of preference for different species of plants. Thickleaf groundsel (*Senecio crassulus*) was most preferred, according to RPI_1 and RPI_4 but not according to RPI_2 or RPI_3. Sticky geranium (*Geranium viscossisimum*) was least preferred of the twelve plants used to evaluate the different indices (Table 1). All plants except mountain knotweed (*Polygonum montanum*) and sticky geranium were preferred species, i.e., $RPI > 1.0$. This was probably a result of high production of unpalatable geranium which made up 46% of the total production.

RPI_4 more closely approximated RPI_1 than the other indices. It showed a high correlation to RPI_1 ($r = .97$). RPI_2 and RPI_3 were similar to each other but greatly different from RPI_1. The correlation of RPI_3 with RPI_1 was low ($r = .69$) and RPI_2 showed an even lower correlation with RPI_1 ($r = .51$).

The relative ranking of animal preference for the twelve plants was different for all indices. RPI_2 showed 50% agreement with RPI_1. RPI_3 agreed with RPI_1 for 42% of the plants, and RPI_4 ranked 67% of the plants in the same order as RPI_1.

Discussion

The primary benefit received from calculating relative preference indices is comparison of preference by animals for forage plants. Comparison of animal preference for different plant species is more meaningful if every plant has the same value when selection by animals is completely random. The index proposed by Van Dyne and Heady incorporating only diet and availability (range composition) and an index using frequency measurements for both diet and availability in conjunction with these factors meet this criterion. Indices using diet composition and range composition in combination with either frequency measurements of occurrence in the diet or occurrence on the range but not both, do not meet this criterion. For these indices, the value at completely random selection would vary for each plant species according to the frequency measurement used.

Table 2. Hypothetical plant community and expected diets for completely random animal selection. Species A is irregularly distributed and species B is uniformly distributed.

Plant species	Diet composition (%)	Frequency in diet (%)	Range composition (%)	Frequency on range (%)
A	50	20	50	20
B	50	100	50	100

In order to illustrate the relationship of plant frequency on the range to the four relative preference indices examined, a hypothetical plant community was developed (Table 2). Plant species A comprised 50% of the total vegetation and was irregularly distributed. Species B also comprised 50% of the vegetation present and was uniformly distributed. If animals grazed this community and forage selection was completely random, the diet composition and frequency values would be equal to the range composition and frequency values for each plant species. Using the information from this hypothetical situation, the four relative preference indices were computed for both plant species (Table 3). Indices using neither or both frequency values had a base value at random selection of 1.00 for both plant species. When the index incorporating frequency in the diet but not frequency on the range was used and the plants had an irregular distribution, the index base value at random selection was low. The index value would approach and then equal the value for indices with uniform range frequency at completely random selection (1.00) as diet frequency approaches and then equals 100%. Conversely, when the index incorporating frequency on the range but not frequency in the diet was used, the base value at random

Table 3. Relative preference indices for an irregularly distributed plant (species A) and a uniformly distributed plant (species B) when animal selection is completely random.

Plant species	RPI_1[1]	RPI_2[2]	RPI_3[3]	RPI_4[4]
A	1.00	1.00	.20	5.00
B	1.00	1.00	1.00	1.00

[1] $RPI_1 = \dfrac{\%\text{ diet frequency} \times \%\text{ diet composition}}{\%\text{ range frequency} \times \%\text{ range composition}}$

[2] $RPI_2 = \dfrac{\%\text{ diet composition}}{\%\text{ range composition}}$

[3] $RPI_3 = \dfrac{\%\text{ diet frequency} \times \%\text{ diet composition}}{\%\text{ range composition} \times 100}$

[4] $RPI_4 = \dfrac{\%\text{ diet composition} \times 100}{\%\text{ range frequency} \times \%\text{ range composition}}$

selection for scattered plants was high. This index value would decrease to the value for the plants with uniform distribution (1.00) as range frequency increases to 100%.

Frequency measurements can be useful in determining relative preference of sheep. Since consistency of selection and distribution of plants are related to animal preference, an index incorporating both of these factors (RPI_1) is more sensitive in ranking preference values compared to indices lacking one or both of these factors. It was decided RPI_1 was the most useful index because it has the same value for all plant species when selection is completely random (1.00); it provides a wider spread of values than the indices not incorporating range frequency, so preference differences are more obvious; and it considers more factors related to preference than the other indices.

Frequency measurements are dependent on plot size. As the size of a plot increases the frequency of occurrence of a plant species would be expected to increase. If plot sizes are equal, comparison of frequency values is straight forward. If plot sizes are unequal, comparison of frequency values becomes more complex. To facilitate the use of range frequency data a plot size should be selected that provides a fairly wide range in values so differences in distribution of various plant species can be identified. In this study percent frequency on the range of the twelve plant species studied ranged from 22 to 100%.

Diet frequency values are a measure of consistency of selection. These values are primarily dependent on distribution of the various plant species on the range and animal preference. While a sheep is grazing it will more frequently encounter the plants with more uniform distribution and less frequently encounter plants with an irregular distribution. So, if precent frequency on the range is 20% for a particular plant species a sheep would find and be able to graze that plant one-fifth as often as a plant with 100% range frequency. Consequently, the range in values for percent frequency in the diet would be expected to be modified by percent frequency of species within a plant community and according to the relative palatability of the various plant species. Length of time spent grazing can also influence the frequency of a plant species in the diet. Enough time should be allowed so the fistulated animals can adequately cover the area to be sampled, but short enough so frequency differences can be identified. The number of microscopic points examined per sample will also influence the diet frequency value. As more points are examined the possibility of recording a very sparse plant in the sample increases. This influence can be minimized by setting a lower limit on values to be included in the frequency calculation, e.g., any plant making up less than 1% of the composition could be recorded as absent in determining frequency in the diet. In this study the range of diet frequency values was 30 to 100%, with most of the values above 60%.

In theory, the ratio of percent frequency of a plant in the diet and percent frequency on the range should give some insight into the animal's preference for the plant. If the ratio is less than one it would indicate the animal rejected the plant when it was encountered on the range. If the value is very close to one it would indicate the animal consumed some of the plant whenever the animal discovered its presence. If the ratio is greater than one it would indicate the animal was actively seeking the plant and thus enhancing the possibility of grazing preferred vegetation.

Because of the dependency of frequency measurements on plot size and time spent grazing, it is difficult to interpret the ratio of diet and range frequency from field data. However, if it is assumed that the proper plot size was selected and frequency measurements of the range and diet are satisfactory, then comparisons of the two different frequency measurements can be considered. In this study the ratio of the frequency measurements tended to decline as preference for the different plants declined (Table 1). Plants that were highly preferred had a high ratio and plants that were rejected had a ratio value much less than one.

Spike trisetum (*Trisetum spicatum*) was evaluated as highly preferred by all of the relative preference indices used, yet, the ratio of frequency measurements was almost one. Based on the frequency ratios for other plant species, the value for spike trisetum indicated it should have been of low to moderate palatability. But, as previously indicated, preference is not based on frequency of selection and distribution alone. The amount of the plant consumed in relation to the amount available must also be considered. In the case of spike trisetum, frequency measurements added little to preference evaluation. The animals apparently did not seek it out but did consume a large proportion of the plant when it was encountered. Thus, it appeared that animal preference for different plant species was related to composition of intake and availability as well as frequency of intake and plant distribution.

The four preference indices were computed for twelve representative plant species and then compared with RPI_1 which was accepted as the standard evaluation. The index that did not incorporate any frequency measurements (RPI_2) did have a constant value for all plant species when selection was completely random (Table 3) but did not have as wide a spread of index values as RPI_1 (Table 1) and did not consider the effects of plant distribution or consistency of intake. This index had the lowest correlation with RPI_1 and ranked the plant species in the same order as RPI_1 only 50% of the time. Because of the low level of agreement of these two indices and difference in sensitivity RPI_2 was considered to be less useful.

