Journal of Range Management

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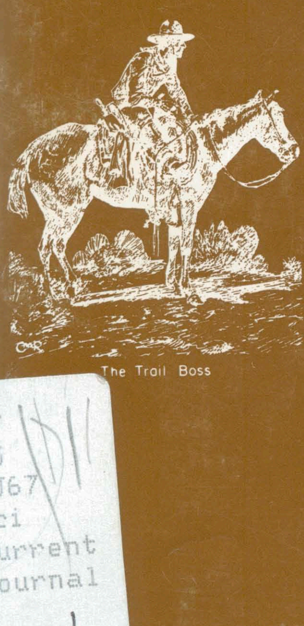
FEATURE ARTICLES



The Trail Boss

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

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

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

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

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

—*to promote professional development of its members.*

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Range research in the far western United States: the first generation

JAMES A. YOUNG

The author is range scientist, USDA, Agricultural Research Service, 920 Valley Road, Reno, Nevada 89512.

Abstract

The scientific study of rangelands in the western United States, started with the first collection of natural history specimens in the 18th century. Gradually over the 19th century, a basic catalog of the plants, animals, and geography of the far west was assembled. After the U. S. Department of Agriculture (USDA) was organized, scientists were sent to the western ranges on fact-finding missions designed to assess the existing range livestock industry and its potential. At the turn of the 19th to the 20th century, a few visionary scientist began to conduct actual experiments in rangeland environments. The Forest Service, USDA, was established in 1905, and what had been Forest Reserves from the U. S. Department of Interior (USDI) were transferred to the new agency. It was responsible for sustainable timber product and watershed management on millions of acres of wild lands. The Forest Service soon discovered that livestock grazed on four-fifths of the National Forest land and it was estimated that 85% of these rangelands were over-grazed and subject to accelerated erosion. The Forest Service started preliminary research on rangelands in 1907 and formally started an Office of Grazing Studies in 1910. Beginning with the Great Basin Experiment Station in 1912, a series of stations were developed by the Forest Service. As agricultural experiment stations developed at Land Grant colleges in the western states, state sponsored research on rangelands increased in importance.

Key Words: History, Forest Service, Experiment Stations, range ecology

Resumen

En el oeste de los Estados Unidos el estudio científico de los pastizales inicio en el siglo 18 con la primer colección de especímes de historia natural. Gradualmente, en el siglo 19, se conformó el primer catálogo básico de plantas, animales y geografía del lejano oeste de los Estados Unidos. Posteriormente, el Departamento de Agricultura de los Estados Unidos fue organizado y se enviaron científicos a los pastizales del oeste en misiones para estudiar y evaluar la industria ganadera existente en los pastizales y su potencial. A fines del siglo 19 e inicios del siglo 20, unos pocos científicos visionarios iniciaron la conducción de los experimentos actuales en pastizales. El Servicio Forestal del Servicio de Agricultura de los Estados Unidos se estableció en 1905, y lo que habían sido las reservas forestales del Departamento del Interior de Estadios Unidos se transfirieron a la nueva agencia. El Servicio Forestal era responsable del uso sutentable de los productos forestales y el manejo de las cuencas hidrológicas en millones de acres de tierras no colonizadas. El Servicio Forestal pronto descubrió que el ganado apacentaba cuatro quintas partes de la tierra de los bosques nacionales, y estimó que el 85% de estos pastizales estaban sobreutilizados y sujetos a una erosión acelerada. En 1907, el Servicio Forestal inicia investigaciones preliminares en los pastizales y en 1910 inicio formalmente una oficina de estudios de apacentamiento. Iniciando con la Estación Experimental Great Basins en 1912, el Servicio Forestal desarrollo una serie de estaciones experimentales fundadas como estaciones experimentales agrícolas en las universidades de los estados del oeste y el estado financio la investigación en pastizales y esta aumento en importancia.

The basic concepts of what we know as range science were formulated early in the 20th century. They often were formulated out of necessity as the nation faced precipitous declines in productivity from the western range in association with accelerated erosion. In the far west, the growth in range science was contemporaneous with the establishment of the Federal range, vast acerages of rangeland managed by agencies of the Federal government. The demands placed upon rangeland resources have changed during the 20th century, but the scientific basis for range management has remained relatively constant. The scientific basis of range management has always been open to a variety of interpretations. How these interpretations were originally made, how such interpretations have changed over time, and the outside influences that may have shaped such decisions are the intricate fabric of the history of range science. By assignment, this presentation was restricted to the mountainous and intermoutain portions of the west. The constraints of time and manuscript length have resulted in a lack of emphasis on the range research conducted in the Southwestern portion of the United States, but in no way is meant slight the significant achievements made in range science in that region.

The period of range research we wish to review can be subdivided into logical, but unequal length intervals: 1) exploration of the west, enumeration of the resource; 2) agricultural surveys; 3) visionary scientists; and 4) establishment and development of the Forest Service.

Exploration of the West: Enumeration of the Resource

Before you can manage the resource, you have to know its component parts. We have, through education and experience, accepted that the basic units of rangeland environments are the assemblages of plants and soils plus the animals they support. To

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communicate knowledge about the environment, the components must have near universally recognizable names. In the mid 19th century when the range livestock industry was expanding through the far west, many of the plants, some of the animals, and virtually all of the soils did not have such names.

Biological explorers came to the far western range for a variety of reasons. The great botanical gardens of England and Scotland sent botanical collectors such as David Douglas to the American west in search of specimens for their herbariums and gardens and for potential economic cultivars. In the process the plants were classified, given binomial names, descriptions published, and type specimens were filed in herbariums. Often the collections included at least rudimentary descriptions of the sites where the plants were collected.

If we had to pick one botanist of the early 19th century to represent the scientific enumeration of the resources of what became the western range, perhaps it should be Fredrick Traugott Pursh. He did not face the hazards of collecting in the western wilderness, but he was the first to describe such pillars of range management as bluebunch wheatgrass [*Pseudorogneria spicata* (Pursh) A. Love] and antelope bitterbrush [*Purshia tridentata* (Pursh) DC.]. Collected on the "Plains of the Columbia" these specimens were transported by the members of the Lewis and Clark Expedition back across the Rocky Mountains and down the Missouri River and eventually to Pursh at Philadelphia.

Much of the formal exploration of the American west during the 19th century was conducted by the Corps of Engineers, U. S. Army. The topographic engineers who explored the west sometimes acted as biological collectors while other expeditions included trained naturalists as members. One of the later and most intensive surveys was that led by First Lieutenant George M. Wheeler under the auspices of United States Geographical Surveys West of the One Hundredth Meridian. The survey results were reported in 7 volumes with titles ranging from geographical reports to archaeology. Volume 6 was Botany under the editorship of Joseph Trimble Rothrock (1878). He was born in 1839 and served on the Wheeler Survey as surgeon and botanist. Contributors to the botany volume included Sereno Watson, George Engelmann and George Vasey. These names are abundantly recognized in both specific names and authorities for western range plants.

Grasses have always been considered the backbone of forage resources on most cattle ranges. Starting with the botanical magnificence of the Great Plains, agrostologists worked westward through the mountain slopes, meadows and deserts collecting, preserving and often describing type specimens of grasses. Outstanding among the early agrostologists were George Vasey and F. Lamson-Scribner (sometimes given as F. L. Scribner). Vasey (1890) published *Illustrations of North American Grasses and Grasses of the Southwest*. Lamson-Scribner (for example 1897) published a series of USDA bulletins titled *American Grasses.* The dominant figure in agrostology into the 20th century was Albert Spear Hitchcock, born 1865 and died 1935. He was appointed assistant chief of the Division of Agrostology, USDA in 1901. In the following 34 years, Hitchcock produced over 250 publications and established himself as one of the truly great American botanists (Gould and Shaw 1968). The most significant of Hitchcock's publications were *The Genera of Grasses of the United States with Special Reference to the Economic Species* (1920) and *Manual of Grasses* (1935 and 1951). Throughout most of his career he was assisted by Mary Agnes Chase, who came to USDA as a botanical illustrator and became an assistant agrostologist in 1907 (Gould and Shaw 1968). After Hitchcock's death, she continued her work on grasses and published a revision of the *Manual of Grasses* in 1951. She became the Custodian of Grasses at the U. S. National Herbarium. We now have several excellent treatments of the grasses available. We all are aware of the recent taxonomic revisions in several grass genera, but how many generations of range managers and scientist have learned the grasses of the western range from Hitchcock's *Manual of Grasses*?

After the Forest Service was established, it became a required duty that range and forest personnel collect, press, and ship to headquarters botanical specimens. By 1937 the Forest Service herbarium contained 80,000 annotated specimens of 1,400 genera and 8,000 different species (Chapline 1937). They had been collected by an astonishing 1,200 different individuals.

Agricultural Surveys

At the end of the 19th century, the USDA began sending trained agriculturalists on surveys of the western range livestock industry. When the topographical engineering parties crossed the far west, there was no appreciable agriculture except in parts of the southwest. The USDA surveys were designed to assess the nature of the range livestock industry that had grown since mid century. David Griffiths made several of these surveys. He was born in Aberistwyth, Wales in 1867 and emigrated to South Dakota. His undergraduate education was received at South Dakota Agricultural College and he received his Ph.D. from Columbia University in botany. His first professional employment was as a botanist with the Arizona Agricultural Experiment Station. When he conducted the range surveys, he was an assistant with the Division of Agrostology, USDA.

Under the title of "Expert in Charge of Field Management", Griffiths (1902) reported on a study titled, "*Forage Conditions on the Northern Border of the Great Basin*". The subtitle explained the bulletin was a report upon investigations made during July and August, 1901, in the region between Winnemucca, Nevada, and Ontario, Oregon. Even today, destination resorts are not abundant between these 2 towns. In the Preface to the bulletin, F. Lamson-Scribner, then Leader of the Grass and Forage Plant Investigations in the Bureau of Plant Industry, stated the purpose of the study was to investigate range conditions in an unknown region. Lamson-Scribner justified the study as showing the need for reforms in range management, a matter that applied not only to this remote area, but to the entire west. The Preface also contained the information that transportation, living expenses, and guides for Dr. Griffiths' 700 mile trip were provided by the superintendents of the Miller and Lux and Pacific Livestock Companies. At the time Miller and Lux was the largest ranching company in the far west. They boasted that you could ride from Canada to Mexico and stop at one of their ranches every night. Not surprisingly, among Griffiths' conclusions were that tramp sheepmen (see Coville below for definition) were over grazing summer ranges in the mountains that were traditional cattle ranges and practicing promiscuous burning. Apparently, it did not occur to him that over-grazing would have eliminated the herbaceous fuel necessary for promiscuous burning.

What did surveys such as the one conducted by Griffiths accomplish? At a time when the population center of the United States was east of the Mississippi, Griffiths' report and similar bulletins reporting on other such surveys gave the interested public and Congressional decision makers a view of an environment and type of agriculture that was completely

Fig. 1. Severely over grazed range on the Steen Mountains of eastern Oregon. Photograph taken by David Griffiths in 1901 during a survey of range conditions in the northern Great Basin. Such surveys helped to describe the range livestock industry which was based on public lands in the far west.

foreign to residents of the humid east. Griffiths literally brought views of the western range to the east because, although he traveled by buckboard, he hauled along a huge camera with which he recorded on glass plate negatives views of the desert rangelands. Perhaps, his most famous photograph showed the damage caused by excessive sheep grazing on the Steins (modern spelling Steen) Mountains of Oregon (Fig. 1). Griffths collected information on what plant species cattle and sheep preferred, or refused to eat, or which were reportedly poisonous.

Such surveys were not limited to Federal scientists. P. Beveridge Kennedy conducted and reported on 2 such surveys of the range sheep industry in Nevada at the beginning of the 20th century (Kennedy and Doten 1901, Kennedy 1903). Kennedy was born in Scotland, received his initial college education in Canada, and earned his Ph.D. at Cornell. His first professional experience started in 1899 with USDA, Division of Agrostology as an Expert in Charge of Field Management. It is little wonder he followed the same format as Griffiths, loading a large format camera in a buckboard and tracing the route of sheep bands across deserts and mountain ranges in their seasonal migration. Kennedy's photographs are probably even better than Griffiths', in that he took high contrast, close views of important forage species. Perhaps, his most famous photograph was a panoramic view of a very large band (3,000 head) of sheep taking their mid day "shading-up" break on a large snow bank in the high Sierra Nevada (Fig. 2).

During the first decade of the 20th century virtually every far western state had pioneering scientists who made tours of their state's rangelands trying to assess the problems facing the range livestock industry. The 55-day botanical expedition through New Mexico that was made by Elmer Ottis Wooton in 1904 is an outstanding example of such tours (Allred 1993).

Visionary Scientists

By the end of the 19th century the bloom was definitely gone from the western range. Virtually all available range was occupied and often over-utilized. Noted historian William Rowley sets the scene, "Before 1894, seventeen forest reserves with a total area of 17.5 million acres were under the Department of Interior and its land agency, the General Land Office. What the department was supposed to accomplish with the reserves other than protect the trees from depredation remained a mystery" (Rowley 1985). Officially the lands were closed, but no one knew if they were to be managed or if natural resources such as timber and grazing could be harvested from the reserves. Every Congressional attempt to define the management of the Forest Reserves ran afoul of one or more of the special interest groups such as mining, timber, grazing or watershed protection. An increasingly vocal conservation interest group was beginning to make its desires felt on a national level. A noted spokesperson for this loose federation of conservationists (we would now term them environmentalists) was John Muir of the Sierra Nevada of California. He submitted stirring articles to *Century* magazine on the evils of grazing mountain forest and rangelands.

The first official statement of administrative policy on grazing matters was in a regulation dated April 14, 1894 (Rowley 1985). On all Forest Reserves the "driving, feeding, grazing, pasturing, or herding of cattle and sheep, or other livestock is prohibited". As expected, this brought a howl of protest from western ranching interests. A National Academy of Science Committee was appointed to review the status of the reserves. The secretary and

Fig. 2. A band of 3,000 range sheep resting during the mid-day heat on a snow bank in the high Sierra Nevada. Photograph taken by P. B. Kennedy in 1901.

only forester on the committee was Gifford Pinchot. The chair was Charles S. Sargent, director of the Harvard Botanical Garden and author of *Silva of North America* (Pinchot 1947). Sargent had previously suggested that foresters, necessary to protect the Forest Reserves, should be trained at the United States Military Academy at West Point. At one time it was proposed that Federal troops should patrol and protect the Forest Reserves. At the time European, especially German, foresters were members of para-military organizations.

John Muir traveled with the committee as they toured the west and probably greatly influenced their decision to support a ban on grazing in the Forest Reserves. About the same time the report was released, outgoing President Grover Cleveland added over 21 million acres to the reserves. The report and the enlarged reserves brought more protest from the west and protracted Congressional debates and infighting in the form of amendments to appropriation bills (Rowley 1985). The end result was the issuance by the General Land Office of regulations permitting grazing of livestock except sheep on most of the Forest Reserves. Sheep were permitted to graze on the Cascade Forest Reserve located in Oregon and Washington.

During the period the Forest Reserves were in effect, USDA was supposed to be providing, in some vague way, technical guidance for the management of the reserves. Toward this goal, Frederick V. Coville was sent west in the summer of 1897 to assess the influence of sheep grazing on the Forest Reserves of Oregon and Washington. Coville was then Chief of the Division of Botany of USDA and was a strong proponent of a governmental system of leasing vacant rangeland to overcome the evils of over stocking and land misuse (Anon. 1944). Coville was born in New York in 1867. He completed his under graduate education at Cornell. His previous experience in the west was as a member of an expedition studying Death Valley during 1890–1891.

Binger Herman, Commissioner of the General Land Office, gave Coville a letter of introduction to the prominent sheepman John Minto of Salem, Ore. The rancher, who at the time was an outspoken opponent of John Muir, helped the botanist get started on his inspection. Coville left Klamath Falls in south-central Oregon on 23 July with 2 saddle horses and 5 pack animals. He reached The Dalles, Oregon, on the Columbia River on September 6th.

Coville was astounded to find sheep did not graze in fenced paddocks as was common in the eastern United States, but were *herded* by a sheep herder who had to be constantly on guard to protect the animals from predators and to search for new areas to forage (Coville 1898). To reduce cost, each herder had to be responsible for as many animals as possible. These units of grazing sheep were called *bands* and consisted of 1,000 to 3,000 animals. This meant that the grazing of range sheep was concentrated in a relatively limited area each day. If the herder returned his flock to a fixed camp each night, the vegetation in the immediate neighborhood of the camp was devastated. Coville introduced the idea of *trampling* as the major damage caused by livestock grazing on the range.

As Coville wandered along the crest of the Oregon portion of the Cascade Mountains, he discussed the grazing of sheep with everyone he met. He discovered the movement of sheep to the mountains in summer had begun only 20 years before. Prior to that time sheep production in eastern Oregon had been based year-round on sagebrush (*Artemisia*)/bunchgrass rangelands. As the productivity of these rangelands had declined, sheep ranchers had moved to the high mountains in the summer for forage. This transhumance form of grazing had allowed sheep production in one county to increase from 6,000 to 25,000 animals. Coville used this as evidence of the importance of the high mountain ranges to the sheep industry.

The sheep bands were highly mobile. Coville considered the continued movement of several bands to be a sure indication of over-grazing. In the Three Sisters-Upper Deschutes portion of the Cascades he discovered 101,960 sheep that summer. Only 6,660 of these were considered local sheep from the adjoining county. The sheep from outside the local area or *tramp* sheep became an important issue throughout the mountains of the west. As Coville described the problem, "There is no law, except the questionable law of the Winchester, by which the rancher can defend his home, and he earnestly supports the demand for exclusion, believing that if sheep are kept out of the mountains the industry would be ruined and his own little range left free." (Coville 1898).

Coville was the first to state what has become a basic principle of range science. Grazing livestock on rangelands can be destructive if not managed. Managed grazing can be a sustainable use of rangelands. These statements are so deceptively simple it would seem ridiculous to consider them a foundation of range science. A century after Coville's studies, there is still a vocal segment of the environmental movement that considers any grazing of rangelands by domestic livestock to be an unacceptable use of the resource. Such individuals often choose not to distinguish between managed and destructive grazing. The question should be, is grazing a sustainable biological and physical process and if it is or is not, why?

In conclusion, Coville suggested that: 1) individual ranchers should be given the grazing rights on a specific range; 2) the number of animals permitted should not exceed the capacity of the forage resource on a sustainable basis; 3) in return, the rancher would agree not to burn promiscuously and to help suppress natural fires; and 4) the administrative cost of the program would be paid by the rancher in the form of a fee based on the number of animals grazed. There had to be an administrative fee because experience had shown that voluntary programs developed by grazing associations did not work. Someone had to enforce the rules. Coville saw nothing wrong with livestock being excluded from specific landscapes of great value to the public, such as Crater Lake in Oregon.

Note that Coville suggested that ranchers be given the right to graze specific portions of the public domain. In the 20th century when the Forest Service was established, grazing was classed as a *privilege* and not a right. This policy was established because in Germany grazing rights in forest often dated from feudal times and caused endless problems for German foresters who were greatly admired by their American fledgling counterparts (Sampson 1919a).

Frederick Coville was a large scale, national scientist with a vision of the future. Each western state had similar visionary scientists interested in rangelands. Some were local or regional in their influence and some soared to national prominence. We have previously introduced P. B. Kennedy of the University of Nevada, who went on to prominence at the University of California at Berkeley. F. H. Hillman was a contemporary of Kennedy whose contributions were more local in character. Hillman was a botanist-naturalist who liked to walk the fields, meadows, and semi-arid rangelands near the Truckee River and observe the nature of things. He wrote in 1896, "On looking over the American literature upon our various forage plants, one can not fail to note the very meager information to be had relating to the many plants that are native to the western part of the United States" (Hillman 1896). Hillman compiled local floras and annotated lists of introduced weeds, each a building block toward the whole of understanding the western range. The first generation of range science was built by many such seemingly small contributions from scientists in many different states.

Forest Service Period

In 1905, when the Forest Service was established in the USDA and the Forest Reserves were transferred from USDI to become National Forests, there were millions of cattle, sheep, goats and horses grazing on these lands (Chapline 1937). The Forest Service, which was created from the former Bureau of Forestry, was primarily charged with protection of timber production and watersheds. In the west, livestock grazed over four-fifths of the area of the National Forest and these rangelands constituted 85% of the watershed for the major western rivers (Chapline 1937). The Secretary of Agriculture informed Chief Forester Pinchot, 4 days after the Forest Service was formed, that a probably jubilant General Lands Office had already set in motion a permit grazing system for 1905 for the former Forest Reserve lands (Rowley 1985). The General Lands Office was getting rid of more than 2 decades of grief. The Secretary of Agriculture charged Pinchot to use "whatever plan, in your judgement, will act for the best permanent use of the range." Pinchot believed the Forest Service had 3 essential jobs: protection, management, and the effective application of science (Rowley 1985).

The vast majority of the American population at the end of the 19th century was not far removed from the farm environment. This certainly applied to the majority of administrators in USDA. It was logical that the first attempts to restore deteriorated rangelands would involve planting forage species. It was also logical that the species of choice would be the perennial grasses redtop (*Agrostis alba* L.) and timothy (*Phleum alpinum* L.), both exotic species native to Eurasian. Today it would seem ludicrous to choose 2 exotic, invasive species adapted to humid pastures for seeding of rangelands in the west where they were only adapted to wet meadow or irrigated conditions. These 2 grasses had revolutionized forage production in the humid east. To the agricultural public east of the Mississippi River, they were the wonder forage plants of the 19th century. At the same time that redtop and timothy were being considered for the mountainous ranges of the far west P. B. Kennedy was writing with a thunderous pen, "When the average man begins to think about restoring depleted ranges, he is apt to imagine that somewhere on earth, in Australia, or South Africa, or even in Siberia, there must be a wonderful grass or salt bush, or something else which can be made to grow on his ranges high up on the dry mountains and down in the wooded dark valleys, furnishing abundant food for all his stock." (Kennedy and Doten 1901). Kennedy equated the chances of finding such a plant were the same as finding a cure in a 1 dollar bottle of patent medicine. He claimed the only adapted plants were those that grew on the range at the time, but Kennedy also considered the whole idea of *government* doing range improvement to be a socialist plot. Contemporaneously, F. H. Hillman mused, "How would we, if ever, domesticate the wonderful native bunchgrasses?" (Hillman 1896).

As early as 1902, USDA had scientists experimenting with the seeding of depleted meadows (Cotton 1908). Cotton was a scientific assistant with the farm management investigations unit of the Bureau of Plant Industry. The first plantings were seeded in 1902 on what later became the Wenatchee National Forest in Washington. The plots were established in cooperation with the Washington Agricultural Experiment Station. In 1903 he established similar experiments in northern California in the Sierra Nevada and Warner Mountains. Cotton used a wide variety of plant material, including several native grass species. He concluded that with proper seedbed preparation tame grasses could be established on degraded meadows.

The first Forest Service experiments with seeding began in 1907. The experiments were initiated by Arthur William Sampson who later was often credited with being the father of range management. Sampson was born in Oakland, Nebraska in 1884. He received his B. S. from the University of Nebraska in 1906, M. S. from John Hopkins in 1914, and his Ph.D. from George Washington University with a major in plant ecology and climatology (Anon. 1968). He had apparently just finished or was finishing his undergraduate degree, when he went to the Wallowa Mountains of northeastern Oregon to conduct seeding trials at high elevations sites.

In the forward to a preliminary report on the research, Frederick V. Coville explained the selection of the Wallowa National Forest (Sampson 1908). Much of the higher elevation portions of the Wallowa Mountains were grazed exclusively by sheep. An estimated 252,000 sheep grazed in the area in 1906 (Strickler and Hall 1980). Forage production had decreased so drastically that many of the sheepmen had proposed closing the range to grazing for a few years. Sending Sampson to conduct research on these degraded, high elevation ranges was in response to the sheep rancher's request for help. This is one of the few examples from the time period where the Federal government responded favorably to the sheep industry compared to cattle ranching.

Sampson's principle experimental site was called the Stanley (modern spelling Standley) Range and consisted of about 20 acres (Fig. 3). The site was severely overgrazed and had originally supported the bunchgrass green needlegrass (*Stipa viridula* Thin.). Sampson seeded timothy, redtop, and Kentucky bluegrass (*Poa pratensis* L.). He reported on these trials in 1908 and 1909 with USDA Circulars and more completely with a USDA Bulletin in 1913 (Sampson 1908, 1909 and 1913a). In a footnote in the first Circular, Sampson reported he used the techniques of F. E. Clements in his research. It is important to note that Sampson published preliminary results of these experiments in the 1908 and 1909 Circulars. Apparently, this reflects how badly the information was needed. By the time the 1913 bulletin was published, Sampson reported that the Forest Service had conducted some 500 seeding trials across the western forest. Sampson summarized his results: "It is not to be presumed, however, that all overgrazed ranges can be successfully reseeded to cultivated plants. On the contrary, it is unquestionably true that existing conditions in the major portion of the native grazing lands are antagonistic to the establishment of introduced plants, this is due to excessive elevation, poor soil, insufficient moisture, or too much too aggressive native vegetation" (Sampson 1913a).

Sampson established 2 points in this research that remain standards, 1) if you are going to seed on rangelands you have to prepare a seedbed, and 2) the seeded area has to be protected from grazing. Sampson was to develop such a monumental reputation in range science that his words became cast-in-stone for range managers. His early research became interpreted to mean that it was impossible to seed rangelands. This interpretation remained in force until the late 1930s and

Fig. 3. [A] A portion the Standley sheep allotment in Wallowa National Forest in 1907. A. W. Sampson took the photograph of severely depleted rangeland he was trying to restore. [B] Photograph taken in exactly the same location in 1992 (from Skovlin and Thomas 1995). Subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albiculis*), and Engelmann spruce (*Picea engelmannii*) have invaded the former needlegrass (*Stipa*) grassland.

1940s when another generation of Forest Service scientists were successful with artificially seeding rangelands and expanding range restoration from only wet meadows to the vast sagebrush (*Artemisia*)/bunchgrass rangelands (Young and McKenzie 1982).

The Forest Service officially established an Office of Grazing Studies and appointed James J. Jardine as its head in 1910 (Anon. 1944) (Fig. 4). Jardine was to become one of the most influential individuals in range science and agricultural research in general during the first half of the 20th century. He was born in Cherry Creek, Idaho in 1881. He received a B. S. from Utah College in 1905. Later he received honorary degrees from Kansas State, Clemson, and Utah State Universities. He was to leave the Forest Service in 1920 to become the Director of the Oregon Agricultural Experiment Station where he remained until 1931, when he returned to USDA as Director of the Office of State Experiment Stations, a position in which he served until 1946. Jardine made many contributions to range science over his career, but his greatest initial achievement was the co-authoring of the USDA bulletin, *Range Management on the National Forest* which probably was designed as an instructional text for Forest Service Range Examiners (Jardine and Anderson 1919). The bulletin was lavishly illustrated with excellent photographs (Fig. 5) and it contained a list of references arranged by subject matter. The bulletin covered subjects from determining the appropriate class of livestock for different range environments, to how to collect plant specimens. It is not hard to imagine a fledgling range examiner sitting at a rough table in a log cabin in the wilderness studying by lantern light Jardine's instructions for managing the range.

Jardine had been conducting research during the period before 1910 when he became head of the Office of Grazing Studies. It was an unusual type of research inspired by Coville's concern that sheep had to be herded on the range. Jardine experimented with coyote (*Canis latrans*) proof fences for sheep (Jardine 1908 and 1910). These studies were conducted at Billy Meadows in the Wallowa Mountains of Oregon. His experiences during these studies led to his development of range resource inventory procedures that were adopted by the Forest Service as their standard range reconnaissance procedure (Anon. 1944). The basic procedure was not significantly changed until after World War II. These reconnaissance instructions were placed in the Forest Service *Use Book.* These shirt pocket sized books contained the rules and regulations governing grazing on the National Forest. A range examiner would not be caught out on the range without the latest edition. Chapline claimed that the Billy Meadows studies were the crucible where a generation of future range scientist learned their trade (Chapline 1937) (Fig. 6).

Forest Service dominance of range research in the far west did not mean it was the exclusive agency for research. The state agricultural experiment stations continued and expanded their role in answering problems on rangelands. At the same time Jardine was feeding sheep to coyotes, P. Beveridge Kennedy and a chemist Sanford C. Dinsmore were conducting forage digestion experiments with sheep on summer ranges (Kennedy and Dinsmore 1909). In the introduction to the bulletin reporting this work the authors said, "One important point that has been determined (in previous research by Kennedy) is that succulent plants and shrubs are preferred by sheep to the grasses. Before advocating any method for restoring the depleted ranges we thought we would like to find out from the standpoint of nutrition, as well as palatability, which plants would give the optimum return in mutton production for the labor involved." They built digestion stalls on Hunter Creek in the Carson Range of the Sierra Nevada and conducted their trials with freshly collected forage from the range (Fig. 7). They were among the very first to recognize that broad leaved herbaceous species were

Fig. 4. James T. Jardine, first director of the USDA, Forest Service, Office of Grazing Studies that was established in 1910. In the photograph, Jardine is on the Chico Trail in Wallowa National Forest in 1907 (from Skovlin and Thomas 1995). Jardine was conducting research on range sheep grazing under fenced conditions at the time.

important in the diet of sheep. For some time after their work, the broadleaf herbaceous species, which we now term forbs, were called weeds in range research papers.

The Forest Service moved in 1910 to establish Offices of Grazing Studies in the Regional Forests that had been established as administrative units. The first field offices were established in 1911 in the Pacific Northwest, Intermountain, Rocky Mountain, and Southwestern regions with Charles E. Fleming, Alfred E. Aldous, Lynn H. Douglas, and Robert Hill in charge, respectively (Anon. 1944). Several of these individuals were to have careers in range research that extended into the 1940s.

The Forest Service launched into a new idea in range research by establishing experiment stations on the National Forest. The first was the Great Basin Experiment Station created in 1912 by administrative decision of Forester Henry S. Graves (Keck 1972). The headquarters unit is located in an aspen grove on the west front of the Wasatch Plateau in central Utah at an elevation of 8,500 feet. The first director of the station was A. W. Sampson. The Great Basin Station proved to be the site of perhaps his most noteworthy research.

The Great Basin Station was established, at least partially, because of the numerous letters the Secretary of Agriculture had received complaining of the numerous destructive floods that swept down from the forested range watersheds of the Wasatch Plateau to the towns and irrigated farm lands in the canyons and valleys below (Keck 1972).

Robert Reynolds, Forest Examiner, was perhaps the first to publish on the relation between grazing and watershed characteristics. Reynolds described the condition of the mountain ranges. "Settlement of the Sanpete Valley began about 1850, and the following 30 years saw a steady increase in the numbers of cattle and horses grazed on the mountains in the summer. Cattle numbers peaked in 1880, about the same time a large range sheep industry developed. Sheep were wintered on desert ranges and spent their summers in the high aspen park lands at the head of the canyons of the Wasatch Plateau. Cattle and sheepmen fought for the use of the same range. The result was that, between 1888 and 1905, the Wasatch Range, from Thistle to Salina, was a vast dust bed, grazed, trampled and burned to the utmost. . . . .The basins at the head of the canyons suffered most, relatively, because they contained the best feed for sheep and were less broken in topography and more easily accessible.....These high mountain pastures, therefore, received not only the most abuse, but have been proportionately longer in recovering from its effects" (Reynolds 1911).

During the 19th and early 20th century, the sheep versus cattle conflicts were endless on the far western range. A. W. Sampson stated these conflicts were the greatest initial barrier to development of the range livestock industry after the Indian

Fig. 5. Billy Meadows ranger station in Wallowa National Forest. This is the location where many of the first generation range scientist went to work sheep grazing and revegetation experiments. The fenced area in the fore ground was a grass nursery (from Skovlin and Thomas 1995).

Fig. 6. [A] A photograph taken in 1917 of depleted range near Mammoth Springs, Baker County, Oregon. It was used by Jardine and Anderson (1919) to illustrate a site where reductions in grazing had started the process of restoration of the plant community.
[B] Same site re-photographed in 1967 (from Skovlin and Thomas 1995). In 1967 the site was grazed by sheep and the herder is pointing to where the sheep will bed for the night.

wars and continued to be a barrier to management of the range (Sampson 1919a). Many portions of the National Forest that were established in Nevada were virtually without trees. Long established large cattle operations petitioned for their establishment in an attempt to control tramp sheep operations (Young and Sparks 1985).

The concern about the damaged watersheds, which were considered by many to be sheep damaged watersheds, resulted in Sampson starting his research efforts at the Great Basin Station in the sub-alpine bowls at the head of canyons in the high mountains. Sampson produced an annual report for the Great Basin Experiment Station (initially known as the Utah Experiment Station) in 1913, but at the same time he was organizing the station and building the facilities, he published articles based on research previously conducted in the Wallowa Mountains from 1907 through 1910. In the introduction to the Wallowa Mountains paper Sampson made this statement, "Ideal range management would mean the utilization of the forage crop in a way to maintain the lands at their highest state of productiveness and at the same time afford the greatest possible returns to the stock industry. To maintain the maximum productivity, the annual herbage crop must be used in a manner which will not retard the growth or prevent the perpetuation of the most desirable forage species" (Sampson 1914a). Sampson considered the decline in carrying capacity of the western grazing lands was brought about in part by injury due to trampling (Coville's great concern), but perhaps in greater part by *premature grazing* and *over stocking*. He was recognizing a physiological influence on the plants besides physical destruction. Sampson built on the classical studies of C. Hart Merrian (1898) in describing the various life zones of the Wallowa Mountains. He related plant phenology to life zones and in turn related these to the ability of the plants to resist grazing. Among his conclusions were, "Removal of the herbage year after year during the early part of the growing season weakens the plant, delays the resumption of growth, advances the time of maturity, and decreases the seed production and fertility of the seed" (Sampson 1914a). One of Sampson's basic building blocks of range science, that is often lost in modern grazing management, was, "Yearlong protection of the range favors plant growth and seed production, but does not insure the planting of seed. Moreover, it is impracticable, because of the entire loss of the forage crop and the danger resulting from the *accumulations of inflammable material*." Sampson suggested deferment of grazing until after seed ripe was the grazing management alternative most suited to restoring over grazed ranges.

With the benefit of hindsight, it has become obvious that Forest Service science and policy was making a huge error in regard to their policy towards suppression of all fires. At the time, promiscuous burning was viewed as a major threat to the forest (for example Plummer 1924). When these policies were formulated there were not a lot of wildfires on rangelands because of apparent lack of herbaceous fuel. In the first decade of National Forest in Nevada, virtually all rangeland, a total of 2,000 acres burned and in some years the total area burned was 10 acres (Plummer 1912).

Fig. 7. P. Beveridge Kennedy and Sanford C. Dismore collecting forage species on summer range in the Sierra Nevada for use in digestion trials (Photograph from Kennedy and Dinsmore 1909).

One would think that A. W. Sampson would have been fully occupied with development of the Great Basin Experiment Station, especially as his personal research was establishing many of the fundamental principles of range science. Somehow Sampson found the time to write a series of articles on the basis of range management for the industry journal *The National Wool Grower*. This series apparently started in 1913 with an article entitled *Scientific Range Management* (Sampson 1913b) and continued the next year with *Distribution and Function of Range Plants* (Sampson 1914b). He continued over the remainder of the decade with articles on grasses and poisonous plants. He used scientific names for plants in these articles and explained technical points in plant identification and growth requirements. Sampson not only conducted highly original, appropriate research, he went a step beyond into technology transfer.

Perhaps the apex of A. W. Sampson's career as a research range scientist occurred with his publication *Plant Succession In Relation To Range Management* (Sampson 1919b). It is one of the few early research efforts he reported both as a journal article and a USDA bulletin (Sampson 1917 and 1919b). The article was only 3 pages long and reported a paper he had read at a meeting of the Botanical Society of Washington, D. C. The introduction to the bulletin states, apparently for the first time, several fundamental issues in range management. Sampson (1919b) stated, "Enterprising stockmen and those concerned with administration of grazing know that the livestock industry has now reached a point where the intensity of the use of the forage crop must be governed by a finer discrimination than mere observation of the density of the plant cover and the condition of the stock". He introduced to range science the concept of the regular replacement of one assemblage of plants on a given site with another assemblage of plants in response to disturbance or freedom from disturbance. He used the term *succession* for this biological phenomenon. Sampson did not claim to have originated the concept of succession. In footnotes he cited Henry C. Cowles (1901), C. E. Moss (1910), and R. S. Hole (1911). Sampson suggested that the fundamental controlling processes in succession were simultaneous changes in the substratum. Plant growth influenced soil development and soil development controlled the composition and structure of plant communities. Sampson's bulletin was lavishly illustrated with drawings signed by A. E. Hoyle. The illustrations included both representations of individual plants and plants together in communities. Both types of illustrations featured above and below ground representations.

Sampson's conclusions thundered down from the Wasatch Front with the power of a snow slide or a summer flash flood and flowed across the desert ranges to reach all corners of the western range, "Grazing may cause either progression or retrogression succession, depending chiefly upon the *closeness* with which the herbage is grazed annually and the *time* when it is cropped" (italics added). Sampson reached a staggering 46 individually numbered conclusions. He set the stage in his first conclusions that there was no question that much of the western range was over grazed. In conclusion number 3 he stated, "The most rational and reliable way of recognizing the incipient destruction of the forage supply is to note the replacement of one type of plant cover by another, a phenomenon which is usually much in evidence on lands used for the grazing of live stock". By recognizing the replacement of plant species he stated the concept of range condition, and by using the term incipient he obliquely referred to range trend.

A major problem for ranchers whose cattle grazed high mountain ranges in the west was the hazard of poisoning from consumption of larkspur (*Delphinium* sp.). It was estimated in 1917 that 5,000 head of cattle were poisoned annually on the National Forest (Aldous 1917). This was another of the cattle versus sheep issues, because sheep were not usually poisoned by tall larkspur because they did not prefer the species. Early research on poisonous plants was conducted by scientists employed by USDA, Bureau of Animal Industry and Plant Industry. The Forest Service conducted trials on the control of tall larkspur on several National Forest. Aldous (1917) reported on the efficacy and cost of hand grubbing as a control measure. It cost about $10.00 per acre to grub tall larkspur plants by hand. This practice continued until World War II and hundreds of acres of high elevation rangeland were treated in this manner. Poisonous plant research became a major aspect of range science.

Federal research on all rangelands, public and private, was assigned to the Forest Service in 1915 (Chapline 1937). It remained this way until the McSweeney-McNary Forest Research Act of 1928 provided a coordinated attack on all forest research and a 10 year financial program. Six bureaus within USDA either cooperated with the Forest Service or worked independently on range research. They were:

Bureau of Plant Industry—pastures and range revegetation, later plant breeding.
Bureau of Animal Industry—animal husbandry and poisonous plants.
Biological Survey—wildlife
Bureau of Entomology and Quarantine—insect problems
Bureau of Chemistry and Soils—plant analysis and soils
Bureau of Agricultural Economics

Forest Service experiment stations and research sites spread across the west during the 1920s. Among the earliest and most famous were the Jornada in New Mexico and Santa Rita in Arizona. Lincoln Ellison once stated that to be a successful first generation range scientist in the far west you had to have gained experience at either the Great Basin or the Jornada experiment stations (Keck 1972). Some were in cooperation with other USDA agencies such as the U. S. Range Experiment Station at Miles City, Mont. and the U. S. Sheep Experiment Station at Dubois, Ida. Stations such as the San Joaquin in California and Desert in Utah were located off National Forests and were designed to solve problems for ranchers when their animals were grazing off the forest. Forest Service scientists always chafed against the restriction that they could not work with the domestic range animals themselves, only with the ranges on which they grazed.

Conclusion

The first generation of range scientists established that the range livestock industry that used the National Forests for grazing must be regulated. This was a near revolutionary concept at the time. The researchers confirmed that productivity of many ranges was declining and accelerated erosion was common. They established a link between this decline and early season grazing year after year with no chance for the plants to flower and reproduce. Establishing the capacity of the range to support grazing on a sustainable basis was required to prevent over utilization of the resource. The crown jewel of scientific achievement by the first generation of range scientist was the innovative concept that changes in the species composition of plant assemblages provided the most biologically sensitive index of range condition.

In the early 1920s, several of the first generation range scientists left for university appointments. For example, A. W. Sampson went to the University of California at Berkeley and C. E. Fleming to the University of Nevada. It was becoming obvious that mistakes had been made in trying to optimize meat and wool production on the National Forest as a part of the World War I effort. In the post war years, agricultural depressions were to devastate livestock producers. Despite seemingly endless debate, millions of acres of vacant Federal rangelands outside the National Forest still received no management. Despite all this gloom and doom, a new generation of range scientists was to arise to build upon the achievements of the pioneers of the first generation.

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Achievements in management and utilization of privately-owned rangelands

CLENTON E. OWENSBY

Author is professor of Range Management, Kansas State University, Department of Agronomy, Thorckmorton Hall, Manhattan, Kans. 66506-5501, owensby@ksu.edu.

Abstract

Historically, there have been several seminal achievements in management and utilization of privately-owned rangelands. The most important of the early achievements were domestication of livestock, fencing, haying, and the transfer of federal lands to private ownership. Later, federal programs to stimulate range research and extension were the springboard for the modern range research complex. The Morrill Acts established the land-grant institutions with agricultural research as one of the founding principles. The Hatch Act later provided funding for agricultural research, and the Smith-Lever Act funding for the extension of that research to the agricultural industry. Recent trends have been away from funding applied research and towards funding for basic research defined by the political scientific bureaucracy. Those achievements that I consider of major influence in management and utilization of rangelands include: defining stocking rate-animal performance relationships, refining prescribed burning techniques, formulation of selective-translocated herbicides, developing plant varieties and seeding methods for reseeding, matching forage quality with nutritional requirements of livestock, basic research on morphologic and physiologic characterics of range plants, and information dispersal through extension and federal agencies for better management of rangelands. The future is uncertain, and unless we can reverse the trend away from applied to wholly basic research funding, we will have fewer achievements in managements of privately-owned rangeland.

Key Words: range management, range utilization, Hatch Act, Smith-Lever Act, university research, ARS research

On 27 January 1955, Arthur Sampson, called by many the Father of Range Management, delivered an address at the 8th Annual Meeting of the American Society for Range Management in San Jose, California (Sampson 1955). That address dealt with 2 aspects of range management: 1) an appraisal of the influence of research in formulating range management practices at that time, and 2) the future research needs of the field of range management. This paper is retrospective, evaluating the impact of past research efforts and other events that may have shaped the management and utilization of rangelands. In 1989, Dr. Sampson's widow and her sister bequeathed almost 3,000 acres of excellent bluestem range to the range research program at Kansas State University. Not only did Dr. Sampson contribute greatly to the range profession, but through his wife's gift, that contribution continues. In his talk, Dr. Sampson stated, "In future years, progress in range rehabilitation will depend upon the effectiveness of the research program and the extent to which the findings have been applied". This talk will, in part, deal with whether we have been effective in research and whether we have applied those research findings extensively.

Achievements are relative. Obviously, the first step by a child is monumental in the eyes of proud parents, but hardly earthshaking to others. However, that first step may be the first for an Olympic champion. So, my initial task will be to put achievements in management and utilization of privately-owned ranches into a framework that highlights the simple, but monumental, first steps towards better use of rangelands.

The initial achievement that started all management of rangelands was the domestication of ungulate herbivores. The hunter/gatherer society merely existed within the framework of natural ecosystems and did not alter resource allocation or control population dynamics. Once animals were domesticated and controlled, mankind became a harvestor/manipulator (Van Dyne 1966) with the power to alter temporal and spatial utilization of rangelands. His wealth was determined largely by the numbers of animals and range resources that he controlled. With only the range resource with which to work, movement away from the hunter/gatherer system was minimal. Agrarian pursuits allowed for greater control over livestock numbers. One single achievement in range and forage science, haying, had profound historical consequences. Dyson (1988), a theoretical physicist, summarized that monumental achievement in management and utilization of forages as follows:

> "The technologies which have had the most profound effects on human life are usually simple. A good example of a simple technology with profound historical consequences is hay. Nobody knows who invented hay, the idea of cutting grass in the autumn and storing it in large enough quantities to keep horses and cows alive through the winter. All we know is that the technology of hay was unknown to the Roman Empire but was known to every village of medieval Europe. Like many other crucially important technologies, hay emerged anonymously during the so-called Dark Ages. According to the Hay Theory of History, the invention of hay was the decisive event which moved the center of gravity of urban civilization from the Mediterranean basin to Northern and Western Europe. The Roman Empire did not need hay because in a Mediterranean climate the grass grows well enough in winter for animals to graze. North of the Alps, great cities dependent on horses and oxen for motive power could not exist without hay. So it was hay that allowed populations to grow and civilizations to flourish among the forests of Northern Europe. Hay moved the greatness of Rome to Paris and London, and later to Berlin and Moscow and New York."

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Certainly, there are few in the forage and range professions who can lay claim to such an achievement as that provided by an anonymous visionary centuries ago. Therefore, park your egos at the door, while many recent achievements have been noteworthy, they pale in comparison to those simple yet essential achievements of yesteryear.

Fast forward to the late 19th and early 20th centuries. A general statement that rangelands had been abusively grazed during the latter half of the 19th century is largely accepted. Certainly, those areas that remained in federal ownership and were grazed as open range were subject to overgrazing. Cotton (1904) reported on range conditions of Central Washington and stated that "the deterioration of the range is due to overgrazing, and so long as it remains public domain little can be done to improve its condition. In most cases, the stockman using the range is trying to get all out of it that he can without reference to the future. He is not to be blamed for using it in this manner, for he knows that if he does not, some one else will." One could conclude from that statement that a singularly great achievement in rangeland use would be the transfer of that land to private ownership. While that conclusion may be valid, it would be an egregious error to lay range deterioration due to overgrazing entirely at the foot of ownership. It is likely a misconception that free grazing leads to overstocking. Certainly, private rangelands have been rated as having a higher range condition by the various schemes for determining that elusive somewhat arbitrary value judgment. Land ownership lies in the private sector in the Great Plains and eastern forest ranges, while over half the western range area is federally owned. Ownership has had an impact on the condition of rangelands. Estimates of range condition for North and South Dakota, Nebraska, and Kansas indicated 66% of the private rangeland in those states was in good to excellent condition, while western rangelands had 72% of their area in poor to fair condition. Private ownership apparently was incentive to maintain quality rangeland (USDA 1974). Unfortunately, conclusions have been drawn with that limited scope. Perhaps, the most convincing evidence that rangelands in the Public Domain were in the poorest condition lies in the land alienation scheme. Those lands with deeper soils and with water were taken under the various land alienation acts, leaving extremely low-productivity areas as public rangeland (Kollmorgen 1969). During the late 19th century throughout the Great Plains region, even privately-owned range areas were considered severely deteriorated. Ownership issues did not entirely explain the apparent abusive grazing behavior.

Economic incentive on privately-owned rangelands is almost always the reason for change (Conner 1991). Possibly, the salvation of privately-owned rangelands in this country can be attributed to the a single mechanical device, the livestock scale. Until such time as there was an economic penalty for reduced individual animal performance due to overgrazing, the economic advantage was for maximum numbers with reasonable weight and health considered. As long as livestock were sold on a per head basis with little economic penalty for differences in weight, most livestock producers grazed at rates which supported the greatest numbers of livestock, not the fattest. With the advent of marketing of livestock on a per pound basis, the first true impact of range research programs could be realized. Stocking rate studies sprouted in almost every state to quantify stocking rate/animal gain relationships. While these studies were not revolutionary in their design or outcome (they were designed such that a rate that had been shown to be sustainable and with the greatest number of animals would be the most desirable, i.e., moderate stocking), they allowed range management specialists to show economic benefit from stocking rates that were less than could be sustained with reduced individual performance but highest gain per unit area (heavy grazing).

Certainly, domestication of ungulates, planting and harvesting of crops, hay making, and changes in marketing were the prominent features that set range management and utilization on its present course. Before enumerating the modern-day achievements, it is necessary to detail the research setting that produced those achievements.

Range Research

Certainly, one of the major achievements in utilization and management of rangelands was the development of the research and extension infrastructure. That infrastructure has its roots in several acts of Congress that centered the range research capacity in the states. By providing land grants, the First Morrill Act (1862) was intended to provide colleges for the benefit of agriculture and mechanical arts. Those lands were to be used to provide funding for establishment and operation of the land-grant institutions. To further stimulate agricultural research, the Hatch Act (1887) provided funding to establish agricultural experiment stations in connection with the colleges previously established by the Morrill Act. Other subsequent acts including the Adams Act - 1906, the Purnell Act - 1925, and the Bankhead-Jones Act -1925 and 1946 reaffirmed the policy of the Congress to continue support of the state agricultural experiment stations. In 1890, Congress passed the Second Morrill Act which provided direct appropriations to states that showed race or color was not an admissions criterion. In the segregated south, separate institutions were allowed under this bill, thereby creating the so-called 1890's institutions. The American Indian Higher Education Council (AIHEC) successfully lobbied Congress in 1994 to attain land-grant status for 29 tribal colleges. The other piece of the research puzzle was the Agricultural Research Service (ARS) which was established on 2 November 1953, which merely renamed the research by USDA personnel. Congress first authorized federally supported agricultural research in the Organic Act of 1862, which established what is now USDA.

Since knowledge, not communicated, is not knowledge, the establishment in 1914 of a partnership between the USDA and the land-grant universities, as the Cooperative Extension Service under the Smith-Lever Act, was seminal in the goal of improved management and utilization of rangelands. Further dispersal of range research findings was precipitated by the passage of the Soil Conservation Act in April of 1935 in response to soil erosion, primarily associated with recurring droughts. Without a doubt, the Information Age has dawned, and with the almost instantaneous electronic dissemination of information will accelerate the changes wrought by current and future research.

Our current research is only as good as the foundation that was laid earlier. That foundation was based on a different research philosophy than currently exists. Imagine getting extramural funding to do a stocking rate study or a life history study today. Originally, research on rangelands was largely funded by agricultural experiment stations with formula funding from federal and state sources and the ARS. Recently, there has been great concern over funding sources for applied and basic research (Engle and Waller 1993). Derner

(1994) provided support for that contention. He concluded that the decline in federal and state funding for applied research has led to an increased emphasis on extramural funding that is largely in the basic research area. With only 5% of all grant proposals funded, a premium is being placed on recruits to the range research system with the ability to attract extramural funding. That funding is inherently inefficient with typical projects lasting only 2–3 years, with a startup time of several months to a year and a phase out time of several months as well, research topics are severely limited and are in no way conducive to long-term answers to complex issues. Research topics are selected at a national level to ostensibly reduce the chance of failure and to spend research dollars wisely. To insure that the research will be successful, 3 or more peer reviews are conducted to further reduce the risk of failure. **The magnitude of the risk taken is likely the magnitude of the discovery.** Our research infrastructure is designed to minimize risk, thereby minimizing the magnitude of our discovery. While more emphasis should likely be placed on applied research, basic research must be funded as well, but not at the expense of the applied area.

What does the privately-owned ranching community want from research? There is certainly an indication from my years in the Kansas Flint Hills that changing management strategies is relatively rare. Woodrow Wilson said," If you want to make enemies, try to change something". Change has occurred and some of that change has been good and some bad. In general, the research that the rancher wants on privately-held rangelands leads to a greater profit while maintaining a diverse healthy resource (Conner 1991). He wants that knowledge provided to him in clear, concise language easily applied to his operation. That requires a strong link between those who communicate with the rancher and the researcher. In general , the rancher wants to be respected for his conservation of the resource as well. While it is certainly to his benefit to maintain a healthy resource, there are management strategies that may significantly alter the resource and still maintain a profit. The rancher typically shuns those.