The index incorporating diet frequency but not range frequency (RPI_3) did not have a constant value when selection was completely random, it did not have as wide a spread of index values as RPI_1, and did not consider the effects of plant distribution. This index ranked the preference values the same as RPI_1 least frequently of the indices studied and showed a low correlation with RPI_1. When ranking preference values for unpalatable plants, RPI_3 values were the same as those of RPI_1, but in these cases range frequency equaled 100%, so mathematically the indices were identical. It appeared the addition of diet frequency measurements alone added very little to the usefulness of the index.

The index using range frequency measurements but not diet frequency did not have a constant value when selection was completely random, it did provide as wide a spread of index values as RPI_1, but did not consider the effects of consistency of intake. This index (RPI_4) agreed most frequently with RPI_1 in ranking preference values for plants and had a high correlation with RPI_1. The preference index values for RPI_4 and RPI_1 were very similar. RPI_4 tended to rate plants higher as in the model (Table 3) and agreed with RPI_1 when diet frequency equaled 100%. If diet frequency measurements cannot be obtained, as in determining diet from utilization and production estimates, RPI_4 can be a satisfactory substitute for RPI_1 on this range.

Summary and Conclusions

Four different relative preference indices were compared and the contribution of frequency measurements was evaluated. The preference indices incorporating both frequency of occurrence in the diet and on the range or neither frequency measurement had the same base value for all plants when selection was completely random, while preference indices using either diet or range frequency, but not both, did not have a common base value. The index that included diet and range composition and diet and range frequency not only had a common base value at random selection but also more clearly showed preference differences than indices not using range frequency and considered more factors related to preference than the other indices, so it was considered to be the most useful of the four relative preference indices studied.

While frequency ratios do provide added information concerning animal preference for most plants, they are not a satisfactory substitute for composition measurements of the diet and available forage. For some plant species frequency measurements would not be expected to modify preference values and for other plant species frequency measurements may raise or lower preference values, as determined from composition ratios.

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THE BENEFICENCE OF PROMPTNESS

In spite of constantly rising operating costs, as well as an expanded program, the Society for Range Management has been able to hold the line on membership dues for the last five years. Whether or not we are able to maintain the present modest dues schedule will depend largely on two things: (1) on-time dues payments, and (2) a continued increase in membership.

Concerning the first, everyone is probably aware that dues are on a calendar year basis and, in accordance with the bylaws, are payable on or before January 1 of each year —in other words, dues for 1973 should be remitted by this coming first day of January. In the past only about 55%–60% of the membership has renewed by the specified time and, consequently, it has been necessary to send out second notices, perform additional clerical work, and frequently engage in some fancy footwork with the budget for the coming year (which is not a particularly desirable activity). Since SRM's income—mostly from membership dues—is seasonal while expenses are fairly constant throughout the year, it is most important to have operating money in hand before a firm program can be established. Thus, payment of dues on or before January 1 can be of significant help in achieving a steady state with regard to Society activities—fewer contingencies, less stop-and-go in getting things done, and less likelihood of some future dues increase.

On-time dues payments are, therefore, of great benefit not only to SRM as an organization but to *you*, the individual member.

Between July 31, 1971, and July 31, 1972, SRM registered a 10% increase in total membership and we should work diligently for similar increases in the years immediately ahead. Membership applications are available from time to time in *Rangeman's News*, from the Executive Secretary's office, or from your Section membership chairman. There are literally thousands of people who would benefit from SRM membership; each present member should bring in at least one.

Incidentally, the number of people who have elected to provide additional support to the Society by becoming an Individual Sustaining member has roughly *doubled* each year since 1969. Won't you please consider adding your name to this list for 1973?

Computer Processing of Chart Quadrat Maps and Their Use in Plant Demographic Studies

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Highlight

Chart quadrat maps offer a unique source of data on long-term trends in grasslands. Through the use of film scanning computer systems, this information can be more easily processed and used in plant demographic studies.

There is a large and varied assemblage of data that has been collected over the years on the semiarid grasslands—information that can be valuable in studying today's important natural resource management problems. To a large extent, however, much of this information has not been sufficiently utilized because of the time involved in the effort. One such source of data of this type is that available from chart quadrat mappings.

Background

A chart quadrat usually consists of a 1 m² field plot in which the basal cover of the vegetation is mapped by species over time, usually at yearly intervals. The quadrats are normally read utilizing a pantograph; and, since the plots are permanently marked, they can be relocated accurately and reread year after year. The data obtained are in essence maps of what has happened to the vegetation on a given piece of ground over time. These maps are usually drawn on a standard 8 × 8 inch form.

Because of the long time span often covered by the readings and the abundance of the records, such maps represent a valuable source of data which can be used to examine, for example, long-term plant demographic processes in response to climatic changes over time.

This paper presents a method which enables one to more easily quantify and use the information on chart quadrat maps and some examples of how these data can be used in plant demographic work.

Methods

The quadrat maps used were collected on the Journada Experimental Range, a semidesert grassland located near Las Cruces, New Mexico. The records were obtained and collated through the help and courtesy of Dr. Carlton Herbel. Chart quadrats were originally established on the Jornada range in 1915 and have been mapped each year since with the exception of a few years during the period of 1954 through 1967. The last charting was in August 1968 by the author and personnel from Colorado State and New Mexico State Universities.

There are about 90 quadrats on the Jornada Experimental Range that can be classified as long-term (greater than 30 years) and a slightly greater number that were established for short-term studies (5 to 30 years). All have been coded in the method described herein. Forty of the long-term quadrats have been used in the work on plant demography discussed here. Reviews of these data are included in Herbel, Dittberner, and Bickle (1970), Nelson (1934), and Paulsen and Ares (1962).

The first step in processing the data was to retrace all of the original field forms emphasizing in solid color the basal areas of the individual plants. All other pertinent information on the original forms, e.g., presence of stolons and partially or totally dead areas, was recorded and punched onto a card deck. This helped to eliminate much of the "noise" and artifacts which appeared on the original data and gave a clear contrasting figure. The tracings were then photographed serially on high-contrast 35 mm film for use as an input to a scanning device in step two.

Siegel (1967) and Harmon and Knowlton (1969) have discussed the use of film images in this form as input to one of several types of cathode-ray-tube scanning devices. The instrument in use in this study is a flying-spot scanner and is located at Argonne National Laboratory. A complete review of this system is available in Butler et al. (1964, 1966, 1967, 1968).

Briefly, there are two main components of the scanning system: a digital computer and a cathode-ray-tube optical scanner. The system operates by horizontally scanning each frame of film from bottom to top in a specified grid pattern through a point of light projected onto the film by the cathode-ray-tube and picked up by a photomultiplier. When this photomultiplier detects a change in the intensity of the transmitted light from one point on the frame to the next, the x,y grid coordinates of this point are recorded on magnetic tape. This intensity change process occurs when either edge of a charted plant is encountered. The effect is that only the coordinates of the perimeters of each plant are recorded on tape. The time required to scan each frame of film varies directly with the amount of information the number of plants contained, but in general takes about 4 seconds.

The magnetic tape is then transferred to a Control Data Corp. computer (CDC-3600) where a program reconstructs the shape and position of each plant and calculates several measures described below that are descriptive of the shape and area of each plant.

The computer output is in the form of: (i) magnetic tape containing complete information on each plant per year per quadrat, (ii)

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Table 1. Mean life-spans (years), standard deviations (s) and number of occurrences (n) for principal perennial grasses on the Jornada Experimental Range. Table also contains the mean life-span as a percent of maximum longevity attained in the data and the mean life-span of those plants living more than one year as a percent of maximum attained.