What has the research community provided to the ranching industry? Those major achievements in the management of privately-owned rangeland are enumerated below. Certainly, there will be those I miss, but quoting Desai, "An expert gives an objective view. He gives his own view." Larry Newell, a former grass breeder at the University of Nebraska-Lincoln, rose at the Western Grass Breeders Conference in Manhattan, Kans. in 1965 and opined, "I am particularly impressed with my views on this matter and they are....". I don't profess to be as confident as Dr. Newell was at that time, but here are my candidates for significant achievements in utilization and management of privately-owned rangelands.

• Documentation of the relationship between stocking rate and animal performance.

Undoubtedly, the major modern achievement was characterizing and quantifying the relationships among stocking rate and per animal and per head gains on rangelands. Undoubtedly, economic forces would have defined stocking rate in a similar manner, but the huge database that was created by stocking rate studies throughout the country offered experimental results that could be used in convincing ranchers that proper stocking rates were the most advantageous. Because economic health required good rangeland health, rangelands generally have improved during this century. Misconceptions still abound within this basic relationship. One common problem arises when range specialists advise that increased range condition will ultimately lead to a greater total amount of livestock product to sell. Improved range condition, any way you wish to define it, relies on reduction in stocking rate which improves per head production but reduces production per unit area. Ranchers know that! Apparently, we as range researchers do not. The illusion that the improvement in range condition will increase livestock production per unit area seems like common sense. Common sense is what tells you the world is flat. To this day, there is a perception in the minds of many that the reason for reductions in livestock gains or reproductive performance is due to a lack of forage quantity, when in reality, for almost all situations, it is the quantity of quality forage that determines livestock productivity.

• Formulation of selective, translocated herbicides.

The secret discovery of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic (2,4,5-T) during World War II was not one of those contributions of war. In reality, the work had begun much before and only because of the potential of many compounds in biological warfare was there any restriction on the publication or use of the phenoxy herbicides for agricultural purposes (Peterson 1967). Phenoxy herbicides have their origin in the 1930's with work by familiar faces such as F.W. Went, A.E. Hitchcock, P.W. Zimmerman who were working with growth regulators. By late 1944, the first publication concerning herbicidal activity of 2,4-D was reported in by Hamner and Tukey (1944). Because phenoxy herbicides selected mostly dicot plants, they were ideal in control of broadleaf plants in grassland range. While this important achievement was important to improving rangelands that had changed from grass dominance to weedy forb and woody species, it provided an escape from the ultimate question, why did the change occur. The popular whipping boy was of course overgrazing. It is likely that overgrazing was only one cause. Many changes from natural controls likely could be identified as culprits in weed and brush invasions in rangelands. Reductions in fire frequency and change from multifaunal to monofaunal grazing were likely as important or more important than overgrazing. As herbicides have been banned from use on rangeland, i.e. 2,4,5-T, new research has and will continue to focus on the natural controls of many weed species, including prescribed fire and grazing with more than one species of livestock.

• Implementation of prescribed burning.

The reintroduction of fire into range plant communities has promoted changes in plant populations that may more nearly represent stable natural ecosystems. Timing, frequency and fire intensity have been the primary areas of research and fire prescriptions can attain many and varied range management objectives. Included in those objectives are weed and brush control, improved grazing distribution, increasing forage quality, wildlife habitat manipulation, removal of excessive litter accumulations, and seedbed preparation.

• Reseeding and genotypic identity of range plant materials.

Because large areas of rangeland which were plowed could not sustain tillage agriculture, there was a need to return them to self-sustaining ecosystems. Also there were areas where mechanical brush control left rangelands devoid of grazeable vegetation. Secondary successions on these sites were slow to extremely slow, so reseeding was introduced to speed the transition of formerly-tilled areas to ecosystems that approximated the former natural rangeland. Research has addressed time and depth of planting, seedbed preparation, rangeland drill design and function, and plant materials. One important achievement was the development of so-called "named varieties", cultivars that had known genetic origin and adaptation. The range seed production industry has provided those cultivars for revegetation during the past 50 years or so. Soil Bank and Conservation Reserve Programs have benefited greatly from the ability to supply adapted seed to diverse ecologic zones throughout the privately-owned range areas.

• Matching forage quality with forage requirement.

Over many decades, there has been a concerted, mostly successful effort to describe quality of numerous forages using various quality tests. Concurrently, range animal nutrition groups have defined the nutritional requirements of range livestock. The admirable achievement of these groups has been to provide, through supplementation or complementary forages, diets which match requirement and availability for growth and reproductive livestock enterprises. While use of complementary forages and supplements has been a part of range use a century or more, the refinement provided by recent research has improved livestock production efficiency greatly.

• Basic research on the physiology and morphology of range plants.

Management strategies have been tailored to accomplish certain management objectives using information on food reserve cycles, meristem placements, nutrient status, propagation strategies, and water relations. Examples of improved utilization of rangelands include proper timing of herbicide application, haying, mechanical brush control, and prescribed fire based on translocation of storage carbohydrates to reserve storage organs. Knowledge of translocation of nutrients from senescing leaves is important in forage quality decisions. Grazing system design relies heavily on source/sink relationships of carbon and other nutrients. The use of mechanisms elucidated through basic research has fueled the modeling effort in range ecosystems. Indeed, the why of plant physiology and morphology is critical in development of the management practices applied to rangelands.

• Implementation of grazing systems that improve both plant and animal components.

Research on grazing systems was likely fueled most by the desire to improve range areas that had suffered from overgrazing. Indeed, a critical look at the results from most grazing studies shows that in almost all cases plant productivity improved, but in almost all cases individual animal productivity declined. The greatest achievements in grazing system research and application comes from those systems that have fostered improvement of range health without reduced or with improved individual animal productivity (Launchbaugh et al. 1978). Research in the grazing systems area has been difficult because of the tremendous capitol required for experimental designs to test those systems. Research on grazing systems requires that each treatment be compared using equal stocking rates and equal pasture size and uniformity. When those design criteria have been met, it is difficult to justify use of most grazing systems if both animal and plant health is considered. Recent work has explained much of the perceived greater plant production on many specialized grazing systems. If there is reduced animal performance, then there is reduced forage quality, and if there is reduced forage quality then there is reduced intake. That translates into a greater amount of herbage remaining at the close of the grazing season. Increasing stocking rates to take advantage of the increased forage remaining further reduces individual animal performance. One could conclude that after almost a century of grazing systems research that few systems address the needs of both the plant and the animal.

• Information dispersal.

The development of the state and local extension systems has given the range research community an opportunity disperse discovery to the entire ranching community. Combined with the Natural Resource Conservation Service conservation districts, we have been fortunate to be able to reach the individual rancher with relative ease, provided that rancher wished to be reached and the message was legitimate. The owner/operator on privately owned rangelands has no obligation to seek or take advice from those dispensing it. There must be a 2-way street in ranchers relations. Much of the research that has proved successful in the past has originated in communication between the ranching community and the research/extension groups. The future promises an even greater opportunity. Through electronic access, information will become available more quickly and extensively. All extension and research publications within a state will be available and direct access to the researcher through e-mail will aid in greater achievements in management and utilization of privately-owned rangelands.

What other clientele groups exist for the range research community? Privately-owned rangelands, while an economic enterprise, may and likely should serve others groups as well. Quality water resources, wildlife, and aesthetic values are derived from those areas. These resources offer another potential income source, but the ranching community in many areas has not exploited that area. Hunting leases are common in certain range areas, almost nonexistent in others. Scenic easements have been purchased in some areas for their aesthetic value. Because these resources reside in private hands, both government and the individual must interact with the ranching community to serve the needs of the broader population. There must be a cooperative spirit with little confrontation and a great deal of understanding on both sides, private and public.

Where have we failed? Failure in the research area is not defined as research which was not useful in improving rangelands. We have spent huge amounts on range fertilization, grazing systems, plant introductions, and trying to predict herbage production with little success, but the information we received has been useful in selecting profitable practices. Alternatively, failure should be defined as not addressing problems which were known. Probably the greatest deficiency in the range research effort has been the lack of resources devoted to the economic area. If one enumerates the number of research publications devoted to different research areas, they will find that there are relatively few published studies in the range economics area. In fact, the number of research programs that regularly include an economic component is minuscule. We have generally failed to provide cost/benefit information for most of our recommendations. It seems the rancher must be the researcher when it comes to risk of capitol and labor.

Conclusions

In most ways, the management and utilization of private rangelands has changed little since Dr. Sampson's address, and that is likely the course that should have been followed. With natural ecosystems constrained by numerous resource deficiencies, management strategies must conform to those natural mechanisms that define rangeland productivity and response to perturbations. Because of the low economic output from the range enterprise, costly inputs must be justified economically. Rarely have we found management inputs that significantly improved the profitability of the ranching enterprise. Indeed, the most significant research findings and their application have been the reimposition of some natural ecosystem process, such as fire, that had been eliminated from the ecosystem previously. Research that improves the efficiencies of resource allocation and utilization will offer opportunity to improve management and utilization of privately-owned rangelands. Examples of research that has and will improve the economic status of the rancher include those that improve the conversion of ingested forages to the maximum amount of salable product, and research that improves the conversion efficiency of scarce ecosystem resources to forage for wildlife and livestock. I tell my class at the beginning of each semester that they can have the short version of the course or the semester-long version. The short version is "to put the proper number of livestock on the range at the proper time of year and for the proper duration". Our job in research is to define the proper livestock number, the proper time of the year, and the proper duration. The semester-long version merely justifies my existence.

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Achievements in management and utilization of southern grasslands

CARL S. HOVELAND

Hoveland is Terrell distinguished professor in the Department of Crop & Soil Sciences at the University of Georgia, Athens, Georgia 30602.

Abstract

Grasslands in the humid southern USA are utilized primarily for grazing on improved pastures, most of which were developed since the 1930s and 1940s. Virtually all of these grasslands were developed from species introduced from other areas of the world. Major achievements in successfully developing these grasslands, often on eroded cropland, were: (a) introduction of Kentucky 31 tall fescue (*Festuca arundinacea* Schreb.); (b) introduction of Pensacola bahiagrass (*Paspalum notatum* Flugge); (c) breeding of Coastal bermudagrass [*Cynodon dactylon* (L.) Pers.]; (d) fertilizer and lime use along with availability of low-cost N; (e) no-till planting of winter annual grasses; (f) pasture renovation with legumes; (g) herbicides for weed control; (h) recycling of agricultural wastes in forage production; (i) development of round hay baler; (j) controlled grazing; (k) discovery of the tall fescue fungal endophyte and its effect on livestock and the grass plant; (l) development of grazing-tolerant alfalfa; (m) improved cool season annual grasses and legumes for winter grazing; and (n) near infrared reflectance spectroscopy for rapid and low-cost forage analysis. Future areas of emphasis in improvement of these grasslands may include: (a) greater use of grazing-tolerant grasses and legumes; (b) stress-tolerant tall fescue with "friendly" non-toxic endophytes; (c) feed antidotes to the toxins of endophyte-infected tall fescue; (d) use of herbicide-and pest-resistant biotechnology genes in forage plants; (e) use of gypsum to alleviate subsoil acidity and improve rooting depth of aluminum-sensitive forage cultivars; (f) greater use of computers in information access and decision making by livestock producers; (g) greater use of forages for wildlife food; (h) breeding of pasture plants with greater winter productivity; (i) development of a perennial grass biomass energy industry for electrical generation and liquid fuel production.

Resumen

Los pastizales de la región húmeda del sudeste de E.U.A. son utilizados principalmente para el apacentamiento en pastizales mejorados, la mayoría de los cuales se desarrollaron desde las décadas de 1930 y 1940. Virtualmente todos estos pastizales se son de especies introducidas de otras áreas del mundo. Los mayores logros que contribuyeron al establecimiento exitoso de estos pastizales, los cuales a menudo se establecieron en áreas de cultivo erosionadas, fueron: (a) la introducción del "Kentucky 31 tall fesuce" (*Festuca arundinacea* Schreb.); (b) la introducción del "Pensacola bahiagrass" (*Paspalum notatum* Flugge); (c) el mejoramiento del "Costal Bermuda" (*Cynodon Dactylon* (L.) Pers.); (d) El uso de fertilizantes y cal junto con la disponibilidad de nitrógeno a bajo costo; (e) la siembra de zacates anuales invernales en sistemas de cero labranza; (f) la renovación de praderas con leguminosas; (g) el uso de herbicidas para el control de maleza; (h) el reciclaje de subproductos agrícolas en la producción de forraje; (i) el desarrollo de la empacadora de pacas redondas; (j) el apacentamiento controlado; (k) el descubrimiento del hongo endófito del "Tall fescue" y sus efectos en el ganado y la planta; (l) el desarrollo de alfalfa tolerante al apacentamiento; (m) el uso de especies mejoradas de zacates y leguminosas de estación fría para el apacentamiento en invierno y (n) el uso de la espectroscopia de reflectancia infrarroja para análisis rápidos de forraje a bajo costo. Las áreas a enfatizar en el futuro para mejorar estos pastizales pueden incluir: (a) un mayor uso de zacates y leguminosas tolerantes al apacentamiento; (b) el uso de "Tall fescue" tolerante al estrés con hongos endófitos no tóxicos; (c) el uso antídotos alimenticios para las toxinas producidas por el "Tall fescue" infectado por hongos endófitos; (d) el uso de biotecnología para la inclusión de genes que le confieran a las plantas forrajeras resistencia a herbicidas y plagas; (e) el uso de yeso para disminuir la acidez del subsuelo y mejorar la profundidad de enraizamiento de cultivares forrajeros sensitivos al aluminio; (f) un mayor uso de computadoras como herramienta de los ganaderos para el acceso información y tomar decisiones; (g) un mayor uso de forrajes como alimento para la fauna silvestre; (h) el mejoramiento de plantas de pastizal con una mayor productividad en invierno; (i) el desarrollo de una biomasa de zacates perennes para la generación de energía eléctrica y combustibles líquidos.

Key Words: forage achievements, southern USA, grazing, future forage emphasis

The southern USA from eastern Texas and Oklahoma to Virginia and Georgia on the Atlantic coast is a humid region with annual rainfall ranging from 1,000 mm to over 1,600 mm (Ball et al. 1996). The native vegetation was mainly deciduous and coniferous forest. Much of this land was cleared and continuously cropped with cotton (*Gossypium hirsutum* L.) and other row crops for over a century, often resulting in severe soil erosion. Soils throughout much of the region tend to be acid and low in nutrients. Acid subsoils which cause aluminum or manganese toxicity are a problem in subtropical clay and sandy soils of the lower South. Water-holding capacity of many soils in this region is low and this is compounded by acid subsoils which often results in shallow plant root development. Thus, droughts can be a problem in this relatively high rainfall region, a major factor in the shift from crop production to forestry or improved grasslands.

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Southern grasslands are overwhelmingly utilized for grazing rather than for harvested and stored forage as is common in many other areas of the USA. There are about 24 million hectares of pasture in the South which is 75% of the total pastureland in humid regions of the USA (Hoveland 1992). In the upper South states of Kentucky, Tennessee, Virginia, and much of North Carolina, tall fescue (*Festuca arundinacea* Schreb.) is the dominant grass, with lesser amounts of orchardgrass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis* L.), and timothy (*Phleum pratense* L.). Tall fescue is dominant in northern parts of Arkansas, Mississippi, Alabama, Georgia, and South Carolina. In the lower South, from eastern Oklahoma and Texas to the Atlantic Ocean, the major grasses are bermudagrass [*Cynodon dactylon* (L.) Pers.], bahiagrass (*Paspalum notatum* Flugge), dallisgrass (*Paspalum dilatatum* Poir.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), annual ryegrass (*Lolium multiflorum* Lam.), and smaller amounts of tall fescue. Major legumes in the upper South include white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), and alfalfa (*Medicago sativa* L.). Although legumes are less important in the lower South because of greater environmental stress, they include white clover, red clover, sericea lespedeza [*Lespedeza cuneata* (Dum-Cours) G. Don], alfalfa, Korean lespedeza (*Lespedeza stipulacea* Maxim.), perennial peanut (*Aarachis glabrata* Benth.), and the winter annual clovers, arrowleaf (*T. vesiculosum* Savi), crimson (*T. incarna - tum* L.), berseem (*T. alexandrinum* L.), and rose (*T. hirtum* All.).

Southern grasslands are mainly used for beef cow-calf production, this region having nearly one-half of USA beef cows (Anon. 1998). Grazing of weaned beef calves on high-quality pastures to feeder weight is another important enterprise. Dairying, mainly in the upper South, utilizes a considerable amount of grassland. Pleasure horses continue to increase in number and utilize substantial areas of pasture as well as hay. Goat and deer farming for meat production on pasture are also increasing.

Achievements in Management and Utilization

Although the South was primarily a forested landscape, on favorable sites with better soils there were native warm season bunchgrasses such as big bluestem (*Andropogon geraardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], switchgrass (*Panicum virgatum* L.), and eastern gamagrass [*Tripsacum dactyloides* (L.) L.]. These grasses were soon overgrazed by cattle of early settlers and replaced by less palatable poor quality species such as broomsedge (*Andropogon virginicus* L.) (Ball et al. 1996). Thus, when animal agriculture replaced much of the row cropping on eroded, acid, low fertility soils during the 1930s to1950s it was based on introduced forage species from other areas of the world. The transformation of the Southern landscape to planted grasslands in a humid environment was dependent on research and extension achievements since the 1930s. Some of the most significant of these achievements are reviewed here.

Introduction of Kentucky 31 tall fescue

Cool season grasses such as orchardgrass, timothy, and Kentucky bluegrass had been reasonably successful on favorable sites in the upper South but on droughty soils and in the lower South they did not persist. Thus, over much of the Southern region there was no adapted cool season perennial grass to provide grazing during the long winter dormancy season of warm season perennial grasses. The release of 'Kentucky 31' tall fescue in 1943 by E.N. Fergus (1952) at the University of Kentucky is without doubt the single greatest achievement in the development of Southern grasslands. The rapid acceptance and planting of Kentucky 31 tall fescue covered pastureland and roadsides over much of the South, making it difficult today to visualize the landscape without this grass which has contributed so much to livestock production and soil conservation. Tall fescue is the most widely grown grass in the humid area of the USA, covering over 14 million ha, most of which is the Kentucky 31 cultivar (Buckner et al. 1979). The reasons for its acceptance are probably the features originally listed by Fergus (1952): dependability, adaptability to a wide range of soils, affording grazing most of the year, and palatability to livestock, although the latter feature may be questioned in view of the toxic fungal endophyte problem.

Breeding of Coastal bermudagrass

Common bermudagrass was brought to Savannah, Georgia in 1751 and spread throughout the South where it became a valuable pasture plant (Burton and Hanna 1995). However, when Dr. Glenn Burton came to Tifton, Georgia in 1936 to begin a forage grass breeding program, common bermudagrass was a serious weed in cotton and corn crops. Thus, his choice of bermudagrass for the forage breeding program was not well received by local row crop farmers. 'Coastal' bermudagrass, released in 1943, was the first warm season perennial grass cultivar developed with modern breeding technology (Burton 1954). However, it had the handicap of requiring vegetative propagation so methodology had to be developed for dependable establishment. In spite of this, Coastal eventually became widely planted because of its superior characteristics: much higher yields than common bermudagrass, a longer productive season, greater disease resistance, deeper root development and more drought tolerance, and rapidity of hay drying. Coastal bermudagrass filled an important need in supplying dependable forage for livestock in the lower South, becoming the most important hay plant in the lower South, grown on about 2 million ha. Since then, additional improved cultivars have been developed by Dr. Burton with characteristics such as better cold hardiness, forage yield, and digestibility (Burton and Hanna 1995).

Introduction of Pensacola bahiagrass

Common bahiagrass, a relatively low-yielding grass with little winter hardiness, had been grown in the sandy Gulf Coastal Plain area since the early 1920s (Burson and Watson 1995). In 1935 an observant county agent, E. H. Finlayson, discovered a superior bahiagrass growing near the docks in Pensacola, Fla. which was increased as the 'Pensacola' cultivar (Finlayson 1941). This chance introduction, probably from southern Brazil, has been widely planted on sandy Coastal Plain soils and makes up most of the USA bahiagrass hectarage. This aggressive and competitive grass continues to be highly popular among beef cow-calf producers for dependable low-input pasture because of its tolerance to soil acidity and low fertility, drought, and close continuous grazing. More recently, the 'Tifton 9' cultivar with 40% higher yield was released by Burton (1989) and is having an important impact.

Fertilizers, lime, and low-cost nitrogen

High analysis fertilizer and lime use has been a major factor in Southern grassland improvement, mainly because most soils in the region are acid and low in nutrients. Without these inputs, higher yielding forage cultivars would not have achieved their potential. Most of all, the availability of high-analysis synthetic N fertilizers at lower cost made it possible to produce dependable high yields from improved forages such as Coastal bermudagrass (Wilkinson and Langdale 1974). An unfortunate effect of low-cost N fertilizer has been to discourage the use of clovers and reduce the emphasis on development of adapted clovers and other legumes.

No-till planting of winter annual grasses

Winter dormancy of bermudagrass and bahiagrass in the Lower South offered an opportunity to grow N-fertilized rye or wheat (Ball et al. 1996). However, unsatisfactory sod penetration by conventional grain drills limited this practice until development of sturdy no-till drills which greatly expanded winter and spring pasture.

Pasture renovation with legumes

Planting of alfalfa, red and white clovers into tall fescue pastures supplies N to the ecosystem, improves nutrient quality of grazing, and often increases length of the grazing season (Ball et al. 1996). This has allowed the establishment of legumes in the grass sod by cattle trampling or drilling without plowing, an important consideration on erodible land. Herbicides have been useful to kill or suppress tall fescue in no-till planting. No-till planting of legumes has been widely adopted in the upper South but it has been much less successful in the lower South because of greater environmental stress.

Herbicides for weed control

The advent of dependable herbicides has greatly aided forage establishment and reduced weeds in pasture and hay land, improving productivity and eliminating some livestock toxicity problems

Use of agricultural wastes in forage production

In intensive poultry producing areas, broiler and layer litter has been commonly utilized to improve productivity of pastures and hay land. Dairy and swine wastes are also important in some areas. Application of these wastes has been beneficial in reducing pasture fertilizer costs but they have also had adverse effects in eliminating legumes and accentuating the toxicity of endophyte-infected tall fescue.

Development of round hay baler

Haymaking was at one time a labor intensive operation when it was handled as a loose commodity. Mobile balers making rectangular small bales improved on this but were relatively slow. Machines that picked up hay from a windrow and rolled it into a large round bale required more power than balers making small rectangular bales but were a major achievement in reducing labor requirements and speeding up the operation to avoid rain damage at critical times (Rotz and Muhtar 1991). Unfortunately, this has been a mixed blessing as most of these large round bales are generally stored outside on the ground exposed to weather so losses of edible forage often approach 40% (Rotz and Muck 1994).

Controlled grazing

Uncontrolled grazing practices often result in substantial waste during periods of surplus growth, along with reduced forage quality and tiller development. The fundamental work of Mott (1960) established the effects of grazing pressure on gain per animal and gain/unit area in pasture. From this, practical methods of grazing management were devised to improve livestock productivity (Blaser et al. 1973). The development of improved polywire and polytape electric fences with low impedence chargers greatly reduced the cost of erecting cross fences on livestock farms. This made it possible to cheaply fence off areas to conserve unneeded pasture for hay and reduce waste. Further, it has allowed practical development of controlled grazing systems to improve pasture utilization and reduce waste.

Discovery of the tall fescue fungal endophyte and its effect on livestock and the grass plant

Although tall fescue flourished in stressful environments, it earned a reputation for poor animal performance. This stimulated a great deal of research effort for a number of years but no success in determining the cause of the toxicity problem until in 1976 USDA scientists at Athens, Ga. identified a fungal endophyte in tall fescue as the probable causal agent (Bacon et al. 1977). The endophyte toxicity relationship was conclusively shown in a 4-year Alabama grazing study (Hoveland et al. 1983). Since then, cultural management practices such as dilution with legumes or other grasses and feeding non-toxic hay have been utilized by many livestock producers to reduce toxicity problems. In spite of this, economic losses from reduced conception rates and weaning weights of beef cattle grazing tall fescue in the USA have been conservatively estimated at $609 million annually (Hoveland 1993). Identifying the causal agent has allowed researchers to develop improved non-toxic endophyte-free cultivars that with good management can give excellent animal performance. Unfortunately, these endophyte-free cultivars are less tolerant than infected tall fescue of drought and overgrazing in summer than infected grass, often resulting in serious stand losses. The endophyte discovery stimulated research on endophyte-plant relationships, and the development of more persistent endophyte-free tall fescue cultivars.

Development of grazing-tolerant alfalfa

Alfalfa, the most productive long-season forage legume in the USA, was primarily harvested because successful grazing required very careful rotational stocking to maintain stands and vigor. The development of a truly grazing-tolerant alfalfa cultivar in Georgia made it possible to utilize this legume in pastures for dairy cattle, beef steers and heifers, and creep grazing of calves (Bouton et al. 1991). This development opened new opportunities for livestock producers, resulting in grazing-tolerant alfalfa being widely planted in the upper South and Midwest. Equally important, the technique pioneered by Bouton is now being used to enhance grazing tolerance in other forage species (Bouton et al. 1997).

Improved cool season annual grasses and legumes for winter grazing

Winter annual grasses and legumes are used in the lower South for high-quality pastures grazed by dairy cattle and weaned beef calves destined for western feedlots. Rye, wheat, and oats are widely grown with many dependable disease-resistant cultivars such as ‘Wrens Abruzzi’ rye developed by cereal breeders. ‘Gulf’ annual ryegrass had a major impact because it was the first cultivar with resistance to crown rust, a major problem in the Gulf Coast area (Weihing 1963). ‘Marshall’, a more recent annual ryegrass cultivar with more cold tolerance and higher yields, has produced 27 to 77% greater steer gains than Gulf annual ryegrass in Alabama grazing trials (Bransby et al. 1997). ‘Dixie’, the first naturally reseeding crimson clover, was released in 1946 and has remained the dominant cultivar (Hoveland and Evers 1995). ‘Yuchi’ arrowleaf clover, released in the mid 1960s, had a longer productive season and less bloat potential than crimson so by 1992 it was the most widely grown winter annual clover (Hoveland and Evers 1995). Since then, disease problems have reduced the hectarage of this clover.

Near infrared reflectance spectroscopy for forage quality analysis

Hay and silage analysis for nutritive quality is necessary in feeding to meet nutrient needs of animals. Unfortunately, chemical procedures for quality evaluation are slow and expensive. Near infrared reflectance spectroscopy for forage quality analysis, first used in 1976, has been rapidly adopted by laboratories because it is accurate, rapid, repeatable, and inexpensive (Norris et al. 1976). It has given livestock producers useful information in feeding, a better appreciation of forage quality, and encouraged better forage management. As a result, more hay is being bought and sold on the basis of forage analysis rather than on color, smell, or leafiness.

Future Areas of Emphasis in Grassland Improvement

Predicting the future is always risky because a single innovation, research breakthrough, political decision, consumer attitude change, or economic shift may alter the production and market arenas. Science is unpredictable and one can never say where a given field of research will lead (Jacob 1998). This is complicated by the interrelationships of world trade, political instability of many countries, and pressures of growing populations on land and other resources. It is likely that humid grasslands will shrink in area with more urbanization and pressure for cropping on the best soils. Thus, it is likely that future humid grasslands will increasingly be located on less desirable sites with greater environmental stresses on forage plants. Pasture cultivars of the future must be able to tolerate the stresses of poor soils, grazing, and possibly more heat and drought if global warming becomes a reality. In this context, some future areas of emphasis on grassland improvement and use are considered.

Greater use of grazing-tolerant grasses and legumes

Most perennial cool season grass and legume cultivars in the USA have not been selected under grazing for pasture use (Bouton et al. 1997). These cultivars perform well when harvested as hay or silage but often do not persist under close continuous grazing common on beef cattle farms. The most successful pasture grasses have been those selected from old pastures such as Kentucky 31 tall fescue. Future pasture grass and legume cultivars will be selected under close grazing by livestock so they are tolerant of frequent close defoliation and hoof treading. Total forage yield of grass and legume cultivars will be of less importance than dependability and persistence under grazing in competition with other species.

Stress-tolerant tall fescue with "friendly" non-toxic endophytes

The fungal endophyte *Neotyphodium coenophialum* is best known for its toxic effects on livestock consuming the forage but there is also a mutualistic relationship which benefits the host plant, in this case tall fescue. The most important benefit appears to be drought tolerance by several means such as faster and deeper root development, higher stomatal resistance, lower net photosynthetic rate, enhanced osmotic adjustment in the meristematic and growing zone, and better maintenance of water content in the growing zone (Latch 1997). Other benefits appear to be increased herbage production and plant tillering, more efficient utilization of N, improved seed production, and improved resistance to several diseases and nematodes.

The discovery of non-toxic endophytes has opened exciting opportunities for the future that have the potential to overcome the serious livestock losses with tall fescue. These non-toxic endophytes can be inserted into endophyte-free tall fescue and furnish excellent animal performance while the host plant appears to have benefits similar to plants containing toxin-producing endophytes (Latch 1997). Pastures planted with tall fescue containing a "friendly" endophyte will be non-toxic but be as persistent under grazing as infected toxic tall fescue. In addition to benefitting traditional tall fescue production areas, this development should allow expansion of non-toxic tall fescue planting into stressful environments where endophyte-free cultivars do not persist.

Antidotes to the toxins of endophyte-infected tall fescue

Immunization of animals against various disease organisms is a common practice. A similar system for fescue toxicity would be an effective way to protect animals from the syndrome while utilizing low-cost existing endophyte-infected tall fescue pastures. Research in progress suggests that this approach has promise. Immunization would involve direct introduction of a generated immunogen or antigen against which the recipient animal produces antibodies which protect against the toxins (Larson 1997). To be successful, it will be necessary in stimulating the intestinal immune system to secrete antibodies at rumen and intestinal surfaces in sufficient quantity to neutralize ingested toxins if the antibody/antigen complex is not degraded. Another approach with promise is treatment of animals with domperidone when grazing toxic tall fescue. This D2 dopamine receptor antagonist has been effective in alleviating toxicity symptoms in cattle (Campbell et al. 1999) and gravid mares (Dooley et al. 1999).

Use of herbicide- and pest-resistant genes in forage plants

Molecular approaches for weed, insect, and disease problems by transforming or inserting new DNA in plant cells have been successful in crop plants (Wilkinson 1997). 'Roundup ready' cotton and soybeans give the crop plant resistance to the herbicide while weeds are killed. Genes for insect resistance have been introduced into crops such as corn, cotton, and potato. Efforts to accomplish this have been concentrated on crop plants as the market potential is larger. However, it is expected that 'Roundup ready' alfalfa should be on the market within 3 years and other forages will probably follow. Forage establishment, often a difficult period, would be much more dependable with excellent weed control from this new technology. Greater insect resistance would reduce the need for insecticides to control alfalfa weevil, leaf hoppers, and other insects.

Use of gypsum to alleviate subsoil acidity

Many soils, particularly in the lower South, have very acid subsoils which inhibit root growth because of aluminum toxicity at pH levels below 5.2. Thus, the root zone is restricted to a shallow layer having a favorable soil pH and many forage plants cannot utilize water deeper in the soil. Even short periods of drought result in water stress to forage legumes such as alfalfa. Putting limestone deep into the soil is expensive. In contrast, gypsum (calcium sulfate) mixed into the soil surface will after a year move into the subsoil, inactivating the toxic aluminum, supplying calcium, and allowing roots to grow deeper in the soil to obtain water for continued growth during dry periods (Sumner et al. 1986). The effects of one gypsum application will benefit yields for 10 to 15 years. Gypsum application on many soils will allow successful production of alfalfa for pasture or stored feed on many soils where it was not well adapted.

Greater use of computers in information access and decision making

Reduction in funding for extension personnel will probably continue in the future. Forage information will increasingly be available on computer networks. The opportunity for access to research information on the internet will allow rapid utilization of new findings. In addition, more software programs will be available to assist forage and livestock producers in making decisions based on expected cost/benefit.

Greater use of forages for wildlife food

More forages will continue to be planted to attract deer, wild turkey, quail, and other wildlife. In addition to existing hunting preserves in many areas of the South, many cattle producers will be encouraging wildlife with special plantings to attract wildlife for hunters and also urban families wishing to enjoy nature. Many of these livestock producers will also rent cottages or efficiency apartments for guests on their farms.

Breeding of pasture plants with greater winter productivity

Many of the widely grown perennial cool season grass and legume cultivars have considerable winter dormancy which is useful in the north for cold hardiness but in the lower South winter productivity would be an advantage. 'AU Triumph' was the first tall fescue cultivar with substantially more winter production, furnishing generally 6 weeks more grazing than Kentucky 31 and similar cultivars (Hoveland et al. 1982). Unfortunately, the lower environmental stress tolerance of this first endophyte-free cultivar along with a more erect growth habit made it less persistent under close continuous grazing so it fell into disfavor by livestock producers. However, greater breeding efforts for cool season productivity using stress-tolerant germplasm in the future should result in cultivars that furnish more winter grazing, thereby reducing hay requirements.

Development of a perennial grass biomass energy industry

The USA imports one-half of its petroleum requirements and this is expected to increase as domestic reserves of oil decline. Research has been active in developing renewable energy sources from plant biomass, resulting in viable processing methods for production of ethanol or methanol (McLaughlin et al. 1996). Biomass is also a useful component in generation of electric power. Switchgrass is one of the most productive perennial grasses for these purposes and yields are higher in the southern USA than in other parts of the country (Bransby et al. 1993). Also, this grass can be grown on poor land not suited to crops, soil is protected from erosion, wildlife are encouraged, and harvesting can be mechanized. Increasing dependence on import of petroleum seriously affects our national balance of payments deficit. The cost of imported oil could be vastly reduced and rural communities benefitted by development of processing plants and production of grass biomass to create jobs and income.

Conclusions

Southern grasslands, developed from former row crop land since the 1930's, consist mainly of tall fescue, bermudagrass, and bahiagrass pastures utilized for beef cow-calf production. Legumes are an important component of pastures in the upper South but are generally undependable and often absent in the stressful environment of the lower South. Research accomplishments have had a major impact on grassland development in the South.

In addition to the lower input beef cow-calf industry, grazing of stocker steers from weaning to feeder weight on intensively managed winter annual pastures has been increasing. With consolidation of the beef finishing and processing industries, it is likely that contract grazing will increase on high-quality annual and perennial pastures. With greater emphasis on higher quality pastures and management, there will be a continuing need for innovative research on utilization of Southern grasslands.

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Policy prospects for brush control to increase off-site water yield

T.L. THUROW, A.P. THUROW, AND M.D. GARRIGA

Authors are professor and head, Department of Renewable Resources, University of Wyoming, Laramie, Wyo. 82071, natural resource economics consultant, 1071 Duna Dr., Laramie, Wyo. 82072, and project manager, Phytokinetics, 1770 N. Research Park Way, Logan, Ut. 84341. At the time of the research authors were associate professor, Department of Rangeland Ecology and Management, assistant professor, Department of Agricultural Economics, and graduate research assistant, Texas A&MUniversity, College Station, Tex. 77843.

Abstract

Water yield from rangeland on the Edwards Plateau, Texas is significantly greater if a site is dominated by grass instead of brush. Brush control programs are being considered by policy-makers as a way to relieve water shortages in the region. This research analyzed ranchers' willingness to participate in a publicly-funded brush control cost-sharing program that would be ranch-revenue neutral. A survey instrument was mailed to 226 ranchers, 119 were completed and returned (53%). The cost-sharing program required that brush on enrolled land be cleared and maintained at 3% cover for a 10-year period. Respondents estimated that current brush cover on their land averaged 41%, which contrasted with their preference that brush cover average 27%. This expression of preferred brush cover was similar to an independent estimate by a panel of experts in the region which indicated ranch livestock and deer-hunting lease value would be maximized at 30% brush cover. These estimates indicate that a program designed to increase water yield by reducing brush cover to 3% would likely require a financial incentive to offset the cost of brush control that exceeded the preference of the owner. Sixty-six percent of respondents indicated a willingness to enroll some portion of their land in the cost-sharing program described in the survey instrument. Ranch size, the percentage of ranch income earned from deer-hunting leases and livestock, and whether or not ranchers indicated that expense limited past brush control efforts were the variables measured by the survey instrument which best explained the probability of participation and the amount of land the owner was willing to enroll.

Key Words: watershed management, ranch management, cost-share, Edwards Plateau, Texas

Resumen

La producción de agua en el Edwards Plateau en Texas, es significativamente mayor si el sitio es dominado por pastos en lugar de arbustos. Los programas de control de arbustos están siendo considerados por los formuladores de políticas como una manera de aliviar la escasez de agua en la región. Esta investigación analiza la voluntad de los rancheros en participar en un programa financiado con fondos públicos para el control de arbustos con costos compartidos con beneficios neutros para el rancho. Se envió por correo un instrumento de encuesta a 226 rancheros, de los que 119 fueron completados y devueltos (53%). El programa de costos compartidos requería que los arbustos fuesen cortados y que se mantuvieran a una cobertura arbustiva del 3% por un período de 10 años. Los respondientes estimaron que la cobertura actual en sus tierras era en promedio 41%, lo que contrastaba con su preferencia de un promedio de 27% de cobertura arbustiva. Esta expresión de preferencias de cobertura arbustiva fue similar a la estimada independientemente por un panel de expertos en la región, que indicaron que el valor del ganado del rancho y licencia de caza de ciervos sería maximizado con una cobertura del 30%. Estos estimados indican que un programa designado para aumentar la producción de agua a través de la reducción de la cobertura arbustiva a un 3% probablemente requiriría de un incentivo financiero que compense los costos de control de arbustos que excediesen la preferencia del propietario. Sesenta y seis porciento de los respondientes estarían de acuerdo en enrolar una porción de sus tierras en el programa de costos compartidos descrito en el instrumento de encuesta. Las variables medidas en la encuesta sobre el tamaño del rancho, el porcentaje de ingresos del rancho derivados de las licencias de caza de ciervos y ganadería, y si los rancherosindicaban o no que los gastos limitaron en el pasado sus esfuerzos en el control de arbustos fueron las que explicaron mejor la probabilidad de participación y la cantidad de tierra que el proprietario tendría voluntad de enrolar en el programa.

Consumptive water use in the western U.S. exceeds recharge by an estimated 2.7 x 10^{13} liters per year (22 million acre-feet per year) (Fredrick 1995). This imbalance of supply and demand has resulted in a significant depletion of aquifers and stream flows throughout much of the region (van der Leeden et al. 1990). Reconciling the regional water budget is a fundamental challenge for public policy and is prompting consideration of non-traditional approaches that can increase supply and/or reduce demand (Reisner and Bates 1990). One option involves increasing the water yield of rangeland through brush management. There are hydrology, ecology, socioeconomic, and policy aspects to consider when analyzing the viability of this option. The fundamental hydrology considerations are whether increased water yield as a result of brush management is technically possible and, if so,

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what type of management would be required and how much water yield could be expected. The ecology, socioeconomic, and policy considerations are associated primarily with the costs and benefits of implementing brush control designed to increase water yield.

Hydrology Rationale

The theoretical basis for using brush management to increase water yield is founded on the premise that shifting vegetation composition from species associated with high evapotranspiration potential (trees and shrubs) to species with lower evapotranspiration potential (grass) will increase the likelihood of water yield (runoff and/or deep drainage). Climatic and soil traits influence whether reduction in transpiration and interception loss associated with brush to grass conversion would be offset by increased evaporation from soil. An analysis of climate and evapotranspiration characteristics of vegetation types indicated that tree and shrub communities of the Colorado River Basin need to annually receive over 460 mm precipitation and have a potential evapotranspiration rate of over 380 mm to yield significantly more water if converted to grasslands (Hibbert 1983). Studies in many other forest and rangeland habitats throughout the world corroborate that a water yield increase can occur when the dominant vegetation cover is shifted from brush to grass (Douglass 1983, Jofre and Randal 1993).

A summary of lysimeter and catchment research conducted on the Edwards Plateau at the Texas A&M Experiment Station at Sonora concluded that pastures cleared of brush and managed as grassland yielded approximately 940,000 liters ha^{-1} yr^{-1} more runoff and deep drainage than rangeland vegetated with dense brush (60% cover) (Thurow and Hester 1997). Similar estimates of vegetation effects on water yield at the site were independently obtained using the Simulation of Production and Utilization of Rangelands (SPUR-91) model (Redeker 1998). This model has been validated on Texas rangelands (Carlson et al. 1995, Carlson and Thurow 1996).

Both the empirical and modeling investigations conclude that water yield increases exponentially as brush cover declines (i.e., very little change in water yield from dense brush cover to about 15% brush cover and a rapid rise in water yield from 15% brush cover to 0% brush cover). These findings imply that it is necessary to remove most of the brush cover to maximize water yield potential. This conclusion is corroborated by numerous anecdotal observations by ranchers and agency personnel with brush control experience in the region (Kelton 1975, Willard et al. 1993). The exponential pattern of water yield increase relative to a decrease in brush cover has been postulated for the Colorado River Basin as well (Hibbert 1983). The exponential relationship is believed to occur because the intraspecific competition among trees (Ansley et al. 1998) and interspecific competition with herbaceous vegetation results in little increase in water yield until the tree density becomes sparse.

Policy Considerations Regarding Brush Control to Increase Water Yield

Landowners do not receive direct financial benefits from increased off-ranch water yields associated with brush management, therefore water yield considerations are unlikely to influence their current behavior. Decisions of a landowner to control brush are based on the expected benefits from an improved vegetation complex that promotes livestock and wildlife production and various non-financial criteria, such as aesthetic considerations. Maintenance of sustainable ecosystems is an implied assumption of range management, therefore some sites that are susceptible to accelerated erosion (steeplands) or are critical wildlife habitat would not be considered acceptable sites for brush control.

In Texas, ranchers choose the level of brush control since 98% of the rangelands in the state are privately owned. The value of increased forage for livestock associated with controlling brush offsets neither the cost of clearing brush and maintaining grass pastures nor the reduced revenues from deer-hunting leases (Reinecke et al. 1997). Moreover, the expected benefits of brush control accrue over time whereas most of the cost is up-front (Rowan and Conner 1994). Accordingly, without publicly-funded cost-sharing, few ranchers in Texas are likely to engage in the level of brush control needed to improve water yields accruing to off-ranch beneficiaries.

In Central Texas, 2.1 million people depend exclusively on rangeland water recharge to the Edwards Aquifer and to the many streams and rivers that originate on the Edwards Plateau. Over the past century Ashe juniper (*Juniperus ashei* Buchh.), redberry juniper (*Juniperus pinchotii* Sudw.), and live oak (*Quercus virginiana* Mill.) have become dominant on much of the Plateau that was previously characterized as grassland or open savanna (Smeins et al. 1997) resulting in a decrease in water yield (TWDB 1990). A public policy rationale for government support of cost-sharing for brush control is based on the belief that improved water yields from suitable range sites will raise groundwater levels and/or increase stream flow in the region thus benefitting off-site water users.

The objective of this research was to estimate responsiveness to a cost-share offer that would compensate ranchers for the estimated financial outlay and opportunity costs associated with reducing brush cover to 3% (with a corresponding increase in grasses), and then maintaining that level of brush cover for ten years. This is a first step in gauging the extent to which landowners would be willing to participate in a program that could significantly alter the appearance of their land—i.e., there may be hydrology and policy reasons for a program designed to increase water yield but would landowners be willing to participate? A related objective was to develop the capability to predict the participation pattern by analyzing the demographic profile of landowners likely to participate in such a program.

Methods

The survey research protocol of Dillman (1978) was followed in implementing the mail survey. A survey instrument and a postage-paid return envelope were sent in November, 1996 to 226 landowners from 21 counties on the Edwards Plateau, Tex. The sample was developed using mailing lists provided by 6 National Resource Conservation Service (NRCS) range conservationists and the mailing list of ranchers that receive information distributed by the Texas Agricultural Experiment Station at Sonora. The survey instrument was accompanied by a letter on Texas A&M University stationery providing a brief overview of why the survey was being conducted. The name and phone number of the authors, as well as the person who provided the rancher's name, was provided and the recipient was encouraged to call collect if they had any questions. A follow-up post-card was mailed to everyone on the list (the survey instrument maintained the anonymity of the respondents) 2 weeks after the initial mailing to request completion of the survey if they had not already done so. A second copy of the survey instrument was mailed 6 weeks after the original mailing.

The theoretical and methodological foundation for analysis of the value of public goods (in particular, changes in environmental amenities) in the absence of market transactions is contingent valuation (CV) methodology (Mitchell and Carson 1989, Smith 1993). In the context of this study, CV methods were used to estimate the responsiveness to a hypothetical program by prospective participants. Such analysis has been used by policy-makers to fine-tune the design of prospective policy implementation strategies (Purvis et al. 1989, Lohr and Parks 1995, Cooper and Keim 1996).

Survey Instrument

The following description provides a summary of the content and order of information in the 9-page survey instrument. An overview of the rationale for increasing water yield through brush control was provided as an introduction describing why the survey was conducted. This was followed by questions to determine the ranch location (county), ranch size, percent of ranch income from livestock, income from deer-hunting leases, income from wood harvests, and the percent of household income obtained from ranching enterprises.

A set of 6 color photographs of typical Edwards Plateau rangeland with brush cover of 3%, 15%, 30%, 45%, 60% and 75% (everything else being constant), was provided for reference in answering a question requesting an estimate of the portion of the ranch in each brush cover category. Following this, the respondent was asked to indicate how much of each brush cover category was preferred for the ranch. Space was allocated for respondents to comment on the management constraints that prevented current brush cover from matching the preferred brush cover.

Further explanation of the rationale and implementation requirements for a brush control cost-sharing program was then provided. The terms of this hypothetical Texas Brush Control Cost-Sharing Program required the prospective participant to identify how much land in each of the brush cover categories was to be enrolled. The agreement required that the landowner would be responsible for clearing and maintaining the brush so that the enrolled area would have no more than 3% brush cover for the 10-year program period. A 3% brush cover was chosen instead of removing all brush cover because it was presumed there would be a desire to use the area for grazing, thus there is a practical animal physiology consideration for maintaining some shelter provided by brush (Bird et al. 1984). It was stated that the enrolled area would be monitored by Texas authorities to ensure management in accord with the hypothetical contract agreement.

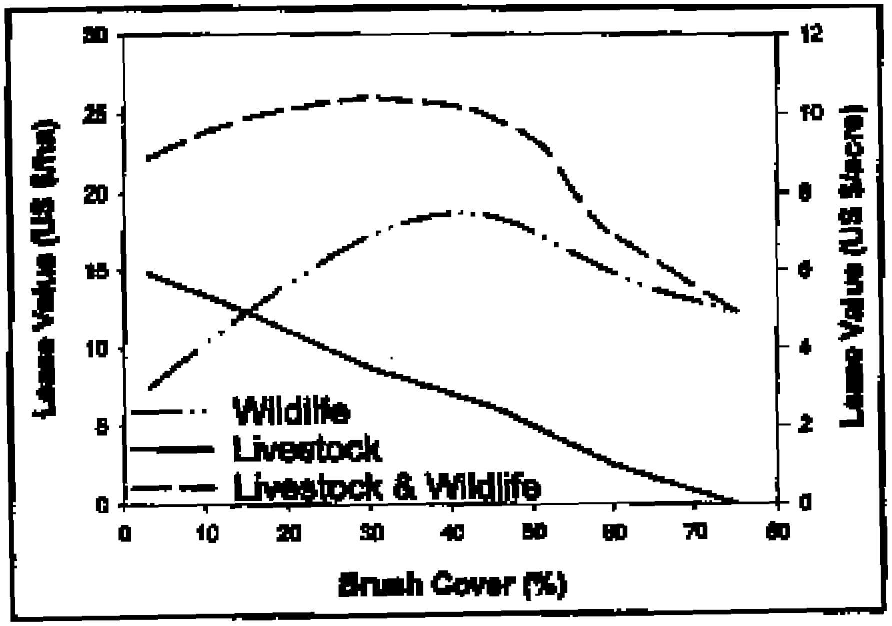

Fig. 1. Lease values for the Edwards Plateau, Texas as influenced by brush cover.

The payment offer for the cost-share agreement was presented in a dichotomous-choice format (i.e., the survey respondent either accepted or rejected a specific cost-share offer). This procedure was preferable to asking the respondent to propose a level of compensation needed to trigger participation because it reduced the potential for them to inflate their required payment above a threshold they would actually be willing to accept (Mitchell and Carson 1989, Hoehn and Randall 1987). A stratified sample posing dichotomous-choice cost-share offers at increasing increments would have enabled the development of a function to describe how participation is likely to increase as cost-share offers increase, following standard contingent valuation techniques (Hanemann 1984). Such an effort requires a significantly larger sample size and was not warranted given the uncertain state of knowledge regarding Texas ranchers' preferences for brush control, their willingness to participate in government programs yielding off-ranch benefits, and other personal values that might influence participation. Rather, this survey was designed to begin the process of understanding factors that influence a decision to reduce brush to a level necessary for significantly enhancing water yield.

The cost-share offer depended on the amount of brush cover on the enrolled land. Participants characterized the brush cover by estimating the amount of land that was in each of the brush cover categories according to the photo key described above. In the first year of the contract, prospective participants would receive a check issued by the State of Texas for their full ten years of participation. Cost-share offers aimed to cover the net present value of the expected cost of the initial brush treatment and its management over ten subsequent years, plus or minus the net expected change in ranch revenues from livestock over 10 years, plus or minus the net expected change in ranch revenues from wildlife over 10 years. A discount rate of 8% was applied to calculate the net present value of the 10-year stream of payments.

Cost-share criteria were developed using expert opinion. Estimates of livestock and deer-hunting lease values (Fig. 1) (i.e., the current market rental rates for land used for grazing and for hunting), were calculated based on a round-table discussion with 7 NRCS range conservationists who have extensive experience on the Edwards Plateau. Input was also obtained from 4 range management specialists, a wildlife ecologist, and a range economist, all with long-term experience gained while employed by the Texas Agricultural Experiment Station and/or the Texas Agricultural Extension Service. Estimated deer-hunting lease rates, which can provide substantial revenues to landowners in Central Texas, were corroborated by county-level data (Texas Comptroller of Public Accounts 1996). Moderate brush cover is preferable to dense or sparse brush cover in terms of providing wildlife habitat that supports a significant source of prospective ranch income (Rollins et al. 1988). The brush management and maintenance regimes used as the basis for the cost-share calculations were based on regional costs for chaining as the initial treatment and follow-up treatments at 3 year intervals with spot herbicide application. Garriga (1998) provides a detailed discussion of the brush management and maintenance regimes for the 5 types of sites with differing brush densities.

The exact wording of the payment question was as follows: "Enrolling in the Texas Brush Control Cost-sharing Program means converting your acreage to make it look like Site 1 {keyed to the color photograph of 3% brush cover} and maintaining that range condition for 10 years. How many acres of your ranch would you consider enrolling in the Texas Brush Control Cost-sharing Program? (Please write in how many acres you would consider enrolling.)"

Survey respondents indicated how much land they were willing to enroll for a given cost-share payment, expressed in English units (dollars per acres). Five enrollment options were offered: (1) land which now looks like Site 2 {15% cover} would receive a cost-share payment of $146 per ha, (2) land which now looks like Site 3 {30% cover} would receive a cost-share payment of $188 per ha, (3) land which now looks like Site 4 {45% cover} would receive a cost-share payment of $205 per ha, (4) land which now looks like Site 5 {60% cover} would receive a cost-share payment of $173 per ha, and (5) land which now looks like Site 6 {75% cover} would receive a cost-share payment of $188 per ha.