Species	Mean life-span	s	n	Mean as % of maximum life-span	Mean of those living at least one year as a % of maximum
Black grama (*Bouteloua gracilis*)	2.2	2.4	6528	8	14
Red three-awn (*Aristida longiseta*)	1.9	1.7	355	21	40
Mesa dropseed (*Sporobolus flexuosus*)	1.7	1.4	1509	9	18
Poverty three-awn (*Aristida divaricata*)	1.8	1.5	380	19	33
Ear muhly (*Muhlenbergia arenacea*)	1.8	1.3	932	20	31
Burro grass (*Scleropogon brevifolius*)	1.8	1.5	1274	15	25
Tobosa grass (*Hilaria mutica*)	2.0	1.5	112	29	44

print listing all plants plotted per year with similar information, and (iii) microfilm picturing the chart quadrat map as perceived by the scanner.

In the third and final step, the tape output is converted to punched cards for easier manipulation. Each card represents all the information calculated for a given plant in a particular year and includes: the basal area occupied by the plant (converted to cm^2), the location coordinates of the plant on the quadrat, and six statistical moments descriptive of the shape of the plant. The scanning system cannot descriminate between species in the usual sense. If each species had a characteristic basal area growth form that is unique, then this would be possible. Lastly, information on the presence or absence of stolons and dead or partially dead areas is added into the set.

Data from the Jornada range have already undergone extensive preliminary analyses (Wright and Van Dyne, 1970). The vegetative cover on the Jornada Experimental Range is less than 5%, normally occurring as bunchgrasses and small areas of sod. This fact aids in ease of scanning discrimination. The system, however, should work well for areas of up to 60% discontinuous cover. In the computer program governing the scanner, there is a direct relation between the size of the smallest plant detectable and the smallest detectable distance between two separate plants. In practice, however, this has caused no problem.

Demographic Analyses

The area of study that might be defined as plant demography, the statistical study of plant populations, has been an often neglected part of plant ecology. This is principally because of the plasticity in size and reproductive capacity inherent in plants, the difficulty in isolating the individual in the population, vegetative reproduction, and factors in plant distribution (Harper, 1960, 1967). Since individuals in the population are fixed in position and these positions are rarely at random, more commonly more or less clumped, the population size is difficult to determine.

The regular charting of individual plants in permanent quadrats has generally been the best way of looking at the population changes for particular systems (Williams, 1968). However, as Williams points out, this technique is fraught with difficulty. Crucial events may occur so infrequently as to be missed in the course of the experiment, and the need for the maintenance of long-term plots contributed to the near absence of studies on plant community population changes. The result is that the question of plant longevity is often answered with little more precision than an estimate of eternity to a few years.

Plant longevity was investigated on the Jornada quadrat data using a computer program which uses the coordinate position of each plant and searches the yearly records in a serial manner for a given quadrat. Using this approach, reliable estimates of the life-spans or more accurately the spans of existence for the major perennial grasses on the Jornada have been obtained. The mean life-spans for the eight most important species over all grazing and soil treatments are shown in Table 1. Statistical analysis has shown that soil type and grazing intensity did not have a significant effect on the plant life-spans in this data (Wright, unpublished).

Robbins (1957) has discussed the difficulties with respect to the physiological aging in plants. It is probably not unreasonable to conclude that all plants have a physiological maximum life-span which is invariant across all ranges. The mean life-span of a species is probably not fixed, but differs from the physiological maximum in response to a multitude of environmental factors. The proximity of the two measures depends in part on the success of a given species in "learning" how to cope with environmental fluctuations in order to stretch its mean life-span toward the maximum.

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Table 2. Survival probabilities for black grama on one grazing and soil treatment of the Jornada Experimental Range. Each entry represents the proportion of plants surviving from year 1 to 8 between years i and i + 1. Table shows only first eight years of age as an example of the many possible years.

Date	Years of age							
	1	2	3	4	5	6	7	8
1915	.379	.583	.571	.750	1.000	1.000	.500	1.000
1916	.125	.455	.429	.500	.667	1.000	.500	1.000
*	*	*	*	*	*	*	*	*
1966	.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1967	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
1968	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* Data for the years 1917 to 1965 inclusive is available but is not included in this example.

southern New Mexico, the values listed in Table 1 give a good representation of the true mean physiological life-span of these grasses over the period of study. Table 1 also lists these means as a percent of the physiological maximum life-span of the respective species. (The maximum life-span is that achieved by at least one plant over the period of study.) The longest lived plant on any of the quadrats analyzed was one black grama clump which persisted for 27 years. Several black grama clumps persisted for 20 years. Likewise, while the longest lived mesa dropseed plant persisted for 18 years, several survived for up to 12 years. For all other species listed the maximum calculated life-span was not only much shorter but only rarely approached. These findings coincide directly with the amount of data available on each species (note the values for n). It appears that the more data that are available, the more chance there is of finding those few long-lived plants. The amount of data available does not, however, seem to alter the mean life-spans. To illustrate the effect of environmental adaptation, the means of those plants living at least one year as a percentage of the maximum are also shown. The percentages are in many cases almost double those calculated from establishment and only point out the lower survival probabilities between the first and second age classes.

The coded quadrat data also provide an exciting avenue for examining the dynamics of the demographic changes. Dittberner (1971) recently used these coded data in computing life tables for the same species. One method of treating the dynamics of change is to look at the age specific survival rates for a given species for each year. Table 2 shows an example of this type of data. Studies are now being conducted which are attempting to adjust survival matrices of this type by the population-age specific survival rates as derived from life tables and then to relate the adjusted values to climatic changes. Thus far, the results from this endeavor look promising.

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Winterfat Seeds Undergo After-Ripening[1]

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Highlight

Seed characteristics of winterfat are being investigated because this shrub species has value in revegetation. Seeds collected 4 consecutive years in New Mexico were tested for viability at 1- to 4-week intervals after collection. After-ripening was completed within 10 weeks for all except one collection, which required 25 weeks. Variation in the after-ripening process among years probably resulted from differences in environmental conditions during seed formation. Seed technologists and others working with winterfat need to be aware of the after-ripening requirement.

Due to increasing interest in winterfat (*Eurotia lanata* (Pursh) Moq.) as a desirable shrub for revegetation, we need to know more about its seed characteristics. After-ripening has been suspected because of erratic germination of freshly collected seeds in previous studies (Springfield, 1968a). Some collections of seeds germinated slowly and incompletely, whereas others germinated rapidly and completely, under the same moisture and temperature regimes.

After-ripening has been defined as any changes in seeds during storage that improve germination, or as ". . . those processes that must occur in the embryo, can occur only with time, and cannot be caused by any known means other than suitable storage" (Mayer and Poljakoff-Mayber, 1963). In many species, germination is prevented by blocking mechanisms, and the seed remains in a resting or "blocked dormant" state until changes (after-ripening) remove the blocks (Pollock and Toole, 1961). According to Koller et al. (1962), post-harvest dormancy of seed is wide-spread and complex; the loss of dormancy (after-ripening) manifests itself as a gradual relaxation in strictness of requirements for germination. Evenari (1965) mentioned inhibitory substances and physiological or morphological immaturity as possible reasons for embryo dormancy at dispersal time.

Studies were initiated in 1967 to determine if winterfat seeds undergo after-ripening.

Methods

Seeds were collected in late October or early November of 1967, 1968, 1969, and 1970, from a group of about thirty representative plants within an experimental site 15 miles west of Corona, New Mexico. Elevation of the site is 6300 feet, annual precipitation 15 inches, and the soil is a sandy loam. Principal associated species are one-seed juniper (*Juniperus monosperma*) and blue grama (*Bouteloua gracilis*). Date of collection depended on when the cottony fruits began to shatter and fall to the ground. Only fruits that offered no resistance to removal from the plant were gathered. After collection, the fruits were put in paper bags and stored in a refrigerator at 36 to 44 F (Springfield, 1968c).

Germination tests were started at 1- to 4-week intervals after each seed collection. At the start of each test, seeds were threshed from the fruits by hand. Fifty seeds were placed on germination blotters in petri dishes which contained 100 ml of vermiculite and 60 ml of distilled water. The blotters remained moist throughout the test. Treatments were replicated 4 times. The 1967 seeds were tested at constant temperatures of 44 and 56 F without light in modified refrigerators. In subsequent years, seeds were germinated only at 56 F, which was expected to be near-optimum (Springfield, 1968b). Seedlings were counted at 1- or 2-day intervals. Seeds were considered germinated when seedlings measured ½ inch long, and both the cotyledons and radicle were detached from the seed coat.

Results and Discussion

After-ripening of the 1967 seeds apparently was not complete until 25 weeks after collection (Table 1). Seeds tested 13 weeks after harvest germinated 92% in 30 days at 56 F, while those tested 25 weeks after harvest germinated 98% in 10 days. Germination generally improved from week to week regardless of temperature, indicating changes in the physiological makeup of the stored seeds. Somewhat unexpected were the 30-day germination percentages for seeds tested at 44 F; for the first 9 weeks after collection, more seeds germinated in 30 days at 44 than at 56 F. The moist, cold conditions may have stimulated biochemical processes involved in after-ripening.

Seeds collected in 1968, 1969, 1970

Table 1. Germination (%) of winterfat seeds collected 11/1/67 and germinated at 1- to 4-week intervals at 44 and 56 F.

Age of seeds (weeks from collection date)	44 F germ temp			56 F germ temp		
	10 days	20 days	30 days	10 days	20 days	30 days
1	2	4	18	8	14	21
3	6	35	67	20	36	49
6	8	46	72	32	50	60
9	24	66	82	47	65	74
13	43	73	83	82	88	92
17	75	86	88	81	85	90
21	87	91	97	82	94	97
25	81	92	96	98	99	99

[1] Received for publication March 23, 1972.

[2] Forest Service, U.S. Department of Agriculture, with central headquarters maintained at Fort Collins in cooperation with Colorado State University; author is located at Albuquerque in cooperation with the University of New Mexico.

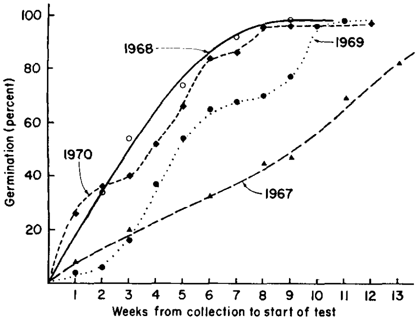

FIG. 1. After-ripening curves for winterfat seeds collected four consecutive years near Corona, New Mexico.

completed after-ripening within a relatively short time, compared with the 1967 seeds (Fig. 1). After-ripening of the 1968 and 1970 seeds was essentially complete 9 weeks after collection. Ten-day germination percentages were used in the last three years, mainly because winterfat seeds germinate promptly once they have finished after-ripening. After 6 months storage under refrigeration or at room temperatures, all viable seeds will germinate within 5 days at 59 F and within 7 days at 50 F (Springfield, 1972).

Variations in the after-ripening process among the winterfat seeds collected in different years are notable. These variations probably were due to differences in environmental conditions during the time of seed formation and maturation. Evenari (1965) claims the influence of the environment on the parent plant during the ripening of seeds is very pronounced, and determines to a great extent their germination behavior. Recent investigations in Canada with freshly collected green foxtail seeds from different locations indicated that degree of dormancy was not a fixed characteristic of each ecological strain, but was due mainly to differences in local weather conditions prior to collection time (Vanden Born, 1971).

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An Experiment in Deer Detection by Thermal Scanning[1]

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Highlight

An airborne, thermal infrared scanner was tested for deer detection over penned mule deer (*Odocoileus hemionus hemionus*) near Fort Collins, Colorado. The animals were detected at 300- and 500-ft altitudes, but not at 1,000 ft.

[1] Received for publication June 3, 1972.

[2] Forest Service, U.S. Department of Agriculture, with central headquarters maintained at Fort Collins in cooperation with Colorado State University.

Although the theoretical potential of airborne thermal scanning in big game censusing has been speculated by numerous authors (Zanon, 1964; Bartholomew and Hoffer, 1966; Cain, 1966), no published results of field trials have been found since 1968 (Croon et al., 1968).

Personnel of the Rocky Mountain Forest and Range Experiment Station, in cooperation with the Colorado Division of Game, Fish and Parks, have been studying the basic principles that underlie the technique since 1969. This report describes the results of our first attempt at deer detection by aerial thermal scanning.

Methods and Equipment

The thermal imagery was obtained during a flight on August 20, 1971, before sunrise, between 4:00 and 4:30 AM, MST. The wind was calm, air temperature was 56 F (13.3 C), and humidity was near 100%. The imagery was produced by a Bendix model 7M/LN-2-LW thermal infrared scanner,[3] mounted in an Aerocommander 500B owned by Colorado State University. Operating characteristics of the scanner, as quoted by the manufacturer, were: instantaneous angular field of view, 2.5 milliradians; total angular field of view, 120°; detector, HCT (mercury-cadmium-telluride); thermal resolution, 0.2 C; wavelength response, 0.8 to 13.0 micrometers; and data output mode, continuous 70 mm film strip.

The target area for the test was a complex of six animal holding pens at the foothills campus of Colorado State University west of Fort Collins. The pens were used to retain mule deer and other animals for various kinds of research. At the time of the flight, the pens contained 55 adult mule deer and 11 adult pronghorn antelope

[3] Trade names are mentioned for the benefit of the reader only, and do not constitute endorsement or preferential treatment by the U.S. Department of Agriculture.

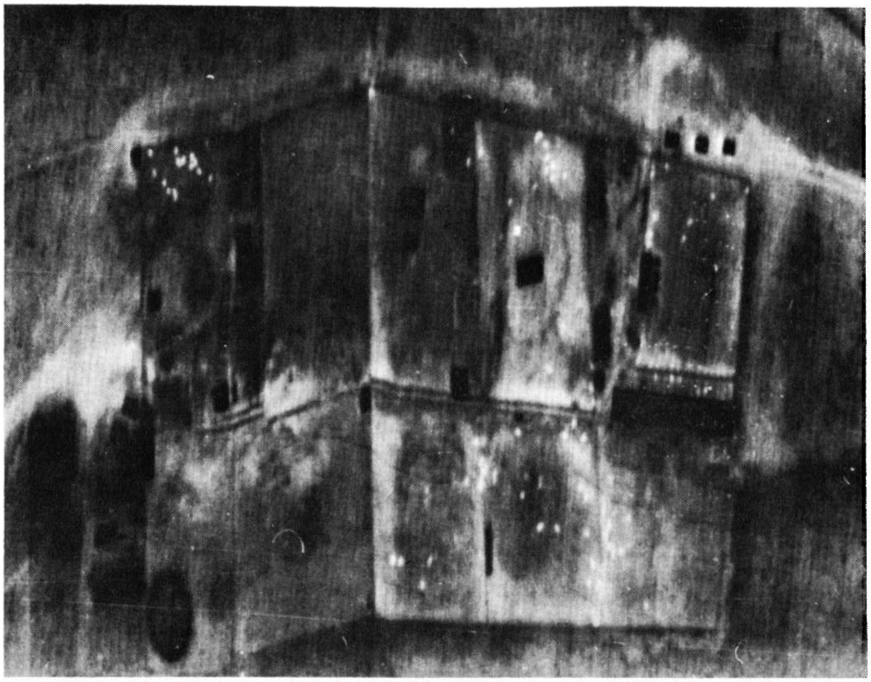

FIG. 1. Photograph of the original imagery at 500-ft altitude.

(*Antilocapra americana*). During the flight, surface radiant temperatures of the animals and of the ground surface in the pens were sampled with a Barnes PRT-5 infrared radiometer. Three north-south passes were made at altitudes of 300, 500, and 1,000 ft above the ground.