Immediately following the payment question, the text in the survey instrument explained why the cost-share offers differed for sites with different starting brush cover levels. An explanation was presented for why the cost-share offers were highest for sites with 30% and 45% cover (rather than for the more densely vegetated sites): "Please note: You might expect the payments to be highest for ranchers enrolling acreage which looks like Site 5 and Site 6. In fact, the compensation for the estimated cost per ha of the initial brush treatment and the 10-year maintenance is highest for the most densely-vegetated sites: it's $217 per ha for land resembling Site 6, $170 for land resembling Site 5, $153 for land resembling Site 4, $138 for land resembling Site 3, and $101 for land resembling Site 2. However, for ranchers enrolling acreage which looks like Site 5 and Site 6, there are large gains in forage for livestock which help to offset the cost of brush management. Furthermore, ranchers enrolling acreage which looks like Site 3 and Site 4 are losing relatively more revenues from wildlife, thus payments to these ranchers are slightly higher than payments to those enrolling acreage resembling Site 5 and Site 6." The survey concluded by soliciting written comments to explain non-participation or to express concerns from those willing to participate.

Statistical analysis

The probit model was used to estimate the likelihood of participation (PARTICIPATE) in the Texas Brush Control Cost-sharing Program, fitting the equation

$$Participate = f\,(size, livestock, deer, expensive) + \varepsilon$$

where PARTICIPATE is the probability of the respondent being willing to accept the offered cost-share payments and enroll in the program for 10 years, SIZE is the land area of the ranch, LIVESTOCK and DEER are the percentage of ranch income earned from livestock enterprises and deer-hunting leases, respectively, EXPENSIVE indicates identifying cost as a constraint to past investments in brush control, and ε is a normally-distributed random variate.

The Cragg model, also known as a double-hurdle model (Cragg 1971, Lin and Schmidt 1984), was used to estimate the joint relationship between a respondent's decision about whether or not to participate and the subsequent choice of how much land to enroll in the program (ENROLL). In this 2-stage estimation process, the level of the censored variable, ENROLL, was estimated, conditional on PARTICIPATE being a non-limit (positive) observation. Fitting this Cragg model involved comparing the fit of a truncated regression model and a tobit model, their estimation being contingent on the probit results estimating the probability of participation. The key advantage of the Cragg model is that the same set of 4 variables were hypothesized to be important in determining both ENROLL and PARTICIPATE, but the model allows that the explanatory variables may have opposing effects on the two dependent variables. For this application, positive relationships between LIVESTOCK, DEER, and SIZE and ENROLL were hypothesized, following the same rationales as for the probit model. However, a negative correlation between EXPENSIVE and ENROLL was hypothesized, on grounds that prospective participants who expressed concern about controlling brush being too expensive were more likely to be conservative in the number of acres they were willing to enroll than were prospective participants who had not named EXPENSIVE as a constraint to such investments. Likelihood-ratio tests were conducted to evaluate the specification and the fit of the Cragg model (Greene 1995, p. 596-597).

Results and Discussion

Of the 226 surveys mailed to ranchers, 119 were completed and returned (53%). The total area managed by the respondents was 178,543 ha (or approximately 2.2% of the land area of the Edwards Plateau). Sixty-six percent of the respondents (78 of 119) indicated a willingness to enroll at least part of their land in the cost-sharing program described in the survey instrument. These 78 respondents manage 129,199 ha and were willing to reduce brush cover to 3% on 65,182 ha. This represents 51% of prospective participants' land and 37% of the overall land area managed by both prospective participants and non-participants.

Brush Cover Preferences

The average brush cover on the ranches was estimated by the respondents to be 41%. There was no difference in the amount of existing (current) brush cover between respondents willing or unwilling to participate in the program. There were, however, differences in preferred brush cover between prospective participants and respondents who were not willing to participate (Fig. 2). As a group, those who indicated a willingness to enroll in the program had a brush cover preference skewed to favoring the 3% and 15% brush cover classes; the mode of the 6 cover classes was 15% brush cover for prospective participants as opposed to 30% for non-participants. Both groups preferred a significant reduction of area in the 60% to 75% brush cover categories. Given the survey constraint of requiring land to be cleared to 3% brush cover, the prospective participants were willing to accept having much more of their land in the 3% brush cover category than they would prefer. Since clearing pastures to 3% brush cover would mean removing most of the oaks along with the juniper, ranchers apparently felt

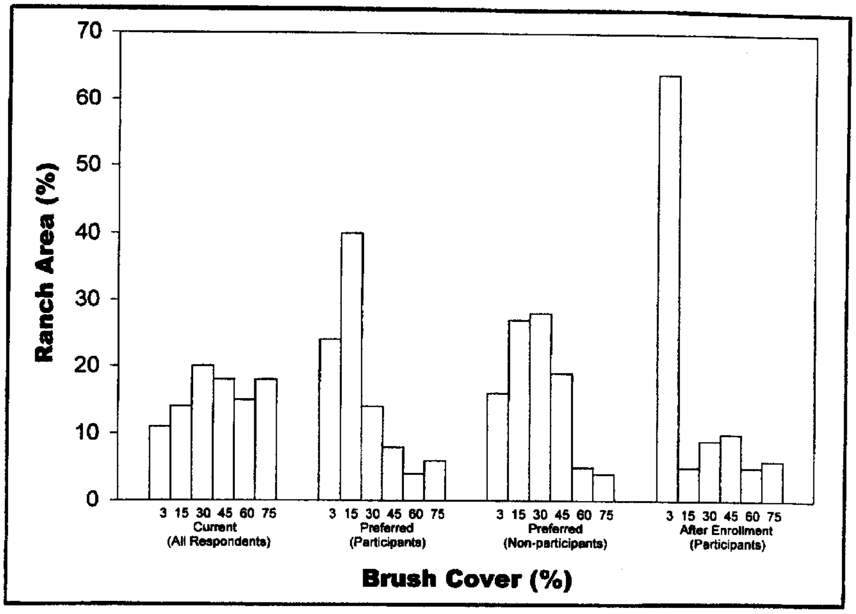

Fig. 2. Current and preferred brush cover as reported by respondents to a survey on willingness to participate in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

that the loss of oaks which have dietary (browse and acorn) and cover value for both livestock and wildlife was an acceptable tradeoff for more herbaceous forage production and more open spaces making it easier to manage livestock.

Reported differences between actual and preferred brush cover indicate that ranchers have encountered obstacles to controlling brush on their ranches. The reasons offered by respondents to explain why current brush cover differed from preferred brush cover included concerns about: expense (73%), the difficulty of achieving effective brush control (30%), degrading wildlife habitat (6%), liability regarding U.S. Endangered Species Act protection of critical habitat for the Golden-cheeked Warbler (*Dendroica chrysoparia*) and Black-capped Vireo (*Vireo atricapilla*) (5%), and killing desirable woody species (2%).

Ranch Enterprise Considerations

The percent of ranch income currently derived from livestock and deer-hunting leases was markedly different from the prospective livestock and deer-hunting leases that would maximize income from the current brush cover (Table 1). The prevailing market lease rates for livestock grazing and for deer-hunting in the Edwards Plateau (Fig. 1) were used as a proxy for the value-in-use of land, whether actually rented or owned. Given these lease values, survey respondents' descriptions of the current and preferred brush density on their ranches, and their prospective enrollment rates, the value-in-use of land was imputed for prospective participants (the top three rows) and for respondents unwilling to enroll land in the program (the bottom 2 rows). The first row of Table 1 describes the value-in-use of prospective participants' land with brush densities as they were when the survey was conducted. The second row of Table 1 describes the value-in-use of prospective participants' land if they converted it to the level of brush density which they would most prefer. The third row of Table 1 describes the value-in-use of prospective participants' land if they were to enroll in a Texas Brush Control Cost-sharing Program as indicated by their survey response.

A comparison of the imputed lease values in Table 1 implies that ranchers derive a greater percentage of ranch income from livestock and a smaller percentage from deer-hunting leases than is warranted by the brush cover resources they are working with. This corroborates the conclusion by Baen (1997) that the market for deer-hunting leases in Texas is promising, but informal and, therefore, often inefficient. Liability concerns and confusion about the

Table 1. Reported and prospective optimal livestock and deer-hunting lease revenues associated with current and preferred brush cover, as reported by respondents to a survey on willingness to enroll in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

	Imputed Actual, Optimal, and Prospective Post-Enrollment Lease Values			Mean Proportion of Ranch Income From Livestock Leases		Mean Proportion of Ranch Income From Deer-hunting Leases	
Respondents willing to enroll in a Texas Brush Control Cost-sharing Program**	Livestock	Deer-hunting	Total	Reported	Optimal	Reported	Optimal
		($/ha)*		(%)		(%)	
Lease value associated with current brush cover, pre-enrollment	6.47	14.30	20.77	78	31	22	69
Lease value associated with preferred brush cover, pre-enrollment	10.40	12.15	22.55	–	46	–	54
Lease value associated with brush cover, post-enrollment	11.66	10.32	21.98	–	53	–	47
Respondents unwilling to enroll in a Texas Brush Control Cost-sharing Program**							
Lease value associated with current brush cover	6.57	14.87	21.44	69	31	31	69
Lease value associated with preferred brush cover	9.14	14.30	23.44	–	39	–	61

*Prospective optimal lease values are calculated based on expert opinion estimates (Fig. 1).
**Calculations based on average current and preferred brush cover for prospective enrollees (as a group) and for those unwilling to enroll (as a group).

Table 2. Relationship between ranch size category, participation, and variables used to characterize enrollment. P = Participation, NP = Non-Participation.

	Ranch Size Category							
	< 203 ha		203-810 ha		811-4,049 ha		>4,049 ha	
	P	NP	P	NP	P	NP	P	NP
Number of Respondents	13	13	23	14	29	11	13	3
Respondents Willing to Enroll Divided by the Total Portion of Respondents Within the Ranch Size Category (%)	50		62		73		81	
Ranch Area Enrollment (%)	37		43		46		52	
Median Net Annual Ranch Income From Livestock Enterprises (%)	100	0	75	60	60	80	85	55
Median Net Annual Ranch Income From Deer-hunting Enterprises (%)	0	0	25	30	35	15	15	10
Median Net Annual Household Income From Livestock and Deer-hunting Enterprises (%)	4	0	25	35	55	65	60	35
Portion of Respondents Who Stated that Cost Restricted Their Brush Control Efforts (%)	67	46	79	74	80	94	92	66

potential market prices for deer-hunting leases are cited as key reasons that ranchers fail to realize the potential value associated with their hunting enterprises (Baen 1997). Another reason is that maximizing profit from the ranch is not a primary objective for many small-scale landowners (Rowan and White 1994); the people-management requirements associated with maximizing the value of deer-hunting leases are often not consistent with their expressed primary goals of country lifestyle and managing livestock (Rowan 1994, Rowan and Conner 1995).

Tradeoffs of decreased deer-hunting lease value and reduced total lease value associated with brush control (Fig. 1) did not dissuade individuals who indicated a willingness to participate in the brush control program. A willingness to forego some of the deer-hunting lease value corroborates research indicating that forage and livestock considerations are consistently ranked higher than wildlife considerations when making decisions regarding stocking rate and grazing program benefits (Rowan et al. 1994).

Ranch Size Considerations

Most of the ranches in the survey that were less than 810 ha (2,000 acres) in size were located in the counties adjacent to 1 of 2 large cities of the region: San Antonio (population 1,410,400) or Austin (population 465,622). The configuration of counties around these cities was such that a 1 county radius from the city limit was consistently about 125 km. Regardless of distance from 1 of these cities, participation in the outlined brush control program increased as the ranch size category increased (Table 2).

The percent of median net annual household income from livestock and deer-hunting enterprises tended to increase with ranch size (Table 2). The likelihood of participation and the degree of enrollment increased as the dependence on these enterprises for generating household income increased. Landowners with a ranch size less than 203 ha (500 acres) were not dependent on the ranch for their household income. Landowners in this category who did not derive at least some income from livestock were not willing to enroll in the program.

Predictions of program participation

Concern about whether the cost-share offer would cover the costs of enrollment was the most common issue cited by respondents as an obstacle to participation (Table 3). This concern tended to rise as dependence on livestock and deer-hunting enterprises for household income rose. Non-participants expressed concerns regarding wildlife, land value, and aesthetics more frequently than willing participants.

According to the probit model results (Table 4), the most important variables that influenced prospective participation were the percentage of ranch income derived from livestock and deer-hunting enterprises, and whether or not the respondent indicated that expense was a major constraint to their past range management activities. The fitted probit equation predicted that 71% of the respondents would participate in a Texas Brush Control Cost-sharing Program; indeed, 66% were willing to participate. These probit results

Table 3. Write-in comments from survey respondents willing to enroll in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

Comments	Concerns of Respondents Unwilling to Participate (n=41)	Concerns of Respondents Willing to Participate (n=78)
	(%)	(%)
The cost-share offer would not cover costs of initial treatment and brush management in subsequent years	41	29
The cost-share offer would not offset the negative impact on wildlife values	27	8
The cost-share offer would not offset the negative impact on prospective real estate values	24	3
Brush control negatively impacts aesthetic values	15	3
Respondent does not understand the cost-share offer	15	3
Respondent has a mistrust of government programs	12	9
Benefits of increased forage production would not offset collective negative impacts of brush control	10	3
Brush cover is satisfactory as is	10	0
Respondent too old to fully implement the 10-year cost-share agreement	10	4
Respondent uncertain about how Endangered Species Act habitat preservation restrictions would apply to their land	2	4

Table 4. Probit results, analyzing willingness to participate in a Texas Brush Control Cost-sharing Program

Variable	Coefficient	Standard Error	Z-statistic	Mean	Elasticity
SIZE	0.24 x 10-4	0.37 x 10-4	0.67	3715.00	0.89 x 10-5
LIVESTOCK	0.77 x 10-2	0.42 x 10-2	1.83*	60.52	0.27 x 10-2
WILDLIFE	0.14 x 10-1	0.64 x 10-2	2.09**	23.86	0.49 x 10-2
EXPENSIVE	0.99	0.30	3.24**	0.73	0.36
Intercept	-1.16	0.38	-3.04		-0.42
n	119				
Log-likelihood	-62.16				

Notes: The dependent variable is PARTICIPATE. Elasticities were calculated at the mean. **Indicates significance at the 95% confidence interval and *indicates significance at the 90% confidence interval.

indicated that at the sample mean, if the percentage of ranch income earned from livestock enterprises (LIVESTOCK) were to increase by 1%, then the likelihood of an average respondent (who earns 61% of ranch income from livestock enterprises) enrolling in the program would go up by 0.3%. At the sample mean, if the percentage of ranch income earned from deer-hunting enterprises (DEER) were to increase by 1%, then the likelihood of an average respondent's participation (who earns 24% of ranch income from deer-hunting leases) would go up by 0.5%. An average respondent who offered the explanation that past brush control efforts were constrained by expense (EXPENSIVE) was 36% more likely to enroll in the program than those who did not offer this as an explanation for the discrepancy between the current and preferred brush densities on their ranch.

Results of the Cragg estimation (Table 5) indicate that ranch size, and the percentage of ranch income earned from livestock and deer-hunting leases were statistically significant at the 95% confidence interval in explaining the number of acres the prospective participant was willing to enroll (ENROLL). This equation indicates that at the sample mean, a 1% increase in the portion of ranch income earned from livestock enterprises (LIVESTOCK) increases the amount of land the average prospective participant (who earns 64% of ranch income from livestock enterprises) would enroll in the program by 4.5 ha. At the sample mean, a 1% increase in the proportion of ranch income earned from deer-hunting enterprise (DEER) increased the estimated amount of land which the average prospective participant (who earns 28% of ranch income from deer-hunting leases) would enroll in the program by 6.1 ha. At the sample mean, raising the size of the ranch (SIZE) by 1% would increase the expected amount of land enrolled in the program by the average prospective participant (whose average ranch size is 1,660 ha) by 0.1 ha.

Using the probit and Cragg equations, enrollment in a Texas Brush Control Cost-sharing Program was estimated for five brush density categories among those respondents who were willing to participate (Table 6). Prospective participants had the most eligible land area in the 45% brush density category, in absolute terms, and relatively more densely vegetated land (60% and 75% brush density) than more open land (15% and 30% brush density) was eligible. They were most likely to enroll their most densely vegetated land (45% brush density). The enrolled lands which generate the greatest water yield relative to the cost-share payment are 60% brush density (the most) and 75% brush density (the second most). If response to an actual program were similar to survey respondents' willingness to enroll in this hypothetical program, therefore, the land categories with the highest water yield payoffs would be among those which respondents would be most likely to enroll.

Table 5. Cragg model results, analyzing the number of acres enrolled in a Texas Brush Control Cost-sharing Program.

Variable	Coefficient	Standard Error	Z-statistic	Mean	Elasticity
SIZE	1.45	0.26	5.54**	4099.00	0.28
LIVESTOCK	56.34	26.77	2.11**	64.37	10.77
WILDLIFE	80.20	31.99	2.51**	28.40	15.33
EXPENSIVE	-1023.20	1542.80	-0.66	0.87	-195.55
Intercept	-13806	2957.00	-4.67		-2638.40
n	119				
Log-likelihood	-637.76				

Notes: The dependent variable is ENROLL. Elasticities were calculated at the mean. **Indicates significance at the 95% confidence interval.

Estimated costs of increasing water yield

Increases in water yield from enrollment in a Texas Brush Control Cost-sharing Program depend on the starting level of brush cover on the sites enrolled. Based on analysis of the relationship between brush control and water yield using the SPUR-91 model (Redeker 1998), the estimated increases in water yield associated with clearing brush to 3% density are presented in Table 6. If the program were offered and those who responded to this survey were those who enrolled, an estimated increase of 454 million m^3 (1234 m^3 = 1 acre-foot) water yield from central Texas over the 10 year program would be obtained for a cost of $12.3 million to the taxpayers. Clearing the most densely vegetated sites (i.e., 75% brush cover) generates the greatest total increases in water yield per unit of land area enrolled. However, for the cost-share offers presented to survey respondents evaluating prospective enrollment in a hypothetical Texas Brush Control Cost-sharing Program, the most cost-effective policy option (i.e., the most significant increase in water yield per cost-share dollar) is from enrollment of sites with initial brush cover of 60%.

Management Implications

The complex hydrogeology of the fractured limestone structures which compose the Edwards Aquifer does not allow analysis of where or when downstream benefits from extra water yield associated with brush control would be realized. This limits the ability to conduct a cost/benefit analysis of individual investments in brush control or public investments in a cost-sharing program to support brush control. Given increased pressure on scarce water resources in central Texas, and the legally-mandated concern for maintenance of aquatic habitat of 9 endangered species dependent on seeps and springs from the Edwards Aquifer, however, it is a maintained assumption of this research that a policy to increase water availability would be valuable. If the program were implemented with the primary policy objective

Table 6. Cost share offers in the survey instrument associated with brush cover categories, the estimated water yield associated with the brush control program, and the annualized (over the 10-year program) estimated water yield cost of the water.

Change in Brush Cover	Cost-share Offer	Estimated Land Area Eligible	Estimated Land Area Enrolled	Estimated Percentage of Enrollment Among Eligible Land	Annual Water Yield	Estimated Water Yield Cost
(%)	(dollars/ha)[a]	(ha)[b]	(ha)[b]		(liters/ha/yr)[c]	(liters/dollar)
15 → 3	145.73	16,796	1,554	9%	360,555	24,741
30 → 3	187.72	28,424	11,424	40%	578,915	30,839
45 → 3	205.01	24,548	19,810	81%	680,474	33,192
60 → 3	172.90	18,088	12,503	69%	728,720	42,147
75 → 3	187.72	27,132	19,891	73%	738,874	39,360
Total		129,199	65,182	/[d]		

[a]English units (dollars per acre) were used in the survey instrument.
[b]Eligible land area and enrollment of survey respondents who indicated a willingness to participate in a Texas Brush Control Cost-sharing Program, estimated using the probit and Cragg equations.
[c] Source: Redeker, 1998.
[d]Percentages do not sum to one; calculated as column 4 divided by column 3.
Note: These SPUR-91 model estimates of water yield (Redeker 1998) were not presented in the survey instrument, but are included here to illustrate the annualized estimated cost for expected water yield.

of protecting threatened and endangered species, then federal funding would be appropriate. If, on the other hand, the driving policy impetus for a brush control cost-sharing program were to relax water constraints on central Texas' growing cities, then the program should rely on state and municipal financial support.

Some policy inferences about the estimated costs of a cost-sharing program can be drawn from the results of this survey research. Based on the estimates of water yield increases associated with enrolling land with different starting brush densities, as presented in Table 6, Texas policy makers could develop a protocol for targeting participation by landowners whose enrollment would generate the greatest expected downstream increases in water yield. For example, if alternative sources of water supply were available at a cost of 38,000 liters per dollar, then policy makers might elect to recruit only sites with starting brush cover of 60% or above. If, however, the cost of alternative sources of water supply were greater than 24,000 liters per dollar, then they might elect to open the program to any site with more than 15% brush density and concentrate recruitment efforts on those with sites with the most dense starting brush cover. Another effective policy lever would be to raise the cost-share offers, thus recruiting greater participation among sites with the desired brush density. The cost-share offers presented here were set at the opportunity cost of participation; raising these offers would raise the expected level of participation. An enrollment elasticity of participation cannot be estimated based on these survey data but could be estimated from a follow-up study using a format demonstrated by Purvis et al.(1989).

This sampling frame was comprised of individuals who had a past record of contact with the NRCS range conservationists or were part of the mailing list used by the Texas A&M Agricultural Research Station at Sonora. This sample population is likely to be better informed about brush management and about government-funded cost-share programs than would be a random sample of ranchers from the Edwards Plateau. Currently, if an actual policy were implemented, then the network of ranchers in contact with NRCS range conservationists (those represented in this sampling frame) would be among the most likely to be recruited to enroll in a program like the Texas Brush Control Cost-sharing Program described here. A recent and growing population of ranchers with smaller land holdings and higher off-ranch incomes are under-represented in the sampling frame for this study.

These survey research results offer preliminary support for the development of publicly-funded cost-sharing programs to promote private investment in brush control likely to yield off-site benefits. The survey results suggest that a brush control cost-sharing program, patterned after the 10-year program discussed here, would be most appealing to large landowners who derive a large percentage of their ranch income from livestock and deer-lease revenues. Since clearing land to 3% brush cover would increase livestock income at the expense of deer-lease income, there is an implication that ranchers are willing to sacrifice deer-lease income potential in favor of obtaining brush control funds that would benefit their livestock income potential. Since respondents to this survey generally did not maximize their deer-lease income potential, there appears to be some reluctance and/or lack of knowledge regarding pursuit of this income source. If the under performance of deer-lease income is a knowledge constraint, as asserted by Baen (1997), then the desire to invest in brush control, with or without cost-sharing, would be likely to decrease as knowledge regarding this income option increased.

Landowners with less than 203 ha derived little to no income from the ranch. None of the 26 respondents in this group obtained revenue from deer-hunting leases, probably because of the ranch size limitations and their land management goals. The landowners with less than 203 ha who earned income from livestock derived only 4% of median household income from this source. As a group, landowners in this ranch size class were least likely to participate in the cost-sharing program and, if they did participate, enrolled a relatively small portion of their land. U.S. census results from the past several decades reflect a marked increase in this small ranch category and an overall trend of declining mean ranch size in the 21 counties that compose the Edwards Plateau. The results of this study indicate that there is lower likelihood of participation in the type of brush control program specified by the survey instrument as ranch size and dependence on ranch-derived income decreases. The regional trend toward smaller ranch size and less dependence on ranch-derived income implies that it will likely be more difficult to persuade landowners to participate in a brush control designed to increase water yield.

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Breed and stocking rate effects on Chihuahuan Desert cattle production

JOHN A. WINDER, CALVIN C. BAILEY, MILTON THOMAS, AND JERRY HOLECHEK

Authors are associate professor, senior research assistant, assistant professor, and professor, Dept. of Animal and Range Sciences, New Mexico State Univ., Las Cruces, N.M. 88003. J. Winder is presently livestock specialist, Samuel Roberts Noble Foundation, P.O. Box 2180, Ardmore, Okla. 73402.

Abstract

Productivity of Barzona, Brangus, and Beefmaster cattle was evaluated on conservatively (n=2) (40 ha AU^{-1}) and moderately (28.5 ha AU^{-1}) stocked pastures (n=2) in the Chihuahuan Desert of south-central New Mexico. Equivalent numbers of suckled, first-calf heifers of each breed (n = 31) weighing 333±11 kg were randomly assigned to the study pastures in the spring of 1992. Pastures were grazed continuously and herd productivity data were collected from 1992–1994. In late August 1994, all pastures were destocked due to onset of severe drought. No effect of breed (P>0.10) was detected in the analyses, so data were pooled across breeds and compared between the stocking rates. Calf crop percentages (1993, 1994) were higher in conservative than moderate stocked pastures (82 vs 62%, respectively, P<0.01). Financial analyses standardized to a hypothetical medium size (8,094 ha) New Mexico Chihuahuan Desert cattle range showed net returns per ha did not differ (P>0.10) between stocking rates. However, the main effect of year and stocking rate x year interaction were significant (P<0.05). These analyses suggest that the drought in 1994 lowered returns per ha compared to 1993 when precipitation was near average and that conservative stocking may present less financial risk than moderate stocking when drought occurs. These data are consistent with other studies from arid and semi-arid rangelands demonstrating that conservative stocking can give financial returns from cattle production equal to or greater than those from moderate stocking.

Key Words: rangeland, ruminants, grazing management, economics

Resúmen

La productividad de ganado Barzona, Brangus y Beefmaster fue evaluada en potreros (n = 2) sujetos a capacidad de carga animal conservadora (40 ha AU^{-1} y capacidad de carga animal moderada (n=2) (28.5 AU^{-1}) en la región centro-sur de Nuevo Mexico. Números equivalentes de vaquillas primerizas de cada raza (n = 31) amamantando y con peso de 333 ± 11 kg, fueron asignadas al azar en los potreros del area de estudio en la primavera de 1992. Los potreros estuvieron bajo pastoreo continuo y la productividad de los hatos fue recabada durante 1992–1994. En agosto de 1994, debido a la sequía, se dejaron descansar los potreros. Ningún efecto raza (P < 0.10) fué detectado en el análisis, por lo tanto los datos fueron analizados conjuntando todas las razas y comparando éste número al efecto carga animal. El porcentaje de natalidad (1993–1994) fué 20% mas alto bajo condiciones de pastoreo conservador. Los números indican 82% y 62% de natalidad bajo pastoreo conservador y moderado respectivamente (P < 0.10). El peso al momento del destete por vaquilla por año fué también mas alto bajo condiciones de pastoreo conservador (P < 0.10). Los análisis financieros ajustados hipoteticamente a un rancho de tamaño medio (8094 ha) en el centro-sur de Nuevo México, indicaron que la ganancia económica neta por hectárea no fué diferente (P > 0.10) entre los dos tipos de carga animal. Sin embargo, el efecto principal de la interacción capacidad de carga-año fué significante (P < 0.05). Estos resultados sugieren que la sequía de 1994 redujo la ganacia económica por hectárea comparada con el año 1993 cuando la precipitación pluvial estuvo cerca del promedio normal. Asimismo, sugieren que el pastoreo conservador pudiera representar un menor riesgo financiero que el pastoreo moderado sobre todo al momento de la aparición de la sequía. Estos datos son consistentes con otros estudios en zonas áridas y semiáridas, que demuestran que el pastoreo conservador puede proporcionar la misma ganancia económica que el pastoreo moderado. Sin embargo, la diferencia estriba en mejores pastizales y tazas de natalidad mas altas bajo pastoreo conservador.

Chihuahuan Desert rangelands are an important source of forage for beef cattle production in New Mexico (New Mexico Department of Agriculture 1994). Beefmaster, Barzona, and Brangus cattle have become prevalent in the southwestern United States. However, reports are limited regarding the relative merits of these breeds in the Chihuahuan Desert. Past research in south-central New Mexico has shown that Brangus and Brangus crossbred cows are more productive than Hereford cattle (Winder et al. 1992). Furthermore, recent research has shown that grazing behavior and diet selection may differ among breeds (Blanton 1995, Winder et al. 1996).

Stocking rate is also a major factor affecting cattle productivity and financial returns from ranching in semidesert rangelands (Martin 1975, Holechek 1992). It has been hypothesized that conservative stocking involving about 35% use of key forage species will result in enhanced animal performance and financial returns compared to moderate stocking (40–50% use of forage; (Martin 1975, Holechek 1992). The primary objectives of this experiment were to evaluate the effect of breed (Brangus, Barzona, and

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Beefmaster), stocking rate and breed x stocking rate interaction on cow productivity under Chihuahuan Desert conditions in southcentral New Mexico. A secondary objective was to evaluate the implications of our findings on Chihuahuan Desert ranching profitability.

Materials and Methods

Study Area

Four study pastures were located on the Chihuahuan Desert Rangeland Research Center (CDRRC) were used to evaluate the effect of breed and stocking rate on Chihuahuan Desert cattle production. The ranch is 37 km north of Las Cruces, N.M. in Dona Ana County. The ranch is in the southern portion of the Jornada del Muerto Plains between the San Andres Mountains to the east and the Rio Grande Valley to the west (~32.3° Latitude and 106° Longitude). Elevation varies from 1,188 to 1,371 m with level or gently rolling hills.

Soils on the study pastures are mainly light sandy loams underlain by calcium carbonate hardpan (caliche) at depths varying from a few centimeters to 1 m or more (Valentine 1970). They are classified as fine loamy, mixed, thermic, typic haplargids and are in the Simona-Cruces associations (SCS 1980). In areas where the ground cover is sparse, sandy dunes had formed around the invading mesquite plants (Wood 1969). However on most of the study area, the soil profile is relatively well preserved and stable.

The climate on the CDRRC is typical of the Chihuahuan Desert. The ranch is arid with an average frost-free period of 200 days. The only permanent water sources are the wells and pipelines provided for livestock. Temperatures are high in summer, with a mean maximum of 36°C during June, and a mean maximum of 13°C during January (Pieper and Herbel 1982). Temperature differences are substantial between day and night. Solar radiation is generally greatest in June and lowest in December. Winds are strongest in the spring and cause severe erosion problems and water stress on the plants.

The annual precipitation is bi-modal. Summer precipitation is generated from the Gulf of Mexico and is characterized by localized convectional storms of high intensity but low frequency. Winter precipitation (December–February) comes from the Pacific Ocean. Storms in the winter are relatively gentle and evenly distributed. The mean annual precipitation is 230 mm with 52% of the annual rainfall occurring during the summer peak (Pieper and Herbel 1982).

Table 1. Average monthly precipitation (mm) on the Chihuahuan Desert Rangeland Research Center in southcentral New Mexico.

Month	1990	1991	1992	1993	1994	Long term average (1930–1996)
				(mm)		
January	5	12	38	37	8	13
February	10	13	4	14	3	10
March	11	15	9	1	4	7
April	13	0	29	1	4	6
May	10	4	89	7	13	9
June	0	4	11	20	6	13
July	75	74	13	69	25	42
August	49	74	105	62	16	46
September	56	53	6	5	9	36
October	5	0	23	9	23	22
November	19	22	14	14	35	18
December	18	114	46	14	35	18
Total	271	385	386	253	178	235

Rain gauges are located throughout the CDRRC and extensive records were available. The total annual precipitation for the CDRRC in 1991, 1992, and 1993 was above average (Table 1). In the 1994 growing season precipitation was near the all time low (41% of the mean). All pastures were destocked in late August of 1994 due to lack of forage growth.

Vegetation

Primary grass species on our study pastures include black grama (*Bouteloua eriopoda* Torr.), dropseed (*Sporobolus* sp.), three-awns (*Aristida* sp.), bush muhly (*Muhlenbergia porteri* Kunth.), fluffgrass (*Erioneuron pulchellum* Tateoka), and tobosa (*Hilaria mutica* Buckley). The most commonly encountered shrub species is honey mesquite (*Prosopis glandulosa* Torr.). It dominates the overstory and has been increasing over the past 100 years (Pieper and Herbel 1982). Other shrubs commonly found are snakeweed (*Gutierrizea sarothrae* Pursh), soaptree yucca (*Yucca elata* av.), creosote (*Larrea tridentata* [Pursh] Nutt.), and fourwing saltbush (*Atriplex canescens* [Pursh] Nutt). Leatherweed croton (*Croton pottsii* Lam.) is the primary forb occurring on the CDRRC and is an important food for livestock and pronghorn.

During 1991, four pastures with similar soils (sandy loams), topography (flat), and size were delineated and fenced. These include Pasture 15 (1,267 ha), Pasture 4 (974 ha), Pasture 14 (932 ha), and Pasture 1 (1,219 ha). The 4 pastures were adjacent to each other and the spatial ordering of the pastures from west to east was 15, 14, 1, and 4. Proportions of late, mid, and early seral communities in each pasture based on the Dyksterhuis (1949) approach are given in Table 2. Pastures 15 and 4 were stocked to obtain a utilization level of about 30–35% of key forage species while pastures 14 and 1 were selected to be stocked to obtain a utilization level of 40–45%. The Holechek (1988) procedure was used in setting pasture stocking rates. The reliability of this procedure on Chihuahuan Desert rangelands has been established (Holechek and Pieper 1992). A more detailed discussion of the experimental pastures is provided by Nelson (1996).

In June 1993, five transects 1.6 km in length were systematically placed in each pasture to monitor herbage production and plant foliar cover. Foliar cover data were collected in autumn 1993 and 1994 and were reported by Nelson (1996) and Nelson et al. (1997). Standing crop data were collected by clipping to ground level five, 0.5 m^2 quadrats on each transect on each sampling date. Periodically (spring, summer, and fall) grazing intensity on the 4 pastures was evaluated by estimation of percent utilization through ocular reconnaissance and measurement of key perennial grass stubble heights as outlined by Anderson and Currier (1973). This information is reported by Nelson (1996).

Experimental Animals

The pastures were stocked with equal proportions of 3 breeds of cattle (n = 31 heifers per breed averaging 333±11 kg) at the initiation of the study in spring of 1992. The 3 cattle breeds used in this study were Barzona, Brangus, and Beefmaster. Barzona cattle have a red color and are a combination of Hereford, Angus, Santa Gertrudis, and Africander

Table 2. Percentages of open grassland, mixed grass-shrub, and shrubland on pastures 15, 4, 14, and 11.

Pasture	Open grassland late seral condition[2]	Mixed grass-shrub mid seral condition	Shrubland early seral condition
	- - - - - - - -	(%)	- - - - - - - -
15	59	35	6
4	49	51	0
14	55	21	24
1	40	51	9

[1]Determinations were made by Dr. Dee Galt, a certified range consultant.
[2]This category included small areas that were near or at climax ecological condition.

breeds (Ensminger 1976). Brangus cattle include 5/8 Angus + 3/8 Brahman and are characterized by black color, moderate size, and moderate milk production. Beefmaster include 1/4 Hereford, 1/4 Shorthorn, and 1/2 Brahman (Ensminger 1976).

In 1990, the institutional care and use committee of New Mexico State University approved the purchase of 50 Barzona, 49 Beefmaster, and 50 Brangus heifer calves from ranches in New Mexico and Arizona (IACUC protocol #95). Heifers weighed 229±5 kg on arrival at the CDRRC in the autumn of 1990. After an initial receiving program which included vaccinations for brucellosis, leptospirosis, infectious bovine rhinotracheitis, and bovine viral diarrhea, the heifers were placed on native range and supplemented with 1–1.5 kg of a 20% crude protein range cube per day during winter and spring 1991. The heifers gained 0.3±.03 kg/day and weighed 261±6.4 kg at the start of the breeding season (1 May). During the breeding season, heifers were exposed to Hereford bulls for 120 days (May through August) during the first (1991) and subsequent breeding seasons (1992, 1993, 1994). In November, 1991, heifers were tested for pregnancy by rectal palpation; all non-pregnant heifers were culled. Heifers were then calved on native range in the spring of 1992 and then those that supported a calf were blocked by breed and weight and randomized within blocks to either conservative (40 ha^{-1}) or moderately (28.5 ha AU^{-1}) stocked pastures at the beginning of the breeding season in 1992 (i.e., thus, there was a 100% calf crop for each pasture in 1992). Animal unit (AU) was defined as a 1,000 pound (454 kg) cow without or with a calf ≤ 6 months of age (Society for Range Management 1989).

No culling was done in subsequent years after assignment of cows to pastures. Cows remained in their assigned pastures for the duration of the study. They were supplied mineral and salt free-choice, but received no protein or energy supplementation. Three Hereford bulls were placed in each pasture during the May–August period of 1992, 1993, and 1994. All bulls were determined to be fertile with breeding soundness exams before being placed with the herds for breeding. Calves were weighed and tagged at birth. Cows were weighed 3 times per year (precalving: January and February; prebreeding: May-June; weaning, October). Calves were weighed at weaning and these weights were adjusted according to the Beef Improvement Federation Guidelines 205-day adjusted weaning weight to account for differences in weaning weight due to age of calf and cow (BIF 1996). In late August of 1994, grazing was terminated in all 4 pastures due to the onset of severe drought.

Economic Analysis

Effects of stocking rate on Chihuahuan Desert ranching profitability was determined using the procedures of Holechek (1992, 1994). Under these procedures ranching costs and returns are standardized to ranch budgets published annually for different New Mexico grazing regions (Torell and Hawkes 1995, Torell et al. 1998). These budgets are derived for small, medium, and large size ranches based on rancher interviews. The standardized production units were an 8,094 hectare medium sized ranch carrying either 200 animal units (conservatively stocked) or 284 animal units (moderately stocked). In these calculations, actual health care and supplemental feeding costs at the CDRRC were used, rather than those for the average Chihuahuan Desert ranch.

Statistical Analyses

Differences in cattle productivity among breeds and stocking rates were analyzed with a repeated measures model using the General Linear Model (GLM) procedures of SAS (1988). In this analysis individual cattle were used as replicates which maximizes capability to detect treatment differences. Also, treatment means were adjusted for unequal sub-class numbers using least squares procedures. A factorial analysis of variance was also used to compare cattle productivity measures and financial returns among stocking rates (conservative, moderate) and years (1993 and 1994). Pastures 15 and 4 were used as replicates for the conservatively stocked treatment, and pasture 14 and 1 were replicates for the moderately stocked treatment. The LSD test was used to separate means at the 5% significance level (Steel and Torrie 1980).

Results and Discussion

Vegetation Cover and Standing Crop

Previously, we reported that percentage foliage cover of black grama, total grasses, and total vegetation was higher in conservatively than moderately stocked pastures (Nelson et al. 1997). In the current study, standing crops (kg ha^{-1}) of black grama, dropseeds, threeawns, fluffgrass, and total grasses were higher ($P<0.05$) in conservatively than moderately stocked pastures by autumn 1993 (Year 2 of the study; Table 3). A stocking rate x year interaction ($P<0.05$) was detected for the variable total grasses. This is explained by lower growing season precipitation in 1994 compared to 1993 (Table 1). Black grama was the primary forage plant found in conservatively stocked pastures based on both foliar cover and standing crop. In moderately stocked pastures, threeawns were the most prevalent forage plant. Threeawns were the second most observed forage plants in conservatively stocked pastures. Dropseeds were the third most prevalent plant in the conservatively stocked pastures, but second in prevalence in moderately stocked pastures (Nelson et al. 1997 and Table 3).

Foliar cover and forage standing crop data indicated there were some vegetation composition differences between conservatively and moderately stocked pastures. Autumn vegetation surveys and periodic grazing intensity surveys showed lower forage availability in moderately than conservatively stocked pastures in 1993 and 1994 with sizeable areas dominated by black grama existing in all 4 pasturees (Table 2 and 3, Nelson 1996, Nelson et al. 1997). We interpret the data to indicate that forage availability as influenced by stocking rate and the annual precipitation were the primary factors that influenced cattle productivity. However, we do acknowledge that plant species composi-

Table 3. Standing forage crop (kg ha^{-1}) on conservatively (CS) and moderately (MS) stocked pastures on the Chihuahuan Desert Rangeland Research Center in autumn 1993 and autumn 1994.

Plant species	1993 CS	1993 MS	1994 CS	1994 MS
	(kg ha^{-1})			
Grasses				
Bouteloua eriopoda	272[a]	57[b]	367[a]	30[b]
Sporobolus spp.	140[a]	68[b]	29[b]	15[b]
Aristida spp.	179[a]	224[a]	81[b]	179[a]
Erioneuron pulchellum	11	5	2	10
Other grasses	trace	2	trace	47
Total grassesd	592[a]	356[bc]	479[b]	281[c]
Forbs				
Croton pottsii	21	6	4	3
Other forbs	1	6	trace	trace
Total forbs	22	12	4	3
Shrubs				
Gutierrezia sarothrae	325[a]	162[b]	133[b]	187[b]
Total vegetation	939[a]	530[b]	616[b]	471[b]

[abc]Means within rows with different superscripts differ at P < 0.05.

tion differences among conservatively and moderately stocked pastures could have exerted minor influences on the results.

Breed Effects

Beefmaster cows produced 20 and 28 more kilograms of calf at weaning annually than Barzona and Brangus cows, respectively (P<0.02, Table 4). However, no differences (P>0.16) were observed for 205-day adjusted weaning weights, pregnancy rates among yearling heifers, or overall weaning percentages. Breed of cow x stocking rate interactions were nonsignificant (P> 0.10). Based on these similar productivity measures, all 3 cattle breeds appeared to be similarly adapted to Chihuahuan Desert rangelands.

In 1991 and 1992, forage selection and nutritional status of Barzona, Beefmaster, and Brangus cattle were evaluated on the CDRRC (Becerra et al. 1998). This study showed little difference in diet botanical composition and fecal N and P concentrations among Barzona, Beefinaster, and Brangus cattle. Although breed x season interactions did occur for a few diet-botanical composition components, their practical importance was doubtful due to low magnitude and lack of consistency among seasons. Individual animal behavior and physiology rather than diet botanical composition and quality would appear to explain productivity differences that may exist among the cattle breeds studied. Results from Becerra et al. (1998) were inconsistent with reports of Herbel and Nelson (1966) and Winder et al. (1996) that indicated cattle breeds do have differences in diet selection that are of practical importance. Winder et al. (1996) found Brangus cattle had higher shrub consumption in winter than Hereford or Angus cattle on Chihuahuan Desert rangeland. They also found Angus consumed more forbs in summer than Hereford or Brangus cattle. The breeds in the current study were "composites" containing at least some Brahman influence. These breeds were developed in hot arid (Barzona) or hot humid (Brangus, Beefmaster) climates. It is conceivable that adaptations to a semi-desert environment may be similar among these breeds. Thus, the differences observed by Herbel and Nelson (1966 and Winder et al. (1996) in studies involving biologically diverse breeds may not have been present in the current study population.

Production differences among breeds may have been observed if the study had been repeated on rangeland lower in ecological condition with more shrubs present. In summer, Barzona cattle consumed more honey mesquite than Brangus and Beefmaster cattle indicating they may have some potential to improve use of rangelands with a high mesquite component (Becerra et al. 1998). Nevertheless, breed differences were not detected in the study. Therefore, the data were pooled across breeds to evaluate stocking rate effects on cattle productivity.

Stocking Rate Effects

The analyses used to compare conservative to moderate stocking rates revealed that conservative stocking yielded higher calf crop percentages than moderate stocking (P < 0.05, Table 4). A stocking rate x year interaction (P<0.05) was also detected in calf crop percentage with the analyses used to evaluate hypothetical financial differences between conservative and moderate stocked pastures (Table 5). Cows grazing conservatively stocked pastures produced more actual and 205-day adjusted weaning weight per cow per year than cows grazing moderately stocked pastures (Table 4). However, differences in actual calf weaning weights were not detected (P>0.10) with the analyses used to evaluate financial differences between the conservative and moderate stocking rate (Table 5).

Our data are consistent with a wide range of studies (26) reviewed by Vallentine (1994) and Holechek et al. (1999) which indicate that calf crop per-

Table 4. Effect of breed and stocking rate on annual cow productivity on the Chihuahuan Desert Rangeland Research Center for the years 1992, 1993, and 1994 period. Breed of cow x stocking rate interactions were not detected (P>0.10) in the study, so data were pooled across breeds and evaluated based upon stocking rate.

Breed Effects	Barzona[c]		Beefmaster[c]		Brangus[c]		
Trait	LSM[a]	SE[b]	LSM[a]	SE[b]	LSM[a]	SE[b]	OSL[c]
Weaning wt/cow/yr (kg)	159	6	179	7	151	7	.02
205-d wt/cow/yr (kg)	161	7	180	8	162	7	.16
% pregnant as yearlings	78	7	63	7	69	7	.30
% weaned[d]	84	3	86	4	82	4	.74

Stocking Rate Effects	Conservative		Moderate		
Trait	LSM[a]	SE[b]	LSM[a]	SE[b]	OSL[c]
Actual weaning wt/cow/yr (kg)	173	5	153	5	.01
205-d wt/cow/yr (kg)	180	6	156	6	.01
205-d wt/ha/yr (kg)	4.4		5.5		
Calf crop%	89	3	79	3	.02

[a]Least square means.
[b]Standard errors.
[c]Observed significance level.
[d]Percentage weaned after all non-pregnant yearling heifers were culled in fall 1991.

Table 5. Cattle production and financial characteristics for conservative (CS) and moderate stocked (MS) pastures on the Chihuahuan Desert Rangeland Research Center in 1993 and 1994 standardized to a medium sized 8094 ha ranch (see Torell and Hawkes 1995 and Torell et al. 1998).

Characteristic	1993 CS[c]	1993 MS[d]	1994 CS[c]	1994 MS[d]
Ranch size, ha	8094	8094	8094	8094
Number of animal units	200	284	200	284
Total precipitation, cm	253	253	178	178
Growing season precipitation, cm	163	163	69	69
Percent use of forage	30-35	40-45	35-40	45-50
Calf crop, %[1,2]	75[a]	38[b]	90[a]	87[a]
Calf weaning weight, kg[1]	217[a]	217[a]	130[b]	137[b]
Fall cow weight, kg[1,3]	445[a]	495[a]	395[b]	392[b]
Gross income, $	60,214	50,265	42,475	61,098
Fixed costs, $	18,042	18,042	22,102	22,102
Variable cost, $	19,452	27,622	22,352	31,740
Total costs, $	37,494	45,664	44,454	53,842
Net income, $[2]	22,720[a]	4,602[b]	-1,978[b]	7,256[a,b]
Net income, $/AU[2]	114[a]	16[b]	-9[b]	26a,[b]
Net income, $/ha[2,3]	2.80[a]	0.57[b]	-0.24[b]	0.90[a,b]

[1]Actual values are used for all cattle production characteristics.
[a,b]Means within rows with different superscripts are significantly different (P < 0.05).

centages are highly sensitive to stocking rate. Across these studies, calf crop percentages averaged 7% higher under moderate than heavy stocking rates. However, light stocking only gave 3% higher calf crops than moderate stocking. Most of these studies involved humid or semi-arid environments and in some cases cattle received protein and (or) energy supplements. Based on our results, stocking rate effects on calf crop percentages appear to be accentuated in desert, compared with semi-arid and humid environments. Data on autumn foliar cover and standing forage crop (Table 3; Nelson et al., 1997) provide evidence to suggest that cattle in conservatively stocked pastures had access to about 50% more forage than moderately stocked pastures. Although nutritional status of cattle in the current study was not evaluated, the higher standing crop of forage in conservatively stocked pastures potentially reduced energy expenditure in foraging activity and possibly improved diet quality and intake, compared with moderately stocked pastures. The work of Vavra et al. (1973) supports this statement.

Calf crop percentage in 1993 was greater in conservative than moderate stocked pastures, but in 1994, these crops appeared to be equal [year by stocking rate effect (P <0.05); Table 5]. Our explanation of this result is that cows in moderately stocked pastures not producing calves in 1993 probably recovered sufficient body condition to breed and produce calves in 1994. With no supplemental feeding, these data provide evidence to suggest that moderate stocking could result in depressed calf crops every 2-3 years. These results agree with long term research on cow-calf production on semi-arid rangelands in Montana (Houston and Woodard 1966) and South Dakota (Lewis et al. 1956).

Main effect differences were not detected (P>0.10) in calf weaning weights with the analyses used to evaluate financial differences between conservative and moderate stocking rates in the current study (Table 5). Other studies show little difference in calf weaning weight between light and moderate stocking (Bentley and Talbot 1951, Houston and Woodward 1966), but moderate stocking has generally produced heavier calves than heavy stocking (Shoop and Mcllvain 1971, Pieper et al. 1991). During the summers of 1992 and 1993, forage quantity and quality were most likely adequate to meet cow needs for milk production on both the conservatively and moderately stocked pastures. However, we destocked all pastures before lack of forage could greatly affect calf nutritional status in the drought of 1994. Cows on conservatively stocked pastures lost less weight (main effect of year P<0.05) between autumn 1993 and late August 1994 than those on moderately stocked pastures (51±10.3 versus 105± 10 kg, respectively, Table 5). This was most likely a consequence of greater forage availability in the conservatively stocked pastures. Nevertheless, loss of weight and decline in cow body condition in all pastures in the summer of 1994 was an important factor in our decision to destock the pastures. Very little green forage material was available to cattle during July and August of 1994 in contrast to 1992 and 1993.

Economic Analyses

Hypothetical net returns per ha from conservatively and moderately stocked pastures (1993, 1994) did not differ (P > 0.10, Table 5). However, the main effect of year and stocking rate x year interaction were significant (P <0.05). Financial returns were severely depressed during drought in 1994. This was due to reduced calf weaning weights and lower cattle prices in 1994. The stocking rate x year interaction was caused by the depressed calf crop on moderately grazed pastures in 1993 as previously discussed.

Financial returns in Table 5 do not reflect 2 important costs. These include the opportunity cost associated with the funds required to obtain the extra 84 AU moderate stocking and the loss of cattle value associated with destocking due to drought in August 1994. We assigned a 7% interest fee to the $56,700 value of the extra 84 AU under moderate stocking. This was the average amount of interest paid on 30 year U.S. treasury bonds in the 1991 through 1994 period. When this interest income ($3,969) was added to income of conservatively stocked pastures, average net return per ha for the 2-year period was $1.77.

Mature cows were valued at $650 per cow in the autumn of 1990 (Torell and Word 1991). Their liquidation value during drought in late summer 1994 was $525 per cow. On this basis, the total loss in value associated with cattle liquidation in August 1994 was $25,000 for a conservatively stocked ranch (200 AU) and $35,000 for a moderately stocked ranch (284 AU)

Our decision to sell all cattle in late August 1994 was based on a variety of factors that included pasture stubble height levels, loss of cow weight and their poor body condition, historic climatic patterns, and the outlook for cattle prices. Stubble height for black grama averaged 5.2 cm in conservatively stocked pastures compared with 1.9 cm in moderately stocked pastures (Nelson et al. 1996). Mesa dropseed stubble heights averaged 9.6 and 4.2 cm in conservatively and moderately stocked pastures, respectively. These are below recommended minimum levels (7.6 cm for black grama, 16 cm for mesa dropseed; Paulsen and Ares 1962). Historically dry years are clustered together in southwestern New Mexico (Paulsen and Ares 1962). As it turned out, our decision to destock was wise as total precipitation and growing season precipitation in 1995 were both less than 75% of the long term average. Cattle prices in the autumn of 1995 were

20% below those in 1994. Our subsequent forage inventories in the 4 pastures in the autumn of 1995 showed forage production averaged 94 and 47 kg ha^{-1} on conservative and moderately stocked pastures, respectively. This is less than one third the average for the previous 10 years. The financial analysis presented in Table 5 demonstrate the critical importance that calf crop percentage plays in ranching profitability. Other rangeland studies have consistently shown this same effect when supplemented feed inputs were minimized (Bentley and Talbert 1951, Houston and Woodward 1966, Lewis et al. 1956). We recognize that many ranchers who use moderate and heavy stocking rates use supplemental protein and energy to improve calf crop percentages. The average medium sized Chihuahuan Desert rancher in New Mexico in 1993 and 1994 spent about $32.79 and $55.74 per AU on protein and energy supplements while calf crops for these ranchers averaged 75% and 64% in 1993 and 1994, respectively. Calf weaning weights averaged 187 and 210 kg in 1993 and 1994, respectively. In 1993, returns per AU and per ha were $64.44 and $2.26 compared to $11.06 and $0.39 in 1994 (Torell and Hawkes 1995, Torell et al. 1998). Relative to a hypothetical average rancher using supplemental feed and a moderate stocking rate, the conservatively stocked rancher would have made more money ($1. 77/ha versus $1.44/ha) for the 2-year period. Furthermore, the level of risk to drought and low cattle prices was much less than if a moderate stocking rate was applied.