Results

The deer radiant temperatures varied from 21.0 to 26.0 C over the 12 readings taken, with a mean of 23.4 C. The five pronghorn measurements varied from 19.0 to 23.0 C and averaged 21.0 C. The three pen measurements were the most uniform, all 15.0 C.

The imagery obtained at the 500-ft altitude is reproduced in Figure 1. Although considerable quality was lost in reproduction, the animals can be seen as white spots. They were similarly imaged at 300 ft. At 1,000 ft, however, the animals were indistinguishable.

Interpretation of the imagery by three interpreters unfamiliar with the imagery, and having no knowledge of the number of animals present, resulted in counts as shown in Table 1.

There were no errors of commission (type II error) in total counts by any of the interpreters. However, attempts at species separation increased the error considerably. As shown above, deer were frequently mistaken for antelope.

The criterion for species separation was the shading of the spots. The deer imaged lighter than the antelope because of their higher temperatures and larger size.

Table 1.—Species and total count of animals as interpreted from imagery.

	Deer	Antelope	Total
Animals present in pens	55	11	66
Animals counted			
Interpreter 1			
(Trial 1)			65
(Trial 2)	49	12	61
Interpreter 2			
(Trial 1)	42	23	65
Interpreter 3			
(Trial 1)	47	17	64

Discussion

No final conclusion can be drawn from this experiment in regard to the value of the thermal scanning technique for animal detection; too many variations on the basic method must yet be investigated. However, two comments on operational procedures and equipment requirements can be made as a result of the flight.

The failure of the scanner to detect the animals at the 1,000-ft altitude is believed to be mainly the fault of the system's 2.5 mr spatial resolution. The temperature difference between the individual animals and the background (4.0 C or greater) was great enough to permit detection provided the angular resolution of the scanner was sufficiently small to resolve an object the size of an adult deer or antelope. Although an altitude of 500 ft is probably satisfactory for many deer detection applications, the wider area coverage possible from 1,000 ft is often desirable. Moreover, fluctuation in topographic relief may often require mean altitudes of at least 1,000 ft.

An accessory feature, available on most scanners but not used on this mission, is automatic roll compensation. This unit corrects for aircraft roll, thus reducing lateral distortion in the imagery produced. Even though winds appeared to be calm at takeoff, enough turbulence existed during the flight to cause significant distortion in the imagery, especially at the higher altitudes.

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Measurement of Seed Responses to Environment[1,2]

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Highlight

The objective of this work was to develop a method for evaluating seed responses to field environments. Seeds placed in soil in the field were brought into the laboratory for germination tests under controlled conditions. Hastening of germination, an indicator of seed responses to environment, was determined by subtracting the number of days required for samples placed in soils in the field to reach 50% germination from the days required for air-dry control samples to reach 50% germination. A temperature of 5 C provided a more sensitive test for measuring hastening of germination than 10 or 20 C. Measurements of environment and of seed responses to environment will help explain why seeds sometimes fail to germinate on harsh rangeland sites.

Environmental conditions during the interval from planting to germination may be critical in the establishment of perennial grasses on harsh rangeland sites. Yet, we know little concerning responses of seeds to extreme and fluctuating temperature and moisture conditions during this period. We lack this type of information because suitable methods for measuring these responses have not been available.

This paper describes a method for measuring hastening of germination and discusses how it may be used in evaluating responses of seeds to environment. The method is adapted from the work of Keller and Bleak (1968).

The concept of hastening of germination suggests that planted seeds do not remain quiescent until the time germination can be observed. Instead, it suggests that during periods of favorable environment they carry on numerous biochemical reactions which eventually lead to cell division, cell enlargement, and the protrusion of root and shoot. Thus, hastening of germination is an integrated measure of how far seeds have progressed toward germination.

Materials and Methods

Seeds of Nordan crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) were treated with 20 mg of thiram (tetramethylthiuram disulfide) per g dry weight to inhibit microbiological growth.

In a laboratory test, samples of 100 seeds were placed on two layers of moist seed-germinating blotter paper in petri dishes and incubated at 5, 10, or 20 C in a germinator. The objective was to determine the best temperature for measuring hastening of germination.

In a field study, samples of seeds were enclosed in flat cotton screen bags and placed in moist soil at a depth of 2.5 cm. Seeds were removed periodically from the field, promptly placed on moist blotter paper in petri dishes, and germinated at 5 C. Control samples consisted of seeds from air-dry storage, germinated under the same conditions as seeds from the field. Germinated seeds (both root and shoot visible) were removed from petri dishes and counted daily.

Results and Discussion

In the laboratory test, seed samples reached 50% germination in 18.4, 11.5, and 4.4 days at 5, 10, and 20 C, respectively (Fig. 1). Cumulative percent germination over the range of 10 to 70% increased linearly with time. Visually fitting a line to the points eliminated some of the daily variation in the number of germinated seeds. The slope of the line was only slightly greater at 20 C than at 10 and 5 C.

Cumulative percent germination of individual samples taken from the field on different dates is shown in Figure 2. The average cumulative percent germination for eight control samples is also shown in Figure 2. In this case, the control samples reached 50% germination in 18.1 days. Hastening of germination or days gained was calculated by subtracting days to 50% germination for individual field samples from average days to 50% germination for control samples.

At 5 C, the interval from planting to the beginning of germination in the field often represents hastening of germination values ranging from 0 to 12 days (Fig. 2), but at 20 C these values range from 0 to 3 days. Therefore, germination of seeds at 5 C provides a more sensitive test for detecting small differences among seed samples than 10 or 20 C. However, when experiments include species that germinate poorly at low temperatures, it may be more appropriate to conduct the tests at 10 C.

In fall and spring experiments with eight replications, a comparison of days gained on different sampling dates (Duncan's Multiple Range Test, 1% level) indicated Shortest Significant Difference values of 0.7 to 0.9 days. Since crested wheatgrass seeds that have been in soil in the field may germinate (at 5 C) 0 to 12 days ahead of controls, hastening of germination can serve as a sensitive indicator of seed responses to environment.

We have encountered several problems in measuring hastening of germination. In long term experiments, temperature may drift in the facility used for the germination tests. Placing a set of control samples in the germinator at weekly intervals makes it possible to correct for small drifts in temperature.

Another problem relates to the distance between experimental sites and laboratory facilities. Field and control seed samples in petri dishes may be packed with bottles of ice in an insulated chest and transported several hundred miles with good results.

A third problem is that all seeds in a sample may not respond in the same way to environment. In other words, the slope of the germination curve (Fig. 2) for control samples may sometimes be greater than the slope of the curve for field samples. In this case, some seeds from the field

[1] Cooperative investigations of the Plant Science Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Department of Forestry and Range Management, College of Agriculture, Washington State University, Pullman, Washington. College of Agriculture Scientific Paper 3734. Received for publication October 16, 1971.

[2] The excellent assistance of Comfort Asante, Daniel Asante, and Seth Cox is gratefully acknowledged.

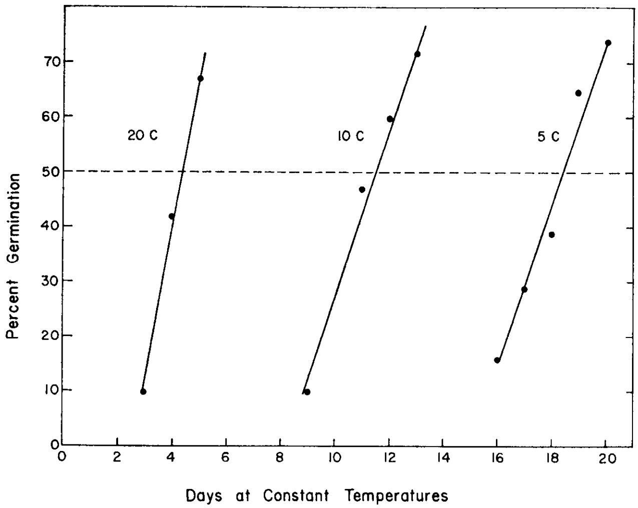

Fig. 1. Cumulative percent germination of crested wheatgrass seeds incubated at constant temperatures of 5, 10, and 20 C. Points are averages of five replications of 100 seeds.