One benefit we could not quantify due to the short time period in our study was stocking rate effects on grazing capacity. Other studies on arid rangelands in the southwestern United States have indicated that over a 10- to 20-year period conservative stocking will increase grazing capacity 15 to 30% over moderate stocking levels (Paulsen and Ares 1962, Martin and Cable 1974, Holechek et al. 1994). In semiarid areas, conservative to light stocking has increased grazing capacity 10-30% over moderate stocking (Klipple and Bement 1961). After a comprehensive review of the literature, Van Poollen and Lacey (1979) found across all studies that herbage production was 28% higher under light versus moderate stocking. Residual perennial forage grasses must be present for conservative stocking to be an effective rangeland improvement tool (Klipple and Bement 1961). This criterion was met on our study pastures.

Experimental Limitations

We consider the short time period (1992–1994) involved in our study to be an important limitation. Several years (at least 10) are often required for stocking rates to have major impacts on rangeland vegetation (Klipple and Costello 1960, Smith 1967, Martin and Cable 1974). Because we used heifers in this study, the initial effects of stocking rate on cattle productivity may have been accentuated compared to mature cows. Young cattle are reproductively more sensitive to rangeland nutritional conditions than mature cows (Wallace 1987).

Our financial analysis supported observations by Martin (1975) and Holechek (1992) that even on a short term basis (2–5 years) conservative stocking is financially more effective than moderate stocking in desert environments. However, we acknowledge that under different climatic conditions, cattle prices, and ranching costs, the results could have been different.

Management Implications

These data provide evidence to suggest that Barzona, Beefinaster, and Brangus cattle are similarly suited to Chihuahuan Desert rangelands. Calf crop percentages were greatly affected by stocking rate averaging 20% higher under conservative than moderate stocking for the 1993–1994 study period. Financial analyses support observations by Houston and Woodward (1966), Martin (1975) and Holechek (1992) that in arid and semi-arid environments conservative stocking provides similar or superior monetary returns to moderate stocking with less risk. Conservative stocking also has benefits of increasing grazing capacity on depleted rangelands with residual forage species (Klipple and Bement 1961, Paulsen and Ares 1962, Valentine 1970, Martin and Cable 1974, Polechek et al. 1994). The data herein provide indication that stocking desert rangelands for 35% use of key forage species as suggested by Paulsen and Ares (1962), Valentine (1970), Martin (1975), and Holechek (1992) is a sound practice from livestock production and financial standpoints. We recognize that our results have the limitation of a short time frame (1992–1994).

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Predictive models for grazing distribution: A GIS approach

BRENT L. BROCK AND CLENTON E. OWENSBY

The authors are research assistant, Div. of Biology, Kansas State University, Manhattan, Kans. 66506; and professor, Dept. of Agronomy, Kansas State University, Manhattan, Kans. 66506. This research was conducted in partial fulfillment of requirements for a Master of Science degree in Range Science for the senior author.

Abstract

Grazing distribution and forage use patterns are important influences on rangeland ecosystems. Spatial patterns of grazing by domestic cattle (*Bos taurus*) were observed over 2 consecutive years under 2 grazing systems, intensive-early stocking and season-long stocking. The purposes were to determine factors influencing observed patterns and develop predictive models for grazing distribution and forage removal. Field-collected data on grazing distribution were linked with associated geophysical properties of pastures utilizing a GIS. Separate models were developed to predict grazing distribution and forage utilization using a backward stepwise regression procedure. The forage utilization model was linked with grazing distribution by utilizing Tobit analysis. Nineteen independent variables were used to interpret the observed variation in grazing distribution. Comparison of predicted probability of grazing values from the model with the observed grazing distribution in a hold-out data set yielded a close fit (R=.99). Eighteen independent variables were included in the forage removal model. Comparison of predicted forage removal with observed values in a hold-out data set yielded a poor fit (R=.28). Lack of forage quality variables probably accounts for the poor performance of the forage removal model. Differences in the success of the 2 models support the hypothesis that grazing distribution and forage utilization operate at different spatial scales and parameters. The use of GIS holds promise as a technique for developing useful predictive models for range management.

Key Words: cattle, grazing patterns, modeling, utilization

Resumen

La distribución del apacentamiento y los patrones de uso del forraje son factores importantes en los ecosistemas de pastizal. Durante 2 años consecutivos se observaron los patrones espaciales de apacentamiento del ganado doméstico (*Bos taurus*) en dos sistemas de apacentamiento, apacentamiento intensivo temprano y apacentamiento continuo. Los objetivos del estudio fueron determinar los factores que influyen en los patrones observados y desarrollar modelos predictivos para la distribución del apacentamiento y la remoción de forraje. Datos de campo de la distribución del apacentamiento se vincularon mediante el uso de GIS con propiedades geofísicas asociadas a los potreros. Con el uso de técnicas de regresión se desarrollaron modelos separados para predecir la distribución del apacentamiento y la utilización del forraje. El modelo de utilización de forraje se vinculó con la distribución del apacentamiento mediante el análisis de "Tobit". Se utilizaron 19 variables independientes para interpretar la variación observada en la distribución del apacentamiento. La comparación de la probabilidad predicha de los valores de apacentamiento del modelo con la distribución del apacentamiento observada en un grupo de datos tuvo un buen ajuste (R=.99). Se incluyeron 18 variables independientes en el modelo de remoción de forraje. La comparación de la remoción de forraje predicha con los valores observados en el juego de datos dio un ajuste pobre (R=.28). La falta de variables de calidad de forraje probablemente contribuyó a la falta de ajuste del modelo de remoción de forraje. La diferencia en el éxito de los 2 modelos soporta la hipótesis que la distribución del apacentamiento y la utilización del forraje operan a diferentes parámetros y escales espaciales. El uso de GIS promete ser una técnica para desarrollar modelos predictivos útiles para el manejo de pastizales.

A major objective in range management is achieving uniform grazing distribution (Holechek et al. 1989, Provenza 1991, Richards and Huntsinger 1994, Walker 1995). Several factors have been identified as important influences on grazing distribution. The most notable of these are slope and distance to water (Martin and Ward 1970, Cook 1966, Gillen et al. 1984, Mueggler 1965, Pinchak et al. 1991, Roath and Krueger 1982, Senft et al. 1983), but grazing distribution can be influenced by multiple factors including: forage quantity or quality, distance to mineral supplement, proximity to fences, pasture size, abundance of weeds, and weather, (Bailey et al. 1989, Clary et al. 1978, Ehrenreich and Bjugstad 1966, Hart et al. 1991, Hein and Miller 1992, Owens et al. 1991, Senft et al. 1983, Smith and Owensby 1978). These factors are interrelated and influence grazing distribution in complex ways (Bailey et al. 1996).

Attempts to model grazing distribution have met with various degrees of success (Cook 1966, Gillen et al. 1984, Pinchak et al. 1991, Senft et al. 1983, Wade et. al. 1998). Regardless, development of models to predict grazing distribution is relatively rare (Senft et al. 1983, Wade et. al. 1998). Difficulties in developing these models arise from the large number of cofactors that create

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a high degree of spatial and temporal heterogeneity across landscapes. The logistical difficulties of calculating and analyzing the many variables necessary to develop a useful model were once enormous. Additionally, a model is of little value, from a range management standpoint, if collecting the data necessary to parameterize the model is cumbersome or expensive. Recent advances in computer technology, particularly in the areas of geographic information systems (GIS), remote sensing and statistics, have significantly ameliorated these barriers. Large volumes of spatial data can now be assembled and manipulated with relative ease.

The objective of this study was to develop separate predictive models of grazing distribution and forage utilization based on pasture physical features using GIS. Additionally, an attempt was made to use only publicly available or easily obtainable data for model development.

Methods

Data were collected in 1993 and 1994 on the Rannells Flint Hills Prairie Preserve (RFHP), a 1,093 hectare tallgrass prairie located immediately south of Manhattan in the Flint Hills region of Kansas (39°10' N, 96°30' W). The climate is continental with an average of 178 frost-free days extending from 22 April to 17 October. Average total annual precipitation is 835 mm, and the average monthly low temperature ranges from –2.7° C in January to 26.6° C in July. The vegetation is predominantly tallgrass prairie dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and Indiangrass [*Sorghastrum nutans* (L.) Nash]. Loamy upland [Benfield (fine, mixed, mesic Udic Argiustolls)-Florence (clayey-skeletal, montmorrillonitic, mesic Udic Arguistolls) complex] and limy upland [Clime (fine, mixed, mesic Udic Haplustolls)-Sogn (loamy, mixed, mesic Lithic Haplustolls) complex] range sites comprise most of RFHP with interspersions of clay upland [Dwight (fine, montmorillonitic, mesic Typic Natrustolls)-Irwin (fine, mixed, mesic Pachic Argiustolls)] and breaks (steep stony land) range sites. The RFHP is subjected to annual prescribed burning in late April, and the entire area is managed for cattle grazing.

Data were collected on 4 contiguous pastures of approximately 30 hectares each. All pastures were stocked with predominantly British x Zebu cross steers (275 kg.). The turnout date for all pastures was approximately 10 May. Two pastures were season-long stocked, and the other 2 were intensive-early stocked (Fig. 1). Stocking rates were 1.6 hectare/steer for season-long stocked pastures and 0.8 hectare/steer for intensive-early stocked pastures. Cattle were removed on approximately 15 July and 1 October for intensive-early stocked and season-long stocked pastures, respectively.

Permanent line transects were marked at 18 m intervals across the entire width of each pasture. Data were recorded every 2 weeks at 10 m intervals along each transect using modified step-pointers (Owensby 1973).

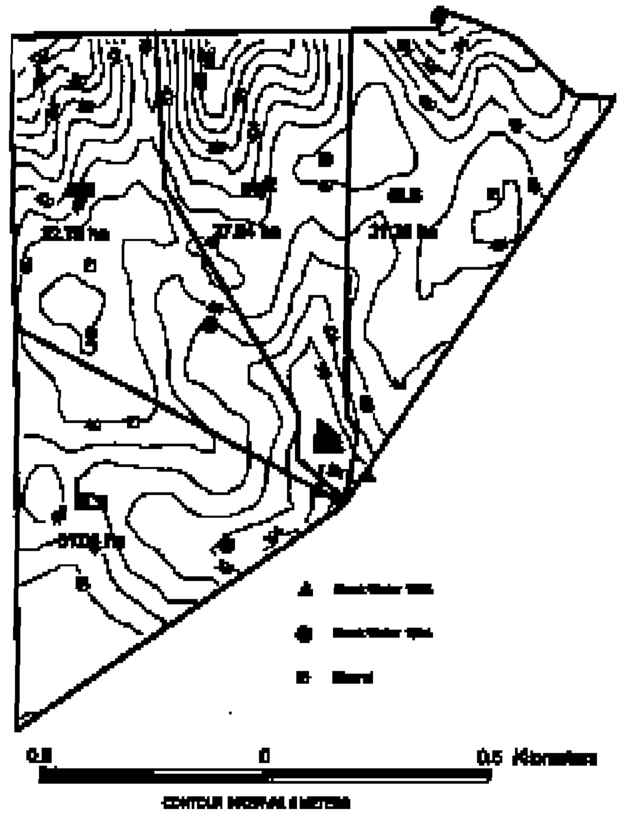

Fig. 1. Pasture boundaries showing grazing treatments and stock water and mineral locations. IES = intensive-early stocked pastures; SLS = season-long stocked pastures.

Each sampling point was scored as grazed or ungrazed, and the canopy height was scored into 1 of 9 height categories using an index pole. Canopy height categories were: 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, and 70-80 cm. Points located in areas lacking palatable forage (e.g. bare ground or impenetrable woody thickets) were scored as ungrazable and were excluded from data analysis because these points were considered outside the range of potential grazing sites. The effect of removing ungrazable points from analysis on the models was probably negligible because ungrazable patches were small (usually < 3 m diameter) and represented < 1% of total points surveyed. Approximately 1,800 points were recorded for each pasture per sampling date. That number varied depending upon the number of points needed to achieve complete pasture coverage. Logistical problems, abnormally high rainfall, and loss of data from failure of a data logger in 1993 limited the number of sampling dates to a single sampling date for the intensive-early stocked pastures. All data points were assigned map coordinates by georeferencing them to a 1:12,000 scale digital ortho images of the study area using ARC/INFO and Arcview (ESRI, Redlands, Calif.) GIS.

Percent forage utilized was calculated by comparing the canopy heights of each grazed point with an estimate of the ungrazed height for the point. All data points were grouped first by range site to account for soil, plant community, and topographical influences on canopy height. Range site boundaries were derived from 1:24,000 scale Soil Survey Geographic Database (SSURGO) data with hand-digitized and ground-truthed modifications. These data were subdivided further into 50 m x 50 m cells to minimize the influence of spatial variability on plant heights. Estimates for ungrazed canopy height were obtained using the GIS by taking the mean of the canopy heights of all ungrazed points within the cell and range site where the grazed point was located. Forage removal was calculated for each grazed data point with the following equation:

$$\mathrm{Fi} = \frac{(\hat{\mathrm{U}}\mathrm{i}-2.5\mathrm{cm})-\mathrm{gi}-2.5\mathrm{cm})}{\hat{\mathrm{U}}\mathrm{i}-2.5\mathrm{cm}} * 100 \qquad \textbf{(1)}$$

where F_i is the percent forage removed at the i^{th} data point, $\hat{U}i$ is the estimated ungrazed canopy height at the i^{th} data point, and g_i is the grazed canopy ht of the ith data point. Under the assumption that cattle could not graze below a 2.5 cm vegetation height, 2.5 cm was subtracted from g and $\hat{U}$.

Independent samples were taken in 1996 to determine the relationship between forage utilization based on canopy height and forage utilization estimates based on biomass. This was accomplished by systematically choosing 10 grazed patches to represent the full range of grazing intensities present. A 0.25 m^2 quadrat of each grazed patch was clipped to a height of 2 cm. Five ungrazed quadrats were selected randomly and clipped within 50 m of each grazed quadrat. Clipped samples were oven dried at 50°C for 48 hours and weighed to the nearest 0.01 g. Forage removal was calculated for each grazed patch as;

$$F = \frac{\bar{u} - g}{\bar{u}} * 100 \qquad \textbf{(2)}$$

where $\bar{u}$ is the mean biomass of ungrazed samples associated with each grazed quadrat, and g is the biomass of the grazed quadrat. The data indicated a log linear relationship (y = 65.812Ln(x) - 205.91, R2 = .87, n = 10, where y = utilization expressed as biomass and x = utilization based on canopy height).

Additional GIS layers were developed to assign attributes to the field-collected data. Slope, slope surface area, and aspect covers were obtained by calculating triangulated irregular networks (TIN) from 1:24,000 scale USGS Digital Elevation Models (DEM). Fence line boundaries were hand digitized from ortho images. Stock water and mineral feeder locations, as well as pond boundaries, were located using a hand-held Global Positioning System (GPS) unit. Shade boundaries were constructed by running a supervised classification on the digital ortho images and correcting for errors with hand digitizing. These map layers were overlaid with the field data to assign attributes to each data point.

Separate models were created to predict grazing distribution and forage removal by cattle. The models were linked following the model described by Tobin (1958) commonly referred to as Tobit analysis. The grazing distribution model was fit using Proc Genmod (SAS Institute Inc.1993), which fits a general linear model with logistic link function and binary distribution of the form:

$$P = \frac{e^{x'ß}}{1+e^{x'ß}} \qquad \textbf{(3)}$$

where P is the predicted probability of grazing, x´ is a matrix of covariates or independent variables, and ß is a vector of unknown regression parameters.

All variables, as well as all possible interaction combinations, were used, and nonsignificant variables were removed iteratively until only significant ($p < 0.05$) variables remained. Predicted values were calculated and mapped for each data point. These values represent the predicted probability of a given location being grazed.

Forage removal was modeled using the Lifereg procedure (SAS Institute Inc. 1996) and the classic Tobit model (Tobin 1958) which has the following form:

$$y = \max(x'ß + \varepsilon, 0) \qquad \textbf{(4)}$$

which is a regression model with left censoring, where y is the vector of response variables, x´ is a matrix of covariates or independent variables, ε is a vector of unknown regression parameters, and e is a vector of errors.

Significant variables determined in the grazing distribution model were used as explanatory variables. The model was defined further by left-censoring on the variable "grazing", so the forage removal model was fit using only the grazed data points. Nonsignificant ($p>0.05$) were again removed iteratively until only significant terms remained in the model. The model was fit with a normal distribution, and predicted values were calculated using the following formulas adapted from Greene (1993):

$$pred = xß + \sigma \frac{\varphi}{\Phi} \qquad \textbf{(5)}$$

where

$$\phi = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{xβ}{\sigma}\right)^2} \qquad \textbf{(6)}$$

and

$$\Phi = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{xβ}{\sigma}\right)^2} d_x \qquad \textbf{(7)}$$

Significant interactions occurred between year and several variables in both models. The inclusion of year as an explanatory variable would have destroyed the predictive capabilities of the models, because separate models would be required for any year. We hypothesized that the observed differences in years were due to substantial differences in weather conditions. A new variable (P:E) was created to account for these differences. This is the ratio of total precipitation for the 2-week period prior to the sampling date to the total pan water evaporation for the same period. This ratio was chosen because it incorporates the effects of temperature, humidity, and rainfall into a single index. Inclusion of this variable achieved the objective of causing all year interactions to drop out of the models.

Both models were tested by randomly withholding 20% of the data from the model fitting procedure. Calculating predicted values for this hold-out data set provided insights regarding the accuracy of the models. This was accomplished by regression analysis of predicted values for the hold-out data set plotted against the actual values. Spearman's rank correlation was used to test the forage removal model (SAS Institute Inc. 1996). To test the grazing distribution model, predicted probabilities were divided into 10 categories and plotted against the percentage of points within each prediction class that actually were grazed.

Results

Figures 2 and 3 show plots of actual and predicted distributions of grazing (Fig. 2) and forage removal (Fig. 3) for 3 sampling dates. These dates correspond to the beginning of the grazing season, season-long stocked mid-season/intensive-early stocked late-season, and season-long stocked late-season. Nineteen variables were significant for explaining the observed grazing distributions and 18 variables for explaining forage removal (Table 1). Grazing treatment had the largest effect on both models, with coefficients of 2.281 and 50.900 for grazing distribution and forage removal, respectively. No other variables exhibited dominant effects on the models (Appendix 1). The large number of significant variables with small associated coefficients demonstrates the complexity of the mechanisms regulating grazing distribution and forage removal.

The grazing distribution model was better at prediction than the forage removal model. A linear increase (R=.99) occurred in the proportion of observed grazed points with increases in predicted probability of grazing (Fig. 4). The scatter plot of observed versus predicted forage removal yields a very weak (R=.28) relationship between observed and expected values (Fig. 5).

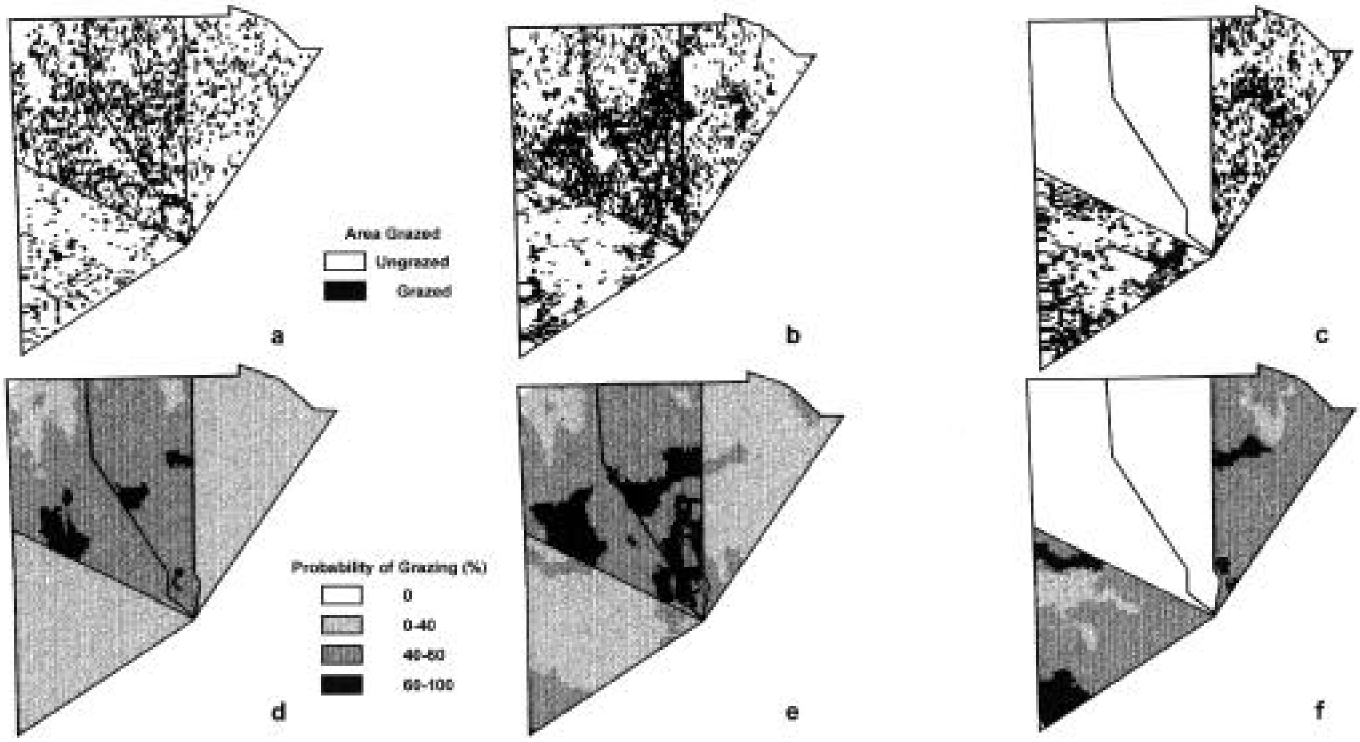

Fig. 2. Actual and predicted grazing distributions for 3 selected dates. a) actual distribution, 25 May, 1994. b) actual distribution, 20 July, 1994. c) actual distribution, 27 Sept., 1994. d) predicted distribution, 25 May, 1994. e) predicted distribution, 20 July, 1994. f) predicted distribution, 27 Sept., 1994.

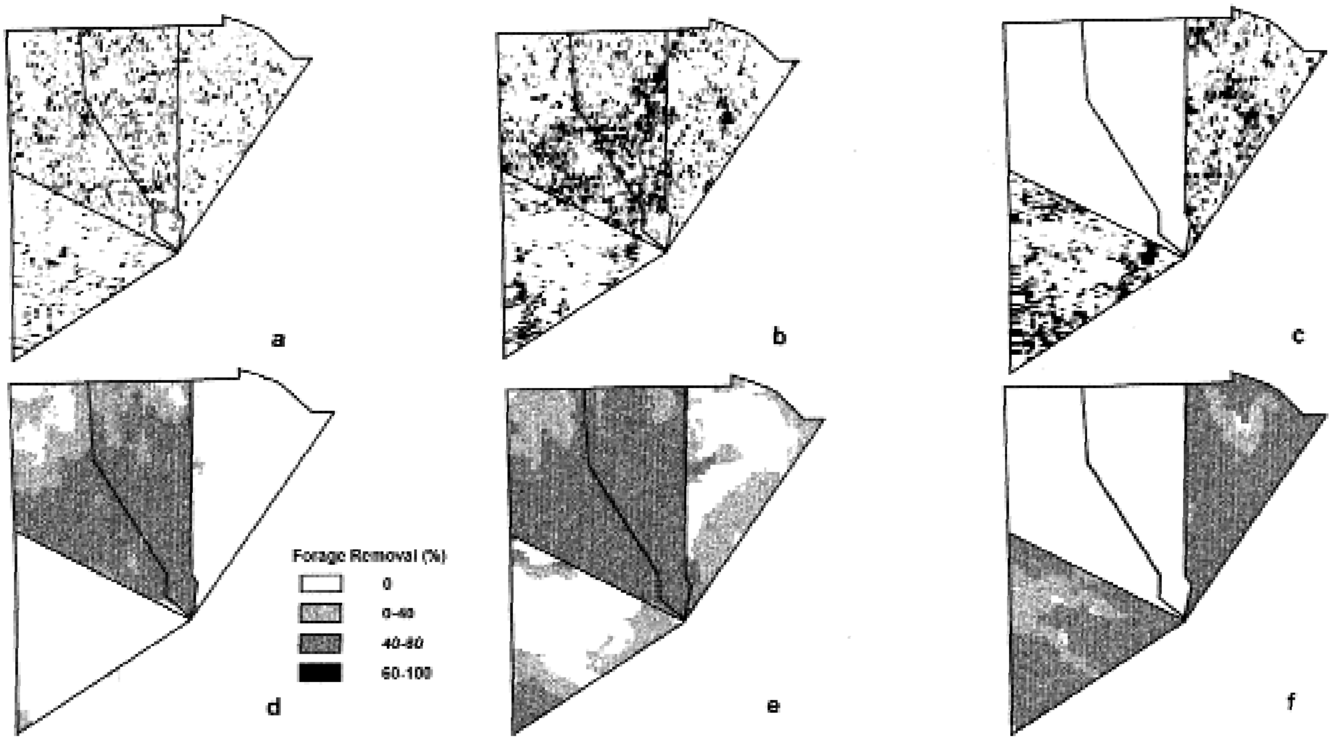

Fig. 3. Actual and predicted forage removals for 3 selected dates. a) actual removal, 25 May, 1994. b) actual removal, 20 July, 1994. c) actual removal, 27 Sept., 1994. d) predicted removal, 25 May, 1994. e) predicted removal, 20 July, 1994. f) predicted removal, 27 Sept., 1994.

Table 1. Significant (P < 0.05) terms in forage resource use models.

Source	Grazing Distribution	Forage Removal
TRT[1]	*	*
Date[2] x Slope[3]	*	*
Date x SAREA[4]	*	*
Date x Aspect[5] x TRT	*	
Date x Range Site[6] x TRT	*	*
Date x Distance to H2O x TRT	*	*
Date x Distance to Mineral x TRT	*	*
Date x Distance to Shade x TRT	*	*
Date x Distance to Range Site Boundary x TRT	*	*
Date x Distance to Fence Corner[7] x TRT	*	*
SAREA x P:E	*	*
Distance to Range Site Boundary x P:E	*	*
Aspect x P:E x TRT	*	*
Slope x P:E x TRT	*	*
P:E x Range Site x TRT	*	*
Distance to H2O x P:E x TRT	*	*
Distance to Mineral x P:E x TRT	*	*
Distance to Shade x P:E x TRT	*	*
P:E x Distance to Fence x TRT	*	*

*Significant at P < 0.05
[1]TRT=Grazing Treatment; intensive early stocked (IES), or season-long stocked (SLS).
[2]DATE=Calendar day of year.
[3]SLOPE=Percent slope.
[4]SAREA=Surface area of a plane with equal slope
[5]Aspect=Slope aspect in degrees, assigned to 8 equal classes from 0° (North) clockwise to 360°.
[6]The study area contained 5 range sites: Breaks (Steep Stoney land), Clay Upland, Limey Upland, Loamy Upland, and Loamy Lowland.
[7]Fence corners were defined by 2 fence lines connecting at [3] 90°.

Discussion

Influence of Scale on Models

Mechanisms that affect large herbivore foraging operate over a range of spatial and temporal scales (Bailey et al. 1996, Senft et al. 1987, Senft 1989). General grazing patterns are landscape-level processes and are constrained by geophysical, or abiotic, features. Within the constraints of the abiotic landscape, resource utilization patterns are dictated by smaller-scale foraging decision processes. These processes are influenced by biotic factors at the plant community level or lower. Chief among these factors are forage abundance, quality, and palatability (Bailey et al. 1989, Clary et al. 1978, Owens et al. 1991, Senft et al. 1985, Senft et al. 1987, Senft 1989). In light of this, it is not surprising that the model presented here for grazing distribution succeeded, whereas the model for forage removal failed in predicting patterns of grazing resource use. The models developed relied almost entirely on abiotic variables, which are reasonably good estimators of landscape-level grazing patterns. However, the degree of forage usage within grazed sites is determined by characteristics of the plant community at relatively small scales. Descriptive variables for these characteristics were virtually absent from the models. Among the variables fitted, range site was the only variable containing information about plant community structures, and even this variable is limited because it integrates influences of soil and topography. Additionally, range site is only an estimate of a potential plant community and is not a measure of the actual community present.

Although the models were unable to accurately predict forage removal, the concept of linking the models is valid. Herbivore forage removal does not operate independently of grazing distribution but, rather, is constrained by grazing distribution patterns. A direct relationship will always exist between forage utilization and the probability of grazing. Other models for forage preference have been developed, but they should be used in the context of larger scale processes that guide herbivore habitat selection (Loehle and Rittenhouse 1982, Senft 1989). The influence of landscape-scale abiotic features on smaller scale foraging decisions is accounted for by linking the models.

Model Limitations

To be of value to range managers, models of forage resource utilization should be accurate over a wide range of conditions. Previous grazing models have been limited by being site specific (Bailey et al. 1996, Senft et al. 1985, Senft 1989). In their current form, the models presented here also suffer this limitation. Several limitations were imposed by the experimental design and the data from which descriptive variables were derived. The models were derived from data collected on relatively small, equally-sized pastures. Pasture size can interact with other factors and influence grazing patterns (Hart et al. 1993), this term probably would need to be added before the model could be applied to a variety of pastures.

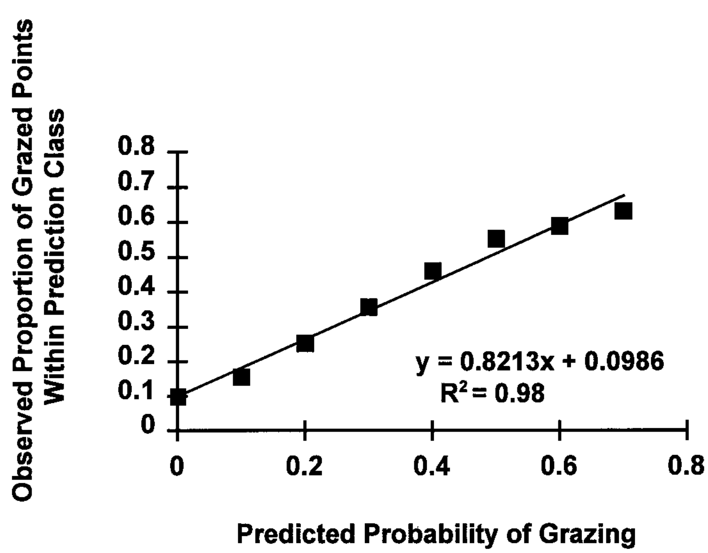

Fig. 4. Observed proportion of grazed points within a prediction class vs. predicted probability of a point being grazed. Regression was obtained from data that were withheld from the model-fitting process.

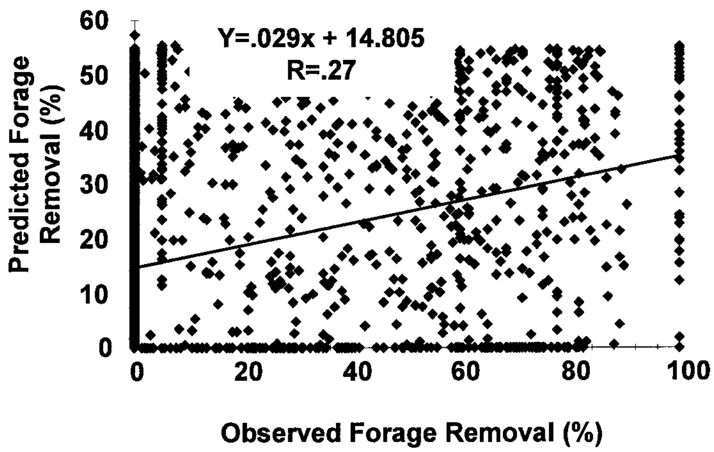

Fig. 5. Observed forage removal vs. predicted from model. The plot has been reduced to 3,000 randomly chosen points for clarity, but the regression equation is calculated from the entire hold-out data set.

Additionally, all 4 pastures were burned, which also could limit the use of these models on unburned pastures. Grazers are attracted to burned areas (Lewis 1953), and cattle will concentrate grazing on burned patches (Wright 1974). Conversely, burning can remove the attractive influence of previously grazed patches to grazers (Coppock and Detling 1986, Hobbs et al. 1991). Application of our models to unburned or partially burned pastures may require additional terms to account for the influence of burning on grazing distribution. Such data are readily available in the form of remotely sensed images.

The use of classification variables limits the applicability of models by requiring new coefficients to be determined for each new class encountered. The current models include 2 classification variables: grazing treatment and range site. An alternative to determining separate coefficients for each possible class is to substitute continuous variables that explain effects the classification variables are having on the models. Grazing treatment actually may be a continuous variable, which could be expressed as AU/unit area, because these treatments represent 1x versus 2x of normal stocking rates. However, with only 2 classes, fitting a regression line with any degree of confidence is impossible. Therefore, it is safer to leave grazing treatment as a classification variable until further data on a variety of stocking rates are obtained. Similarly, the influence of range site on these models may be due to differences in forage abundance and quality, which might be good candidates for substitution.

The usefulness of models of forage resource utilization to range managers is enhanced if they are easily derived. Previous models have been limited by reliance on field-collected data as descriptive parameters. Such data often are time-consuming and expensive to obtain. Models that rely on readily available public data should enjoy wider use among range professionals. In this respect, the models presented are superior, because they rely almost exclusively on publicly available digital data. The only additional data required are water and mineral locations and pasture fence boundaries. However, limiting model parameters to publicly available data can result in reduction in model performance, as is demonstrated by the relative performance of our 2 models. Although the public domain is relatively rich in digital data describing geophysical features, useful information about plant communities is lacking at small scales/high resolution. Although several indices for plant community structure can be calculated from remotely sensed data, such data generally are too coarse in spatial and/or spectral resolution to accurately model small-scale herbivore foraging processes. However, as the trend toward remotely sensed data with higher spectral and spatial resolutions continues, this situation is likely to improve.

Management implications

Easily derived predictive models for forage resource utilization would be powerful tools for range resource professionals. Within the limitations discussed, the grazing distribution model presented here is reasonably accurate in predicting landscape-level grazing patterns. Such information is useful to range professionals because most range management problems occur at these larger scales (Bailey et al. 1996). Our model has advantages in relying on existing and readily available predictive data and has the potential, with further development, to be applied over a wide area and combination of pasture conditions.

Perhaps the greatest advantage of this model is incorporation into a GIS. This allows for the automation of model simulations and the production of high quality maps of model predictions. With these tools, a range professional could easily explore the outcome of a variety of management possibilities before committing resources to a particular plan.

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Appendix 1. Coefficients of significant model terms.

Variable	Level 1	Level 2	Coefficiant (Grazing)[1]	Coefficiant (Forage)[2]
TRT	IES		2.281E+00	5.090E+01
P:E[3] x Range Site[4] x TRT[5]	LL	SLS	3.350E-02	
P:E x Range Site x TRT	LiU	SLS	3.130E-02	9.770E-01
P:E x Range Site x TRT	LU	SLS	2.766E-02	1.040E+00
Date[6] x Range Site x TRT	LL	IES	1.724E-02	7.330E-01
Date x Range Site x TRT	LiU	IES	1.512E-02	6.803E-01
Date x Range Site x TRT	CU	SLS	1.417E-02	5.004E-01
Date x Range Site x TRT	CU	IES	1.387E-02	6.370E-01
Date x Range Site x TRT	Br	SLS	1.275E-02	4.506E-01
Date x Range Site x TRT	LU	IES	1.236E-02	5.840E-01
Date x Range Site x TRT	LiU	SLS	1.146E-02	4.230E-01
Date x Range Site x TRT	LL	SLS	1.143E-02	4.320E-01
Date x Range Site x TRT	Br	IES	1.034E-02	4.956E-01
P:E x Range Site x TRT	Br	SLS	1.031E-02	4.020E-01
Date x Range Site x TRT	LU	SLS	9.448E-03	3.310E-01
Slope[7] x P:E x TRT	IES		4.511E-04	1.310E-02
Dist. H2O x P:E x TRT	IES		1.889E-04	6.586E-03
Dist. Mineral x P:E x TRT	IES		5.598E-05	1.636E-03
Date x Dist. Shade x TRT	IES		4.093E-05	1.273E-03
Aspect[8]x P:E x TRT	SLS		3.784E-05	1.101E-03
Aspect x P:E x TRT	IES		2.665E-05	
Date x Dist. Range Site Bound. x TRT	SLS		1.175E-05	5.037E-04
Date x Dist. Shade x TRT	SLS		9.757E-06	3.230E-04
Date x Dist. H2O x TRT	SLS		9.164E-06	1.164E-03
Date x Dist. Mineral x TRT	SLS		5.165E-06	1.770E-04
Dist. Shade x P:E x TRT	SLS		2.439E-06	
Date x Dist. Corner[9] x TRT	IES		2.315E-06	3.694E-05
Date x SAREA[10]			1.354E-07	5.610E-06
TRT	SLS		0.000E+00	0.000E+00
Date x Aspect x TRT	SLS		-2.310E-07	
SAREA x P:E			-1.077E-06	-4.400E-05
Dist. Mineral x P:E x TRT	SLS		-2.259E-06	
Date x Aspect x TRT	IES		-2.665E-06	

(Continued on page 46).

Appendix 1. Continued.

Variable	Level 1	Level 2	Coefficiant (Grazing)[1]	Coefficiant (Forage)[2]
Date x Dist. Corner x TRT	SLS		-2.786E-06	-1.200E-04
Date x Dist. Range Site Bound. x TRT	IES		-6.837E-06	3.176E-04
Date x Dist. Mineral x TRT	IES		-9.171E-06	-2.820E-04
Date x Dist. H2O x TRT	IES		-2.087E-05	-7.297E-04
P:E x Dist. FENCE x TRT	IES		-3.400E-05	-1.880E-03
Date x Slope			-4.188E-05	-1.190E-03
Dist. H2O x P:E x TRT	SLS		-4.312E-05	-2.425E-03
Dist. Range Site Bound. x P:E			-1.114E-04	-4.380E-03
P:E x Dist. FENCE x TRT	SLS		-1.817E-04	-6.390E-03
Dist. Shade x P:E x TRT	IES		-1.829E-04	-5.401E-03
Slope x P:E x TRT	SLS		-9.121E-04	-3.480E-02
P:E x Range Site x TRT	CU	SLS	-1.236E-03	
P:E x Range Site x TRT	Br	IES	-6.224E-02	-2.020E+00
P:E x Range Site x TRT	LiU	IES	-6.703E-02	-2.290E+00
P:E x Range Site x TRT	LU	IES	-7.157E-02	-2.410E+00
P:E x Range Site x TRT	CU	IES	-7.267E-02	-2.380E+00
P:E x Range Site x TRT	LL	IES	-9.074E-02	-2.570E+00
INTERCEPT			-3.832E+00	-1.407E+02

[1]Coefficients for grazing distribution model.
[2]Coefficients for forage removal model.
[3]Ratio of total precipitation to total pan water evaporation for 2 week interval prior to sampling date.
[4]The study area contained 5 range sites: Breaks (Steep Stoney land), Clay Upland, Limey Upland, Loamy Upland, and Loamy Lowland.
[5]TRT=Grazing Treatment; intensive-early stocked (IES), or season-long stocked (SLS).
[6]DATE=Calender day of year.
[7]Slope=Percent slope.
[8]Aspect=Slope aspect in degrees, assigned to 8 equal classes from 0° (North) clockwise to 360°.
[9]Fence corners were defined by 2 fences connecting at [3] 90°
[10]SAREA=Surface area of a plane with equal slope.

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Adaptation of tall-grass prairie cultivars to West Louisiana

W.D. PITMAN

Author is associate professor, Louisiana State University Agricultural Center, Rosepine Research Station, Rosepine, La. 70659.

Abstract

Big bluestem (*Andropogon gerardii* Vitman) indiangrass [*Sorghastrum nutans* (L.) Nash] and switchgrass (*Panicum virgatum* L.) are widely recognized as valuable forage and conservation species in the Great Plains and the upper South. These species occurred in natural fire-maintained longleaf pine (*Pinus palustris* Mill.) woodland ecosystems from southeast Texas eastward. Recent interest and even recommendations of cultivars of these species have been developed in the Louisiana longleaf pine area. Genotype origin of these species is known to affect adaptation. Adaptation of the cultivars Kaw big bluestem, Lometa indiangrass, Osage indiangrass, Blackwell switchgrass, and Alamo switchgrass to the Louisiana Coastal Plain was assessed under a natural stand of longleaf pines and in full sun at Rosepine, La. Plots were seeded in 1995, and stands were monitored through the spring of 1998. Only Alamo switchgrass and Lometa indiangrass under the pines produced sufficient stands for harvest. Production potential was greatest for Alamo switchgrass with the highest annual yield of 5,580 kg ha^{-1} from 2 harvests in 1996. Herbage production of 1,500 kg ha^{-1} did not differ between Alamo switchgrass and Lometa indiangrass in the second year of harvest when harvested in June and September for 2 consecutive years. The longleaf pine overstory apparently provided a competitive advantage during establishment, since weeds dominated plots in full sun. The 2 cultivars from southern latitudes, Alamo switchgrass and Lometa indiangrass, were superior in establishment, productivity, and stand survival. Aggressive competition from dense-growing subtropical grasses was detrimental during establishment and following defoliation.

Key Words: big bluestem, indiangrass, switchgrass, Coastal Plain

Resumen

En las regiones Great Plains y Upper South las especies "Big bluestem" (*Andropogon gerardii* Vitman), "Indiangrass" [*Sorghastrum nutans* (L.) Nash] y "Switchgrass" (*Panicum virgatum* L.) son ampliamente reconocidos como valiosas especies forrajeras y de conservación. Estas especies, ocurren en forma natural en los ecosistemas forestales de "Longleaf pine" (*Pinus palustris* Mill.) del Sudeste de Texas. Recomendaciones de cultivares de estas especies han sido desarrolladas en el área de "Longleaf pine" de Louisiana. Se sabe que el origen de los genotipos de estas especies afecta la adaptación. Se evaluó la adaptación de los cultivares "Kaw" ("Big bluestem"), "Lometa" ("Indiangrass"), "Osage" ("Indiangrass"), 'Blackwell' ("Switchgrass") y "Alamo" ("Switchgrass") a las planicies costeras de Louisiana en una población natural de "Longleaf pine" y en condiciones de iluminación solar total en Rosepine, Louisiana. Las parcelas se sembraron en 1995 y las poblaciones de zacates se monitorearon de 1995 hasta la primavera de 1998. Bajo los pinos, solo los cultivares "Alamo" ("Switchgrass") y "Lometa" ("Indiangrass") produjeron suficiente forraje para cosecharlo. La producción potencial fue mayor para 'Alamo' y su mayor rendimiento anual fue en 1996 con 5,500 kg ha^{-1} obtenidos en dos cortes. En el segundo año consecutivo de cosecha, la producción de "Alamo" ("Switchgrass") y "Lometa" ("Indiangrass") fue de 1,500 kg ha^{-1} para ambos cultivares cuando se cosecharen en Junio y Septiembre durante 2 años consecutivos. Durante el establecimiento, la biomasa aérea de "Longleaf pine" aparentemente proveyó una ventaja competitiva, ya que la maleza domino en las parcelas con iluminación solar total. Los dos cultivares de las latitudes del sur. 'Alamo' ("Switchgrass") y "Lometa" ("Indiangrass") fueron superiores en establecimiento, productividad y sobrevivencia de la población. La competencia agresiva de los zacates subtropicales de crecimiento denso fue detrimental durante el establecimiento y después en de la defoliación.

Livestock production is a traditional use of longleaf pine forests in the Southeast due to relatively abundant forage production (Grelen 1974). Lightning-caused fires allowed a longleaf pine-bluestem subclimax community to persist on the lower Coastal Plain from East Texas to West Florida (Grelen and Duvall 1966). Langdon et al. (1952) suggested that, "The bluestem forage type of Louisiana and east Texas is essentially a woodland continuation of the tall grass prairie, . . ." The productive, palatable grasses big bluestem, indiangrass, and switchgrass occurred throughout the region. However, they were not abundant, and their frequency of occurrence decreased even under moderate grazing pressure (Grelen and Duvall 1966; Byrd 1980). Currently, extensive areas of commercial timber land in this region are not grazed. Wildfire control and limited use of controlled burning contribute to increased occurrence of loblolly pine (*Pinus taeda* L.), slash pine (*P. elliottii* Engelm), and mixed hardwoods. These trees reduce herbaceous understory vegetation. Following timber harvest, slash and loblolly pines are often planted rather than the more open-growing longleaf pine (Grelen and Duvall 1966). Fencing laws associated with highway safety led to additional decreases in grazing, since the low stocking rates and open range grazing practices often made the necessary fencing uneconomical. Thus, the longleaf pine-bluestem forested range of the lower South has been greatly reduced in area and economic importance as a grazing resource.

The forestry and livestock industries in the region have become highly specialized, distinct enterprises rather than the integrated

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enterprises of the past. Livestock production is primarily based on introduced pastures of bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass (*Paspalum notatum* Flugge var. *saurae* Parodi). Several limitations of these well adapted, highly productive, grazing tolerant, introduced grasses have contributed to continuing interest in the native grass species. Beaty and Powell (1976) noted that switchgrass growth began 60 days earlier than bahiagrass or bermudagrass on the Coastal Plain in Georgia. Their evaluation indicated that with appropriate defoliation management, switchgrass could provide spring grazing and some dormant-season forage. A 1991 compilation of information regarding adaptation of selected native grasses identified several cultivars of big bluestem, indiangrass, and switchgrass as adapted to the southeastern states (Everett, 1991). This publication indicated that forage, either grazing or hay production, was an appropriate use of these grasses in particular areas within the region. Unfortunately, these generalizations were made with limited field data and no actual evaluations of most cultivars on the west Louisiana Coastal Plain. Recent interest in these species for conservation uses such as buffer strips, plantings for wildlife cover, and natural area restoration provide additional possibilities. Everett's (1991) compilation included 16 switchgrass entries, with 5 of these reported as adapted to at least part of the Coastal Plain in Louisiana. Only 1 of these, Alamo switchgrass, originated from a latitude similar to that of the Louisiana Coastal Plain. Of the 10 indiangrass entries, 4 were noted as adapted within the Louisiana Coastal Plain area, with only Lometa indiangrass originating at a similar latitude. Of 7 big bluestem entries, only Kaw, which originated at a much higher latitude, was shown as adapted within Louisiana. Early evaluations of ecotypes of these species demonstrated latitude-related differences in flowering date and dormancy initiation (McMillan 1959; Newell 1968). Recently, geographical origin of genotypes of tallgrass species has been suggested to affect adaptation through both photoperiod effect and through susceptibility to foliar diseases associated with precipitation zones (Moser and Vogel 1995). Thus, cultivars should be developed from ecotypes originating near the area of intended use. Information on suitability of available cultivars of the tall-grass species for the Louisiana Coastal Plain is needed. The objective of this research was to assess the adaptation of selected cultivars of switchgrass, big bluestem, and indiangrass on a site representative of the west Louisiana Coastal Plain.

Materials and Methods

Experiment I

Field plots of 5 tall-grass cultivars were established under a natural stand of longleaf pines at Rosepine, La. (30°57' N, 93°20' W, 67 m elevation) in 1995. A randomized complete block design with 6 replications was used. Cultivars evaluated were Alamo switchgrass, Blackwell switchgrass, Kaw big bluestem, Lometa indiangrass, and Osage indiangrass. Seeding rates were 5 kg PLS ha^{-1} for switchgrass, 15 kg PLS ha^{-1} for big bluestem, and 11 kg PLS ha^{-1} for indiangrass. Plots were 6 by 50 m. The soil was a Bowie fine sandy loam (loamy, siliceous, thermic Plinthic Paleudult) with initial soil P of 33 mg kg^{-1}, K of 55 mg kg^{-1}, Ca of 320 mg kg^{-1}, Mg of 98 mg kg^{-1}, and pH of 5.8. An existing stand of bahiagrass was sprayed with 11.5 liters ha^{-1} of glyphosate [N-(phosphonomethyl) glycine] herbicide in April 1995. A rough seedbed was prepared by disking in late May and again in early June. Seed were broadcast by hand on 7 June 1995 and packed with a roller immediately following sowing.

This experiment was located within a 4-ha stand of 45- to 50-year-old longleaf pines. The tree stand had been thinned to an average 11.5 m^2 basal area ha^{-1} in the summer of 1986. A solid stand of bahiagrass was present in April 1995, and pasture management practices had prevented development of a woody plant understory.

Visual stand ratings were made in Oct. 1995, June 1996, Oct. 1996, Oct. 1997, and June 1998. Stand ratings were based on a scale of 0 to 9 with 0 indicating no plants present and 9 indicating a complete stand of the planted cultivar. Effects of defoliation on productivity and persistence were assessed by sampling at different frequencies and seasons. Two, 1.5- by 6-m areas per plot were sampled for each defoliation treatment at a 20-cm stubble height. The 4 defoliation treatments were (1) harvest in June 1996, Sept. 1996, June 1997, and Sept. 1997; (2) harvest in Sept. 1996 and Sept. 1997; (3) harvest in June 1997 and Sept. 1997; and (4) harvest only in Sept. 1997. Harvested samples were weighed and subsampled for dry matter determination, and dry matter yields were calculated. As an index of shade by the longleaf pine overstory , measurements of photosynthetically active radiation were made during 6 days in late July and early August 1997. Each day, 1 replication was evaluated with 6 readings taken from each plot between 1100 and 1300 hours. Readings were taken only on days with clear sky conditions. The point quantum sensor for the LI-COR Model LI-189 light meter (LI-COR Inc., Lincoln, Nebr.) was held at the top of the grass canopy for each reading.

Statistical analyses included analysis of variance and treatment means comparisons by least significant difference procedures at each assessment date for both visual stand ratings and herbage mass. Herbage mass at each clipping date and total annual dry matter production for each year were compared among clipping treatments.

Experiment II

The same 5 tall-grass cultivars evaluated in Experiment I were planted on an adjacent site in full sunlight. This site had the same soil type with only slightly different analysis (P, 25 mg kg^{-1}; K, 45 mg kg^{-1}; Ca, 431 mg kg^{-1}; Mg, 93 mg kg^{-1}; and pH, 5.9.) from those of Experiment I. The same seeding rates were used as in Experiment I. Two seedbed types were evaluated with a split-plot arrangement of treatments in a randomized complete block design with 4 replications. Main plots were seedbed types with grass cultivars as subplots. Main plots were 9 by 18 m. Subplots were 3.6 by 9 m. Main plot treatments consisted of a prepared seedbed and the living stubble of a grazed-out ryegrass (*Lolium multiflorum* Lam.) stand. Planting date was 10 May 1995. Data collected consisted of visual stand ratings in October of each year after planting and in June 1998. Stand ratings were as described for Experiment I. Statistical analysis consisted of analysis of variance at each rating date with assessment of differences among grass cultivars by least significant difference procedures.

Results

In Experiment I, Alamo switchgrass established earlier and maintained the highest rated stands throughout the 3-year evaluation period (Table 1). At the 2 June evaluation dates (in 1996 and 1998), stand ratings of Lometa indiangrass were not significantly different from those of Alamo switchgrass. The similar stand ratings for these 2 grasses in June were in spite of earlier growth each spring observed for Alamo switchgrass. The con-

Table 1. Stand ratings[1] of tall-grass cultivars planted under longleaf pines at Rosepine, La. on 7 June 1995.

Grass cultivar	Stand rating date				
	Oct. 1995	June 1996	Oct. 1996	Oct. 1997	June 1998
Alamo switchgrass	6.2 a[2]	7.0 a	7.8 a	6.3 a	6.5 a
Blackwell switchgrass	2.7 bc	2.5 b	2.2 c	1.2 c	1.5 b
Kaw big bluestem	2.0 c	1.2 b	1.2 c	1.0 c	1.0 b
Lometa indiangrass	3.7 b	5.3 a	5.0 b	4.0 b	5.2 a
Osage indiangrass	2.5 bc	1.7 b	1.2 c	1.0 c	1.2 b

[1]Stand ratings are visual ratings based on a scale of 0 for no plants present to 9 for a complete stand.
[2]Means within a column followed by a common letter do not differ (P>0.05) according to LSD means separation.

sistent superiority of Alamo switchgrass in October ratings suggests relative differences between spring and fall stand density of these 2 grasses. Stands of Lometa indiangrass were superior only to those of Kaw big bluestem in October of the establishment year. At all subsequent rating dates, Lometa indiangrass stands were superior to those of Blackwell switchgrass, Kaw big bluestem, and Osage indiangrass. Stand ratings of these latter 3 cultivars did not differ from one another throughout the experiment. Individual plants of all cultivars produced vigorous growth and matured seed each fall. Despite this seed production, substantial improvement in stand density did not occur following initial establishment. Lack of such stand development is probably associated with the re-establishment of dense bahiagrass stands where sparse tall-grass stands developed in the first year. By fall of 1996, all plots had complete grass cover. Bahiagrass predominated except in the Alamo switchgrass and Lometa indiangrass plots. Substantial portions of plots of these 2 cultivars produced complete canopies which excluded bahiagrass. Only Alamo switchgrass and Lometa indiangrass produced sufficient stands for sampling of standing herbage in plots to reflect productivity of the planted grasses.

Physiological stage at harvest in June for these indeterminate grasses differed considerably within grass stands; however, Alamo switchgrass was predominately from boot to early seedhead exsertion stages, and Lometa indiangrass was primarily at advanced stem elongation stages. In September, previously harvested plants of both species and Lometa indiangrass plants not previously harvested ranged from boot to anthesis stages. Plants of Alamo switchgrass which had not previously been harvested ranged from the seedhead exsertion stage to past anthesis with some seed shattering. Superior production potential was indicated for Alamo switchgrass (Fig. 1). Although numerically greater, yields of Alamo switchgrass were not significantly (P>0.05) improved by harvesting in both June and September rather than only one annual harvest in September. Yields in a second consecutive year of harvest, whether from 1 or 2 clippings per year, were lower (P<0.05) than yields from areas not previously clipped. Clipping opened the sampled area, and bahiagrass invaded. Where harvested for 2 consecutive years, Alamo switchgrass only maintained a few sparse plants within a dense bahiagrass stand. In contrast, Lometa indiangrass produced more (P<0.05) herbage when clipped in both June and September than when clipped only in September. Yields were similar for the two cultivars only in 1997 from areas harvested in both June and September in both years. A single September clipping each year for 2 consecutive years resulted in lower (P<0.05) herbage yields of Lometa indiangrass than did harvests in both June and September. The observed decumbent then ascending stem growth of Lometa indiangrass may provide tolerance of defoliation early in the growing season.

Under full sunlight conditions of Experiment II, dense crabgrass [*Digitaria sanguinalis* (L.) Scop.] stands developed initially on plots with prepared seedbeds and subsequently also on plots with ryegrass stubble. The ryegrass stubble, which was heavily grazed prior to planting this experiment, produced sparse regrowth from the approximate 10-cm stubble to an average height of about 20 cm. This regrowth was primarily stem and seedheads. All plots were assessed as complete stand failures at the end of the 1995 growing season. Stand ratings revealed sparse stands on some plots of all entries at the end of the 1996 growing season (Table 2), with no differences (P>0.05) among entries for stand ratings. Stand ratings of both Alamo switchgrass and Lometa indiangrass in October 1996 on the prepared seedbed treatment from the previous establishment year were superior to the ryegrass stubble treatment (Table 2). This difference persisted through June 1998, when stands of Blackwell switchgrass also reflected this initial seedbed treatment effect. This response is associated with the persisting reseeded stands of annual rye-

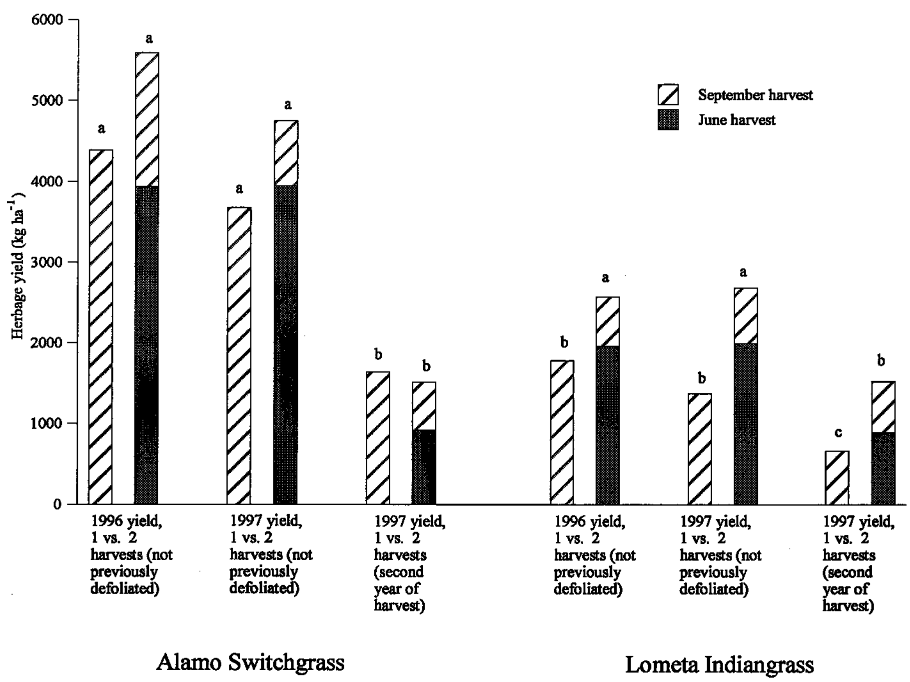

Fig. 1. Herbage yields of Alamo switchgrass and Lometa indiangrass under a natural longleaf pine stand at Rosepine, La. as affected by clipping treatment. Yields within a species do not differ (P>0.05) for bars marked with a common letter. Yields differed (P<0.05) between species, except in the second year of harvest with 2 clippings.

Table 2. Stand ratings[1] of tall-grass cultivars in open-field plantings sown on 10 May 1995 at Rosepine, La.

	Stand rating date								
	Oct. 1996			Oct. 1997			June 1998		
Grass cultivar	Ryegrass stubble		Prepared seedbed	Ryegrass stubble		Prepared seedbed	Ryegrass stubble		Prepared seedbed
Alamo switchgrass	0.3 a[2]	*[3]	1.0 a *	1.5 a	*	4.5 a	1.0 a	*	4.8 a
Blackwell switchgrass	0.5 a		1.0 a	0.5 a		1.8 ab	0.5 a	*	2.5 ab
Kaw big bluestem	0.0 a		0.5 a	0.5 a		0.3 b	0.8 a		0.8 b
Lometa indiangrass	0.0 a	*	1.0 a *	0.5 a	*	2.0 ab	0.5 a	*	3.0 ab
Osage indiangrass	0.3 a		0.8 a	0.5 a		0.8 b	0.5 a		0.5 b

[1]Stand ratings are visual ratings based on a scale of 0 for no plants present to 9 for a complete stand.
[2]Means within a column followed by a common letter do not differ (P>0.05) according to LSD means separation.
[3]Means differ between seedbed treatments for a grass cultivar on a specific rating date when marked by an*.

grass each year. Spring growth of the unfertilized ryegrass was sparse and not productive, but was apparently sufficient to compete with early establishment of warm-season grass seedlings. In the absence of soil disturbance, the summer-annual crabgrass competition decreased after the 1995 summer growing season. Due to limited existing seed supplies of bahiagrass and bermudagrass, these species invaded slowly with sparse stands by June 1998. With this limited competition, stand increases were particularly noticeable for Alamo switchgrass. In October 1997 and June 1998, Alamo switchgrass stands on the original prepared-seedbed treatment were superior to those of Kaw big bluestem and Osage indiangrass. Other treatments did not differ. Sufficient stands of Alamo switchgrass developed by fall of 1997 for samples from 3 plots to be taken to estimate yield potential in full sunlight in this environment. These three samples from 1.2 by 3.0 m areas of mature plants produced average 1997 growing season biomass of 6,100 kg ha^{-1} (with maximum of highest yielding plot of 8,600 kg ha^{-1}).

Discussion

Planting dates were within the period recommended locally for warm-season forage species and appear appropriate for the tall-grass species. Initial establishment differences between the 2 experiments corresponded with differences in herbaceous plant competition. Shade of longleaf pines reduced competition and enhanced stand establishment. In full sun, dense crabgrass competition was delayed, but not prevented, by the living ryegrass stubble. Even the sparse ryegrass apparently had an early detrimental effect on tall-grass stand establishment. Light measurements taken near noon under the longleaf pine canopy ranged from 10% to 100% of full sunlight with an average of 65% throughout the plot area. This level of light reduction apparently provided a competitive advantage to the tall-grass seedlings. Such a competitive advantage may be necessary for successful establishment of these species under the highly competitive conditions of such a humid environment. Where environmentally acceptable and economically feasible, the benefits of pesticides should be assessed. Herbicide enhancement of tall-grass establishment is apparently influenced by grass species and soil type (Martin et al., 1982). Benefits of insecticide have also been reported (McKenna and Wolf, 1990).

Even following the establishment period, plant competition from aggressive sod-forming grasses was a key limitation to survival of the tall-grass species. When not clipped, the adapted tall-grass cultivars were able to maintain stands even though dense bahiagrass stands surrounded the plot. When the tall grasses were defoliated, especially repeatedly, the sod-forming bahiagrass had a distinct competitive advantage and dominated the area within 1 or 2 growing seasons. Even in the tall-grass prairie region, defoliation can reduce dominance by the tall-grass species and increase species diversity (Collins et al. 1998). Cuomo et al. (1996) reported that in Nebraska, switchgrass was the most tolerant of defoliation among these 3 species, however, yields of all 3 species decreased with increased harvest frequency. Haferkamp and Copeland (1984) reported decreases in plant vigor of switchgrass subjected to differing defoliation treatments which were similar to our responses. Their results suggest that removal of apical meristems is a critical factor, especially when repeated a second time in the same growing season. In a review of research on switchgrass for biomass, Sanderson et al. (1996) indicated that yields were similar, or only slightly greater, from 2 harvests per season compared to a single harvest. While our results with Alamo switchgrass are in agreement with this response, Lometa indiangrass consistently produced higher yields from 2 harvests than from a single harvest per season. Haferkamp and Copeland (1984) reported herbage yield increases, but not increased vigor of fall defoliated switchgrass, due to fertilization. In high rainfall environments, fertilization could be detrimental due to increased competition.

Comparisons among cultivars indicate a distinct superiority of Alamo switchgrass, although this advantage over Lometa indiangrass was lost when stands were clipped repeatedly. Responses indicate that observations regarding adaptation of these tall-grass species in the Great Plains region (Voigt and MacLauchlan 1985) also apply to the Coastal Plain region. Cultivars which originated near the same latitude (Alamo switchgrass and Lometa indiangrass) were better adapted than those from more northern latitudes. Not only was this reflected in earlier growth each spring and later growth in the fall for the more southern ecotypes, but establishment success was also improved. Alamo switchgrass was superior despite tolerance of acid soils by seedlings of Blackwell switchgrass (Hopkins and Taliaferro 1997).

Potential exists for establishment and use of Alamo switchgrass and Lometa indiangrass for conservation uses such as buffer zones, for wildlife plantings, and for restoration plantings. Suitability of these grasses for pasture plantings is limited by the distinct competitive advantage of the widespread, aggressive, introduced grasses bahiagrass, bermudagrass, and crabgrass. Shading from open longleaf pine stands, along with low fertility and periodic moisture limitations characteristic of west Louisiana Coastal Plain soils, can reduce the competitiveness of the introduced sod-forming grasses. Defoliation increases the advantage of the sod-forming grasses over the upright growing tall-grass species. Thus, while Alamo switchgrass and Lometa indiangrass are adapted to at least some sites on the west Louisiana Coastal Plain, their usefulness appears to be restricted to situations of infrequent defoliation and resource (light, fertility, or moisture) limitations.

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Response of 2 semiarid grasslands to cool-season prescribed fire

CARLETON S. WHITE AND SAMUEL R. LOFTIN

Authors are senior research scientist, Department of Biology, University of New Mexico, Albuquerque, N.M. 87131-1091; and plant ecologist, Rocky Mountain Research Station, 2205 Columbia SE, Albuquerque, N.M. 87106 (current address: Los Alamos National Laboratory, ESH-20, MS-M887, Los Alamos, N.M. 87545).

Abstract

Woody perennials have invaded semiarid grasslands throughout the Southwestern United States. This invasion was coupled with decreased grass cover and increased runoff and soil erosion. Fire, which was a natural force that shaped and maintained the grasslands, is a management tool that may aid in restoring and maintaining grass cover. However, fire also poses the risk of increasing erosion and further soil degradation because protection afforded by vegetation is reduced immediately after the fire. Using a randomized block study design, this study measured vegetation cover, soil potentially mineralizable N, and erosion associated with the first application of prescribed fire on 2 semiarid grasslands. The potential for adverse effects from these fires was great because the fires occurred at the beginning of a drought period. However, the effects of the burn were minor relative to the effects of the drought, which caused the greatest change. Grass cover on the burn plots was nearly equal to grass cover on the controls 1 year after the fire. After 2 growing seasons, grass cover was equal on the control and burn plots. Potentially mineralizable soil N and sediment transport were similar on the control and burned plots during the 2 years following the fire. Thus, prescribed fire for reducing the cover of woody perennials may not increase the risk of site degradation over that caused by drought and weather fluctuations.

Key Words: Shrub control, vegetation cover, soil mineralizable N, erosion, soil erosion bridge, drought

Resumen

Las especies arbustivas leñosas perennes han invadido los pastizales semiáridos del sudoeste de los Estados Unidos. Esta invasión se acompaño de una reducción de la cobertura de zacates y un aumento de escurrimiento y erosión del suelo. El fuego, el cual es una fuerza natural que moldea y mantiene los pastizales, es una herramienta de manejo que puede ayudar a restaurar y mantener la cobertura de zacates. Sin embargo, el fuego también posee el riesgo de incrementar la erosión y la posterior degradación del suelo, esto debido a que la protección brindada por la vegetación se reduce inmediatamente después del fuego. En este estudio se midió la cobertura de vegetación, el nitrógeno potencialmente mineralizable del suelo y la erosión asociada con la primer aplicación de fuego prescrito en dos pastizales semiáridos, los datos se analizaron con un diseño de bloques al azar. El potencial de efectos adversos de estos fuegos fue alto porque ocurrieron al inicio de un período de sequía. Sin embargo, los efectos del fuego fueron menores comparados con los de la sequía, la cual causó el mayor cambio. Un año después del fuego, la cobertura de zacate en las parcelas quemadas fue casi igual que la cobertura de zacates en las parcelas control. Después de 2 estaciones de crecimiento, la cobertura de gramíneas fue igual en las parcelas quemadas y las parcelas control. Durante los 2 años siguientes a la quema, el nitrógeno potencialmente mineralizable del suelo y el transporte de sedimento fueron similares tanto en las parcelas quemadas como las control. Así, el riesgo de degradación del sitio por el fuego prescrito para reducir la cobertura de especies leñosas perennes no es mayor que la degradación causada por la sequía y las fluctuaciones climáticas.

In the Southwestern United States, widespread fires at 5 to 10-year intervals probably maintained the semiarid grasslands (Collins and Wallace 1990, Cook 1995, Gottfried et al. 1995, Mitchell 1978, Wright 1980, Wright and Bailey 1982). Past research has demonstrated that woody perennials invaded grasslands in the absence of fire (Briggs and Gibson 1992, Wright 1980). Invasion by shrubs and trees occurred after periods of intensive grazing coupled with periods of drought that began in the late 1800s and extended to the middle 1900's (Buffington and Herbel 1965, Frederickson et al. 1998). In the absence of grazing impacts, fire suppression in the mid-1900's created optimum conditions for shrub invasion (Brown 1982). Soil-binding perennial grasses have been replaced with shrubs such as mesquite *Prosopis* sp.), burroweed (*Isocoma tenuisecta* Greene), snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby), and four-wing saltbush (*Atriplex canescens* (Pursh) Nutt.) in lower elevation and drier sites (Brown 1982), with juniper (*Juniperus* sp.) and Piñon (*Pinus edulis* Engelm.) invading at higher elevations or wetter sites (Davenport et al. 1998). Burroweed and snakeweed, in particular, have invaded or replaced grasslands on millions of

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acres in the Southwest (Brown 1982).

In New Mexico, sediment from rangelands constitutes the second leading cause of stream impairment by nonpoint source pollutants (NMWQCC 1994). Sediment represents a direct degradation to water resources, but it also represents the loss of soil nutrients and potential productivity from the rangelands. Erosion in the Southwest is episodic in nature, with most soil movement occurring after large, intense storms (DeBano 1977, DeBano et al. 1998, Wilcox 1994). Erosion is initiated by raindrop impaction, which breaks down soil aggregates and suspends clays in surface waters (Brooks et al. 1991). A decrease in vegetation, which intercepts raindrops and protects soil aggregates from raindrop impact, increases bare soil that is very susceptible to movement in rainsplash. The infrequent "big" storms are the major cause of erosion and carry a disproportionately large amount of sediment (DeBano 1977). Arroyo cutting during these runoff events favors shrubs that can reach deeper soil moisture with their root system and out-compete grasses with more shallow root systems, which may cause a further decline in grass cover (Wood et al. 1987). These "flash flood" events contribute large amounts of sediment to flood control structures, irrigation ditches, perennial streams and stream diversion structures. An average of 80,000 cubic yards of sediment is removed from the flood control system in the Albuquerque metropolitan area each year (Albuquerque Metropolitan Area Flood Control Authority, personal communication).

Invasion of grasslands by desert shrubs has increased bare soil, erosion, and runoff in central New Mexico (Weltz and Wood 1986) and in southern Arizona (Parsons et al. 1996). However, Belsky (1996) cited a number of studies where expansion of pinyon-juniper woodlands into grasslands did not lead to greater erosion. Davenport et al. (1998) provided a conceptual model that involved soil erosion thresholds to explain why some systems show large increases in erosion with woodland invasion and others do not. As vegetation cover declines with shrub invasion, Davenport et al. (1998) demonstrated how a system could cross a threshold in ground cover, resulting in a large increase in the connectivity of soil patches that contribute to runoff and a large increase in erosion. Conversely, erosion may decline dramatically if grass cover can be increased and shrubs and bare soils decreased (Brooks et al. 1991, Morgan and Rickson 1995).

Runoff and erosion also increases following a drought or when precipitation occurs during a drought. Molles et al. (1992) reported that periods of high runoff follow periods of winter/spring drought in the semiarid Southwest. They provided examples of streams that demonstrate a hyperbolic relationship between runoff and precipitation where the generally positive relationship between runoff and precipitation changes below a certain amount of precipitation and runoff increases with lower precipitation. Mechanisms proposed by Molles et al. (1992) to explain this phenomenon include: (1) decreased vegetation and herbaceous cover during drought increases the area subject to rainsplash, which increases runoff and sediment transport; (2) soil hydrophobicity (water-repellency) increased during drought and increased runoff; and (3) increased bare soil and the associated solar/albedo relationships may have contributed to generation of higher-intensity summer thunderstorms following drought. Regardless of the specific causes, variation in local weather patterns (in contrast to global climate change) can cause variation in runoff and erosion, which may accelerate erosion in grasslands following shrub invasion. A major, region-wide, record-setting drought occurred during the 1950's (Betancourt et al. 1993) from which the region may still be showing effects (Frederickson et al. 1998).

Perhaps the most cost-effective management tool for shrub control is through the use of prescribed fire. Fire favors grass growth by killing shrubs (reducing competition for shallow soil moisture), increases essential nutrients through ash deposition (DeBano et al. 1998), reduces litter that acts as mulch, and increases light at the soil surface (Wright 1980). However, the use of fire faces several potential problems in shrub-invaded grasslands. The lack of fuel continuity can prohibit a fire from carrying across the landscape, except when pushed by high winds that usually exceed those allowed under current burn prescriptions. Areas with very dispersed fuels may have a higher treatment cost per unit area because they may require multiple applications of fire to significantly reduce shrub cover. Loss of shrub and grass canopy following fire increases the potential for soil erosion. The area remains more susceptible to erosion until the grass canopy can regain or exceed pre-burn coverage. The combination of increased available nutrients and reduced vegetation cover creates the possibility for significant loss of nutrient and soil resources through wind and rain erosion (Baker 1990, Vitousek and Howarth 1991). Also, exposure of bare soil may favor broom snakeweed germination and establishment (McDaniel et al. 1997), which could increase rather than decrease shrub cover in later years.

The management objective for the prescribed fires in this study was to reduce shrub cover for maintenance of local grasslands. The objective of this research component was to document the effects of cool-season prescribed fire in 2 semi-arid grasslands on vegetation cover-type (grass, shrub, or bare ground), potentially mineralizable N (as a measure of site fertility), and soil erosion. Hypothesized patterns included: (1) after an initial decline in vegetation cover, grasses should respond more rapidly than shrubs and achieve greater cover relative to shrubs; (2) the amount of mineralizable N should increase following the fire, but mineralizable N should return to that of control or unburned soils following regrowth of vegetation; and (3) high intensity precipitation could increase erosion following burning until the vegetation cover recovers and potential for erosion would decline. This article presents the 2-year results of the first in what is expected to be the repeated use of prescribed fire to reduce cover of perennial woody species in semiarid grasslands in central New Mexico and to reduce soil erosion.

Methods

Site Description

The research is being conducted at 2 study sites near Albuquerque, N. M. The Bernalillo Watershed lies on the mesa north of the City within the Cibola National Forest. The West Mesa site lies on the mesa west of the City and belongs to the Open Space Division of the Parks and Recreation Department. The elevation of the Bernalillo Watershed is about 1,660 m and the West Mesa site is about 1,820 m. The Bernalillo Watershed soil is a clayey loam and the West Mesa soil is a fine sandy loam (C.S. White, unpublished data, 1996). Dominant perennial grasses on the Bernalillo Watershed were: black, blue, and sideoats grama (*Bouteloua eriopoda* (Torr.) Torr., *B. gracilis* (Willd. ex Kunth) Lag. ex Griffiths, *B. curtipendula* (Michx.) Torr., respectively); purple 3-awn (*Aristida purpurea* Nutt.); galleta (*Hilaria jamesii* (Torr.) Benth); and dropseed (*Sporobolus* sp.). The West Mesa grassland represents a Great Basin Desertscrub/Desert Grassland ecotone,

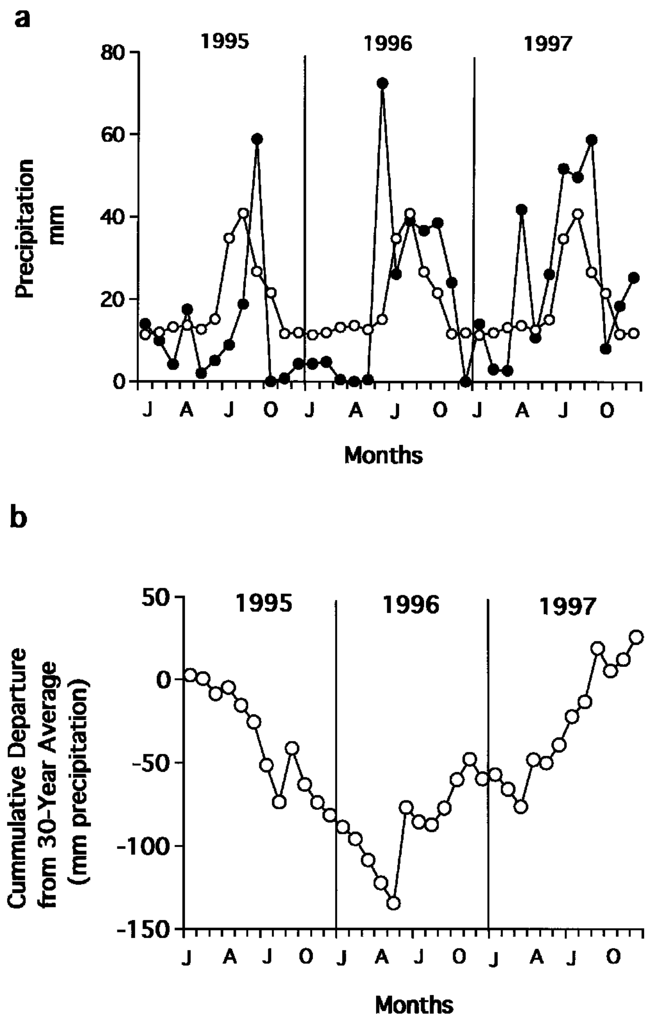

Fig. 1. Monthly mean precipitation volume for the period from 1960 through 1990 (open) and monthly precipitation (solid) during 1995, 1996, and 1997 for the Albuquerque International Airport station of the National Weather Service (a), and cumulative departure from monthly means for the period from 1960 through 1990 during the years of 1995 through 1997 (b)

and the Bernalillo Watershed represents a Plains Mesa Grassland/Desert Grassland ecotone (Brown 1982). Dominant perennial grasses on the West Mesa were: Indian ricegrass (*Oryzopsis hymenoides* (Roem & Schult.) Ricker): needle-and-thread grass (*Stipa comata* (Trin. & Rupr.)); purple threeawn; galleta; black grama; and dropseed. Within the study sites, broom snakeweed was the dominant woody perennial (included as shrub) at both sites. Other shrubs included fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), winter fat (*Krascheninnikovia* (*Ceratoides*) *lanata* (Pursh) Guldenstaedt), sand sage (*Artemisia filifolia* Torr.), and one-seed juniper (*Juniperus monosperma* (Engelm.) Sarg.).

Annual precipitation for both sites averages about 200 to 250 millimeters. With the exception of 1 month, precipitation in the area around Albuquerque, N.M., during 1995 and the first 5 months of 1996 was consistently less than the monthly mean of the previous 30 years (Fig. 1a). Cumulative monthly departure from the 30-year mean precipitation values indicate the drought period reached a maximum in May of 1996, after which slightly higher than normal precipitation generally occurred through the rest of 1996 and 1997 (Fig.1b). The normal growing period for this region is from March through September.

Livestock grazing was stopped in 1947 on the Bernalillo Watershed and in the early 1970's on the West Mesa. The Bernalillo Watershed had extensive flood and erosion control features constructed by the Soil Conservation Service and the Forest Service in the 1950s, including steep-slope terraces, furrow plowing, pitting, check dams and grass seeding. These efforts followed blockage of the main north-south highway with sediment contributed during a flood in 1954. Surface disturbance at the West Mesa includes abandoned roads for powerline construction and use by off-road vehicles before the early 1970's. Sediment and runoff from the West Mesa are direct concerns to the local flood control authority.

Experimental Design

Each site includes 8 plots; 4 control and 4 burned, which were arranged in a randomized block design as described by Hurlbert (1984). At the Bernalillo Watershed site, 6 plots (3 pairs of treatment and control) are located on 1 mesa, while the other 2 (1 treatment and 1 control) are located on a mesa to the south. On the West Mesa, plots were arranged in a linear fashion along the contour below a ridge-line. At both sites, each plot is 1 ha (100 m on a side) with at least 30 m separating the plots. Soil and vegetation sampling took place within a 60 m by 60 m area within each 1-ha plot to protect against edge effects (Fig. 2). Within each plot, 3 permanently marked 60-m lines were used for vegetation cover and density measurements. Soils were collected by cover-type (shrub, grass, or bare soil) along 3 adjacent 60-m lines. In the Bernalillo Watershed, each plot had two, 3 X 10 m runoff-erosion collectors (described below) with only 1 per plot at the West Mesa because concern for archeological resources.

Prescribed Fires

The Bernalillo Watershed was treated with prescribed fire 15-16 November, 1995, with a total of about 168 ha burned. The experimental plots were within the burned area. The control plots were protected by fire-retardant foam applied around their perimeters. Weather conditions were favorable for prescribed burning with seasonably warm temperatures (about 55°F), moderate relative humidity (20 to 30%), and light winds (0 to 10 mph) from the WNW in the morning, shifting to light with gusts (5–10 mph, gusts to 20) from the SW in the afternoon. The fuels were discontinuous, which resulted in patchy coverage by the fire. Lines of fire were set with drip torches at about 10 m intervals across the area. Fire was set to large individual patches that did not burn from the original drip-lines.

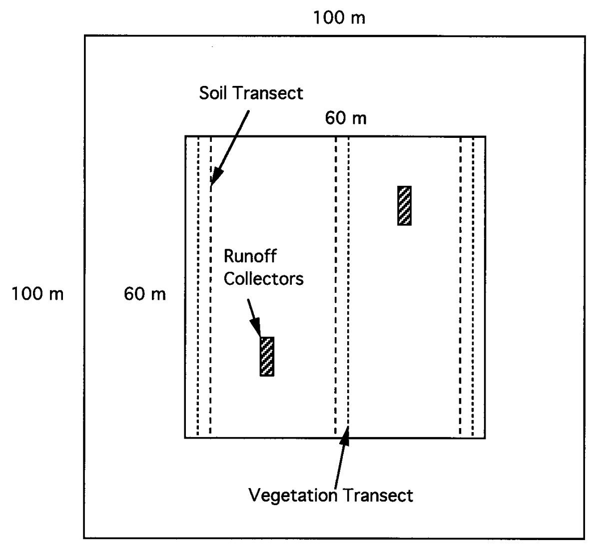

Fig. 2. Design of experimental plots showing the interior 60 m by 60 m area actually sampled, the soil and vegetation transects (dashed lines) and the relative placement of the runoff collector (rectangular shaded area in plot). Erosion bridges were installed about 30 cm from the border of the runoff collector centered along the top and one side of the collector. Sediment was trapped in rain gutter connected to a 20-liter bucket at bottom of of the collector.

The West Mesa site was treated with prescribed fire 14 February, 1996. At this site, only the treatment plots were burned. Weather conditions were favorable for prescribed burning with warm temperatures for the season (55–58 °F), moderate relative humidity (17–25%), and light (≤ 7 mph) but steady winds from the WSW. Fuels were more continuous at this site and the grasses were of taller stature, which allowed for nearly complete burn coverage. The plots were blacklined on the downwind sides, then lit across the windward side. The fire moved with the wind across the entire plot. Rate of spread was about 0.1 to 0.3 m sec^{-1} with average flame length of about 0.2 m.

Vegetation Community Structure Analysis

Aboveground cover of individual plant species, as well as non-vegetation ground cover by categories (bare soil, litter, gravel and rock), were measured using the Community Structure Analysis technique (Pase 1981). We estimated percent cover by species on a 5 by 10-cm grid at 1-m intervals along each of the three, 60-m vegetation transects (a total of 180 cover samples). These transects were measured before the prescribed fire, after the prescribed fire (within 3 months at the Bernalillo Watershed and within 1 month at the West Mesa), and after the first and second growing seasons after the fire. Cover by grass or shrub was determined by summing of the respective species' cover.

Soil Measurements and Analyses

Soil samples were collected 4 times at both sites; before the prescribed fire, shortly after the prescribed fire, and following the first and second growing seasons after the fire. Surface soil samples were collected under 3 cover-types (shrub, grass, and bare soil) by taking 4-cm wide cores to a depth of 20 cm at 2 locations along three, 60-m belt transects inside the sampling area. The 6 soil cores of each cover type from each plot were composited into a single sample. This sample design produced 1 composite sample from each plot for bare, grass, and shrub cover-types (sample-size of 4 for treatment and control).

Samples were transported on ice to the University of New Mexico, where they were sieved (2 mm), mixed, and stored at 5°C for further analyses. After determining water-holding capacity (WHC)(White and McDonnell 1988), a portion of each sample was adjusted to 50% of determined WHC and up to 11 subsamples were apportioned into plastic cups. Each cup contained approximately 30 g dry-weight mineral soil. One subsample of each sample was immediately extracted with 100 ml 2 N KCl for NH_4+-N and NO_3^- –N+NO_2^- –N analyses. The remainder of the cups were covered with plastic wrap, sealed with a rubber band, and incubated in the dark at 20°C. The plastic wrap minimized water loss during incubation, yet exchange of CO_2 and O_2 was sufficient to keep the subsamples aerobic during incubation. Moisture content was monitored by mass loss and replenished as needed. At weekly intervals, 1 subsample of each sample was removed and extracted with KCl for 18–24 hours. The clarified KCl was filtered through a Kimwipe® and analyzed for NH_4+-N and NO_3^- –N+NO_2^- –N on a Technicon AutoAnalyzer (Technicon, Tarrytown, N.Y.) as described in White (1986). Potentially mineralizable N equalled the amount of N (sum of NH_4-N and NO_3-N) at the end of the 70-day incubation period. Water content of the composited sample was measured gravimetrically after 24-hour desiccation at 105°C. Soil texture was measured by the hydrometer method (Day 1965). These sampling and analysis methods allowed for the determination of soil characteristics by cover-type.

Sediment Yield

Runoff-sediment collectors, designed after those used by the Water Erosion Prediction Project (WEPP; USDA, 1196 Building SOIL, Purdue University, West Lafayette, Ind. 47907-1196), measured 3 by 10 m. Placement of the collectors at the West Mesa site were negotiated with and approved by Albuquerque Open Space archaeologists to minimize or eliminate soil disturbance and damage to articles of archeological value. Following site approval by the State Historic Preservation Office, 1 collector per plot was installed at the West Mesa site. Two collectors per site were installed at the Bernalillo Watershed. All collectors were placed on slopes representative of the area; depressions were avoided. The average maximum change in elevation across the collectors was 1.18 m at the Bernalillo Watershed and 1.12 m at the West Mesa. At both sites, change in elevation across the runoff-sediment collectors was not significantly different between the plots to be treated with fire and the controls. Flashing was placed around the perimeter of the collectors after the fire treatments because we did not want to impede the fire spread with the flashing and the associated disturbance from installation. Along the bottom 3-m side, a plastic raingutter was installed at ground level to collect runoff and sediment (Fig. 2). Galvanized flashing was attached with a hinge to each gutter and secured to allow about a 3-cm opening for sediment and runoff to enter the gutter. At the end of the gutter, a hole was dug and a 20-liter bucket was placed in the hole and attached to the end-cap on the gutter by a section of garden hose. Both sediment in the gutter and bucket were collected at periodic intervals the first year. Sediment and runoff occurred primarily with summer rains. After the first year (1996), it was determined that sediment trapped in the buckets was insignificant relative to that in the raingutter, and only sediment in the raingutter was collected after the first year. This experimental design resulted in 4 treatment and 4 control sediment samplers at the West Mesa site, and 8 treatment and control sediment samplers at the Bernalillo Watershed (2 collectors per plot).

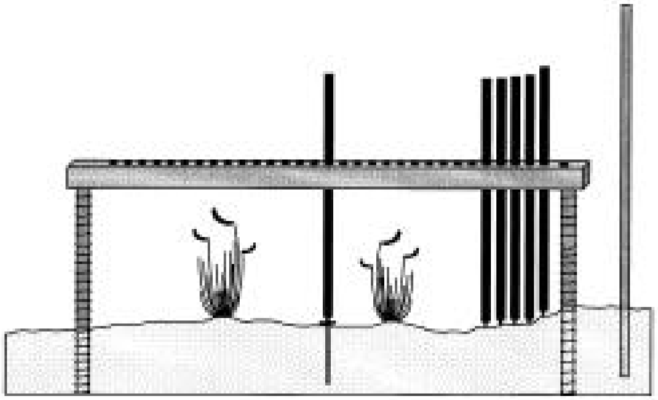

Fig. 3. Schematic drawing of soil erosion bridge showing end rebar, center nail and 5 measuring pins.

Soil Erosion Bridge

Change in soil microtopography within each runoff collector was monitored using 2 soil erosion bridges established within the area of the runoff-sediment collectors prior to the burn (1 bridge parallel to the top and 1 centered along the side of each collector; Fig. 2). A soil erosion bridge measures small-scale changes in soil microtopography (Shakesby 1993, Wilcox et al. 1994). The purpose of the bridge is to accurately determine small changes in soil elevation over time. Following a burn, removal of vegetation could coincide with soil loss. Regrowth of the vegetation may entrap wind-blown soil. Rain splash could transport soils from bare areas to vegetated areas. Movement of soil at this scale could result in a simple redistribution of soil with little net gain or loss. Similar to the pattern described by Watt (1947), the soil surface may rise as individual plants become established and mature, then degenerate upon plant mortality, but the area as a whole could remain in equilibrium with simple redistribution occurring within the area.

The actual bridge was constructed from an aluminum bar (35 mm square), 1.5 m in length, with 31 holes machined and fitted with brass bushings at 5 cm intervals (Fig. 3). The bridge is situated on 2 permanent rebar stakes, leveled with the help of a bubble level on the bridge, and secured with wood shims to prevent movement of the bridge during measurements. To increase the accuracy of this method, a spike with a dimple in the head is driven into the ground below the center pin (hole #16). An aluminum pin is then inserted through the bridge and into the dimple in the head of the nail. The end rebar stakes and the center nail create a 3 point line, which increases the accuracy over what would normally be a 2 point line (Shakesby 1993, Wilcox et al. 1994). Once the bridge is secured, pins are inserted through holes in the bridge to the soil surface and the portion of each pin extending above the bar is measured. The 30-point profile reflects the soil surface topography. The soil erosion bridges were measured upon installation in the summer of 1995, immediately after each fire, and twice each year in 1996 and 1997.

Statistical Analyses

Each site (Bernalillo and West Mesa) was analyzed separately. Effect of prescribed fire on soil potentially mineralizable N was analyzed using Analysis of Variance (ANOVA) procedures in SAS (SAS 1989). Soil bridge measurements and sediment transport were analyzed using repeated measures ANOVA procedures in SAS, which generated an analysis for the treatment, collection, and their interaction factors. Effect of the prescribed fire on vegetation cover was determined using the GLM repeated measures procedure on SPSS/PC+ 4.0 (SPSS 1990). Unless otherwise indicated, a significance level of $P \leq 0.05$ was used.

Results

Bernalillo Watershed: Vegetation Cover

Vegetation cover both before and after the prescribed fire was relatively sparse and patchy, which lead to high within treatment variances (note large error bars on Fig. 4). All cover-types declined from May 1995 to Feb. 1996 ($P<0.05$), which was during the period of below-normal precipitation (Fig. 1). The decline in grass cover was greatest on the burned plots, as expected, but grass cover on the burned plots was not significantly different than grass cover on the control plots. Total vegetation and grass cover increased between Feb. 1996 and Jan. 1997; however, shrub cover declined slightly in both the control and treatment plots. By Nov. 1997, grass cover was equal on the burned and control plots, while shrub cover declined or was unchanged. For total vegetation cover, grass cover, and shrub cover, treatment was not a significant factor, nor was the time-of-collection x treatment interaction. Time of collection was significant for the change in vegetation between May 1995 and Feb. 1996 ($P = 0.001$) and between Feb. 1996 and Jan. 1997 ($P = 0.038$), but not significant between Jan. and Nov. 1997.

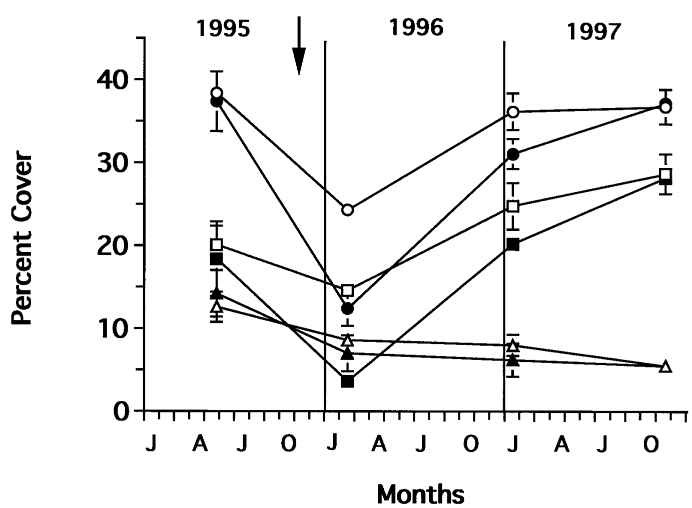

Fig. 4. Changes in mean vegetation cover (circles, total cover; squares, grass cover; triangles, shrub cover) on the control (open symbols) and burned (filled symbols) plots at the Bernalillo Watershed. Bars with each symbol, when large enough to be seen, represent 1 standard error the mean (±SE). Arrow indicates when the prescribed burn occurred.

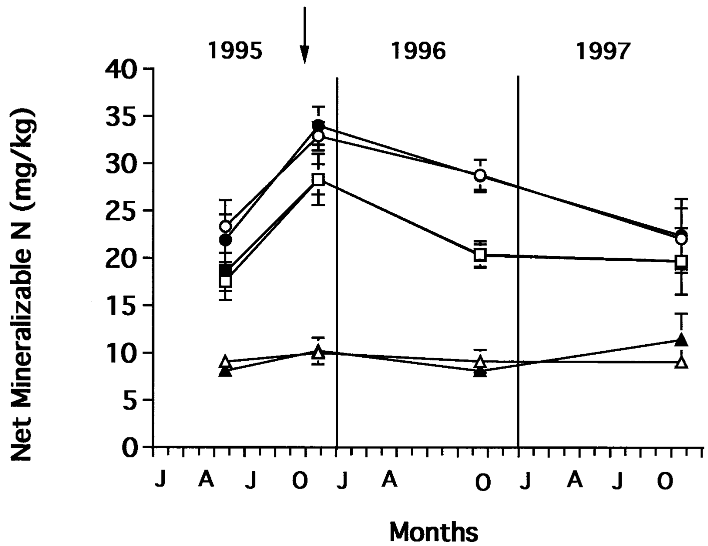

Fig. 5. Changes in mean (±SE) 70 day mineralizable N content of soils beneath different vegetation cover-types (circles, shrub; squares, grass; triangles, bare soil) on the control (open symbols) and burned (filled symbols) plots at the Bernalillo Watershed. Arrow indicates when the prescribed burn occurred.

Mineralizable N

Potentially mineralizable N was greatest in soils under shrub, slightly lower in soils under grass, and lowest in bare soils (Fig. 5) for each collection. Mineralizable N in both treatment and control samples increased after fire, decreased in the Oct. 1996 collection, and stayed the same or declined slightly by the Nov. 1997 collection (Fig. 5). The fire treatment and the interaction of fire and time of collection were not significant factors for mineralizable N, but time of collection was highly significant (P = 0.003).

Erosion

The amount of sediment obtained in each collector was highly variable in 1996 following the fire in both treatment and control plots (Fig. 6). Although the means of the treatment plots were consistently higher than the means of the controls over the first summer following the burn, the treatment was not significant (P = 0.102) for sediment yield (in part due to the high within-treatment variance). Time of collection was a highly significant factor (P< 0.001), while the treatment x time-of-collection interaction factor was nearly significant (P = 0.052). There was a general decline in sediment yield over the course of 1996. During 1997, erosion generally declined over the course of the summer in both control and burned plots, but there was no significant difference between the treatment and control plots. Total sediment yield was much lower the second year relative to the first year on all plots (898 and 1,420 kg ha^{-1} the first year in control and burn, respectively, versus 392 and 495 kg ha^{-1} the second year from the same plots).

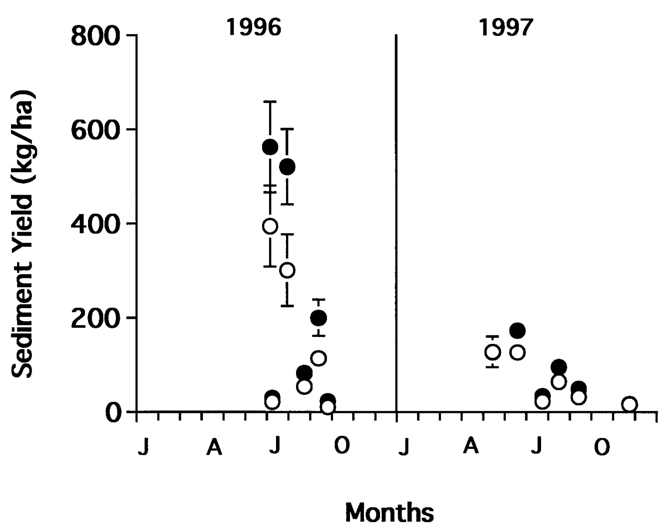

Fig. 6. Amount of mean (±SE) sediment yield from the runoff collectors in the control (open circles) and burned (filled circles) plots during 1996 and 1997 at the Bernalillo Watershed. When paired filled circle is not visible, the values of control and burned plots are nearly equal. The first runoff events occurred in late June 1996.

Soil Erosion Bridges

The repeated measures ANOVA identified that treatment, time of collection, and their interaction were all significant factors (P = 0.038, P = 0.001, and P = 0.045; respectively) for the change in soil microtopography in the Bernalillo Watershed. Both treatment and control soils show a general decline in soil surface (representing net erosion) through 1995 and 1996 (Fig. 7); however, both the burned and control plots show a net rise in both collections in 1997. The soil surface in the control plots is nearly equal to the preburn surface by Nov. 1997 with the burn plots slightly lower (but not significant).

West Mesa

Vegetation Cover

Before the prescribed fire, vegetation cover was relatively uniform across the plots and the grasses were taller than at the Bernalillo Watershed, which led to much more uniform coverage by the prescribed fire treatment. In 1995 before treatment, total cover, grass cover, and shrub cover were similar between the treatment and control plots (Fig. 8). All cover types on the control plots did not show a significant change between the 1995 collection and the Feb. 1996 collection after the fire, but all cover types were significantly lower on the burned plots. By Dec. 1996, grass cover on the burned plots increased from 0.7% cover in the post burn to 20.2% (significant at P < 0.05), while grass cover on the control plots increased from 21.1 to 25.8% (not significant, P>0.05). By the Dec. 1996 collection, grass cover on the control and burned plots was not significantly different. Grass cover on the burned plots was nearly identical to grass cover on the control plots in the Dec. 1997 collection (29.7 and 30.4 percent grass cover, respectively). Shrub cover was significantly reduced on the burned plots after the fire and remained low through Dec. 1997. Shrub cover in the control plots did not change significantly during this study. For

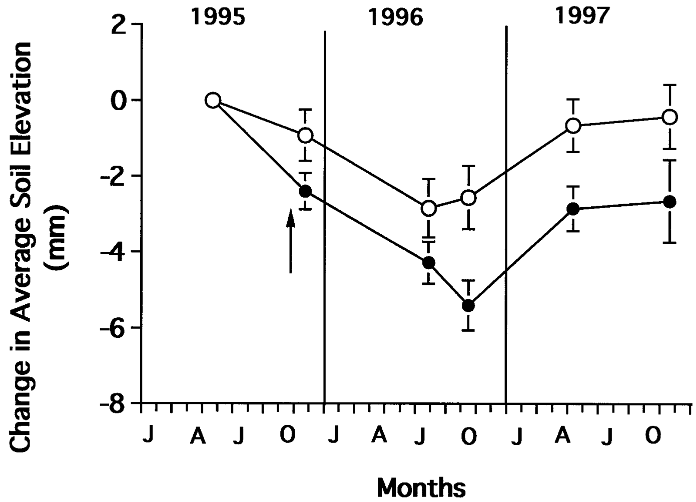

Fig. 7. Mean (±SE) net change in the soil surface measured below the erosion bridges within the control (circles) and burned (filled circles) plots at the Bernalillo Watershed. Arrow indicates when the prescribed burn occurred.

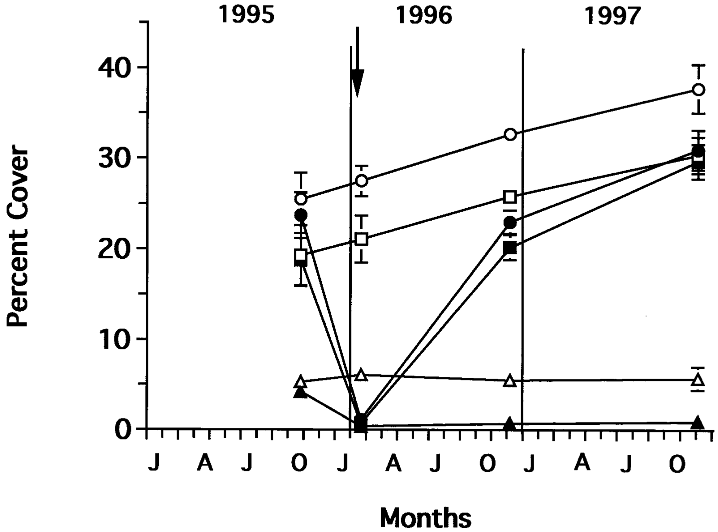

Fig. 8. Changes in mean (±SE) vegetation cover (circles, total cover; squares, grass cover; triangles, shrub cover) on the control (open symbols) and burned (filled symbols) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

total vegetation cover, grass cover, and shrub cover, treatment and the time-of-collection x treatment interaction factors were significant ($P \leq 0.05$).

Mineralizable N

The repeated measures ANOVA identified time of collection to be the only significant factor ($P<0.001$) for mineralizable N in soils of the West Mesa (Fig. 9). Mineralizable N increased (significant at $P<0.05$) in all soil-types following the prescribed fire in both treatment and control plots, except in soils under grass in the control plots. All soils showed a decline in mineralizable N by the Dec. 1996 collection. There were only slight changes in mineralizable N between the Dec. 1996 and Dec. 1997 collections for all soil-types.

Erosion

Treatment, time of collection, and their interaction were not significant factors for soil erosion at the West Mesa site. Variance was very high in all collections in both the treatment and control plots. High variance and small sample size (4 plots per treatment) resulted in no significant differences between treatment and control plots (Fig. 10). As at the Bernalillo Watershed, the burned plots consistently had more sediment than the control plots in 1996, but the difference was not significant. In 1997, the burned and control plots had similar sediment yields. Total sediment yield was less in 1997 than in 1996 for all plots (1,180 and 2,070 kg ha^{-1} in 1996 from the control and burn, respectively, versus 598 and 630 kg ha^{-1} in 1997).

Soil Erosion Bridges

Treatment, time of collection, and their interaction were not statistically significant for changes in soil surfaces. The treatment plots showed a slight, net rise in the soil surface immediately after the prescribed burn, but the trend was to decline in the 2 following collections in 1996 (Fig. 11). The control plots showed no significant change during 1996. During 1997 there was a trend (not significant) toward increasing soil surface elevation for both the control and burned plots (Fig. 11).