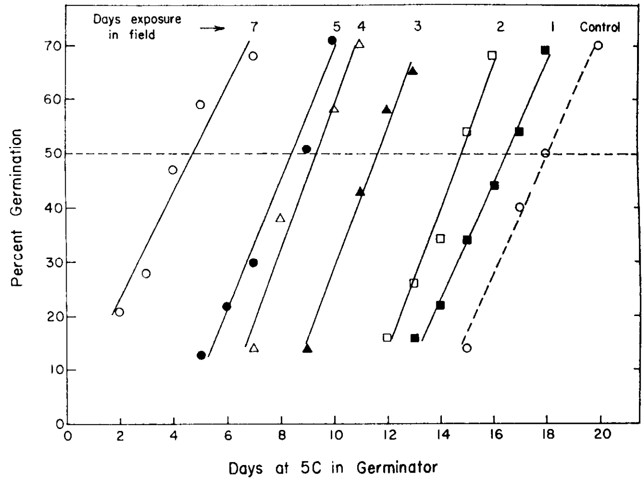

Fig. 2. Cumulative percent germination of crested wheatgrass seeds taken from the field 1 to 7 days after planting. The control consisted of seeds from air-dry storage germinated under the same conditions as samples from the field. Average germination of eight replications is shown for the control, and germination of a single replication is shown for field samples. By the seventh day of exposure, 6% of the seeds had germinated in the field.

may germinate well ahead of control seeds and others only slightly ahead of control seeds. Thus, when 50% (or some other percentage) is used for calculating days gained, one must realize that the values reflect how only part of the sample has responded to environment. In some experiments, the effects of environment may be illustrated best by plotting germination curves as in Figure 2.

Measurements of hastening of germination have several applications. They may be correlated with the progress of specific biochemical reactions and thus aid in discovering mechanisms of cold and drought tolerance in germinating seeds (Wilson, 1971). These measurements may also be correlated with environmental variables, providing models for explaining or predicting seed responses to environment. Hastening of germination values can give a day-to-day indication of how seeds are responding to fluctuating environments and to environments that are too harsh for seeds to germinate (Wilson, in press).

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THESIS: WASHINGTON STATE UNIVERSITY

Early Developmental Response to Low Temperature in *Agropyron spicatum* Collected from Native Stands in Western North America, by Floyd Preston DeWitt. M.S. Range Management 1969.

Agropyron spicatum (Pursh) Scribn. and Smith (Bluebunch wheatgrass), an important perennial forage grass, is rather widely distributed in western North America. Since considerable variation exists within the taxon, it was assumed that the ability to grow at low temperature was not shared equally by all variants. The purpose of this study was to determine the response of plants arising from seed collected at 51 widely scattered source areas, to low temperature. The practical objective was to select sources displaying the fastest rate of seedling root penetration. Rapid root penetration under conditions of low temperature is essential if *A. spicatum* is to become established on areas where *Bromus tectorum* L. (Cheatgrass), a rapid-rooting winter annual, is abundant.

Seedlings were grown in soil-filled glass root tubes in refrigerated rooms, in growth chambers, and in the field. For the indoor experiments, constant temperatures of 2, 5, 8, 11, 14, and 17 C were used. Germination and subsequent early seedling development were observed at constant 11 C and at alternating 2 and 11 C. Two root-growth experiments were conducted under field conditions. The field experiments yielded data closely paralleling that from the indoor experiments.

No *A. spicatum* source approached *B. tectorum* in rapidity of root penetration, but measurable differences were noted among sources. Whitmar, a selection used to a limited extent in rangeland planting, had relatively slow root penetration, but developed a greater number of roots than the others. A Morgan, Utah, source consistently displayed faster root penetration than the others. It was concluded these two sources are genetically distinct with respect

(*Continued on page 486*)

A Bibliography of the Published Works of Charles M. Russell. Compiled by Karl Yost and Frederic G. Renner. University of Nebraska Press, Lincoln. xiii + 317 p. 1971. $25.00.

This work has the appearance (and the price) of what is often called a "coffee table book"—i.e., one that is kept on the living room coffee table to impress visitors, but which is seldom read seriously.

But, as everyone knows, appearances can be deceiving. Although *A Bibliography of the Published Works of Charles M. Russell* is impressively handsome (it looks even better with the dust jacket removed), it is a detailed, expertly done, working reference volume that will be kept within easy reach for frequent consultation.

Why such a book as this? The compilers indirectly answer this question in their Foreword by referring to ". . . the increased public interest in western art in general and in the work of this artist in particular." Also, "Every person who is introduced to Russell's work becomes a collector, in greater or lesser degree. . . ." I believe both of these statements are quite valid and this much-needed work will prove most helpful to both novice and expert in apprising him of the extent of Russell's output and the incredibly extensive use to which it has been put.

Yost and Renner point out that the first attempt at a Russell bibliography, published in 1938, listed only 44 items, and in 1948 Yost compiled a bibliography describing 865 books, magazine articles, and other publications by or about this famous artist. The present bibliography, however, contains approximately 3,500 citations, representing the efforts of the compilers' combined 60 years of collecting and annotating Russell. Their cut-off date was arbitrarily set at December 31, 1966, and they indicate it will be no surprise if something else turns up in the future.

Because of the wide variety of forms in which Russell's works have appeared, Yost and Renner have set up 19 classifications for their bibliography: I—Collations, arranged chronologically, which describe books containing the first publication of one or more Russell illustrations; II—Catalogs, listed chronologically, from museums, galleries, and dealers; III—Periodicals, listed alphabetically, containing illustrations or articles by or about the artist; IV—Newspapers, listed alphabetically, containing illustrations or articles; V—Portfolios of Russell prints; VI—Color Prints, listed alphabetically; VII—Black and White Prints, listed alphabetically; VIII—Postcards, listed alphabetically by title of picture used; IX—Christmas Cards which carry a Russell reproduction; X—Ephemeral Items, 16 pages or less, not otherwise classified (e.g., old ASRM annual meeting programs); XI—Advertisements which used Russell illustrations as an attraction; XII—Broadsides, flyers, and other transitory items; XIII—Dealer Price Lists; XIV—Stationery, letterheads, envelopes, and business forms (including ASRM dues notices!) using Russell art; XV—Related Objects (e.g., beer trays and ASRM Photo Contest ribbons); XVI—Appearances, or a list of books containing previously published illustrations; XVII—References to Russell, but without illustrations; XVIII—Index to paintings, drawings, and sculpture; and XIX—General Index.

The compilers have taken special pains to assign correct titles to Russell's works, since, in the past, many editors and authors "have exhibited an exasperating proclivity to ignore, or fail to determine, the correct, or established, title . . . and to invent new titles." They also note that quite a few publications have carried illustrations of fake Russell paintings, but rather than explain them they have simply been omitted from the bibliography.

This book is not (to employ a favorite advertising cliche) profusely illustrated but the 42 illustrations, 18 of them in color, are extremely interesting in showing the many and varied ways Russell art has been employed.

Fred Renner needs no introduction to SRM members; he has published more than 100 articles in the field of range management as well as five books about Russell. Karl Yost, who lives in Morrison, Illinois, is an attorney with degrees from Northwestern University. In addition to his previous bibliography of Russell, he has published (1937) *A Bibliography of Edna St. Vincent Millay*.—*Francis T. Colbert*, Denver, Colo.

Game Management in Montana. Edited by Thomas W. Mussehl and F. W. Howell. Montana Fish and Game Department, Helena, Montana. 238 p. illus. 1971.