Discussion

Weather plays an important part in determining prescriptions for fires and effects from fires. The original study plan targeted a late September or October prescribed fire at both sites. Although summer may be the season of most frequent natural fires that result from lightning ignitions within this region (Wright 1980), prescribed fires occur most often in the cool seasons. Land managers schedule fall or winter prescribed fires because they are easier to contain and fire fighting equipment and personnel are not in high demand elsewhere. In the Southwest, the fall and winter periods can have warm days with light breezes, but not high winds, and can have abundant fine fuels to carry a fire in areas that are removed from livestock grazing. In 1995 a period of drought that started at the beginning of the year continued through the summer, so there was little new herbaceous or grass growth. In September 1995, the rains exceeded the long-term average (Fig. 1b) and forced both burns to be delayed. The prescribed fires were performed later in the fall (Bernalillo Watershed) or winter (West Mesa) when prescribed weather conditions were met. Little or no precipitation occurred after the fires with below-normal precipitation continuing through the winter and spring of 1996. Rains finally came in June of 1996, in the form of thundershowers, and higher-than-average

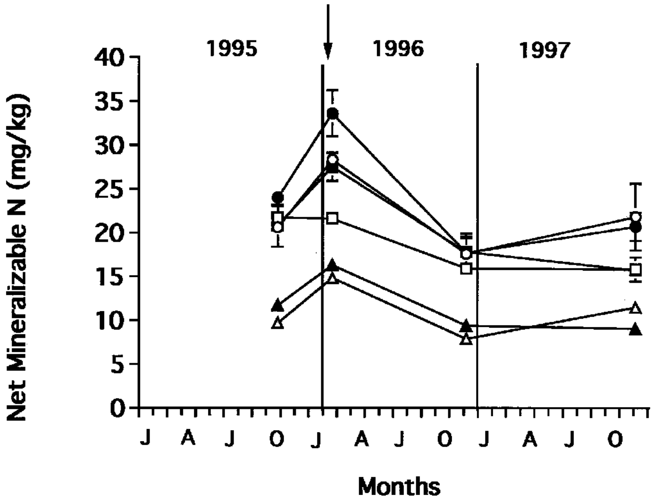

Fig. 9. Changes in mean (±SE) mineralizable N content of soils beneath different vegetation cover types (circles, shrub; squares, grass; triangles, bare soil) on the control (open symbols) and burned (filled symbols) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

precipitation occurred in most months during the rest of the study. The weather also limited the expected benefits from ash on the burned plots because ash was blown off the burned plots, which was evident from ash trapped by vegetation in the surrounding area.

The weather before and after the prescribed fires, and the drought in particular, was the most important factor contributing to changes in plant cover and soil characteristics during this study. The effect of weather, represented by the time-of-collection factor in the statistical analyses, and/or its interaction with the fire treatment were significant factors for all the characteristics at the Bernalillo Watershed and for 2 (vegetation cover and soil mineralizable N) of the 4 characteristics at the West Mesa. The fire treatment was significant only for 1 characteristic (soil erosion bridge measurements) at Bernalillo Watershed and, along with its interaction with time of collection, for only 1 characteristic (vegetation cover) at West Mesa.

The primary management objective of the prescribed fires was to reduce shrub cover to maintain grasslands. This objective was met at the West Mesa (6.1 and 0.4 average percent shrub cover on control and treatment plots, respectively, after the fire), but not at the Bernalillo Watershed. The lack of fire effects on vegetation cover may have resulted from lower fuel continuity at the Bernalillo Watershed relative to the West Mesa. Shrub cover was not reduced at the Bernalillo Watershed where large patches were unburned, even when the area was treated with fire lines at 10-m intervals. In contrast, better fuel continuity allowed a single fire line to spread across the entire plot at the West Mesa where shrub cover was significantly reduced on the burn plots.

Shrub cover tended to decline at the Bernalillo Watershed over the study at both the control and burned plots. The fire treatment was more effective at reducing the grass cover at the West Mesa than at the Bernalillo Watershed. The fire significantly reduced grass cover at the West Mesa, but the reduction in grass cover was not significant at the Bernalillo Watershed. The lack of fuel continuity at the Bernalillo probably limited consumption of grass fuels, but the drought caused a concurrent reduction in grass cover at the control sites (Fig 4). Grass cover was almost the same on the burned and control plots at both sites by the end of 1997, approximately 2 years after the fire. The increase in grass cover on the burned plots indicates the ability of these grasslands to rapidly respond to fire, while the shrubs show limited recovery after fire or drought in both sites. Research from other semiarid grasslands suggest that stimulation of grass growth occurs for up to 4 years following fires in semiarid grasslands (Bock and Bock 1990, Pase and Granfelt 1977). Thus, grass cover in the burn plots may continue to increase while shrub response may be a factor of weather that is independent of the fires.

Ash from low-intensity fires can contain large amounts of NH_4-N and other essential nutrients (DeBano 1991, DeBano et al. 1998). The increase in nutrients can stimulate soil microbial activity and increase mineralizable N, but this response was not seen following the fires at these sites (with the possible exception of soils under grass at West Mesa). The lack of fire effects on soil mineralizable N may be the result of loss of ash due to wind. In the Bernalillo Watershed, redistribution of ash was particularly important because the control plots were "islands" within the treated area and could receive ash from all sides. In contrast, the treatment plots were "islands" within the sea of unburned grasslands at the West Mesa site, so potential ash contribution to the control plots may have been less at the West Mesa site than at the Bernalillo Watershed. The low levels of mineralizable N in both grasslands suggest that net primary production could be limited by available N supply; however, fire

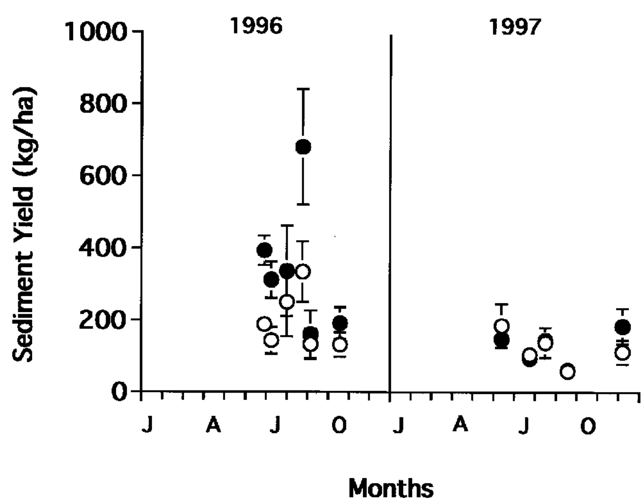

Fig. 10. Amount of mean (±SE) sediment yield from the runoff collectors in the control (open circles) and burned (filled circles) plots during 1996 and 1997 at the West Mesa. When paired filled circle is not visible, the values of control and burned plots are nearly equal. The first runoff events occurred in early July, 1996.

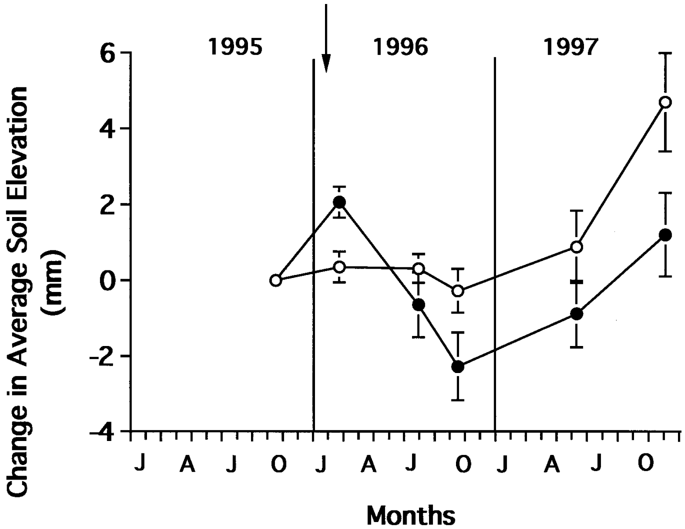

Fig. 11. Mean (±SE) net change in the soil surface measured below the erosion bridges within the control (circles) and burned (filled circles) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

should not change future site productivity since soil mineralizable N pools were unaffected by fire throughout this study. Soil mineralizable N pools declined in treatment and control plots at both sites between the second and third collections (except for bare soils at West Mesa). The decline in mineralizable N coincided with an increase in grass cover, which suggests that part of the available N pool may have been sequestered by the vegetation. However, the decline in mineralizable N also may be due to loss of soil and nutrients through sediment transport since sediment yield was high on both control and burned plots at both sites during 1996 (Fig. 6 and 10).

The effects of fire generally trend toward an increase in the rate of surface erosion (DeBano et al. 1998). However, fire was a significant factor only for the changes measured by the soil erosion bridges at the Bernalillo Watershed. The trend toward increasing vegetation cover during 1996 and 1997 is consistent with a decline in sediment (1,180 and 2,070 kg ha^{-1} in 1996 from the control and burn, respectively, versus 598 and 630 kg ha^{-1} in 1997), but weather was a more significant factor than fire controlling sediment yield at the Bernalillo Watershed and the trends at the West Mesa were not significant. The total amount of sediment at both sites was within the range found by Wilcox (1994) using identical sized plots within pinyon-juniper woodlands. The trend at both sites toward lower sediment yield over the course of each summer also was observed by Wilcox (1994), and Yair et al. (1980) observed similar declines in sediment concentrations with repeated runoff events in arid regions of the northern Negev in Israel. Since similar amounts of and patterns in sediment yield occur elsewhere, control over the changes in sediment yield in this study is likely from causes other than fire. Thus, there is no direct evidence that fire increased the potential for soil erosion at either site although vegetative cover was reduced by the fires.

The soil bridges measured changes in soil surfaces on only a small portion of each runoff/sediment collector. Although the changes over time were significant only at the Bernalillo Watershed, the bridges at both sites showed similar trends with the tendency for the mean soil elevation to decline during 1996 and then increase in 1997. Calculation of the average change in mean soil elevation based upon the sediment yields, assuming that the very topmost soil has a bulk density of 1 g cm^{-3}, shows that the total amount of sediment lost during 1996 would represent a decline of 0.09 mm and 0.14 mm in the mean soil surface on the control and burned plots, respectively, at the Bernalillo Watershed, and 0.12 mm and 0.2 mm, respectively, at the West Mesa. The soil bridges show much greater loss (1.0 mm and more) from most plots, except the control plots on the West Mesa (Fig. 7 and 11). Discrepancies between bridges and sediment yield could reflect the problem that measurements at different scales inherently differ, but bridges also reflect changes in the soil surface due to processes other than runoff. Bridges measure within-collector redistribution of particles by wind, compaction of the soil, freeze-thaw lofting of the soil surface, or other phenomenon that are not expressed at the 30-m^2 scale of the sediment collectors.

Conclusions

Hypothesized pattern 1: After an initial decline in vegetation cover, grasses should respond more rapidly than shrubs and achieve greater cover relative to shrubs. This occurred on both grasslands, but can not be attributed to fire alone because of the importance of weather.

Hypothesized pattern 2: Nitrogen in ash should increase the amount of mineralizable N following the fire, but mineralizable N should return to that of control or unburned soils following regrowth of vegetation. This pattern did not occur because mineralizable N in both treatment and control soils rose after the fire, perhaps due to ash contribution to control sites. Weather played a more important role in soil mineralizable N dynamics than did the fire treatment.

Hypothesized pattern 3: High intensity precipitation could increase erosion following burning until the vegetation cover recovers and potential for erosion would decline. Although there was a trend toward high sediment yields with fire, the fires did not significantly increase sediment yield at these sites. Sediment yield showed greater changes between years than with fire treatment, suggesting that other factors play a greater role in controlling erosion than did the fires.

The results of this study are noteworthy for 2 reasons. First, adverse affects of the fire were not realized. Reduction in vegetation cover after the fire coupled with the extended drought conditions were expected to increase sediment yields from burn plots relative to control plots. If erosion increased, nutrients lost with sediments would lower soil fertility. To our surprise, neither soil erosion nor mineralizable N (our measure of soil fertility) showed adverse effects of fire. Second, our results show that variation in local weather patterns can play an overriding role in vegetation dynamics and erosion at these grasslands. Thus, the potential for adverse effects on local grasslands from use of prescribed fire for shrub control may be minimal even when the fires are followed by adverse weather conditions.

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Disk chain effects on seeded grass establishment

H. T. WIEDEMANN AND B. T. CROSS

Authors are Professor of Agricultural Engineering and Research Associate, Texas Agricultural Experiment Station, P.O. Box 1658, Vernon, Tex. 76385.

Abstract

Preparing a seedbed and seeding rangeland littered with brush debris normally requires extensive land cleanup before conventional equipment can be used. Our 3-year study compared grass densities on seedbeds prepared with an anchor chain, a disk-chain implement, and the disk chain followed by an anchor chain on land rootplowed for mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) control. Seedbeds were aerially seeded with 1 or 2 kg/ha pure live seed of kleingrass (*Panicum coloratum* L.). Treatments were applied to a clay loam and sandy loam site each year. Evaluations were based on established grass densities at the end of the first growing season. A heavy-duty, offset disk was included in the seedbed preparation methods during the third year. The chain, disk-chain, and disk-chain+chain implements traversed the log-littered sites without difficulty. Seedbeds prepared by disk-chaining+chaining significantly (P<0.05) increased plant densities by 100% in clay loam soil and 42% in sandy loam soil compared with seedbeds prepared by chaining. However, in the year when rainfall was 43% below normal at the clay loam site, disk-chaining+chaining increased plant densities by 218% compared with chaining. Plant densities on disk-chained seedbeds were lower than those on disk-chained+chained seedbeds in clay loam soil while densities on disk-chained seedbeds were significantly (P<0.05) lower than densities on disk-chained+chained seedbeds in the sandy loam soil, but densities following disk chaining were significantly (P<0.05) higher than densities following chaining in both soil types. There was no difference in plant densities between disked and disk-chained+chained seedbeds; consequently, there would be little need to rake up the brush so a disk could be used. The 2 kg/ha seeding rate compared with the 1 kg/ha seeding rate significantly (P<0.05) increased plant densities by 75% in the clay loam and 98% in the sandy loam soil. The results from this study indicate the value of using the disk-chain+chain implement, and the higher seeding rate to enhance the establishment of a seeded grass, especially when rainfall is in short supply or not timely.

Key Words: seedbed, rangeland seeding, brush control, mesquite, *Prosopis glandulosa*

Resumen

Preparar una cama de siembra y sembrar un pastizal con muchos residuos de arbustos normalmente requiere de mucha labor de limpieza antes de que un equipo convencional pueda ser utilizado. En nuestro estudio de tres años comparamos 3 densidades de zacates en camas de siembra preparadas con una cadena de ancla, un implemento de cadena de discos y el implemento de cadena de discos seguido por la cadena de ancla en un terreno preparado con arado de subsuelo para el control de mezquite (*Prosopis glandulosa* Torr. Var. *glandulosa*). Las camas de siembra se sembraron vía aérea con una densidad de 1 o 2 kg de semilla pura viable de "Kleingrass" (*Panicum cloratum* L.). Los tratamientos se aplicaron cada año en un sitio franco - arcilloso y otro franco- arenoso. Las evaluaciones fueron realizadas al final de la primera estación de crecimiento en las densidades de zacates establecidos. En el tercer año se incluyo un implemento de discos de trabajo pesado como medio de preparación de la cama de siembra. La cadena, la cadena de discos y el disco + cadeneo + cadeneo funcionaron sin dificultad en los sitios con residuos de arbustos. Las camas de siembra preparadas por el disco + cadeneo + cadeneo incrementaron significativamente (P<0.05) la densidad de plantas, en 100% en el sitio franco arcilloso y en 42% en el sitio franco arenoso, en comparación con la cama de siembra obtenida con el cadeneo. Sin embargo, en el año cuando la precipitación fue 43% debajo de lo normal, en el sitio franco-arcilloso el disco + cadeneo + cadeneo incremento la densidad de plantas en 218% comparado con el cadeneo solo. En el sitio franco arcilloso las densidades de plantas en la cama de siembra de disco + cadeneo fueron menores que las obtenidas en el tratamiento disco + cadeneo + cadeneo. En el sitio franco arenoso las densidades en las camas de siembra disco + cadeneo fueron significativamente menores (P<0.05) que las densidades de las camas de siembra disco + cadeneo + cadeneo,. Las densidades de siembra seguidas por el disco-cadeneo fueron significativamente mayores (P<0.05) que las densidades seguidas por el cadeneo, esto fue similar en ambos tipos de suelo. No hubo diferencias en la densidad de plantas entre las camas se siembra de disco y disco + cadeneo + cadeneo, consecuentemente, habría poca necesidad de rastrillar para limpiar los residuos de arbustos, por lo que un disco puede ser utilizado. La densidad de siembra de 2 kg /ha, comparada con la densidad de 1 kg/ha, incremento significativamente (P<0.05) la densidad de plantas en 75% en el sitio franco arcilloso y en 98% en el franco arenoso. Los resultados obtenidos en este estudio indican el valor de usar el implemento disco + cadena + cadena y la densidad de siembra alta para aumentar el establecimiento del zacate sembrado, especialmente cuando la precipitación es escasa o no ocurre a tiempo.

Mention of a trade name is for identification only and does not imply an endorsement or preference over other products not mentioned.

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Conversion of brush-infested rangeland to a grassland has been shown to increase forage and livestock production (Fisher et al.1959). When the conversion is sculptured into a brush-infested landscape, it can enhance the wildlife habitat, livestock production, watershed management, and recreational enterprises (Rollins 1997). The high cost of removing brush, preparing a seedbed and planting limits the conversion practice. Research to develop cost-effective equipment for seedbed preparation and seeding which requires less land cleanup has been conducted by Wiedemann et al. (1979). We found that seedbeds prepared with heavy-duty, offset disks consistently resulted in better stands of seeded grasses than roller chopped or chained seedbeds on rootplowed land, but log-littered land often precluded the disk's use. Rootplowing, the severing of tree roots by a large horizontal blade pulled through the soil for brush control, leaves the soil surface rough and littered with logs. Chaining with large anchor chains pulled between 2 crawler tractors is well suited for use on log-littered land. This method was much lower in cost than disking, but it resulted in the poorest stands of seeded grass. Combining disking and chaining techniques resulted in the development of a "disk chain" (Fig. 1). The implement provides disking action at costs similar to chaining and could eliminate the need for raking in most brush-infested areas (Wiedemann and Cross 1980). Engineering studies of disk chains reported the pulling requirements of a diagonal unit requiring 2 tractors (Wiedemann and Cross 1982), the development of a triangular unit requiring only 1 tractor (Wiedemann and Cross 1985) (Fig. 2), and the influence of operating mass on pulling requirements and depth of disking (Wiedemann and Cross 1987). Based on results from these studies, a disk chain was developed that could traverse rootplowed land littered with logs or undisturbed land infested with small shrubs (Wiedemann 1990). Moreover, pulling requirements and depth of disking can be predicted for a broad range of conditions when several engineering indices of the implement and soil are known.

Information is lacking on the efficacy of the disk chain for rangeland seeding. The objective of this study was to compare disk chaining with other methods of preparing seedbeds on log-littered, rootplowed rangeland by comparing the density of established grass plants following the first growing season after seeding for each seedbed method.

Table 1. Annual and monthly rainfall near the clay loam site (Vernon) and the sandy loam site (Pitchfork Ranch) for the study period.[1]

Month	Vernon			Pitchfork Ranch		
	1979	1980	1981	1979	1980	1981
	(mm)			(mm)		
Jan.	22	35	3	21	28	0
Feb.	7	11	15	0	10	30
Mar.	64	19	8	67	15	21
Apr.	36	75	72	36	14	68
May	171	119	87	38	160	92
Jun.	66	28	131	132	53	38
Jul.	45	0	31	93	0	11
Aug.	171	4	100	43	25	37
Sep.	0	57	41	37	165	70
Oct.	47	2	82	14	0	115
Nov.	32	33	10	27	30	14
Dec.	44	36	0	43	33	0
Total	705	419	580	550	534	496

[1]Climatological Data, NOAA, Asheville, N.C. 28801.

Fig. 1. Disk chain pulled between 2 crawler tractors for seedbed preparation on land littered with brush debris.

Materials and Procedures

Study Sites

Research sites were located in the Rolling Plains vegetational resource region of northwest Texas, 40 km south of Vernon, Tex. (33° 57' N, 99° 05' W, elevation 367 m) and 20 km west of Guthrie, Tex. (33° 30' N, 100° 30' W, elevation 535 m). Average annual rainfall is 652 mm at Vernon and 556 mm near Guthrie (Pitchfork Ranch). Rainfall is highly variable, and the mean distribution is bimodal, with a peak in May and another in October. Rainfall during the 3-year study is presented in Table 1. The average frost-free growing season is more than 200 days, extending from March into November. Growing-season rainfall was tabulated for the period April through October. The long-term average is 502 mm at Vernon. Long-term records are not available for the Pitchfork Ranch site.

All sites have productive soils suitable for grass seeding. Soils were nearly level to gently sloping uplands (0 to 3% slope), deep, well drained, and slow to moderately permeable. Soils at the 3 Vernon sites were classified as Wichita (mixed, thermic Typic Paleustalfs) in Year-1 and Tillman (mixed, thermic Typic Paleustolls) in Year-2 and Year-3. Texture was clay loam, thus the term "clay loam site." At the 3 Guthrie sites, soils were classified as Carey (mixed, thermic Typic Argiustolls) in Year-1 and Paducah (mixed, thermic Typic Haplustalfs) in Year-2 and Year-3. Texture varied between loam to fine sandy loam, thus the term "sandy loam site." All sites were infested with regrowth mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) varying in height from 1.8 to 3.0 m. Sites had been aerially sprayed, chained, and re-sprayed several times over the past 30 years.

Fig. 2. Disk chain developed for single tractor pulling (Wiedemann and Cross 1985).

Equipment

Integral mounted rootplows were pulled with large crawler tractors (175 kW or larger) at depths of 30 to 35 cm to sever mesquite roots below the bud zone. A 58-mm-diameter anchor chain (70 kg/m) pulled in a U-shape between 2 crawler tractors (104 kW or larger) accomplished the "smooth" chaining operation. The disk chain was constructed from 48-mm-diameter anchor chain with 610-mm-diameter disk blades (33.5 kg/blade) welded to alternate chain links. Tillage was achieved as the chain was pulled diagonally between the lead crawler tractor (104 kW) and the trailing crawler tractor (48 kW) (Fig. 1). Additional disk chain details have been described previously (Wiedemann 1990). A 2.4-m-wide, heavy-duty offset disk with 610-mm-diameter blades was used for comparisons at sites where brush debris was not a serious problem (Year-3).

An Ag-Truck aircraft (Cessna Aircraft Co., Wichita, Kans. 67277) equipped with a Thinline spreader (Transland Inc., Harbor City, Calif. 90710) was used for aerial seeding. Seeds were metered through a standard gate box in Year-1, a standard gate box plus a metering baffle in Year-2 (Wiedemann et al. 1980), and a positive metering system in Year-3 (Wiedemann 1985). Swath widths were 12 or 15 m, and flight lines were 305- to 762-m long.

Treatments and Experimental Design

Rootplowing for mesquite control was conducted in winter months. Seedbeds were prepared 1 to 14 days prior to spring seeding. Chained seedbeds were prepared by 2 passes of the smooth anchor chain pulled in opposite directions (minimal soil disturbance). Disk-chained seedbeds were prepared with a single pass of the modified anchor chain (soil disturbance similar to disking). The third seedbed preparation method, disk-chain+chain, was prepared by disk chaining followed by a single pass of the anchor chain to smooth the rough soil surface. In Year-3, a single pass of an offset disk was added as a fourth method. Treatments were installed in 1979 (Year-1), 1980 (Year-2), and 1981 (Year-3), and plot size varied from 37 x 76 m to 50 x 183 m (width x length).

In Year-1, disk-chaining+chaining, disk-chaining, and chaining treatments were replicated 5 times at the clay loam site. At the sandy loam site, due to an installation problem, 6 replicates of disk-chaining+chaining and chaining and 3 replicates of disk chaining were established. In Year-2, 6 replicates of the 3 methods were installed at both locations. In Year-3, disk-chaining+chaining, disk-chaining, chaining, and disking treatments were replicated 4 times at both locations.

Kleingrass (*Panicum coloratum* L.) 'Selection 75' was aerially seeded at 1 and 2 kg/ha pure live seed at all sites. Seeding dates were 21 April 1979, 17 April 1980, and 4 April 1981 at the clay loam site and 5 March 1979, 8 May 1980, and 20 April 1981 at the sandy loam site. Each swath of the aircraft was perpendicular to all seedbed preparation methods in a block to minimize the effect of any irregularities in the seeding rate during seeding. To accommodate aerial seeding and plot size restrictions, a randomized strip-split block experimental design was used each year.

Plots were evaluated at the end of the first growing season (November). Established plant densities were determined from 100, 0.1 m^2 quadrat samples per plot.

Statistical Analysis

A strip-split block analysis for each soil type was calculated to determine main effects of seedbed methods, seeding rates, and years and their interactions on established plant densities (plants/m^2). A general linear model procedure (SAS System v6.12, SAS Institute, Inc., Cary, N.C. 27511) was used for analysis of variance with a protected Least Significant Difference method of means separation at P=0.05. The error term for seedbeds and error term for rates rather than the whole-model error term was used to test seedbeds and rates and their means separation. Seedbed data were also analyzed each year for each seeding rate and soil type separately. Standard errors were calculated for all means.

Results

Combined Years

Analysis of variance showed that the established plant density of kleingrass varied with seedbed preparation method, seeding rate, and year at the clay loam site, but varied only with seeding method and seeding rate at the sandy loam site (P=0.001). Among the main factors, seeding rate had the greatest influence on plant densities at both locations. Established plant densities on disk-chained+chained and disk-chained seedbeds were significantly greater than chained seedbed densities, but they were not significantly different from one another at the clay loam site (Table 2). At the sandy loam site, plant densities on disk-chained+chained seedbeds were significantly greater than those on disk-chained seedbeds, which were significantly greater than those on chained seedbeds.

The higher seeding rate significantly increased plant densities at both locations (Table 2). Plant densities were significantly different each year at the clay loam site. At the sandy loam site, there was no difference among years.

Table 2. Effects of seedbed methods, seeding rates, and years on established plant densities on 2 different soils ($\bar{x}$ ± SE).

Treatments	Clay loam	Sandy Loam
	(Plants/m^2)	
Seedbed preparation		
Disk-chain+chain	12.1 ± 0.9a[1]	9.2 ± 0.7a
Disk chain	11.6 ± 1.0a	8.0 ± 0.7b
Chain	6.0 ± 0.6b	6.4 ± 0.5c
Seeding rate (kg/ha)		
2	12.6 ± 0.8a	10.5 ± 0.5a
1	7.2 ± 0.4b	5.3 ± 0.3b
Years		
1	8.1 ± 0.5a	7.7 ± 0.6a
2	10.3 ± 1.1b	8.1 ± 0.6a
3	11.5 ± 1.0c	7.8 ± 1.8a

[1]Means in columns within a treatment followed by the same letter are not significantly different (P=0.05).

Year x seedbed method, year x seeding rate, and method x rate interactions were significant at the clay loam site (P<0.004), while year x rate and method x rate interactions were significant at the sandy loam site (P≤0.05).

Year-1

Plant densities on seedbeds prepared by disk-chaining+chaining were significantly greater than those prepared by chaining in each of the four cases (a clay loam site, 1 & 2 kg/ha; sandy loam site, 1 & 2 kg/ha) (Table 3). Plant densities on disk-chained seedbeds were significantly greater than those on chained seedbeds in 2 of 4 cases. At the clay loam site, plant densities following disk-chaining+chaining were not significantly greater than those following disk chaining. However, at the sandy loam site, plant densities following disk-chaining+chaining were significantly greater than those following disk chaining. Average established plant densities were 8.1 plants/m^2 at the clay loam site and 7.6 plants/m^2 at the sandy loam site.

Year-2

In all 4 cases, plant densities on disk-chaining+chaining seedbeds were significantly greater than densities on chained seedbeds, and densities for disk-chained seedbeds were significantly greater than those on chained seedbeds in 3 of 4 cases (Table 3). Additionally, there was no difference between densities due to disk chaining and disk-chaining+chaining. Average established plant densities were 10.2 plants/m^2 at the clay loam and 8.1 plants/m^2 at the sand loam sites.

Year-3

In all cases, there was no difference between plant densities due to disking and disk-chaining+chaining, and no difference due to disking and disk chaining in 3 of 4 cases (Table 3). Plant densities following disk-chaining+chaining were significantly greater than densities following chaining in 2 of 4 cases, and there was no difference between densities following disk-chaining+chaining, disk chaining, or chaining in the other 2 cases. Average established plant densities were 11.5 plants/m^2 at the clay loam site and 7.8 plants/m^2 at the sandy loam sites.

Discussion

Main Effects

Our data indicate that disk-chaining+chaining could increase plant densities as much as 100% in clay loam soil and 42% in sandy loam soil compared with chaining (Table 2). The reason the increase was less in the sandy loam soil was because chaining provided more soil disturbance (tillage) in the sandy loam soil than in the clay loam soil. Moreover, there was no significant difference in plant densities between disked and disk-chained+chained treatments (Table 3), suggesting that there would be little value in raking so a heavy-duty offset disk could be used for seedbed preparation. The disk-chain+chain, disk-chain, and chain implements traversed all debris with ease at our study sites.

The 2-kg/ha seeding rate increased plant densities over the 1-kg/ha rate by 75% at the clay loam site and by 98% at the sandy loam sites. Although the 2-kg/ha seeding rate almost doubled the plant densities over the 1-kg/ha rate, the 1-kg/ha rate achieved stand densities equal to or greater than 5 plants/m^2 which is considered successful for rangeland seeding (GPAC 1966). However, examination of the individual years indicated that the 1-kg/ha rate did not perform that well in a number of situations (see interaction discussions). If the management goal is to insure consistently sufficient stands when environmental conditions are less than favorable or to maximize stand densities, then the 2-kg/ha rate would best meet that goal.

Interactions

Year X Seedbed Method

In Year-2, when growing-season rainfall was 43% below normal (285 mm) at the clay loam site, disk-chaining+chaining improved plant densities by 218% compared with chaining (Table 4). This major difference was present at both seeding rates in the yearly analysis (Table 3). When rainfall was 8% above normal in Year-3 (544 mm), disk-chaining+chaining improved densities by 45% over chaining. A similar trend was present on the sandy loam site but was much less dramatic since there was only 38 mm difference between the high and low growing-season rainfall

Table 3. Effects of seedbed preparation methods on established grass densities within years, soils and seeding rates ($\bar{x}$ ± SE).

Seedbed method	Clay loam site		Sandy loam site	
	Seeding rate (kg/ha)			
	1	2	1	2
	(Plants/m^2)			
-				
Year-1				
Disk-chain+chain	7.5 ± 0.5a[1]	12.1 ± 0.4a	6.1 ± 0.4a	12.9 ± 0.6a
Disk chain	6.8 ± 0.3a	10.5 ± 0.5a	4.7 ± 1.1b	8.4 ± 1.3b
Chain	5.0 ± 0.4b	6.4 ± 0.8b	4.2 ± 0.3b	8.6 ± 0.5b
Year-2				
Disk-chain+chain	9.5 ± 1.0a	17.1 ± 2.2a	6.8 ± 0.6a	12.4 ± 1.5a
Disk chain	8.5 ± 0.8a	17.9 ± 1.2a	6.1 ± 0.8ab	11.0 ± 1.2a
Chain	2.7 ± 0.6b	5.8 ± 0.9b	4.6 ± 0.4b	7.6 ± 0.9b
Year-3				
Disk	11.1 ± 0.3a	19.4 ± 1.0a	6.1 ± 1.1a	12.1 ± 1.3a
Disk-chain+chain	9.7 ± 0.7ab	16.6 ± 2.0a	5.6 ± 1.2a	10.8 ± 2.0a
Disk chain	8.0 ± 0.3b	17.2 ± 3.3a	4.7 ± 1.4ab	11.5 ± 1.4a
Chain	7.9 ± 1.0b	10.1 ± 1.8b	3.7 ± 1.0b	10.1 ± 1.6a

totals during the 3 years. This difference in rainfall at the 2 sites is the likely reason the year x method interaction was significant at the clay loam site and not at the sandy loam site. These data indicate that seedbeds prepared by disk-chaining+chaining were especially beneficial when rainfall was in short supply compared with a seedbed prepared by chaining.

Year X Seeding Rate

Plant densities for the 1-kg/ha seeding rate at the clay loam site increased gradually from Year-1 to Year-3 (Table 4). In Year-1, with slightly above average rainfall, the 2-kg/ha rate increased plant densities by 50% compared with the 1-kg/ha rate; however, in Year-2, when rainfall was 43% below normal, the 2-kg/ha rate increased densities by 97% over the 1-kg/ha rate, resulting in a significant interaction. Thus, it appears that the seeding rate interacts with the climatic factors to give increased performance at the higher seeding rate under drought conditions. At the sandy loam site, the minimal difference in growing-season rainfall among years (38 mm) resulted in very little change in plant densities at the 2-kg/ha rate, a 5% increase between Year-2 and Year-3 (Table 4). This was not the case at the 1-kg/ha rate. The plant densities at the 1-kg/ha rate increased slightly from Year-1 to Year-2, and then in Year-3 the density decreased by 20%. Year-3 had the highest growing-season rainfall, but much of it came in the late summer, which resulted in a decrease in plant densities at the 1-kg/ha rate. The different response between the 1- and 2-kg/ha seeding rates resulted in a marginally significant interaction (P=0.042). These data indicate that the higher seeding rate was beneficial in establishing higher plant densities when rainfall was in short supply or when rainfall was not timely.

Seedbed Method X Seeding Rate

At the clay loam site, disk-chained+chained seedbeds increased plant densities 84% at the 1-kg/ha rate and 112% at the 2-kg/ha rate compared to chained seedbeds at equivalent seeding rates (Table 5). There was a similar response with disk chaining. These responses were due to increased soil disturbance during seedbed preparation by disk chaining and disk-chaining+chaining over chaining. The 2-kg/ha rate resulted in more seed being placed in the microsites suitable for seed germination than did the 1-kg/ha rate. A similar response was present at the sandy loam site, but the response was not as dramatic because chaining provided more soil disturbance in sandy loam soil than clay loam soil in relationship to disk chaining and disk-chaining+chaining. Thus, the interaction was significant at the clay loam site (P=0.001) and only marginally significant at the sandy loam site (P=0.05).

Conclusions and Management Implications

In the past, chaining has been the only means of traversing extensive areas of log-littered land for seedbed preparation, but successful seedings have been minimal (McKenzie 1987). Results from our 3-year study with kleingrass showed that seedbeds prepared by disk-chaining+chaining on land littered with brush debris significantly increased established plant densities by 100% in clay loam soil and 42% in sandy loam soil compared with seedbeds prepared by chaining alone. The disk-chained+chained seedbeds resulted in increased grass stand establishment over a broad range of conditions and were especially effective during years of limited rainfall. Additionally, there was no significant difference between plant densities on the disked or disk-chained+chained seedbeds. Consequently, there would be little need to rake up the brush debris so a disk could be used.

The 2-kg/ha seeding rate significantly increased plant densities by 75% in the clay loam soil and 98% in the sandy loam compared with the 1-kg/ha rate. Plant densities were below the 5 plants/m^2 threshold on the chained seedbeds seeded at the 1-kg/ha rate each year in the sandy loam soil and in the year when growing season rainfall was below average at the clay loam site. Plant densities on disk-chained+chained seedbeds seeded at the 1-kg/ha rate were significantly better than those on seedbeds prepared by chaining alone. In addition, disk-chaining+chaining and a seeding rate of 1 kg/ha resulted in plant densities above the threshold density of 5 plants/m^2 in both soils each of the 3 years. These data indicate the importance of using the disk-chain+chain implement, which provides more tilling action than a chain for seedbed preparation. Our data also showed that the higher seeding rate was especially beneficial in the establishment of a seeded grass when rainfall was in short supply or rainfall was not timely, or where the maximum density of grass is important.

Table 4. Interaction of years on seedbed methods and seeding rates ($\bar{x}$ ± SE).

Treatments	Years		
	1	2	3
	(Plants/m^2)		
Clay Loam Site			
Seedbed methods			
Chain	5.7 ± 0.5	4.2 ± 0.7	9.0 ± 1.0
Disk chain	8.6 ± 0.7	13.1 ± 1.6	12.6 ± 2.3
Disk-chain+chain	9.8 ± 0.8	13.3 ± 1.6	13.1 ± 1.6
Seeding rates			
1	6.5 ± 0.4	6.9 ± 0.9	8.5 ± 0.5
2	9.7 ± 0.7	13.6 ± 1.6	14.6 ± 1.6
Sandy Loam Site			
Seedbed methods			
Chain	6.4 ± 0.7	6.1 ± 0.7	6.9 ± 1.5
Disk chain	6.6 ± 1.1	8.5 ± 1.0	8.1 ± 1.6
Disk-chain+chain	9.6 ± 1.1	9.6 ± 1.2	8.2 ± 1.5
Seeding rates			
1	5.1 ± 0.4	5.8 ± 0.4	4.6 ± 0.7
2	10.2 ± 0.7	10.3 ± 0.8	10.8 ± 0.9

Table 5. Interaction of seedbed methods on seeding rates ($\bar{x}$ ± SE).

Seedbed methods	Rates (kg/ha)	
	1	2
	(Plants/m^2)	
Clay Loam Site		
Chain	4.8 ± 0.7	7.2 ± 0.8
Disk chain	7.8 ± 0.4	15.2 ± 1.3
Disk-chain+chain	8.9 ± 0.5	15.3 ± 1.1
Sandy Loam Site		
Chain	4.2 ± 0.3	8.6 ± 0.6
Disk chain	5.4 ± 0.6	10.5 ± 0.8
Disk-chain+chain	6.2 ± 0.4	12.2 ± 0.8

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Leafy spurge (*Euphorbia esula*) control with glyphosate plus 2,4-D

RODNEY G. LYM

Author is professor, Plant Sciences Dept., North Dakota State University, Fargo, North Dakota 58105.

Abstract

Leafy spurge control with glyphosate [N-(phosphonomethyl)glycine] plus 2,4-D [2,4-dichlorophenoxy)acetic acid] applied annually for 3 years alone or rotated with auxin herbicides was evaluated at 3 locations in North Dakota. Glyphosate applied with 2,4-D averaged 67% leafy spurge control 3 months after treatment which was a 10-fold increase compared to glyphosate alone. Glyphosate plus 2,4-D applied annually for 3 years or rotated with dicamba (3,6-dichloro-2-methoxybenzoic acid) or picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) plus 2,4-D provided 80 to 90% leafy spurge control, which was similar to the standard annual picloram plus 2,4-D treatment but at 30 to 65% less cost. Herbage production was similar regardless of treatment. The absorption and translocation of ^{14}C-2-4-D increased 2- to 3-fold when applied wit glyphosate compared to ^{14}C-2,4-D applied alone. However, both absorption and translocation of ^{14}C-glyphosate was severely reduced when applied with 2,4-D compared to ^{14}C-glyphosate applied alone. The increase in control when glyphosate is applied with 2,4-D may be because sublethal concentrations of glyphosate break root bud dormancy in leafy spurge, thereby increasing the amount of 2,4-D in the root. Glyphosate plus 2,4-D provided good leafy spurge control at less cost than current widely used treatments and should provide a new tool for leafy spurge management.

Key Words: dicamba, herbage production, noxious weed, picloram, rangeland weed control

Resumen

En 3 localidades de North Dakota se evaluó el control de "Leafy spurge" con glifosato [(N-(fosfonometil)glicine] mas 2,4-D [(2,4-diclorofenoxi) ácido acético], aplicado anualmente durante tres años solo o rotado con herbicidas a base de auxina. Después de 3 meses de la aplicación, la mezcla de glifosato con 2,4-D controló el 67% del " Leafy spurge", y el control fue 10 veces mayor que el obtenido con el glifosato solo. El glifosato mas 2,4-D aplicado anualmente por 3 años o rotado con dicamba (3,6-dicloro-2 ácido metooxibenzoico) o picloram (4-amino-3,5,6-tricloro-2acido piridinecarboxilico) mas 2,4-D controlaron del 80 al 90% del "Leafy spurge", que fue similar al control obtenido con el tratamiento estándar de aplicaciones anuales de picloram mas 2,4-D, pero con una reducción de costos entre 30 al 65%. La producción de forraje fue similar independientemente del tratamiento. La absorción y translocación del ^{14}C-2,4-D se incrementó de 2 a 3 veces cuando se aplicó con glifosato en comparación con la aplicación sola de ^{14}C-2,4-D. Sin embargo, la absorción y translocación de 1^{14}C-glifosato fue severamente reducida cuando se aplicó con 2,4-D comparado con el 14C-glifosato aplicado solo. El aumento en el control de "Leafy spurge" cuando se aplicó glifosato con 2,4-D puede deberse a que concentraciones subletales de glifosato rompen la dormancia de la yemas del "Leafy spurge", por lo tanto, se incrementa la cantidad de 2,4-D en las raíces. Glifosato mas 2,4-D proveen un buen control de "Leafy spurge" a menor costo que los tratamientos actuales y debe proveer una nueva herramienta para el manejo de "Leafy spurge"

Leafy spurge infests over 840,000 ha in North Dakota, South Dakota, Montana, and Wyoming and causes an annual loss of over $100 million (Bangsund and Leistritz 1991). Losses are due to reduced carrying capacity, reduced land value, and cost of control. There are several long-term management alternatives for leafy spurge control with herbicides. Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) at 2.2 kg ae/ha will provide greater than 90% leafy spurge control for at least 2 growing seasons, but is cost prohibitive except as a spot-treatment (Lym and Messersmith 1985, Bangsund et al. 1996). The most common herbicide treatment for leafy spurge control on large infestations is picloram plus 2,4-D [2,4-dichlorophenoxy)acetic acid] at 0.3 plus 1.1 kg ae/ha applied during the true-flower growth stage. This treatment controls leafy spurge top-growth in 3 to 5 years (Lym and Messersmith 1990). However, picloram cannot be applied in environmentally sensitive areas such as those with high water tables or those prone to flooding.

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Glyphosate [*N*-(phosphonomethyl)glycine] at 0.8 kg ae/ha fall-applied will provide 80 to 90% leafy spurge control 12 MAFT (months after the first treatment) (Lym and Messersmith 1985), but glyphosate is nonselective and its use is limited to shelterbelts and as a spot treatment in rangeland. Glyphosate is often applied with 2,4-D for broad spectrum weed control in cropland. The combination of glyphosate plus 2,4-D has resulted in reduced grass control compared to glyphosate applied alone (O'Sullivan and O'Donovan 1980, Flint and Barrett 1989), but can be synergistic for broadleaf weed control. The addition of 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid] to glyphosate was either additive or synergistic for control of various morningglory (*Convolvulus*) species (Wehtje and Walker 1997), and 2,4-D did not antagonize glyphosate control for purple netsedge (*Cyperus rotundus* L.) Suwunnamer and Parker 1975).

In North Dakota, glyphosate applied with 2,4-D at 0.45 plus 0.7 kg/ha in the fall provided greater than 85% leafy spurge control but caused 30 to 90% grass injury depending on location and associated grass species (Lym and Messersmith 1994). To avoid severe grass injury, especially to native cool-season species such as western wheatgrass (*Agropyron smithii* Rydb.) and Canada wildrye (*Elymus canadensis* L.) glyphosate plus 2,4-D was annually rotated with picloram plus 2,4-D at 0.6 plus 1 kg/ha or dicamba (3,6-dichloro-2-methoxybenzoic acid) at 2.2 kg ae/ha. This rotation resulted in 90% or greater leafy spurge control and only minor to moderate grass injury, but the practice increased the cost of the control program (Lym and Kirby 1991).

Glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha costs approximately 35% less than the standard spring-applied rate of picloram plus 2,4-D. Adding a glyphosate plus 2,4-D treatment to a leafy spurge management program could annually save thousands of dollars in herbicide costs. These savings would make some herbage reduction by glyphosate plus 2,4-D acceptable if the resulting control were similar to or better than presently used herbicide treatments. The purpose of this research was to evaluate leafy spurge control with spring applications of glyphosate plus 2,4-D applied annually or applied in a rotation with other herbicides. The effect of glyphosate applied with 2,4-D on the absorption and translocation of each herbicide in leafy spurge was also evaluated.

Materials and Methods

Leafy spurge control. A field study to evaluate differences in leafy spurge control with glyphosate used alone and the combination of glyphosate plus 2,4-D was conducted on ungrazed dense stands of leafy spurge (>100 stems/m^2) at 3 locations, Fort Ransom, Jamestown, and Walcott, N.D. Smooth brome (*Bromus inermis* Leyss.) and western wheatgrass [*Pascopyrum smithii* (Rydb.) Love] were the predominate grass species at the Fort Ransom and Walcott locations and Kentucky bluegrass (*Poa pratensis* L.) was the predominate grass at Jamestown. The experimental locations had at least 80% ground cover of leafy spurge with limited amounts of other perennial plants such as western snowberry (*Symphoricarpos occidentalis* Hook.), prairie wild rose (*Rosa arkansana* Porter), and Canada thistle (*Cirsium arvense* L.).

Soils at Fort Ransom were a Forman-Aastad loam (fine-loamy, mixed Udic Argiborolls; fine-loamy; fine loamy, mixed Pachic Udic Haploborolls; 7%) organic matter and 6.8 pH, at Jamestown were a Fordville loamy sand (fine-loamy over sandy or sandy skeletal, mixed Pachic Udic Haploborolls; 6.8% organic matter and pH 6.8), and at Walcott were a Tiffany fine sandy loam (coarse-loamy, mixed, Typic Endoaquolls; 2.9% organic matter and 6.8 pH).

Glyphosate alone at 0.45 kg/ha or glyphosate plus 2,4-D[1] at 0.45 plus 0.7 kg/ha were applied annually for 3 years to the same plots or were alternated with auxin herbicides. The auxin herbicide treatments were selected based on cost and efficacy of leafy spurge control as determined from previous research (Lym and Messersmith 1985, Lym and Messersmith 1990), included picloram plus 2,4-D at 0.28 plus 1.1 kg/ha and dicamba at 2.2 kg/ha.

Herbicides were applied using a tractor-mounted CO_2-pressurized sprayer equipped with flat fan 8001 nozzles[2], delivering 80 liter/ha. The initial treatments were applied at the optimum leafy spurge growth stage for control for the respective herbicides, i.e. picloram plus 2,4-D and dicamba were applied in mid-June 1995 during the leafy spurge true-flower growth stage, while glyphosate alone and alyphosate plus 2,4-D were applied in late June during seed-set. Retreatments were applied in early to mid-July 1996 and 1997 when leafy spurge was in the vegetative to flowering growth stage. Leafy spurge maturity following the initial treatments were delayed due to herbicide effects the previous season.

Experimental units were 2.4 by 9.1 m with a 1-m border between each plot and were replicated 4 times at all locations. Leafy spurge stand reduction and grass injury were evaluated each June and September beginning 3 months after the first treatment. Evaluations of both leafy spurge stand reduction (control) and grass injury were appraised on a scale of 0 to 100, with 0 equal to no stand reduction or grass injury and 100 equal to complete absence of aboveground leafy spurge plants or no perennial grass as compared to plants in the border and the untreated control. In the final year of evaluation (1998), leafy spurge control was determined by counting the number of stems in four, 0.25-m^2 quadrats per plot and data were used to calculate percent control based on stem reduction. Also, two, 0.25-m^2 quadrats per treatment were clipped and separated into leafy spurge and herbage components. The samples were oven dried at 60°C for 72 hours.

Economic comparisons were based on the total herbicide cost for the 3 annual treatments. Application costs were not included as they vary by method of application and terrain and would be the same for each treatment. The average herbicide costs used for economic analysis were 2,4-D amine at \$6.50/kg, dicamba at \$44/kg, glyphosate at \$37/kg, glyphosate plus 2,4-D[1] at \$19/kg (144 g glyphosate isopropylamine plus 227 g 2,4-D isopropylamine/liter), and picloram at \$88/kg.

Absorption and translocation. The absorption and translocation of glyphosate and 2,4-D in vegetative and flowering leafy spurge plants were evaluated in laboratory studies. Leafy spurge plants were propagated from 1 accession and grown as previously described (Lym 1992). Approximately 6 weeks after planting, the topgrowth was removed at the soil surface, and 1 stem per pot was allowed to regrow for 60 or 90 days to provide plants in the vegetative and flowering growth stages, respectively.

Mixtures of ^{14}C-glyphosate isopropylamine and ^{14}C-2,4-D technical acid were prepared by mixing with excess isopropylamine and allowing the excess isopropylamine to evaporate. Approximately 5 µl of 0.15% (v/v) surfactant MON-0818[3] in H_20 was applied to 1 cm^2 each on 2 fully expanded leaves midway on the stem; the surfactant solution also included unlabeled glyphosate or 2,4-D to achieve an application rate equivalent to the broadcast field rate. Immediately thereafter 1700 Bq/leaf of uniformly ring labeled ^{14}C-glyphosate (specific activity 2.0 GBq/mmole) isopropylamine in 5µl H_20 or 1700 Bq/leaf of phenyl ring-labeled ^{14}C-2,4-D (specific activity 1.0 GBq/mmole) isopropylamine in 5µl of 50% ethanol:H_20 (v/v) was added to the treated area. The treatments consisted of a) ^{14}C-glyphosate, b) ^{14}C-glyphosate plus 2,4-D, c) ^{14}C-2,4-D, and d) ^{14}C-2,4-D plus glyphosate.

Plants were harvested 72 hours after application and divided into treated leaves, shoot above treated leaves, shoot below treated leaves, and roots 0 to 6 cm below the soil surface. The treated leaf was hand swirled in 1 ml of H_20 for 10 seconds to remove unabsorbed water-soluble ^{14}C. Then 15 ml of liquid scintillation cocktail'A'{toluene:ethanol, 1:1 v/v, with 5 g/liter PPO (2,5-diphenyloxazole) and 0.5 g/liter dimethyl-POPOP [1,4-*bis*-2-(4-methyl-5-phenyloxazolyl) benzene]} was

[1]Commercial formulation, Campaign by Monssanto Company, St. Louis, Mo. 63167.

[2]Teejet flat fan spray tips, Spraying Systems Co., Box 7900, Wheaton, Ill. 60189.

[3]Monsanto, St. Louis, Mo. 63167.

added and the treated leaf was dipped 10 times to remove the remaining unabsorbed ^{14}C. The ^{14}C was quantified using liquid scintillation spectrometry[4], and absorption was determined by subtracting ^{14}C in the leaf wash from the total ^{14}C applied.

The plant sections were first frozen for 24 hours at –18°C, then dried for 48 hours at 60°C, and weighed. The plant material was combusted, using a biological materials ozidizer[5]. The $^{14}CO_2$ was collected in 15 ml of liquid scintillation cocktail 'B' (toluene:2-methoxyethanol:ethanolamine, 10:7:3 v/v/v, with 5 g/liter PPO and 0.5 g/liter dimethyl-POPOP) and was quantified using liquid scintillation spectrometry.

Statistical analysis. Field experiments were arranged as a randomized complete block design with 4 replications and were analyzed using the general linear models procedure with the Fisher's protected LSD mean separation technique (SAS 1990). Experimental errors were tested for homogeneity of variance using Bartlett's Chi Square test. All experimental errors were homogeneous: thus, combined analysis of variance across locations are shown. The absorption and translocation experiment was in a randomized complete block design with 4 replicates and was duplicated. Treatment means were separated using a Fisher's-protected LSD at the 95% probability level. The data for each ^{14}C experimental had similar variance when repeated therefore data were combined.

Results and Discussion

Leafy spurge control. Three months after the first treatment, glyphosate applied with 2,4-D provided a 10-fold increase in leafy spurge control compared to glyphosate alone and was greater than the standard treatment of picloram plus 2,4-D (Table 1). The 3 first year treatments that started with glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha averaged 67% leafy spurge control 3 months after the first treatment compared to only 7% control with the 2 treatments starting with glyphosate at 0.45 kg/ha applied alone. Leafy spurge control was similar when the glyphosate plus 2,4-D rate was reduced by 25% to 0.33 plus 0.53 kg/ha, but control declined when the application rate was reduced by 50%.

Leafy spurge control with glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha and 0.33 plus 0.53 kg/ha remained consistent between the 3 and 12 months after the first treatment evaluations and averaged 65% 12 months after the first treatment (Table 1). In contrast leafy spurge control with the standard treatment of picloram plus 2,4-D declined from 50% 3 months after the first treatment to 36% 12 months after the first treatment. Control with glyphosate alone increased to 44% between evaluation dates. The plants treated with glyphosate alone were much shorter than untreated plants throughout the summer and exhibited multiple branching from the root crown.

Treatments that included picloram plus 2,4-D in the second year of the rotation (1996) tended to provide the best leafy spurge control 24 months after the treatment (Table 1). Leafy spurge control averaged 77% when picloram plus 2,4-D was applied 2 consecutive years or when preceded by glyphosate or glyphosate plus 2,4-D. Glyphosate plus 2,4-D applied at 0.45 plus 0.7 kg/ha for 2 consecutive years averaged 65% leafy spurge control, and control still averaged over 50% when the application rate was reduced by 25 or 50%.

Glyphosate plus 2,4-D applied annually for 3 years or rotated with auxin herbicides provided similar control as the standard picloram plus 2,4-D treatment but at 30 to 65% less cost (Table 1). Glyphosate plus 2,4-D at rates from 0.22 plus 0.35 to 0.45 plus 0.7 kg/ha averaged 83% leafy spurge control 1 year after the last application (36 months after the first treatment) compared to 90% for the standard picloram plus 2,4-D treatment. When the glyphosate plus 2,4-D treatment was rotated with picloram plus 2,4-D control averaged 91% but the total cost of the 3 years treatment program increased by $11/ha compared to an annual application of glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha. Likewise, annual treatments with either glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha or picloram plus 2,4-D provided similar leafy spurge control but glyphosate plus 2,4-D was $30/ha less expensive. Dicamba at 2.2 kg/ha had the highest cost of $290/ha for 3 annual treatments, but provided only an average of 69% leafy spurge control. Rotation of glyphosate plus 2,4-D with dicamba provided less leafy spurge control than glyphosate plus 2,4-D either applied alone for 3 consecutive years or rotated with picloram plus 2,4-D.

Despite good leafy spurge control at lower costs, land managers are concerned that glyphosate plus 2,4-D applied in pasture and rangeland will injure or kill desirable grass species since glyphosate is nonselective. However, glyphosate plus 2,4-D annually applied for 3 years averaged 15% or less grass injury 36 months after the first treatment (12 months after the final treatment) (Table 2). Initial grass injury averaged approximately 30% 3 months after the first treatment following the third consecutive application. As the glyphosate plus 2,4-D rate was reduced by 25 or 50%, grass injury was minimal to not visible 36 months after the first treatment.

Yield data confirmed that glyphosate plus 2,4-D controlled leafy spurge similar to the standard treatment of picloram plus 2,4-D and did not reduce herbage production (Table 3). Glyphosate plus 2,4-D at 0.45 plus 0.7 kg/ha annually applied for 3 years reduced leafy spurge production nearly 90% 1 year after the last application compared to 2,205 kg/ha in the untreated control. Herbage production was similar regardless of herbicide treatment and is often slow to recover when leafy spurge is controlled by herbicides (Lym and Messersmith 1990). The slow recovery in

Table 1. Leafy spurge control with glyphosate plus 2,4-D applied annually for 3 years or rotated with auxin herbicides averaged over 3 locations in North Dakota.

1995 and 1997		1996		Treatment year/MAFT[1]				
				1995		95 & 96	95–97	Total
Treatment	Rate	Treatment	Rate	3	12	24	36	cost
	(kg/ha)		(kg/ha)	- - (% control) - -				($/ha)
Glyphosate + 2,4-D[2]	0.45+0.7	Glyphosate + 2,4-D[2]	0.45+0.7	65	61	65	85	66
Glyphosate + 2,4-D[2]	0.45+0.7	Picloram + 2,4-D	0.28+1.1	67	72	76	91	77
Glyphosate + 2,4-D[2]	0.45+0.7	Dicamba	2.2	68	64	60	79	146
Picloram + 2,4-D	0.28+1.1	Picloram + 2,4-D	0.28+1.1	50	36	80	90	96
Dicamba + 2,4-D	2.2	Dicamba	2.2	52	37	68	69	290
Glyphosate	0.45	Picloram + 2,4-D	0.28+1.1	7	44	74	73	64
Glyphosate	0.45	Dicamba	2.2	6	43	49	83	131
Glyphosate + 2,4-D[2]	0.22+0.35	Glyphosate + 2,4-D[2]	0.22+0.35	51	39	51	82	33
Glyphosate + 2,4-D[2]	0.33+0.53	Glyphosate + 2,4-D[2]	0.33+0.53	62	63	54	81	49
LSD(0.05)				13	16	17	9	

[1]Months after first treatment in 1995.
[2]Commercial formulation-Campaign by Monsanto Company, St. Louis, Mo. 63167.

[4]Beckman LS 6800 liquid scintillation spectrometer, Beckman Instruments, Irvine, Calif. 92713.
[5]Harvey Model OX-400 biological materials oxidizer. R.J. Harvey Instrument Corporation, Hillsdale, N.J. 07642.

Table 2. Grass injury with glyphosate plus 2,4-D applied annually for 3 years or rotated with auxin herbicides averaged over 3 locations in North Dakota.

1995 and 1997		1996		Treatment year/MAFT[1]					
				1995		95 & 96		95–97	
Treatment	Rate	Treatment	Rate	3	12	15	24	27	36
	(kg/ha)		(kg/ha)	(% injury)					
Glyphosate + 2,4-D[2]	0.45+0.7	Glyphosate + 2,4-D[2]	0.45+0.7	28	0	15	0	36	15
Glyphosate + 2,4-D[2]	0.45+0.7	Picloram + 2,4-D	0.28+1.1	26	0	6	0	21	1
Glyphosate + 2,4-D[2]	0.45+0.7	Dicamba	2.2	31	0	0	0	25	5
Picloram + 2,4-D	0.28+1.1	Picloram + 2,4-D	0.28+1.1	0	0	3	0	4	0
Dicamba + 2,4-D	2.2	Dicamba	2.2	3	0	3	0	5	0
Glyphosate	0.45	Picloram+ 2,4-D	0.28+1.1	11	0	1	0	8	4
Glyphosate	0.45	Dicamba	0.22+0.35	10	0	4	0	6	4
Glyphosate + 2,4-D[2]	0.22+0.35	Glyphosate + 2,4-D[2]	0.33+0.53	19	0	5	0	8	4
Glyphosate + 2,4-D[2]	0.33+0.53	Glyphosate + 2,4-D[2]	0.33+0.53	19	0	2	0	17	0
LSD (0.05)				12	NS	9	NS	7	4

[1]Months after first treatment in 1995.
[2]Commercial formulation-Campaign by Monsanto Company, St. Louis, Mo. 63167.

production may be due to the deep leafy spurge root system that is still competing for moisture and nutrients even though there may be very little visible topgrowth.

The addition of 2,4-D to glyphosate appears to reduce the efficacy of glyphosate on grasses. Glyphosate plus 2,4-D has reduced control of several grass species including wild oat (*Avena fatua* L.) (O'Sullivan and O'Donovan 1980), Johnsongrass (*Sorghum halepense* L.) (Flint and Barrett 1989), and wheat (*Triticum aestivum* L.) (Nalewaja and Matysiak 1992) compared to glyphosate alone. The reason for reduced control has been attributed to reduced glyphosate uptake and translocation (Flint and Barrett 1989) caused by formation of various glyphosate salts with either the 2,4-D molecule or associated compounds within the formulation (Thelen et al. 1995). Thelen et al. (1995) also reported a change in the molecular orientation of the glyphosate molecule caused by 2,4-D, which probably accounts for the reduced absorption of glyphosate in the presence of 2,4-D.

Glyphosate plus 2,4-D annually applied can result in moderate to severe grass injury, especially in dry seasons and/or on certain grass species such as western wheatgrass (Lym and Kirby 1991). To avoid grass injury, a land manager could rotate glyphosate plus 2,4-D with picloram plus 2,4-D in alternate years. The increase in treatment costs of approximately 15% per acre would need to be considered versus the potential for grass injury and loss of herbage production.

The dramatic increase in leafy spurge control when glyphosate was applied with 2,4-D compared to glyphosate alone was surprising. Glyphosate alone applied in spring generally provides poor leafy spurge control especially when applied prior to seed-set (Lym and Messersmith 1985). The application of 2,4-D annually or even biannually provides only short term control of leafy spurge topgrowth. The leafy spurge root system is not killed by 2,4-D because, even though foliar absorption is relatively high (>25% of applied), translocation to the root is low (<3 of applied) (Lym and Moxness 1989). Since leafy spurge control was increased so dramatically by the combination of glyphosate plus 2,4-D compared to either herbicide alone an experiment was conducted to evaluate the effect of the combination on absorption and translocation of each herbicide in leafy spurge.

Absorption and translocation. Absorption of ^{14}C-2,4-D was increased 3-fold when glyphosate was added in both vegetative-to-flowering and seed-set growth stages of leafy spurge compared to ^{14}C-2,4-D applied alone (Table 4). The increased 2,4-D absorption resulted in more herbicide translocated to all leafy spurge plant parts, especially when the plant was in the vegetative-to-flowering growth stage. Translocation of ^{14}C-2,4-D to the leafy spurge roots (0 to 6 cm) increased by nearly 3-fold when the plant was in the vegetative growth stage and by 2-fold when in the seed-set growth stage. Conversely, ^{14}C-glyphosate absorption was decreased by approximately 50% when applied with 2,4-D in both the vegetative to flowering and seed-set growth stages. The translocation of ^{14}C-glyphosate was antagonized by 2,4-D within leafy spurge by 60 to 85%.

The increase in weed control when 2 herbicides are applied together, compared to either alone is generally from an increase in either absorption and/or translocation of one of the components or a change in the metabolism of the herbicide(s) within the plant (Hatzios and Penner 1985). But neither explanation seems likely to adequately explain the increased control of leafy spurge when treated with glyphosate plus 2,4-D. Since both absorption and translocation of glyphosate were severely reduced, the increase in control seems likely due to the 2,4-D component. However, 2,4-D typi-

Table 3. Herbage and leafy spurge yield the season following 3 annual applications of glyphosate plus 2,4-D applied alone or rotated with auxin herbicides averaged over 3 locations in North Dakota.

1995 and 1997		1996		1998 yield	
Treatment	Rate	Treatment	Rate	Leafy Spurge	Herbage
	(kg/ha)		(kg/ha)	(kg/ha)	
Glyphosate + 2,4-D[2]	0.45+0.7	Glyphosate + 2,4-D[1]	0.45+0.7	230	2695
Glyphosate + 2,4-D[2]	0.45+0.7	Picloram + 2,4-D	0.28+1.1	190	3270
Glyphosate + 2,4-D[2]	0.45+0.7	Dicamba	2.2	245	2660
Picloram + 2,4-D	0.28+1.1	Picloram + 2,4-D	0.28+1.1	140	3030
Dicamba + 2,4-D	2.2	Dicamba	2.2	205	2625
Glyphosate	0.45	Picloram+ 2,4-D	0.28+1.1	340	2600
Glyphosate	0.45	Dicamba	2.2	375	2570
Glyphosate + 2,4-D[2]	0.22+0.35	Glyphosate + 2,4-D[1]	0.22+0.35	320	3120
Glyphosate + 2,4-D[2]	0.33+0.53	Glyphosate + 2,4-D[1]	0.33+0.53	300	2530
Control		Control		2205	2030
LSD (0.05)				360	755

[1]Commercial formulation-Campaign by Monsanto Company, St. Louis, Mo. 63167.

Table 4. Glyphosate and 2,4-D absorption and translocation in leafy spurge at 2 growth stages.

Treatment	Growth stage[1]	Absorbed	Plant section[2] ATL	BTL	Root
		----------- (% of applied) ----------			
C^{14} Glyphosate	Veg-flwr	38	2.8	8.2	13.1
C^{14} 2,4-D	Veg-flwr	23	0.7	3.0	1.2
C^{14} Glyphosate + 2,4-D	Veg-flwr	20	0.4	1.4	5.3
C^{14} 2,4-D + glyphosate	Veg-flwr	76	2.8	5.0	3.4
C^{14} Glyphosate	Seed-set	55	4.5	11.1	21.4
C^{14} 2,4-D	Seed-set	18	1.2	2.8	0.6
C^{14} Glyphosate + 2,4-D	Seed-set	26	1.5	2.8	7.2
C^{14} 2,4-D + glyphosate	Seed-set	55	2.9	8.5	1.3
LSD (0.05)		8	2	4.5	3.8

[1]Veg-flwr = vegetative to flowering
[2]ATL = stem and leaves above the treated leaf; BTL = stem and leaves below the treated leaf.

cally provides only short-term leafy spurge control of 4 to 6 weeks (Lym and Messersmith 1985).

Labeled 2,4-D generally remains as the parent acid in leafy spurge when applied alone or with picloram (Lym and Moxness 1989). Since 2,4-D generally remains unmetabolized in leafy spurge, a reduction in 2,4-D metabolism by the presence of glyphosate does not seem a like cause of the increased control. The increase in control when picloram was applied with 2,4-D compared to either alone was due to an increase in unmetabolized picloram translocated to the roots (Lym and Moxness 1989). Perhaps 2,4-D is decreasing glyphosate metabolism in leafy spurge, but a change in metabolism seemingly would not compensate for the large reduction in glyphosate absorption and translocation.

The increase in control when glyphosate is applied with 2,4-D may be because glyphosate at sublethal concentrations alters the bud dormancy regulation system in leafy spurge resulting in a proliferation of new shoots arising from the roots (Maxwell et al. 1987), commonly termed "witches brooming". Glyphosate apparently interfered with correlative inhibition which facilitated prolific shoot bud growth from previously inhibited buds on the leafy spurge root. The release of root bud dormancy could cause an increase in basipetal translocation of 2,4-D to the roots (as observed in this study) because the proliferation in growth would create a metabolic sink. Witches brooming was observed following application of both glyphosate alone and glyphosate plus 2,4-D in the field portion of theses studies.

Hunter and McIntyre (1974) reported that decapitation of leafy spurge stems released apical dominance in leafy spurge root buds and increased the amount of ^{14}C-2-D translocated throughout the plant, including a 5-fold increase to the root buds. If instead of decapitation, glyphosate released bud dormancy, it would allow 2,4-D to translocate directly to the newly growth buds and likely kill them. Although the amount of ^{14}C-2,4-D found in the root was similar in this study and by Lym and Moxness (1989), the specific location of the 2,4-D would be the critical difference in control. Leafy spurge roots could be killed to a greater depth in soil if more 2,4-D entered the root than normally observed. This effect should result in the increased control with glyphosate plus 2,4-D compared to the herbicides alone and this hypothesis is consistent with the observations in the field trials.

Conclusions

The herbicide combination glyphosate plus 2,4-D should become part of a land managers long-term leafy spurge control program. The combination treatment provided similar control to the standard picloram plus 2,4-D treatment in this 4 year study at 30 to 65% less cost. Herbage reduction was short-term even when glyphosate plus 2,4-D was applied annually for 3 years. Although glyphosate uptake and translocation is antagonized by 2,4-D, grass injury may remain a concern for some land managers. Then the glyphosate plus 2,4-D treatment cold be rotated with picloram plus 2,4-D, because this treatment program provided greater than 90% control in 3 years and at least a 2º% cost savings compared to an annual application of picloram plus 2,4-D.

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Activated charcoal attenuates bitterweed toxicosis in sheep

GEORGE W. POAGE III, CODY B. SCOTT, MATTHEW G. BISSON, AND F. STEVE HARTMANN

Authors are former graduate assistant, assistant professor, graduate assistant, Department of Agriculture, Angelo State University, San Angelo, Texas, and University of Texas Lands-Surface Interests, Midland, Texas, respectively.

Abstract

We assessed the potential of activated charcoal to attenuate bitterweed (*Hymenoxys odorata* DC.) toxicosis in 3 trials. In Trial 1, lambs were offered a subacute level (.264% BW) of bitterweed and received either 0, .5, 1, or 1.5 g/kg BW of activated charcoal. In Trial 2, lambs were dosed (by gavage) with .264% BW of bitterweed and varying levels of activated charcoal followed by feeding milo (*Sorghum* sp.) immediately after dosing. A decrease in milo intake, which indicates aversive postingestive feedback, was interpreted to indicate that toxicosis occurred. In Trial 3, lambs were fed a 20% CP supplement with or without activated charcoal and then exposed to bitterweed and other forage species growing in pots; we counted the number of bites of each. In Trial 1, lambs refused to eat bitterweed after 10 days of exposure, thus the study was stopped. In Trial 2, lambs that received 1 or 1.5 g/kg BW of activated charcoal consumed more ($P<0.05$) milo than those receiving 0 g/kg BW. In Trial 3, lambs supplemented with activated charcoal took more ($P<0.05$) bites of bitterweed than lambs receiving a protein supplement alone. Lambs readily ate activated charcoal when added to a 20% crude protein supplement in a 10% mixture. Collectively, these results suggest activated charcoal will result in continued consumption of bitterweed which suggests avoidance of toxicosis. Activated charcoal also may be effective in preventing bitterweed toxicosis when combined with a supplement.

Key Words: bitterweed, activated charcoal, toxicosis, hymenoxon, *Hymenoxys*

Resumen

Se condujeron 3 experimentos para evaluar el potencial del carbón activado para atenuar la intoxicación por "Bitterweed" (*Hymenoxys odorata* D.C.). En el ensayo 1, a los corderos se les ofreció un nivel subagudo [.264% del peso vivo (PV)] de "Bitterweed' y recibieron alguna de las siguientes dosis de carbón activado 0, .5, 1.0, y 1.5 g kg^{-1} PV. En el ensayo 2 a los corderos se les suministró .264% de "Bitterweed", niveles variables de carbón activado y se alimentaron con "milo" (*Sorghum* sp.) inmediatamente después de recibir la dosis de "Bitterweed". Una disminución en el consumo de "milo", lo cual indica un estímulo postingestivo adverso, fue interpretada como un indicador de que la intoxicación ocurrió. El ensayo 3, los corderos se alimentaron con un suplemento con un 20% de proteína cruda con y sin carbón activado y después fueron expuestos al "Bitterweed" y otras especies forrajeras creciendo en macetas, y contamos el número de mordidas que cada especie recibió. En el ensayo 1 los corderos rechazaron consumir "Bitterweed" después de 10 días de expuestos a ella, y aquí el estudio se detuvo. En el experimento 2, los corderos que recibieron 1 o 1.5 g kg-1 PV de carbón activado consumieron mas "milo" ($p<0.05$) que los que no recibieron carbón activado. En el ensayo 3, los corderos suplementados con carbón activado dieron mas mordidas al "Bitterweed" que los corderos que recibieron el suplemento sin carbón activado. Los corderos consumieron fácilmente el carbón activado cuando se agrego al suplemento proteico en una mezcla del 10%. En conjunto, estos resultados sugieren que el carbón activado resultará en un consumo continuo de "Bitterweed" lo cual sugiere que evita la toxicosis. El carbón activado, cuando se combina con el suplemento, también puede ser efectivo en prevenir la intoxicación por "Bitterweed".

Bitterweed (*Hymenoxys odorata* DC.) contains the sesquiterpene lactone hymenoxon, which causes chronic and acute toxicity of sheep in central and western Texas (Ivie et al. 1975, Kim et al. 1975, Pettersen and Kim 1976). Toxicosis typically occurs during winter when nutritious grasses and forbs are dormant (Ueckert and Calhoun 1988). Bitterweed toxicity has reduced economic returns from sheep production in the Edward's Plateau and Trans-Pecos regions of Texas since the early 1900's and has contributed to a 50% reduction in sheep production in this region over the past 30 years (Ueckert et al. 1980, Conner et al. 1988).

Most ranchers reduce stocking rates or provide supplemental feed when bitterweed toxicity is likely to occur. Some protection from toxicosis has been observed by adding the antioxidant Santoquin (6-ethoxy-1,2, dihydro- 2,2,4-trimethylquinoline) to mineral supplements (Kim et al. 1982, Calhoun et al. 1988). However, Santoquin reduces palatability when added to supplements at 0.5% and may be ineffective because of low intake (Calhoun et al. 1986, Ueckert and Calhoun 1988). L-cysteine given intravenously at the proper dosage prevented toxicosis; L-cysteine and hymenoxon must be administered simultaneously and the high cost of cysteine makes this treatment impractical (Rowe et al. 1980, Calhoun et al 1988). Adding a sulfur source to protein supplements also provides some protection from bitterweed toxicosis (Calhoun et al. 1986).

Activated charcoal has been widely documented by human toxicologists to adsorb many classes of poisons (Edwards and McCredie 1967, Decker et al. 1968, Hayden and Comstock 1975,

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Levy 1982), and it has been suggested as an effective treatment for several types of phytotoxicosis (Buck and Bratich 1986). Thus, our objective was to determine if activated charcoal attenuated bitterweed toxicosis. The specific objectives were to determine (1) if activated charcoal increased intake of bitterweed and (2) if sheep consumed a supplement containing activated charcoal.

Methods

Three trials were conducted at the Angelo State University Management, Instruction, and Research (MIR) Center in San Angelo, Texas, USA. Thirty freshly-weaned crossbred lambs were used in Trials 1 and 2, and 16 lambs were used in Trial 3. Water and a calcium/phosphorus mineral with trace elements were provided free choice to all lambs during all trials. Lambs were individually penned and fed 1.5 kg of alfalfa pellets/day from 1000–1700 hours to meet maintenance requirements throughout all trials (NRC 1985).

Bitterweed was harvested from January through April in 1996 from the Texas Range Station in Barnhart, Tex., USA. Samples were air dried and equally mixed from each collection to assure consistency of hymenoxon levels in all samples. Mixed samples were ground through a 2 mm screen prior to dosing.

Trial 1

Thirty freshly weaned, castrated male Rambouillet and Rambouillet x Suffolk lambs weighing approximately 35 kg, were randomly allocated to 1 of 4 treatments (n=8 lambs/treatment except for Treatment 1 which consisted of 6 lambs). An unbalanced sample size was used because 2 lambs died just prior to initiation of the study. All lambs were offered dried, ground bitterweed (.264% BW) in the morning (0800) for 45 min after fasting overnight. Calhoun et al. (1981) showed that .264% BW of bitterweed readily caused toxicosis in another study. Treatments were dosed (by gavage) with varying levels of Darco KB™ activated charcoal (Norit Americas, Inc.). Treatments 1 through 4 received 0, .5, 1, or 1.5 g/kg BW of activated charcoal, respectively. Lambs were offered bitterweed and dosed with activated charcoal for 10 consecutive days.

Lambs typically reduce intake as hymenoxon levels increase (Calhoun et al. 1981), which suggests lambs receive aversive postingestive feedback and develop a conditioned food aversion (CFA) to bitterweed (Provenza et al. 1990, 1992, 1994). If activated charcoal reduces bitterweed toxicosis, presumably by adsorbing hymenoxon, then a CFA to bitterweed should not occur. Thus, increased intake of bitterweed (i.e., lack of CFA) is considered evidence of activated charcoal reducing toxicosis.

Trial 2

Because lambs did not eat bitterweed in Trial 1, a second trial was conducted using the learned aversion paradigm to determine if bitterweed would cause a conditioned food aversion to a novel food, and if activated charcoal would attenuate such aversions. The occurrence of an aversion to a novel food following dosing with bitterweed was considered evidence that bitterweed was causing toxicosis.

Lambs were fed 400 g of milo (*Sorghum* spp.) for 15 min daily followed by gavaging with bitterweed or bitterweed and activated charcoal. Intake of milo was measured on subsequent days to determine level of toxicosis.

Prior to dosing, lambs were fed milo on days 1 through 4 to familiarize lambs with milo. On day 5 through 15, lambs were dosed with a mixture of activated charcoal (depending of treatment) and bitterweed. Bitterweed and activated charcoal were mixed with distilled water and delivered directly to the rumen by gavage.

Trial 3

Trial 3 was conducted to determine if animals would consume activated charcoal in a dietary supplement and to compare intake of bitterweed and 2 other forages when lambs were supplemented with a crude protein supplement with or without activated charcoal. Sixteen lambs were randomly allocated to 2 treatments and placed in individual pens. Treatment 1 received 1g/kg BW of activated charcoal mixed with a 20% CP supplement (i.e., range cubes; Table 1). Range cubes were ground to facilitate mixing with activated charcoal. Treatment 2 received the ground 20% range cube without activated charcoal. Lambs were fed 400 g of supplement each day for 45 min and then exposed to 10 potted plants each of bitterweed, Texas wintergrass (*Stipa leucotricha* Trin.& Rupr.), and engelmanndaisy (*Engelmannia pinnatifida* Nutt.). Both engelmanndaisy and Texas wintergrass are common cool season forages in west Texas. Thirty plants (10 each) were available during each exposure. All potted plants were kept in a vegetative state throughout the study.

Lambs were exposed to the potted plants for 10 min each day for 7 days. The number of bites of each species was recorded. Lambs were exposed in pairs of 2 lambs from the same treatment. When animals depleted forage, fresh plants were placed in the pasture. For the remainder of each day (1000–1700 hrs), lambs were returned to individual pens and fed alfalfa pellets (1.5 kg/day), water, and a calcium/phosphorus mineral with trace elements to meet maintenance requirements.

Statistical Analysis

Data were analyzed using repeated measures analysis of variance with day as the repeat measure; lambs (replications) were nested within treatments (Hicks 1993). Differences among means were assessed by least significant difference when $P < 0.05$ (Gomez and Gomez 1984). Data were analyzed with the statistical package JMP (SAS 1994).

Table 1. Ingredients and nutrient content of the 20% crude protein supplement used in Trial 2. Supplement was ground to facilitate mixing with activated charcoal.

Ingredient	Ration
	(%)
Milo sorghum grain	37.6
Cottonseed meal	34.8
Dehydrated alfalfa	2.5
Peanut hulls	5.0
Wheat middens	7.5
Calcium/phosphorus/salt/trace mineral	12.5
Nutrient Content	
Crude Protein	20.0
Crude Fat	2.8
Crude Fiber	8.5
TDN	60.0

Table 2. Average intake of milo for all days when lambs were dosed with bitterweed or bitterweed and activated charcoal during Trial 2.

Activated Charcoal	Milo Intake	Standard Error (SEM)
(g/kg BW)	(g)	
0.0	216^{C}	17.1
0.5	252^{BC}	17.1
1.0	296^{AB}	17.1
1.5	303^{A}	19.7

$^{A-C}$Means within columns with different superscripts differ (P<0.05).
$LSD_{(0.05)}$= 49.7.

Results

Trial 1

When offered dried ground bitterweed after fasting overnight, lambs did not consume measurable amounts. We mixed bitterweed with corn to improve acceptance, but lambs still refused to eat bitterweed even after several days of exposure. Animals must consume sufficient amounts of a food to pair the flavor of the food with its postingestive consequences (du Toit et al. 1991). No lambs were dosed because of the lack of bitterweed intake. Because lambs refused to bitterweed even after the basal ration was reduced below maintenance requirements, Trial 1 was stopped after 10 days.

Trial 2

After 4 days of eating milo, lambs were eating 340 g on average within 15 min. On day 5 through 15, lambs were dosed with .264% BW of bitterweed and either 0, .5, 1, or 1.5 g/kg BW of activated charcoal according to treatment.

When lambs were dosed with bitterweed and activated charcoal, dose of activated charcoal affected intake of milo (Table 2). Lambs consumed more (P<0.05) milo if they received 1.5 g/kg BW as opposed to 0 or .5 g/kg BW of activated charcoal. Lambs that received 1 g/kg BW consumed more milo than those that received 0 g/kg of activated charcoal, while those that received 0 and 0.5 g/kg BW consumed similar (P>0.05) amounts of milo. As the study continued, intake of milo decreased for all treatments but differences among treatments persisted and the treatment by day interaction was not significant (Fig. 1).

It was important that lambs consume enough milo on a given day to associate the flavor of milo with any postingestive feedback from bitterweed or activated charcoal and bitterweed. An individual was not dosed if it did not consume at least 200 g of milo on a given day. Intake of milo fluctuated daily especially for lambs receiving 0 or .5 g/kg BW of activated charcoal. Thus, not all lambs were dosed every day.

When we examined lambs' intake only on the days after they were dosed with bitterweed or bitterweed and activated charcoal, lambs dosed with bitterweed alone ate less (P<0.05) milo than lambs that received activated charcoal and bitterweed (Table 3). Milo intake was not affected (P>0.05) by dose of activated charcoal on the day directly after dosing.

Trial 3

Lambs readily consumed the 20% CP supplement with (302 g/day) and without (297 g/day) activated charcoal (P>0.05). Lambs that received activated charcoal took more (P<0.05) bites of bitterweed and engelmanndaisy than lambs that received the 20% CP supplement alone (Table 4). All lambs consumed similar amounts of Texas wintergrass.

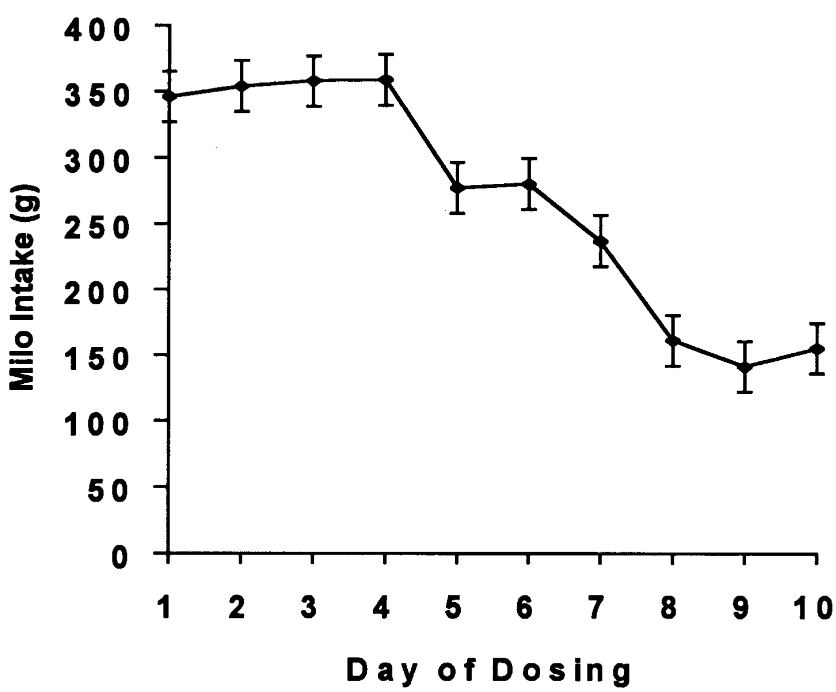

Fig. 1. Average intake of milo following 4 days of familiarization with this food during Trial 2. Throughout the 10 days of exposure, lambs were dosed with either bitterweed alone or bitterweed and activated charcoal at varying levels (0, 0.5, 1.0, or 1.5 g/kg BW). The treatment X day interaction was not significant (P>0.05)

Discussion

Trial 1

In Trial 1, lambs refused to eat bitterweed after several days of exposure even after their basal diet of alfalfa pellets was reduced to half maintenance and bitterweed was mixed with corn. Lambs may have consumed enough during the initial feeding of bitterweed to receive immediate aversive feedback causing avoidance of bitterweed on subsequent days. Some toxins cause rapid aversive postingestive feedback shortly after initiation of intake by ruminants (Provenza 1995, 1996). Similarly, some insects decrease intake in response to toxins within 30 sec through postingestive feedback (Glendinning 1996). Bitterweed can cause death at low levels (LD_{50} =0.5 to 1.3% BW) (Calhoun et al. 1981, Ueckert and Calhoun 1988). Thus, any evolved mechanism of recognizing toxin levels in bitterweed would rely on immediate postingestive feedback when small amounts are consumed.

Sheep typically consume bitterweed when it is actively growing during late winter and early spring (Pfeiffer and

Table 3. Average intake of milo for days directly after dosing with bitterweed or bitterweed and activated charcoal dosing during Trial 2. On days when lambs did not consume ≥ 200 g of milo, they were not dosed and excluded from the analysis.

Activated Charcoal	Milo Intake	Standard Error (SEM)
(g/kg BW)	(g)	
0.0	196[B]	30.3
0.5	263[A]	26.2
1.0	287[A]	19.5
1.5	303[A]	19.2

[A-B]Means within columns with different superscripts differ (P<0.05).
LSD(0.05)= 52.97.

Calhoun 1987). We fed dry, ground bitterweed during the summer and drying and grinding may have depressed intake. However, lambs also refuse to consume bitterweed when other forages are available in field studies during winter (Ueckert and Calhoun 1988). Bitterweed has a very stringent taste which may initially limit intake. Bitter flavors are often associated with toxins (Provenza et al. 1992), and animals may innately avoid bitter flavors to avoid toxicosis (Bartoshuk 1991). However, taste alone cannot explain acceptance or avoidance of foods (Launchbaugh et al. 1993). Animals can be conditioned to prefer bitter-flavored foods if they are paired with nutrients (Mehiel 1991, Sclafani 1991). Because bitterweed grows when most forages are dormant, it may be the only readily digestible and nutritious forage available. Similar situations exist for other poisonous plants; cattle often consume locoweed (*Astragalas* sp., *Oxytropis* sp.) until it reaches maturity and other forages become available (Ralphs et al. 1993).

Trial 2

Lambs dosed with bitterweed alone consumed considerably less than lambs that received bitterweed with activated charcoal, which suggests activated charcoal alleviated some of the toxic effects of bitterweed. Activated charcoal's positively-charged molecular surface binds with the negatively-charged molecular surface of most toxins, resulting in covalent bonding. Thus, most toxins should be adsorbed before digested (Edwards and McCredie 1967). Human deaths by poisoning are prevented when activated charcoal adsorbs toxins already ingested but not digested (Decker et al. 1968, Hayden and Comstock 1975, Levy 1982). Given the design of this study, we were unable to determine if activated charcoal adsorbed hymenoxon prior to digestion. Nevertheless, it seems likely that adsorption occurred given that lambs receiving the higher doses of activated charcoal (1 and 1.5 g/kg BW) consumed more bitterweed. It may be that activated charcoal resulted in higher intake for other reasons. For instance, dosing with activated charcoal may have altered the rumen environment or other digestive functions which affected toxin availability.

Consumption of milo decreased across all treatments over time. Lambs may have experienced some degree of compaction and reduced ingesta flow from the excessive amounts of activated charcoal. Sodium or magnesium sulfate should be used in conjunction with activated charcoal to prevent compaction of the intestinal tract (Buck and Bratich 1986). We did not use a laxative which may explain the decline.

Alternatively, activated charcoal may have failed to prevent continued toxicosis that developed after several days of dosing with bitterweed. Low levels of bitterweed can cause chronic toxicosis when consumed over several days (Witzel et al. 1977, Ueckert and Calhoun 1988). Chronic or subacute bitterweed toxicosis causes relatively obvious, overt symptoms (e.g., disorientation, blindness, listlessness), but we did not observe overt signs of toxicosis during the study. However, in another study, 1 lamb died from chronic bitterweed toxicosis without exhibiting any of the typical overt symptoms (Bisson and Scott unpubl. data).

Table 4. The number of bites of bitterweed, Texas wintergrass, and engelmanndaisy by individual lambs exposed to a simulated pasture for 10 min/day over 7 days during Trial 3. Lambs were exposed as pairs that either received activated charcoal plus a 20% CP supplement or a 20% CP supplement alone.

Activated Charcoal Supplement	Bitterweed	Texas Wintergrass	Engelmanndaisy
	- - - - - - - - - - - - - -	Number of Bites/10 min	- - - - - - - - - - - -
Yes	12.9[A]	15.2	6.6[A]
No	2.3[B]	12.2	1.0[B]

Means within columns with different superscripts differ (P<0.05).

Trial 3

Trial 3 was conducted to determine if sheep would eat activated charcoal in a supplement and to monitor subsequent intake of bitterweed and 2 other common forage plants. Lambs readily ate the 20% crude protein range cube with and without activated charcoal. Lambs supplemented with activated charcoal consumed more bitterweed and engelmanndaisy, suggesting activated charcoal fed with a supplement may prevent bitterweed toxicosis. Engelmanndaisy is considered one of the most palatable forbs in west central Texas, but lambs that not did receive activated charcoal avoided engelmanndaisy. Engelmanndaisy may contain low levels of secondary metabolites that limit intake.

Sheep in Trial 3 took 15–35 bites in 10 min of exposure to potted plants. Other studies have reported sheep taking 50–65 bites in 2–3 min (Burritt and Provenza 1990, Ralphs et al. 1991). Lambs probably took fewer bites of the potted plants because they were satiated; they received 400 g of supplement immediately before exposure to the potted plants.

General Discussion

Other efforts to feed lambs a compound to prevent toxicosis have been unsuccessful because of unpalatability (Ueckert and Calhoun 1988). L-cysteine prevents toxicosis (Rowe et al. 1980), but lambs avoid supplements containing high levels of L-cysteine (Calhoun et al. 1986). The antioxidant Santoquin (6-ethoxy-1,2, dihydro-2,2,4-trimethylquinoline) also prevents toxicosis (Kim et al. 1982, Calhoun et al. 1989), but Santoquin reduces palatability when added to supplements at 0.5% (Calhoun et al. 1986, Ueckert and Calhoun 1988). Activated charcoal may be an effective replacement for other supplement additives because (1) lambs will readily consume sufficient amounts of activated charcoal, and (2) activated charcoal appears to attenuate bitterweed toxicity.

Dollahite et al. (1973) showed similar success in preventing bitterweed toxicosis by dosing lambs with .5% BW of activated charcoal, but they were unable to prevent toxicosis by feeding activated charcoal in a supplement. Their source and type of charcoal was not clear. We used a type of charcoal with a large surface area due to a very small particle size to bind with toxins; differences in charcoal may explain discrepancies between the 2 studies. Dollahite et al. (1973) also fed activated charcoal supplement as a pelleted feed. Pelleting requires extreme heat and pressure to form pellets which may reduce the adsorbative capacity of activated charcoal.

Activated charcoal may be effective in binding other phytotoxins. Buck and Bratich (1986) suggested activated charcoal should be effective in treating toxicosis induced by mycotoxins, plant alkaloids, glycosides, and most other phytotoxins. Activated charcoal effectively adsorbed phenolics from Terminalia catappa and Mangifera indica on the African Island of Zanzibar (Struhsaker et al. 1997). Activated charcoal also reduces toxicity from aflatoxins in chickens (Decker and Corby 1980, Ademoyero and Dalvi 1983, Dalvi and Ademoyero 1984, Dalvi and McGowan 1984) However, other efforts to use activated charcoal to treat phytotoxicosis have produced unfavorable results; activated charcoal has only resulted in limited success in binding terpenes in sagebrush (*Artemisisa* sp.) in northern Utah (Provenza, pers. comm.). Further investigations are needed to quantify the scope of activated charcoal to treat(prevent) plant-induced toxicosis.

Implications

Veterinarians commonly treat a wide variety of toxicosis cases with activated charcoal (Buck and Bratich 1986), yet the use of activated charcoal by livestock producers is rare. Producers typically pen animals suffering from bitterweed toxicosis and feed them a high-protein diet. Drenching with activated charcoal (1 g/kg BW) immediately after observing toxicosis is likely to increase survival if hymenoxon is still in the digestive tract and adsorption occurs. Nevertheless, for activated charcoal to become widely used against bitterweed toxicosis, it should be offered in the form of a supplement. However, there are no data on appropriate supplementing frequencies. Similarly, there are several grades of activated charcoal that may vary in ability to adsorb hymenoxon; commercial varieties of activated charcoal typically differ in ability to adsorb toxins (Cooney and Struhsaker 1997). Finally, the physiological effect of activated charcoal remains unclear. Future studies should investigate activated charcoal's affect on digestive function and animal health.

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Nutrient distribution among metabolic fractions in 2 *Atriplex* spp.

MUHAMMAD ISLAM AND MARK A. ADAMS

Authors are graduate student, Plant Sciences, Faculty of Agriculture, University of Western Australia, Nedlands, Western Australia 6907, Australia, and associate professor, Botany Department, University of Western Australia, Nedlands, Western Australia 6907, Australia.

Abstract

The seasonal variations in nitrogen and phosphorus fractions and cations in 2 species of Atriplex common to Western Australia (*Atriplex amnicola* P. G. Wilson and *Atriplex nummularia* Lindl.) were investigated. Both species contain high concentrations of nitrogen (N) in winter as compared with summer when both species contain high concentrations of sodium. The sum of soluble protein-N, amino acid-N, nucleic acid-N and nitrate-N is about half of the total nitrogen. The remainder includes non-soluble protein-N and other N associated with cell membranes and walls. Phosphorus was more uniformly distributed among pools of inorganic-P, phytate-P, nucleic acid-P and other (residual) fractions. We suggest that interpretation of animal nutrition studies based on similar trichloroacetic acid (TCA) fractionations might be improved by independent estimation of soluble proteins. Fractionation using TCA provides valuable information about the subcellular distribution of both N and P in foliage tissues for studies of plant physiology and animal nutrition.

Concentrations of major nutrients in foliage of both species were significantly and negatively correlated with monthly maximum temperature and significantly and positively correlated with monthly rainfall. In summer and early autumn the apparent nutritive value of both species is well below the basic requirement of sheep or other grazing ruminants such as goats.

Key Words: *Atriplex* spp., saltbush, nitrogen, phosphorus, fractionation, animal nutrition, salinity

Resumen

Se investigo la variación estacional de las fracciones de nitrógeno, fósforo y cationes de dos especies de *Atriplex comúnes* del oeste de Australia (*Atriplex amnicola* P.G. Wilson y *Atriplex nummularia* Lindl.). En invierno, ambas especies contienen altas concentraciones de nitrógeno (N), comparado con el contenido de verano cuando tienen altas concentraciones de sodio. La suma del N-protéico soluble, N-amino ácidos, N- nucleico y el N-nitratos es aproximadamente la mitad del nitrógeno total. El nitrógeno restante incluye el N-protéico no soluble y el N asociado con las membranas y paredes celulares. El fósforo (P) estuvo mas uniformemente distribuido entre las fracciones de P-inorgánico, P-ácido nucleico y otras fracciones (residuales). Sugerimos que la interpretación de los estudios de nutrición animal basados en el fraccionamiento de ácido tricloroacético similar (TCA), pudiera ser mejorada por la estimación independiente de las proteínas solubles. El fraccionamiento utilizando TCA provee valiosa información acerca de la distribución subcelular del N y P en los tejidos foliares,información util en los estudios de fisiología vegetal y nutrición animal.

Las concentraciones de los principales nutrientes en el follaje de ambas especies fueron significativamente y negativamente correlacionadas con la temperatura máxima mensual y significativamente y positivamente correlacionadas con la lluvia mensual. En verano e inicios de otoño el valor nutritivo aparente de ambas especies es menor que los requerimientos básicos de los ovinos y otras especies de rumiantes tales como los caprinos.

Salinity adversely affects the growth and metabolism of many plant species (Greenway and Munns 1980, Flowers et al. 1986, Munns 1993). In arid and semi-arid regions of the world, grasses, herbs and shrubs that can survive in saline soils have been the subject of considerable research. For example, halophytic shrubs have been evaluated as alternative sources of forage for livestock, and *Atriplex* spp. (saltbush) are strong candidates for cultivation in saline areas because of their salt tolerance and productivity (Kleinkopf et al. 1975, O'Leary et al. 1986, Malcolm 1994).

Physiological adaptations of *Atriplex* spp., including the accumulation of high concentrations of sodium and chloride within cell vacuoles and compatible organic solutes in cytoplasm (Cheeseman 1988, Adams et al. 1992), help offset the growth-limiting attributes of soil salinity. Na+/H+ exchangers or "antiporters" at the tonoplast that can increase Na+ accumulation in the vacuole of halophytes, have been suggested as further adaptations to salinity (Staal et al. 1991, Barkala et al. 1995).

The nutritive value of *Atriplex* spp. and other native shrubs for grazing animals has been studied using a variety of techniques (Wilson 1977, Wilson and Graetz 1980, Warren and Casson 1991) which are often based on the work of Van Soest and colleagues (Crooker et al. 1978, Krishnamoorthy et al. 1982, Sniffen et al. 1992, Van Soest 1994). Laboratory procedures for determining nutritive value utilise a range of chemical extractions, especially tungstic and trichloroacetic (TCA) acid in combination with detergents, to fractionate the nitrogen and protein content of plant material into categories which differ in their digestibility (e.g. Licitra et al. 1996). These developments in methodology for studying animal nutrition parallel development of methods for studying plant physiology. For example, Kedrowski (1983) and Chapin and Kedrowski (1983) used a TCA-based fractionation to separate foliar N into classes that differed metabolically and as

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sinks for the storage and retranslocation of N both seasonally and with treatment. This method has since been applied to organic-N in litter with similar results (Polglase et al.1992).

Despite methodological advances in both animal nutrition and plant physiology, there is not always an exact relationship between measured attributes of plants and their value to stock. A piece of long-held, and still conventional, wisdom is that protein concentrations are the major index of nutritive value and can be calculated from the concentration of total nitrogen using a 'conversion factor' (e.g. concentration of protein = 6.25 x concentration of Kjeldahl N). On this basis, the National Academy of Science (1958) reported that the concentration of crude protein in *Atriplex* ranges from about 6% to 24 % and others have argued similarly (Beadle et al.1957, Malcolm 1994). While the foliage of *Atriplex* spp. may contain high concentrations of N, there are no definitive studies of the distribution of this nitrogen among classes now commonly accepted in studies of animal nutrition or plant physiology (as identified above). For example, as much as half of total N in *Atriplex* is non-protein nitrogen and of less certain value to grazing animals (Gihad and El Shear 1994).

Further examination of the accumulation of salts and nitrogen fractions in saltbush, and their relationship with soil salinity and climatic factors, are needed before we can accurately evaluate their role as animal fodder. The present study investigated: (a) the relationship between the nutritive value of foliage of 2 *Atriplex* spp. and environmental factors, such as rainfall and temperature; and, (b) the distribution of total nitrogen and phosphorus (elements that limit growth in Western Australian soils) among discrete 'fractions' in the foliage. We compared 2 perennial species, *A. amnicola* P. G. Wilson (River saltbush) and *A. nummularia* Lindl.(Old man saltbush).

Materials and Methods

Study sites

Field work for this study was conducted between February 1995 and January 1996 at a 10 ha site close to Tammin (31° 39' S, 117° 29' E; 200 km east of Perth, Western Australia). The site has been previously described by Davidson et al. (1991). Briefly, the soil is saline (conductivity of 60–80 ds/m) and has a high sodium absorption ratio (SAR) 80–100. The surface soil horizon lies above a dense clay B horizon and may become waterlogged after rain. The 2 species of saltbush have been grown side by side on the same site for more than 18 years. The species were planted in alternate rows on a 2.5 x 2.5 m grid along a topographic gradient of soil salinity (from low to high salinity).

The climate of the study area is semi-arid, with considerable seasonal and daily variations in temperature. Precipitation and temperature data were obtained from meteorological stations at Tammin and Cunderdin, less than 25 km away from the study site. Mean maximum temperature for the hottest month during the study (January) was 34°C and the mean minimum for the coldest month (July) was 7°C (Fig. 1a). Total precipitation during the study period was 437 mm and almost half of that fell between June and August (Fig. 1b). These values are all close to the long term means for Tammin, and evaporation exceeds precipitation for much of the year.

Sampling

Leaf samples were collected from 6 randomly selected plants of *A. amnicola* and *A. nummularia* at monthly intervals starting in February 1995 along the topographic salinity gradient. Leaf samples were immediately plunged into liquid N_2 and freeze-dried on return to the laboratory. All analyses were conducted on freeze-dried tissues and were made in duplicate. Mean values were used for statistical analyses.

Chemical analysis

Total nitrogen and phosphorus concentrations were measured by digestion of dried and ground leaf samples in H_2SO_4/H_2O_2 at 320°C (Adams and Attiwill 1986) and subsequent colorimetric determination of PO_4^{3-} and NH_4^+. The method of Murphy and Riley (1962) was used to measure PO_4^{3-} and the indophenol

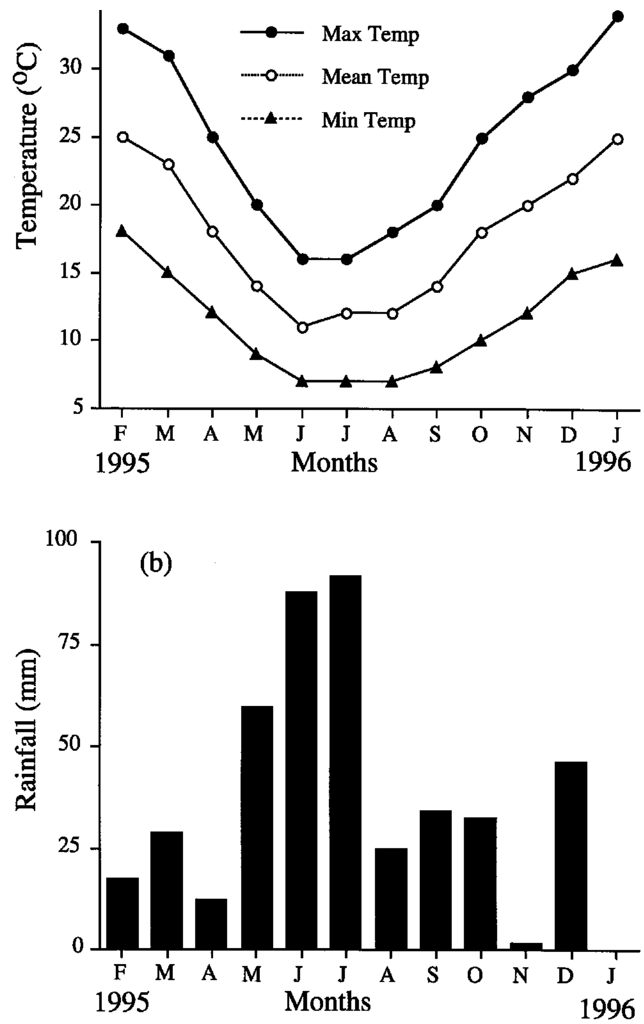

Fig. 1. Climatic conditions at Tammin, Western Australia, from February 1995 to January 1996. (a) Monthly maximum, minimum and mean ambient temperatures. (b) Monthly rainfall.