In this book, the Montana Fish and Game Department acquaints the reader with the history and development of game conservation in the state, and explains the structure, function, and activity of the Department from the time of its inception. The problems confronting wildlife populations which necessitated the establishment of wildlife laws and protective regulations are explained. The book describes the development of scientific game management in Montana resulting from failures of early conservation programs. It presents the financial program of the Department including sources of revenue and expenditures. The criteria used in field surveys and investigations are explained. Current research and land acquisition and development programs are discussed briefly.

Several chapters containing excellent photographs are devoted to individual big game species and individual game bird species. Waterfowl, furbearers, and predators are treated as animal groups in separate chapters. The chapters devoted to individual big game and game bird species includes a discussion of the history, habitat, distribution, and diet of the species. Management objectives, procedures, and problems are also discussed. Data is presented for most species, usually in tabular form, concerning hunter numbers, total harvest, and percent hunter success. The future outlook for each species is presented at the conclusion of each chapter. Waterfowl habitat requirements during migration, breeding and wintering are discussed briefly. Statewide duck and goose harvests are presented in tabular form in the waterfowl chapter. The chapter concerned with furbearers includes a list of classified furbearers and a brief description of the habitat of each species. Management policies and problems are also discussed. A section devoted to fur harvest shows the total harvest and trapper income resulting from the 1950–1951, 1963–1964, and 1967–1968 trapping seasons. Predator control highlights from 1940–1966 including bounty payment rates by species and total expenditures for predator control are presented in the chapter devoted to predators. A list of classified predators is presented and a brief discussion of the future outlook is included.

Appendix I lists the development of conservation programs, laws and regulations and management programs which had an impact on the development of game management during the 1869–1940 period. Listed in Appendix II are the highlights of the scientific game management program during the period of 1941–1970. A list of wildlife management theses, written by students from Montana State University and the University of Montana is presented in Appendix III.

The information presented in this book will be most beneficial to Montana sportsmen. The book will give them an insight into the operation, function and activities of the Montana Game and Fish Department. Maps depicting the distribution of individual game species in the state will be useful. Sportsmen will also benefit by reading about the habitat of Montana game animals and the problems and policies related to their management.—*Larry Sabatka*, Dubois, Wyoming.

Systems Analysis in Agricultural Management. Editors: J. B. Dent and J. R. Anderson. John Wiley & Sons, Australasia Pty. Ltd., Sydney, Australia. 1971, 394 pp, 59 figs., 65 tables. $14.95.

Application of systems analysis to management problems in agriculture and natural resource use is of recent occurrence, as we are frequently reminded in this book. The book is, therefore, a pioneering work and so the reader should not be surprised at a 'feeling-the-way' type of presentation. It is purportedly for use as a reference text by agricultural researchers as well as a course text for advanced undergraduate and graduate students in applied biology, agricultural economics, and farm and resource management.

The book is essentially a British-Australian contribution to systems analysis application although among the 18 contributing authors (including the editors) there are representatives from Canada, Holland, New Zealand and the U.S.A. Apart from introductory and concluding chapters by the editors, there are 15 other chapters, five in each of three sections. The three sections are: Techniques and Methods in Simulation; Crop and Livestock Systems; and Bio-Economic Systems.

In the section on techniques and methods in simulation, an attempt is made to familiarise the reader with the properties of agricultural enterprises that makes them well suited to the application of systems analysis, the necessary tools of systems analysis for such applications, and a perspective of the advantages and limitations of systems analysis. In the five chapters, many general philosophical, methodological, technical and statistical problems of systems analysis application are dealt with. More space could probably have been devoted, with advantage, to details of the stages of applying systems analysis to a situation rather than being so concerned with philosophical, technical and statistical worries of systems analysts. However, the editors may well have hoped that this would be remedied in the later sections.

The sections on crop and livestock systems and on bio-economic systems present case studies of systems analysis application. The fare is concentrated and varied in detail and subject. There is an opportunity to learn something about piggeries and sheep farms, human food chains and farm machinery, cropping and soil conservation, extensive and intensive grazing, and about farm firms in general.

The chapters of more than passing interest to range managers are conceivably Professor Goodall's Extensive grazing systems, Dr. Morley and Mr. Graham's Fodder conservation for drought, Dr. Anderson's Spatial diversification of high-risk sheep farms, Dr. Jones and Mr. Brockington's Intensive grazing systems and Mr. Dumsday's Evaluation of soil conservation policies by systems analysis. The detail of treatment and 'real-life' plausibility of the chapters varies considerably. The chapter of possibly greatest interest to the range manager, that on extensive grazing systems, has much good sense in it with the minimum of concern with technical matters which are quietly taken care of in the background. However, it is concerned with Australian dryland sheep farming which is quite different from most rangeland situations in the U.S.A. Because of this, there is little discussion of season of use or of rotational grazing, because yearlong grazing is the general practice in dryland Australia. The main concern is consequently with animal numbers and drought strategy. This latter concern, that is, how to deal with droughts, is looked at from two differing points of view in Morley and Graham's Chapter 11, and in Anderson's Chapter 12. In Chapter 11, the advantages of hand-feeding during droughts are considered and the cost of fodder conservation by hay is compared with the purchase of wheat as alternative feeds. In Chapter 12, the advantages of having more than one grazing property in different parts of the country as a means of reducing risks due to drought are considered. The conclusion is that economically, over the long term, it matters little whether all enterprises are together or are dispersed. What is more important, however, than noticing particular conclusions, is studying what assumptions and relationships the systems analyst has built into his model, because it is to these, and not necessarily to reality, that the conclusions apply. Many, for example, would find it hard to accept Dumsday's conclusion (Chapter 8) that an 'exploitive system (of cropping) was the most attractive alternative in all situations' as an evaluation of the type of soil conservation policy that should be followed. But then in his model, Dumsday admits, 'there have been no attempts made to relate directly soil loss, runoff, and cropping and fertiliser treatments to crop yield over time'. Chapter 10, on intensive grazing systems, aptly complements that of Goodall. The advantages of rotational grazing and possibilities of irrigation are examined in the context of lamb production. Conclusions are reached on both of these, but equally important was the highlighting of areas in which further research is needed, an important dividend of systems analysis application which is emphasised in several of the case studies.

There is little of direct use for the range manager in this book, but for those who are curious about the possibilities of application of systems analysis to their particular management situation, this is one of the first available texts. It will not, of course, leave the reader able to carry out the application itself.

The editors and contributors are to be congratulated on such a clean text of relatively difficult material in which typographic errors are minimal and editorial slips only three or four. The provision of a list of major subheadings from each chapter in the contents list and at the heading of each chapter is helpful but it may have been considered a device which rendered the provision of a detailed index unnecessary. Should this be so it is to be regretted because the index is woefully inadequate and internally inconsistent.

A pioneer text at reasonable cost, it can expect to reach a place on the occasional enthusiast's shelf, but in general it is probably destined to be largely confined to the shelves of students and researchers of systems analysis application to natural resource management.—*J. K. Marshall*, Fort Collins, Colorado.

My Dobie Collection. By Jeff Dykes, Texas A & M University Press, College Station, Texas, 1971, 43 p., illus., limited $25.00, trade $7.50.

This book has a soft cover, brownish-gold, with a drawing of a "paisano" (roadrunner) and the name "Frank Dobie" in gold. The work includes a section about Dobie's life as it relates to his book and other writings; a summary listing 50 Dobie items considered "Exceedingly Rare," "Rare" and "Very Scarce to Rare"; several pages of photographs of Dobie's books; a bibliography supplementing those of McVickers and Cook; and a list of recent acquisitions of Dobie items.

As the acknowledgements are read, one begins to learn about James Frank Dobie. The preface elaborates on the Dobie collection and how it came to Texas A & M University Library. In the Foreword by Dudley R. Dobie, cousin of Frank, one learns about the latter's early activities and his associations with the author. Facing the title page is a reproduction of a "paisano" given to Mrs. Jeff Dykes by Frank Dobie.

The author gives many facts about Dobie, and inspires one to read his books. For example: "The Mustangs is the top book of all time about range horses. In it, Frank's love of the wild and free sings on every page, and the result is vivid prose that entertains as well as informs. The history is there, based on a tremendous amount of research and gathering of word-of-mouth lore—but it is the painless kind of history you like."

This book contains facts probably available nowhere except in the Dykes collection. Many are in the form of notations by Frank Dobie. Concerning "Guide to Life and Literature of the Southwest," Dykes relates, "In my copy of the second printing, he wrote; 'The original (first) printing of this book bears the imprint of the University of Texas Press, 1943. The University of Texas Press never sold it but gave it away. It made a second run for the Southern Methodist University Press. Donald Day was director; I told him about the plates and told him he could have the book royalty free. It sold well enough that a successor, Allen Maxwell, gave me no rest until I revised the Guide (1952)—on a royalty basis—1954.' "

The section of Dobies Rarities contains gems of information about these books. The author quotes Dobie in explaining the origin of a salesman dummy of "Hacienda of the Five Wounds." Dykes also relates how this book was reissued under another title. He states his reasons for considering many books as Dobie Rarities.

Dykes has also succeeded in incorporating some western history. The summary which groups 50 Dobie Rarities also indicates the number printed of 32 items. All the information on writings by and about J. Frank Dobie could be acquired only by many hours of research and extensive notes.

Those interested in bibliographies will want the section that supplements those of McVickers and Cook. The last three pages contain a bibliographical list of recent acquisitions with the most recent date February 1971. Additional items will most likely be found and surely printed, as in *The Cattleman*, February 1971, page 142.

This book should appeal not only to those interested in Dobieana but to all interested in history and literature of the Southwest.—*Lorenz F. Bredemeier*, Fort Worth, Texas.

(*Continued from page 483*)

to rooting habit. They represented extremes among the *A. spicatum* sources investigated in detail.

Promptness of germination at 5, 10, 15, and 20 C was determined for three of the fastest growing *A. spicatum* sources, Whitmar and *B. tectorum*. No *A. spicatum* selection ever germinated more promptly than *B. tectorum*. In addition, the time lag between the germination of the two species increased as temperature decreased.

Although the Morgan, Utah, source had a faster rate of root penetration than any of the other *A. spicatum* sources, it does not appear likely that the difference is great enough to be of practical value in field establishment of the species in areas where *B. tectorum* is abundant.

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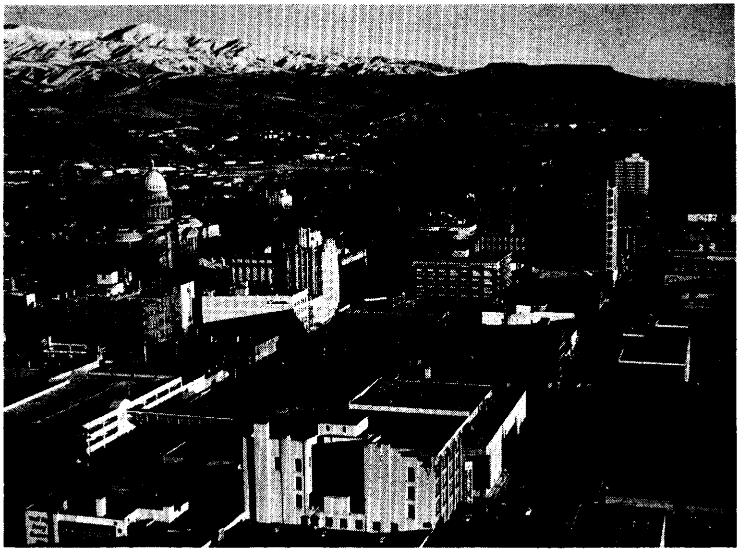

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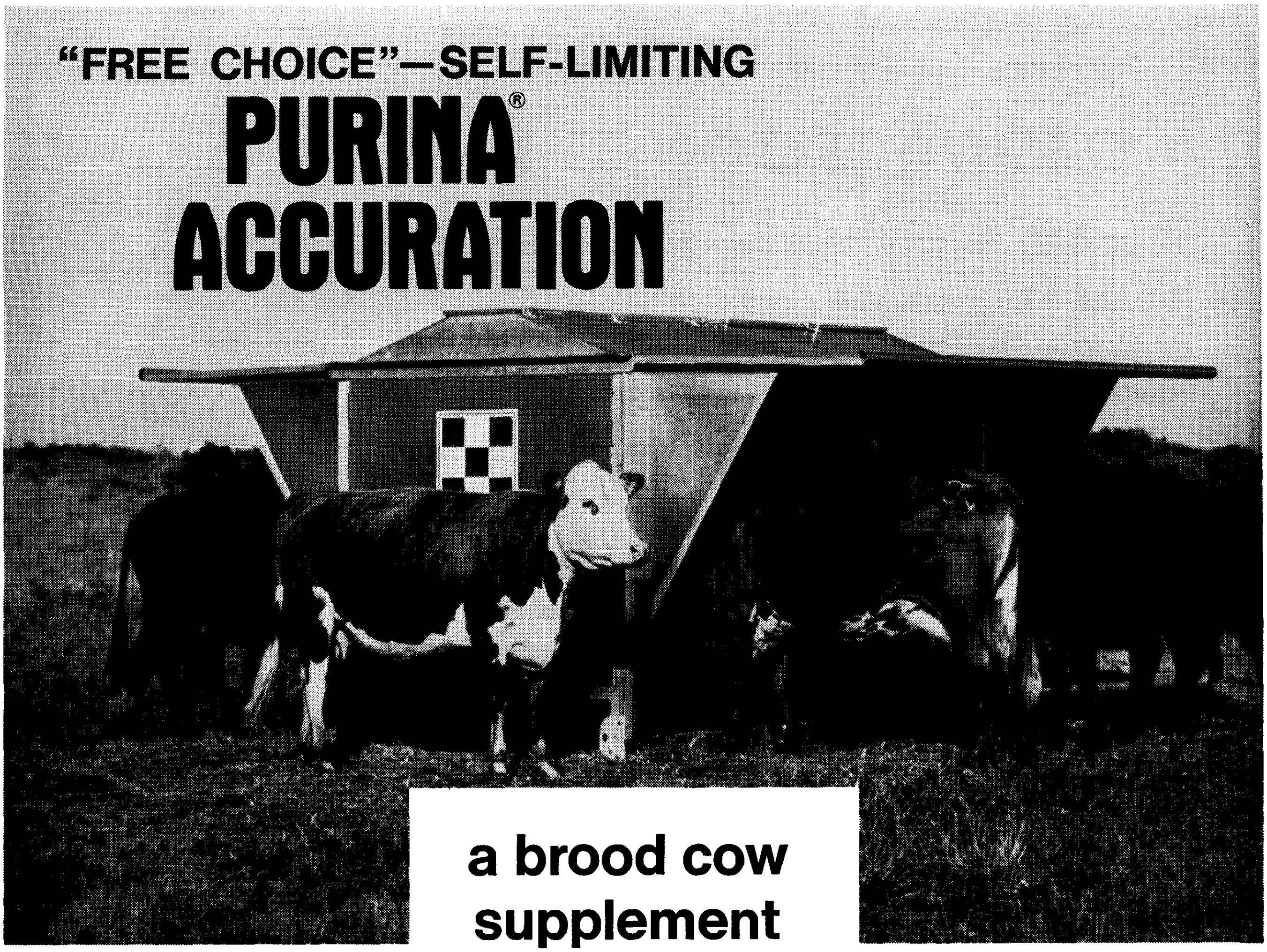

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Journal of Range Management

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