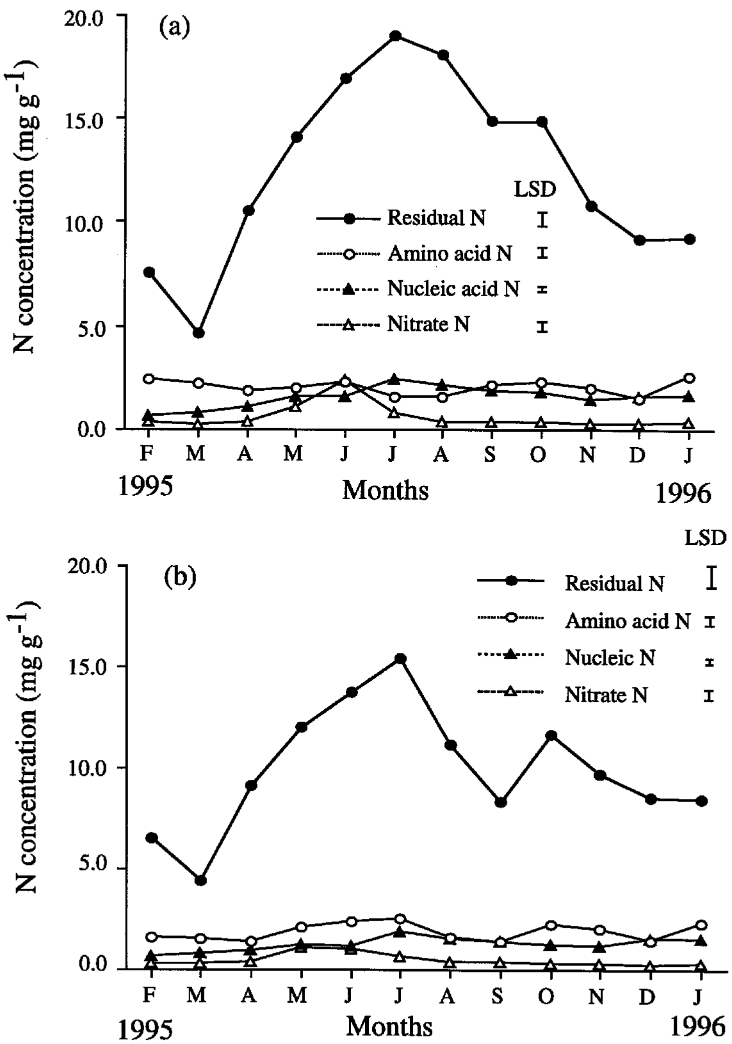

Fig. 2. Seasonal pattern of N fractions in (a) *A. amnicola* and (b) *A. nummularia*. Least significant differences for p = 0.05 (LSD) between months for each fraction are shown.

blue method of Keeney and Nelson (1982) was used to measure NH_4^+.

Leaf N and P were fractionated using sequential extraction with cold (room temperature, 0.3 M) and hot (90°C, 0.15 M) trichloroacetic acid (TCA) by the procedure of Polglase et al. (1992) modified from Chapin and Kedrowski (1983). Usually, extracts would be analysed for inorganic and total N and P and the concentration of organic N and P calculated as the difference. Concentrations of inorganic N in cold TCA extracts were negligible and we assumed that the total N was derived largely from amino acids (Chapin and Kedrowski 1983). Similarly, hot TCA extracted mainly organic N (assumed to be nucleic acids) and there was little inorganic N present.

Inorganic phosphorus was present only in cold TCA extracts. Organic phosphorus (P_o) soluble in cold TCA was assumed to be a combination of phytate P and other ester P, and P_o soluble in hot TCA to be a combination of phytate P and nucleic acid P. The sum of P and N fractions in cold and hot TCA extracts we defined as labile P and labile N (Polglaze et al. 1992). Residual components were defined as those insoluble in TCA.

Nitrate (NO_3^-) concentrations in foliage were measured separately by the extraction and analysis procedures described by Cataldo et al. (1975). The total concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} were determined by digestion of leaf samples in acid (as described above for analysis of total N and P) followed by atomic absorption spectroscopy (e.g. Adams and Attiwill 1986).

Soluble protein was determined by a modified procedure of Wilkins et al. (1994) with 50 mg of leaf tissues homogenised with 1.2 ml of 100 mM Tris /HCl pH 7.6, containing 1.5 mM disodium ethylenediamine tetraacetic acid (EDTA), 1.5 mM $MgCl_2$, 1.5 mM $KHCO_3$, 2.5 % (v/v) Tween 20, 10 % (v/v) glycerol, 100 mg of sand and 10 % (w/v) insoluble polyclar AT. The crude extracts were centrifuged at 15,000 g for 5 minutes, decanted and the supernatant re-centrifuged for 2 min at 15,000 g. The clear extract was analysed for protein using the method of Lowry et al. (1951) with a kit purchased from Bio-Rad.

Statistical analysis was performed using the General Analysis of Variance procedure available in the Genstat computer package. Species and season were considered the independent variables. Harvest dates were treated as repeated measures in time and analysed using a randomised complete block design.

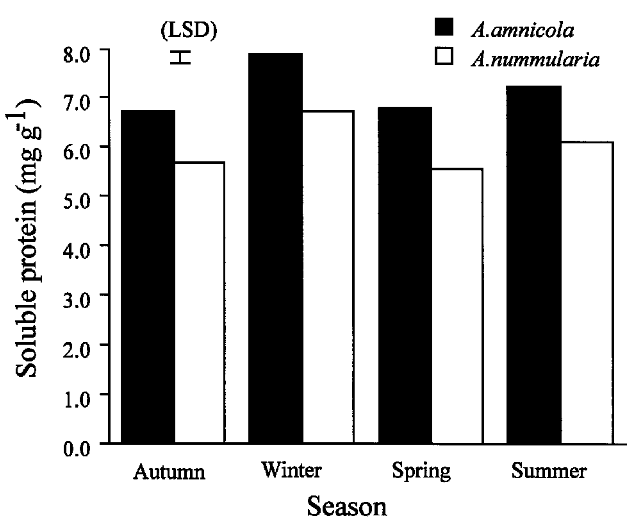

Fig. 3. Concentrations of soluble protein in foliage of *A. amnicola* and *A. nummularia*. The least significant difference for p = 0.05 (LSD) between species for all seasons is shown.

Results

Nitrogen

Concentrations of amino acid nitrogen (soluble in cold TCA) and nucleic acid nitrogen (soluble in hot TCA) for both species varied throughout the year (Figs 2a, 2b). In particular, concentrations of amino acid nitrogen were greatest in summer and early autumn (18–31% of total nitrogen) and least in winter and spring (5–14 % of total nitrogen). Concentrations of nucleic acid nitrogen varied less (between 6 and 14%) and little seasonal pattern was apparent. Separate analysis of nitrate concentrations in foliage of both species showed little seasonal trend but were greater during periods of rainfall (6-11%) than at other times (2–4%). The concentrations of total nitrogen in leaves of both species were greatest in winter months and least in summer. The difference between total N and labile N (nucleic acid N + amino acid N + nitrate N) we defined as residual N and comprised by far the largest N fraction throughout the year (Figs 3a, 3b).

Further estimates of the forms of N in foliage were obtained using a direct extraction technique for soluble protein. On a seasonal basis (Fig 3), concentrations of soluble protein were significantly greater in winter than in other seasons (on the basis of the ratio of protein:N of 6.25, the approximate concentration of N in soluble protein varied between about 0.9 and 1.2 mg N g^{-1} dry weight). Seasonal mean concentrations of total N and their distribution into residual and labile N (Fig 4) followed a similar pattern to those of soluble protein. The concentration of total N was significantly less in *A. nummularia* than in *A. amnicola* throughout the year ($p < 0.01$).

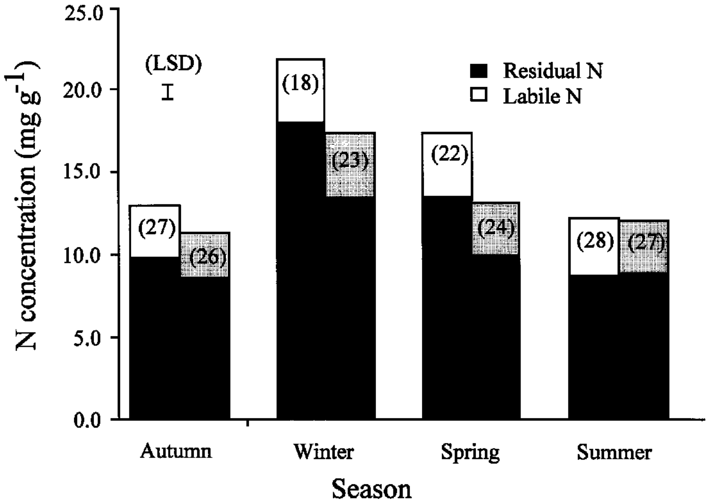

Fig. 4. Residual and labile N in *A. amnicola* (black and white) and *A. nummularia* (shaded). The least significant difference for p = 0.05 (LSD) between species for total N for all seasons is shown. The proportion of labile-N as % is given in brackets.

Phosphorus

Phosphorus was more evenly distributed among fractions than was nitrogen (Figs 2a, 2b, 5a, 5b). Most fractions followed closely the pattern of rainfall (Fig 1b). Inorganic P comprised up to 60% of total leaf P in summer while phosphorus fractions soluble in hot TCA (phytate P plus nucleic acid P) increased to close to 40% of the total in winter. In contrast to nitrogen, residual phosphorus was the smallest fraction in both species throughout the year (Fig 6). Combination of monthly data into seasons shows clearly that total P concentrations were greatest in winter for both species and greater in *A. amnicola* than in *A. nummularia* ($p < 0.01$).

Cations

In *A. amnicola* and *A. nummularia*, the concentration of Na^+ was about 4.5 % in mid-winter, and increased to maximum of 7–8 % by mid-summer (Fig 7a, 7b). In both species the concentration of K^+ increased in winter to 3 % for *A. amnicola* and 3.6% for *A. nummularia*. The concentration of K^+ was significantly ($p < 0.01$) greater in *A. nummularia* than *A. amnicola* during most of the year. In both species, the Na:K ratio in summer and autumn was greater than 3:1 compared with winter and spring when the ratio approached 1-1.5:1.

In *A. amnicola*, the concentration of Mg^{2+} in summer and autumn was 0.16%, which increased to 0.21% in spring and winter. In *A. nummularia*, the concentration of Mg was about 0.10% in summer and autumn and 0.13% in winter and spring. In both species, the concentration of Ca^{2+} slightly increased in late autumn and winter (0.99%), while remaining constant throughout the growing season.

Correlation

The concentrations of total nitrogen, nitrate, total phosphorus and potassium were significantly and negatively correlated with monthly mean maximum temperature ($p > 0.05$) and significantly and positively correlated with monthly rainfall ($p < 0.05$). By contrast, sodium concentration was significantly and positively correlated with maximum mean monthly tem-

Table 1. Pearson correlation coefficients between environmental factors and concentrations of nutrients in *Atriplex amnicola* and *Atriplex nummularia*.

	Atriplex amnicola			*Atriplex nummularia*		
	Max. Tem	Min Temp	Rainfall	Max. Temp	Min Temp	Rainfall
Total Nitrogen	-0.86**	-0.87**	0.59*	-0.73**	-0.74**	0.67*
Nitrate (NO3)	-0.60*	-0.58*	0.72**	-0.69*	-0.66*	0.73*
Total Phosphorus	-0.87**	-0.86**	0.77**	-0.72**	-0.73**	0.67**
Sodium	0.94**	0.90**	-0.72**	0.83**	0.65*	-0.65*
Potassium	-0.75**	-0.66*	0.72**	-0.84**	-0.78**	0.61*
Calcium	-0.46NS	-0.34NS	0.41NS	-0.71**	-0.79**	0.45NS
Magnesium	0.40NS	-0.48NS	0.16NS	-0.63*	-0.64*	0.26NS

Significance * $p < 0.05$, ** $p < 0.01$, NS = not-significant at $p \leq 0.05$.

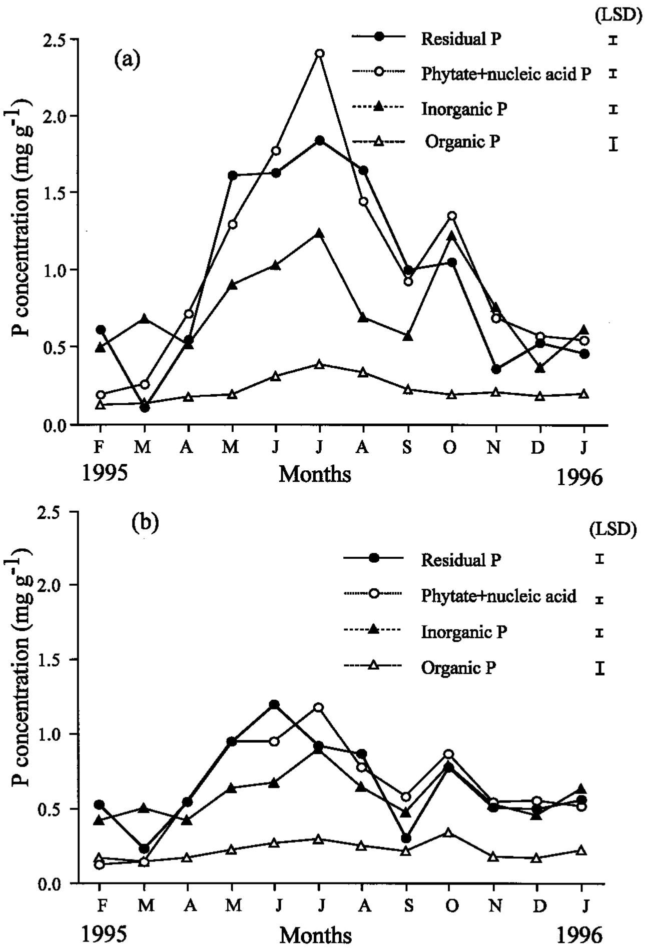

Fig. 5. Seasonal pattern of P fractions in (a) *A. amnicola* and (b) *A. nummularia.* Least significant differences for p = 0.05 (LSD) between months for each fraction are shown.

perature ($p<0.01$) and negatively with total monthly rainfall (Table 1). In both species, throughout the whole growing season, there were highly significant positive correlations between nitrogen and phosphorus concentration ($p<0.01$) and potassium concentration was negatively correlated ($p>0.01$) with sodium concentration.

Discussion

Little, if any, attention has been given to the metabolic fractions of N and P in native Australian shrub species or indeed for many other, non-agricultural, trees and shrubs (Chapin and Kedrowski 1983). By far the greatest proportion of total N in Atriplex was present in the residual fraction that includes the soluble and non-soluble proteins and cell wall components and which varied considerably throughout the year. Amino acid-N, nucleic acid-N and nitrate-N were minor fractions showing little seasonal variation. Separate analysis suggested that the N-content of soluble protein was of the order of 1 mg g^{-1} and hence the majority of the residual –N fraction of 10–18 mg g^{-1} is present as insoluble protein (probably associated with cell or organelle membranes) or cell wall components. The conflicting reports of digestibility and nutritive value for grazing animals of shrubs provide little by way of comparative data for the present study. Indeed, Le Houérou (1992) reported that the "feed value of *Atriplex* spp. has been questioned by a number of scientists and still is a controversial issue". Wilson (1977) assessed nitrogen fractions in a range of shrubs found in western New South Wales using methods based on acid and detergent fractionation. Wilson argued that the true digestibility (in sheep) of organic matter of 2 *Atriplex* species (including *A. nummularia*) was about 75%, that of neutral-detergent fibre about 60%, of acid-detergent fibre about 40% and of nitrogen about 95%. In contrast, Le Houérou (1992) summarised a range of other studies in claiming a digestibility of nitrogen in *Atriplex* of only 65% and in addition pointed out that only about half of that was retained. The N not retained was largely glycinebetaine—a solute which accumulates during drought and especially salinity stress. In our study, glycinebetaine would have been included in the amino acid-N fraction which was always small and while glycinebetaines may reach micro-molar concentrations in salt-tolerant trees (Prat and Fathi-Ettai 1990) or shrubs under drought or saline conditions (Singh et al. 1973, Cyr et al. 1990, Storey et al. 1993, Kozlowski and Pallardy 1997) it is unlikely that this or other osmotically active nitrogenous solutes (e.g. proline) comprise a significant proportion of digestible-N in *Atriplex*. The increases in concentration of amino acid-N during summer were not reflected in total-N which declined possibly due to a) inhibition of nitrate reductase activity by water and salt stress (Hsiao 1973, Kleinkopf et al. 1975), b) NH_4^+/Na^+ competition (Naidoo 1987) or c) competition for sites of NO_3^- uptake by Cl^- on the basis that Cl^- is a major osmoticum in halophytes (Cram 1973).

Our finding that N in non-soluble protein or cell-walls is by far the largest pro-

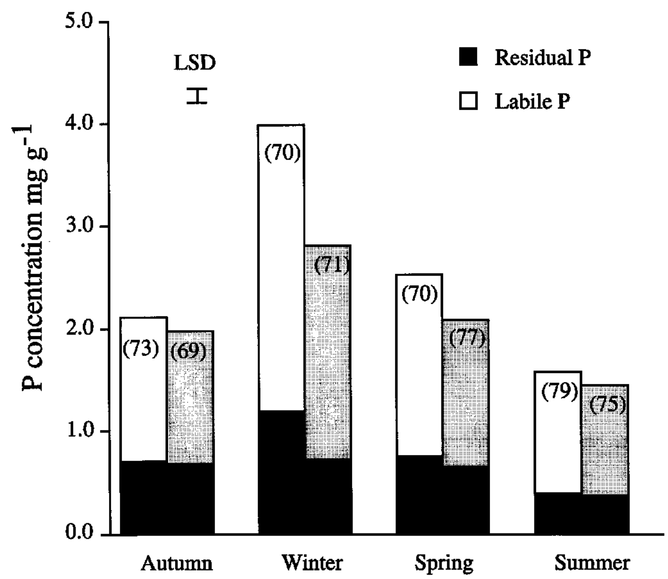

Fig. 6. Residual and labile P in *A .amnicola* (black and white) and *A. nummularia* (shaded). The least significant difference for p = 0.05 (LSD) between species for total P for all seasons is shown. The proportion of labile-P is given in brackets.

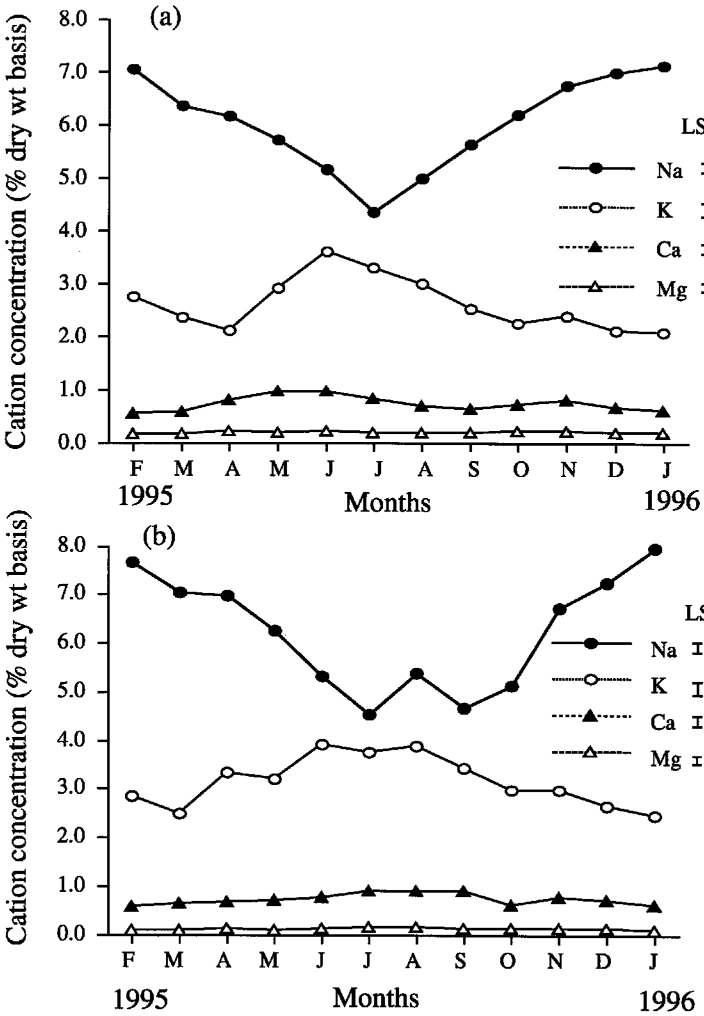

Fig. 7. Seasonal pattern of cation fractions in (a) *A. amnicola* and (b) *A. nummularia.* Least significant differences at p = 0.05 (LSD) between months for each cation are shown.

portion of the largest N-fraction (residual-N) which in turn strongly reflects seasonal fluctuations in growing conditions is consistent with other studies (Chatterton et al. 1971) and with the general physiological pattern that up to half of leaf N is associated with the membrane-associated enzymes of carbon fixation (e.g. RUBISCO, Field and Mooney 1986). It seems axiomatic that studies of plant N from the perspective of animal nutrition might benefit from a better understanding of the digestibility and retention of this N source.

Phosphorus, which has a central role in the energy metabolism of grazing animals as well as plants, was also lower in concentration in both species during summer and early autumn (Grice and Muir 1988) than recommended for grazing animals (0.16–0.37%, National Research Council, 1975), but was adequate during the rest of the year. In summer, the concentration of inorganic phosphorus was greater than that of other P-fractions in both species. Inorganic-P acts as a P-storage pool in the vacuole and can be utilised during the summer period of intense growth (Marschner 1986). In winter, the increase in the phytate and nucleic acid P-fraction coincided with a comparable decline in inorganic phosphorus suggesting that P-storage is a major process during the colder months.

Both *Atriplex* species contain considerably greater Na+ concentrations than that recommended as being suitable for ruminants (0.06% National Research Council 1981). In summer, both species contain more than 6 % by weight of Na^+. These high concentrations make *Atriplex* a poor quality forage and increase the demand of stock for good quality water (Grice and Muir 1988). Again, K^+ concentrations in both species were greater than those recommended by the National Research Council (1975, 1981 0.5–0.8%). Low concentrations of salts in foliage during winter may be a result of leaching from epidermal trichomes (salt bladders) which contain at least 50% of salt of the leaves (Pallaghy 1970).

In recent years, *Atriplex* spp. have increasingly been recognised as poor fodder for stock because of their high concentrations of salts and other metabolites, as found here, and due to the small proportion of total N present in readily digestible forms. In arid and semi-arid areas of developing countries, supplementary feeding will be necessary to overcome deficiencies in *Atriplex* as a stock feed (e.g. Le Houérou 1992). However, our results indicate that there is a substantial variation in the potential forage value throughout the growing season and this variation could be used to increase the value of saltbush for animals at specific times of the year. Clearly, any measure of "nutritional value" based on estimates of total N and thus "crude protein" are inaccurate. Notwithstanding, the fermentation and digestion capability of ruminant animals, alternative measures of the availability of N in foliage, may help in assessing the value of forage species in rangelands (and elsewhere).

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Impact of locoweed poisoning on grazing steer weight gains

MICHAEL H. RALPHS, DAVID GRAHAM, GLEN DUFF, BRYAN L. STEGELMEIER, AND LYNN F. JAMES

Authors are rangeland scientist, USDA/ARS Poisonous Plant Lab, 1150 E. 1400 N., Logan Ut 84341; extension county agent, Clayton N.M.; director NMSU Clayton Research Station; veterinary pathologist; and director USDA/ARS Poisonous Plant Lab.

Abstract

Emaciation is one of the clinical signs of locoweed poisoning but few studies have documented impacts of locoweed poisoning on weight gains. Stocker steers (British x Continental cross, 200–210 kg) were grazed on locoweed-infested, short-grass prairie in 1996 and 1997 in northeast New Mexico. Each year, half the steers were averted to locoweed to allow them to graze locoweed-infested pastures without eating locoweed. They did not graze locoweed and steadily gained weight (0.50 kg/day in 1996 and 0.71 kg/day in 1997). The other group of steers were allowed to graze locoweed under natural grazing conditions and became intoxicated. Weight gains were not affected for the first 3 weeks, but thereafter the steers lost weight in both years. In 1996, non-averted steers consumed locoweed for a season average of 20% of bites. They were severely intoxicated and did not begin gaining weight for 50 days after they stopped eating locoweed. Steers in the 1997 trial consumed less locoweed (11% of bites) than those in 1996 and they recovered more rapidly. Seasonal weight gains were 21 to 30 kg less for locoed steers than control steers in 1996 and 1997, respectively. Locoweed poisoning will cause weight loss, and severely intoxicated cattle require a lengthy recover period after they cease grazing locoweed before weight gains resume. Stocker cattle should not be placed on locoweed-infested rangelands until green grass is abundant and locoweed begins to mature.

Key Words: Poisonous plant, white locoweed, *Oxytropis sericea*, cattle grazing

Emaciation is one of the principal signs of locoweed poisoning (James et al. 1981). Chronic locoweed poisoning may also result in reduced weight gains, or weight loss in livestock grazing locoweed infested rangelands. Barnard (1984) reported calves grazing white locoweed (*Oxytropis serecia* Nutt. ex T&G) gained 9 kg less than calves in an adjacent pasture that was not infested with locoweed on mountain summer rangeland in northwestern Utah. James et al. (1970) reported sheep fed spotted locoweed (*Astragalus lentiginosus* Dougl. ex Hook), Greenriver milkvetch (*Astragalus pubentissimus* T&G) or white locoweed for 12% of their diets gained more than control sheep for the first 2 weeks, but thereafter lost weight for the remainder of an 8 week trial. In a pathological study, Stegelmeier et. al. (1995b) fed rats woolly locoweed (*Astragalus mollissimus* Torr.) and injected others with the locoweed toxin swainsonine at 0.1 to 15 mg/kg BW. Rats consuming locoweed or injected with swainsonine at 0.7 mg/kg and above gained 38% less weight and intake declined 28% over the 4 week trial.

Short-grass prairies from northern Mexico to Montana are important summer grazing areas for stocker cattle. Many of these rangelands are infested with *Oxytropis* and *Astragalus* locoweeds. The objective of this study was to compare weight gains of locoweed-intoxicated steers to gains of non-intoxicated steers grazing the same pastures.

Resumen

La inanición es uno de los síntomas clínicos de intoxicación por "Loco weed", sin embargo, pocos estudios han documentado los impactos de la intoxicación por "Loco weed" en las ganancias de peso. Durante 1996 y 1997, novillos cruzados (British x Continental) de 200 a 210 kg de peso apacentaron en el norte de New Mexico una pradera de pastizal corto infestado de "Loco weed". Cada año a la mitad de los novillos se les condicionó una aversión al "Loco weed" para que apacentaran en el pastizal sin consumir "Loco weed". Estos novillos no consumieron "Loco weed" y gradualmente ganaron peso (0.49 kg dia-1 en 1996, y 0.71 kg dia-1 en 1997). Al otro grupo de novillos se le permitió consumir "Loco weed" bajo condiciones naturales de apacentamiento y se intoxicaron. Las ganancias de peso no se afectaron en las primeras 3 semanas, pero de allí en adelante perdieron peso en ambos años. En 1996, los novillos sin aversión consumieron "Loco weed", en promedio el 20% de las mordidas de estos animales fueron de "Loco weed". Estos novillos se intoxicaron severamente y no ganaron peso por un período de 50 días hasta que dejaron de consumir "Loco weed". En el ensayo de 1997, los novillos consumieron menos "Loco weed" (11% de las mordidas) que en el ensayo de 1996, y se recuperaron mas rápidamente En 1996 y 1997, la ganancia de peso estacional para los novillos intoxicados fue de 21 y 30 kg menos que la de los novillos sin intoxicar. El envenenamiento por "Loco weed" causará perdidas de peso, y para que el ganado intoxicado inicie a ganar peso nuevamente se requeriran de largos períodos de recuperación después de que dejaron de consumir "Loco weed". El ganado no debe meterse en potreros infestados con "Loco weed" hasta que haya abundante zacate verde y el "Loco weed" inice la maduración.

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Methods

Field grazing studies were conducted at 2 locations in northeast New Mexico in the spring and early summer of 1996 and 1997.

1996 Trial

This trial began at the New Mexico State Univ. Research Ranch located 30 km northeast of Maxwell New Mexico. The site was a short-grass prairie dominated by the warm season grass blue gramma (*Bouteloua gracilis* (H.B.K.) Lag. ex Steudel). Cool season grasses, western wheatgrass (*Pascopyrum smithii* (Rybd.) A. Love) and sleepy grass (*Stipa robusta* Scribn.) were abundant in the swales, and squirreltail (*Elymus elymoides* (Raf.) Swezey) grew on the ridges. White locoweed was the dominant forb, but fringed sage (*Artemisia frigida* Willd.) and globe mallow (*Sphaeralcea coccinea* (Nutt.) Rydb.) were abundant. A 12 ha area was selected on a rocky ridge where white locoweed was dense. The site was split into four, 3 ha pastures with electric fence.

Twenty six crossbred steers (British X Continental, 200 kg ± 4 SE) were purchased from a local auction and randomly placed in 2 groups: Loco-eaters or Averted. The averted group was conditioned to avoid eating locoweed to prevent them from becoming intoxicated (Ralphs et al. 1997). Steers were fasted overnight then offered fresh picked locoweed. All steers were observed eating the plant and were gavaged with lithium chloride (LiCl) at 200 mg/kg BW to induce gastrointestinal illness. They associated the induced illness with the taste of the plant and subsequently refused to eat locoweed. Averted steers were held in the pen for 3 days and allowed to recover, then offered locoweed again to validate the aversion. The aversion treatment allowed the Averted groups to graze on the same sites as the Loco-eaters without becoming intoxicated.

The Loco-eaters were not treated with LiCl and were allowed to graze the locoweed infested areas under natural grazing conditions. The 2 treatment groups were divided into 2 replications and randomly allocated to the 4 pastures. The 4 sub-groups were rotated through the 4 pastures on a weekly basis to reduce any pasture bias.

Steers were weighed on site at the beginning of the trial on 25 April and blood samples were taken from the jugular vein. Steers were weighed and bled at 2 week intervals. They were fasted overnight and weighed between 0730 and 0900 hours the next morning. Blood samples were centrifuged at 2000 RPM for 20 min. Serum was decanted and frozen until analysis. Serum samples were analyzed for the locoweed toxin, swainsonine, as a measure of level of intoxication by the method described by Stegelmeier et al. (1995a). Swainsonine inhibits the enzyme -mannosidase. Serum samples were incubated for 30 min with α-mannosidase, then quantified photometrically and compared to a standard curve of increasing swainsonine concentration.

Diets were estimated by a bite count technique. Each animal was observed for 5 min periods and the number of bites of cool-season grasses, warm-season grasses, forbs and locoweed were recorded and their percentage of diets were calculated. Generally, 2 observations were made of each steer each day throughout the trial (25 April–19 June). Vibra-corders were placed on the neck of 4 steers in each group to record the amount of time steers were in a grazing mode. Recording charts were changed on a weekly basis and the amount of time steers spent grazing each day was calculated.

The 2 Loco-eater groups sought-out locoweed and quickly depleted it in the 2 pastures they were grazing. After 5 days, they were rotated to the 2 other pastures, but they grazed most of the locoweed in those 2 pastures by the 10th day. The spring of 1996 was extremely dry and there was little vegetation growth. Steers were weighed and bled on 8 May, then moved to a new location 30 km north near Capulin that had more locoweed.

The new site was an old field that had reverted to short-grass prairie. Blue gramma and western wheatgrass dominated the vegetation. White locoweed was abundant on a 6.5 ha tract. This site and an adjacent 6.5 ha site of similar grass composition, were fenced with electric fence. The Loco-eater group was placed in the pasture with abundant locoweed and the Averted group was placed in the adjacent pasture that did not have locoweed. The original replications were not maintained due to the limited locoweed and the inability to rotate pastures and still maintain access to locoweed for the Loco-eater group.

The Loco-eater group depleted the locoweed in this pasture and were moved to another locoweed-infested pasture (8 ha) 0.5 km to the north on 20 May. The Averted group was allowed to graze the entire 13 ha of the original pastures at the second site. During the intoxication period, both groups had access to essentially the same type of vegetation. However, forage available to the Averted group may have been somewhat less, since they were held on the 13 ha pasture that had been previously grazed by the Loco-eater steers.

Seasonal rains began on 25 May. Abundant precipitation and warm temperatures allowed for adequate forage throughout the remainder of the trial. The steers were then transported back to the New Mexico State Univ. Research Ranch on 19 June and allowed to graze with other stocker cattle until 14 August, when a final weight was taken.

1997 Trial

This trial was also conducted at the New Mexico State Univ. Research Ranch near Maxwell, New Mexico. Precipitation was above average during the 1997 growing season, resulting in abundant locoweed and grass. A gravely hill side (15 ha) was selected for the grazing trial. Juniper (*Juniperus osteosperma* (Torr.) Little) was present on the ridges, and sleepy grass and western wheatgrass (cool-season species) dominated the swales. Blue gramma and purple 3-awn (*Aristida purpurea* Nutt.) dominated the slopes. White locoweed was abundant on the shallow rocky areas. The site was split into 4 pastures with electric fence.

Twenty two steers were purchased (210 kg) and randomly separated into 2 groups: Loco-eaters and Averted. The Averted group was conditioned to avoid eating locoweed as described previously. The groups were divided into 2 replications and randomly allotted to the 4 pastures on 28 April. Steers were rotated through the pastures on a weekly basis to reduce pasture bias. Bite counts (5 min/steer) were taken to estimate diets. The steers were weighed and bled every 3 weeks.

The Loco-eaters stopped grazing locoweed by 10 June. All the steers were moved to an adjacent 9 ha pasture and grazed together for the remainder of the trial. Intensive weighing, bleeding and bite counts stopped on 2 July, but the steers remained on site and a final weight was taken on 19 August.

Standing crop was estimated as steers began grazing in each pasture in each trial. Ten, 0.25 x 1 m quadrats were systematically located at 20 step intervals along transects running through the center of each pasture. Species were grouped into forage classes (cool-season grasses, warm-season grasses, forbs, and locoweed) clipped at ground level, dried in a forced

Table 1. Mean standing crop of forage classes (kg/ha ± SE) averaged over pastures at the beginning of grazing trials in 1996 and 1997.

Year	Location	Cool-season grasses	Warm-season grasses	Forb	Locoweed
		----------	(kg/ha)	----------	
1996	Maxwell	26 ± 11	499 ± 53	263 ± 6	262 ± 129
	Capulin	52 ± 15	450 ± 40	200 ± 19	134 ± 33
1997	Maxwell	38 ± 9	293 ± 23	145 ± 23	302 ± 74

air oven at 60°C for 48 hours, and weighed. Beginning standing crop is presented in Table 1.

Statistical Analysis

Forage classes in diets (cool-season grass, warm-season grass, forbs, and locoweed) were compared among groups in a split-plot design over time using general linear models (GLM). Steers were nested within groups and used to test differences between groups. Weigh periods were the split plot and the period X steer-within group factor was used to test the period and the group X period interaction.

Average daily gains over weigh periods were compared between the 2 groups in a repeated measures model using GLM. In trial 1, the steers were moved to new locations and the original replications were consolidated into the 2 treatment groups. Steers were nested within groups and weigh periods were the repeated factor. Data from the vibra-corders on time spent grazing in 1996 were analyzed in a similar model comparing groups, with weeks as the split plot.

In trial 2, each treatment group was divided into 2 replications and each treatment group/replication combination was rotated through each pasture to minimize pasture bias. However, there was a treatment group X replication interaction (P<0.05). Loco-eater Replicate 2 started eating locoweed, but quit after 8 days and did not become intoxicated. Replicate 1 continued eating locoweed and became visibly intoxicated. The Averted treatment group and Loco-eater Replicate 2 were combined into a single group for the weight gain data analysis. The model was reduced and data were analyzed for the 2 reconstituted groups using repeated measures GLM, with animals nested within groups, and weigh periods as the repeated factor. Total weight gains and overall ADG were compared by 1-way ANOVA each year. Correlation analysis was run between percent of locoweed in diets, swainsonine concentration in blood serum, and average daily gains for the Loco Group in both years.

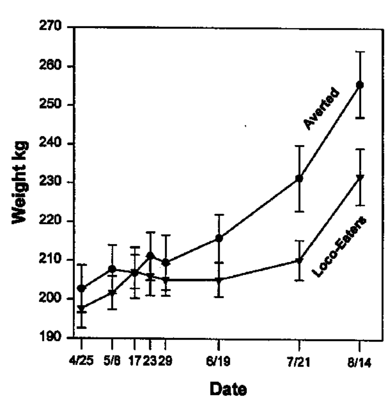

Fig 1. Weight gains of steers that ate locoweed and became intoxicated (loco-eaters), compared to steers that were averted from eating locoweed (averted) in the 1996 trial.

Results

1996 Trial

Averted cattle did not consume any locoweed (Table 2). Steers in the Loco-eater group consumed locoweed for an average of 31 and 27% of bites during intoxication periods 1 and 2 respectively, and reached a high daily consumption of 80% of bites. They reduced locoweed consumption and ceased grazing locoweed after 28 May. Other studies reported cattle ceased grazing locoweed when warm season grasses started rapid growth and locoweed matured (Ralphs et al. 1993, 1997).

Loco-eaters gained 0.45 kg/day during the first intoxication period, but then lost weight during the 2nd period (Table 3). They did not gain during the recovery period (3), and gained less than the Averted steers (P=0.02) during the long-term period 4. They apparently recovered by mid July, and daily gains were comparable with the Averted group for the remainder of the trial (Fig. 1). Total season gains were 21 kg less (P=0.02) than the Averted group (Table 3). Data from the vibra-corders suggested that Loco-eaters grazed for less time than steers in the Averted group (9.4 vs 10.8 hours day^{-1}, P = 0.03).

1997 Trial

There was a treatment X replication interaction in locoweed consumption (P< 0.05). Steers in the Loco-eater Replicate 2 ate locoweed at the beginning of the trial (6% of bites), but stopped after 8 days (Table 4). Steers in Replicate 1 consumed locoweed for an average of 19 and 10% of bites in periods 1 and 2. They consumed little locoweed during the recovery period. The Averted group consumed no locoweed.

There was no difference in weight gains between the Averted group and steers in

Table 2. Forage classes in diets (% of bites ± SE) of steers eating locoweed and steers averted toprevent locoweed consumption, 1996.

Group	Period	Cool-season grass	Warm-season grass	Forb	Locoweed
		----------	(% of bites)	----------	
Loco-eaters	1 Intoxication 4/25 –5/16	15 ± 1 40 ± 3	41 ± 2 18 ± 2	13 ± 1 16 ± 2	31 ± 2 27 ± 3
	2 Intoxicated 5/17–5/28	40 ± 3	18 ± 2	16 ± 2	27 ± 3
	3 Recovery 5/29–6/19	12 ± 2	81 ± 2	7 ± 1	0
	Mean	19 ± 1 a	50 ± 1 b	12 ± 1 a	20 ± 1 a
Averted	1 Intoxication 4/25–5/16	60 ± 2	33 ± 2	7 ± 1	0
	2 Intoxicated 5/17–28	33 ± 3	48 ± 3	18 ± 2	0
	3 Recovery 5/29–6/19	7 ± 1	86 ± 1	5 ± 1	0
	Mean	34 ± 2 a	57 ± 1 a	8 ± 1 a	0 b

[ab]Means of forage classes between groups (within columns) that are not followed by the same letter are different (P<0.05).

Table 3. Average daily gains and total gains (± SE) of steers consuming locoweed and becoming intoxicated, compared with steers averted to prevent locoweed consumption, 1996.

Period	Loco-eaters	Averted	p
	- - - - - - - - - - - - - (kg/day) - - - - - - - - - - - - -		
1Intoxication 4/25–5/16	0.45 ± 0.10	0.19 ± 0.12	0.25
2 Intoxicated 5/17–5/28	–0.01 ± 0.20	0.25 ± 0.26	0.43
3 Recovery 5/29–6/18	0.02 ±0.09	0.31 ± 0.10	0.07
4 Recovery 6/19–7/20	0.17 ± 0.10	0.51 ± 0.090.02	
5 Long term 7/21–8/14	0.91 ± 0.11	1.10 ± 0.13	0.29
Overall ADG	0.29 ± 0.05	0.49 ± 0.04	0.01
	- - - - - - - - - - - - - (kg/steer) - - - - - - - - - - - - -		
Total gain	33 ± 6.1	54 ± 4.4	0.02

Loco-eater Replicate 2 (P>0.05). Therefore, we combined these groups and compared their weight gains with steers in Loco-eater Replicate 1, which became visibly intoxicated. There was no difference in gains during the initial 3 week intoxication period (Table 5). During the next 30 days, loco-eaters lost weight while the Non-eaters gained 0.27 kg/day (P= 0.01). During recovery period 3, gains were similar. However, during the long-term period 4, Loco-eater gains were significantly lower (P<0.01) than the Non-eaters (Fig. 2). Total seasonal gains were 30 kg less (P<0.01) in the Loco-eater group (Table 5).

Swainsonine in Blood

Swainsonine concentration in blood serum followed trends similar to locoweed consumption in both years (Fig. 3). In 1996, swainsonine peaked on 23 May at 453 g/ml, and then started to decline after 29 May as steers stopped eating locoweed. Lower swainsonine levels in 1997 resulted from lower locoweed intake (Table 3).

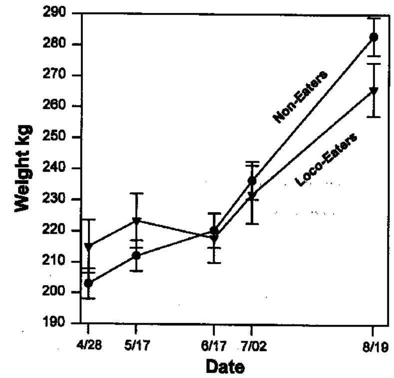

Fig. 2. Weight gains of steers that ate locoweed and became intoxicated (loco-eaters), compared to steers that were averted to locoweed and steers in Rep 2 that did not eat locoweed (non-eaters) in the 1997 trial.

Although weight loss during intoxicated period 2 was similar in both years, steers recovered much faster in 1997 because they were not as severely intoxicated.

Swainsonine concentration in blood serum was positively correlated with locoweed consumption (r=0.65), but there was little correlation with weight gains (r<–0.21). Swainsonine is rapidly cleared from the blood once animals stop eating locoweed (Stegelmeier et al. 1995a). Steers in the Loco group stopped eating locoweed in June, but weight gains did not resume for a period of time after the steers started to recover.

Table 4. Forage classes in diets (% of bites ± SE) of steers in Loco group (Rep 1 and 2) and steers in Averted group, 1997.

Group Rep	Period	Cool-season grass	Warm-season grass	Forb	Locoweed
		- - - - - - - - - - - - - - - - - - - -	(% of bites)	- - - - - - - - - - - - - - - - - - - -	
Loco 1 (loco-eaters)	1 Intoxication 4/28 –5/16	22 ± 3	54 ± 3	5 ± 1	19 ± 2
	2 Intoxicated 5/17–5/28	12 ± 2	63 ± 2	15 ± 1	10 ± 1
	3 Recovery 6/17–7/1	35 ± 4	58 ± 4	6 ± 1	1 ± 1
	Mean	19 ± 2 a	59 ± 2 b	10 ± 1 a	11 ± 1 a
Loco 2 (non-eaters)	1 Intoxication 4/28 –5/16	8 ± 1	78 ± 2	8 ± 1	6 ± 1
	2 Intoxicated 5/17–6/16	8 ± 1	87 ± 1	5 ± 1	0
	3 Recovery 6/17–7/1	13 ± 2	78 ± 2	9 ± 1	0
	Mean	9 ± 1 c	82 ± 1 a	7 ± 1 b	2 ± 1 b
Averted (non-eaters)	1 Intoxication 4/28–5/16	18 ± 2	78 ± 2	4 ± 1	0
	2 Intoxicated 5/17–28	11 ± 1	82 ± 1	7 ± 1	0
	3 Recovery 6/17–7/1	16 ± 2	76 ± 2	7 ± 1	0
	Mean	14 ± 1 b	80 ± 1 a	6 ± 1 b	0 b

[ab]Means of forage classes between groups (within columns) that are not followed by the same letter are different (P<0.05).

Discussion

Averted steers and steers that were not intoxicated by locoweed gained an average of 0.49 kg/day in 1996 and 0.71 kg/day in 1997. Gains on similar shortgrass prairie in central New Mexico averaged 0.82 kg/day over the summer grazing season (Parker et al. 1987). In central Kansas, summer gains averaged 0.63 kg/day (Olsen et al. 1993).

Locoism is a chronic disease. Even though maximum locoweed consumption occurred at the beginning of the trials (up to 80% of bites), weight gains were not affected during the first 3 weeks either year. James et al. (1970) reported sheep on locoweed diets gained more than control sheep during the first 2 weeks of an 8 week feeding trial; and ewes visibly improved in body condition when they first started grazing locoweed in a winter grazing study (James et al. 1968). Locoweed is a succulent cool-season forb containing > 60% moisture and up to 20% crude protein (Ralphs et al. 1993). It is

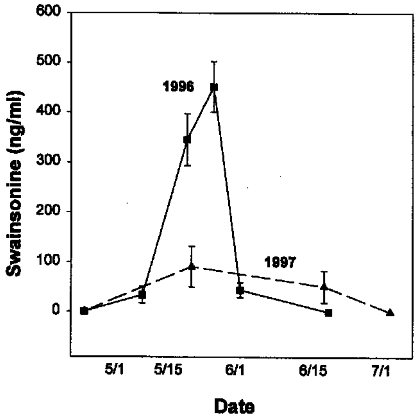

Fig. 3. Swainsonine level in blood serum of loco-eater steers in 1996 and 1997.

nutritionally superior to dormant warm season grasses during the spring and may provide a nutritional boost before the damage from swainsonine accumulates.

Following the initial flush of gains, steers eating locoweed lost weight in both years. From the time steers in the 1996 trial stopped eating locoweed (around the end of May), it took 50 days before they started gaining at a rate similar to non-intoxicated steers (Fig. 1). In the 1997 trial, steers greatly reduced locoweed consumption by the first of June. During recovery period 3 from 17 June until 2 July, they gained similar to the Non-eaters. This appears to be a fairly rapid recovery, and is probably because they consumed less locoweed than the steers in 1996 and were not as intoxicated (Fig. 3). However during the 48-day long-term recovery, they gained 28% less than the Non-eaters (Fig. 2). Long-term gains in the feedlot may also be compromised (unpublished data, Glen Duff).

Reduction in weight gains or weight loss may be due to either reduced intake or inefficient metabolism of feed. Loco-eaters in trial 1 reduced grazing time by 1.4 hours/day compared to Averted steers. Marsh (1909) reported intoxicated cattle grazed less than normal cattle. Ralphs et al. (1991) reported sheep poisoned on locoweed developed tremors in the jaw and did not resume grazing until these seizures passed. Biting rate of intoxicated sheep was 33% less than control sheep. Neurological damage from locoweed poisoning, which causes depression and reduced motor control in prehending and masticating food, may result in anoxeria and emaciation (Stegelmeier et al. 1995b).

Metabolism of feed may also be impaired. Stegelmeier et al. (1995b) reported locoweed intoxication caused vacuolation of parietal cells in the stomach, which may effect nutrient absorption. Pan et al. (1993) reported swainsonine was a potent inhibitor of digestive enzymes (sucrase, glucosidase, and mannosidase) in the intestinal tract of rats. Although simple sugars are not present in the gut of ruminants, glycolysis may be affected in the liver and other areas of the body.

Management Implications

Weight gains were not affected by steers grazing locoweed for the first 3 weeks of the trials. Steers that continued eating locoweed during May and early June lost weight. Severely intoxicated steers in 1996 did not begin gaining weight for 50 days after they stopped eating locoweed. Seasonal weight gains were 21 and 30 kg less for locoed steers than control steers in 1996 and 1997, respectively. Net ranch income was estimated to decline $75 and $282 per head for moderately and severely poisoned stocker steers (Owens et al. 1999). If stocker cattle remain on locoweed-infested pastures, they should not be allowed to enter these pastures until warm season grasses are growing rapidly and locoweed is maturing.

Table 5. Average daily gains and total gains (± SE) of steers consuming locoweed and becoming intoxicated, compared with steers that did not eat locoweed, 1997.

Period	Loco-eaters	Averted	p
	------------- (kg/day)	-------------	
1Intoxication 4/25–5/16	0.41 ± 0.10	0.47 ± 0.10	0.80
2 Intoxicated 5/17–6/16	–0.18 ± 0.09	0.27 ± 0.08	0.01
3 Recovery 6/17–7/1	0.94 ±0.21	1.08 ± 0.14	0.62
4 Long term 7/2–8/19	0.71 ± 0.02	0.97 ± 0.02	0.0001
Overall ADG	0.44 ± 0.04	0.71 ± 0.02	0.0001
	------------- (kg/steer)	-------------	
Total gain	50 ± 4.2	80 ± 2.8	0.007

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Sagebrush ingestion by lambs: Effects of experience and macronutrients

ELIZABETH A. BURRITT, ROGER E. BANNER AND FREDERICK D. PROVENZA

Authors are Research Associate, Associate Professor/Extension Specialist and Professor, Department of Rangeland Resources, Utah State University, Logan, Ut. 84322-5230

Abstract

We investigated how experience early in life and macronutrient content of the diet influenced intake of mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle) by sheep. In the first part of our study, 2-month-old lambs were exposed as a group for 2 mo to a 70% barley-30% soybean meal ration (300 g/hd/day) that contained increasing amounts sagebrush (1 to 20%). Control lambs received grain without sagebrush. All lambs had access to alfalfa hay and pellets ad libitum. When lambs were tested at 6 months of age, prior exposure had no effect on sagebrush consumption after the first 4 days of the trial. When sagebrush comprised 20% of an alfalfa/barley ration, lambs ate the sagebrush ration readily even when a nutritious alternative was offered indicating the flavor of sagebrush did not prevent lambs from feeding. Increasing the amount of sagebrush in the ration from 50% to 75% resulted in lambs eating less of the barley/sagebrush ration, but daily intake of sagebrush remained constant throughout the 4 day trial, presumably because toxins (terpenes) limited intake of sagebrush. In the second part of our study, lambs experienced with sagebrush were fed 250 g/hd/day of barley, and nutritional status was varied by offering alfalfa pellets at 33% or 80% of ad libitum (1.2 and 2.7 times maintenance, respectively) to determine if dietary energy levels affected intake of sagebrush. Each day lambs received a 50/50 sagebrush/barley supplement ad libitum for 1 hour. Lambs fed at 33% of ad libitum consumed more of the sagebrush/barley supplement than lambs fed at 80% of ad libitum. Thus, additional energy did not enable lambs to consume more sagebrush. In the last trial, lambs in both treatments were fed a basal ration of alfalfa pellets at 50% of ad libitum. Each morning for 1 hour, lambs were offered macronutrient supplements containing either 50% barley/50% sagebrush (high energy) or 25% barley/25% soybean meal/50% sagebrush (high energy and protein). Lambs consumed the same amount of sagebrush regardless of supplement. Thus, supplemental protein did not improve sagebrush consumption. We conclude lambs readily ingested a high-energy ration containing sagebrush, regardless of exposure early in life, suggesting toxins, not flavor, control intake of sagebrush. Further, supplementing lambs with energy or protein failed to improve intake of sagebrush, which suggests these macronutrients did not enhance detoxification of sagebrush.

Key Words: ***Artemisia tridentata*, sheep, toxins, intake, terpenes, diets**

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Resumen

Investigamos como la experiencia adquirida a temprana edad y el contenido de micronutrientes de la dieta influye en le consumo de "Mountain big sagebrush" (*Artemisa tridentata* Nutt. *vayesana* (Rydb.) Beetle) por ovinos. En la primer parte de nuestro estudio, corderos de 2 meses de edad se expusieron como grupo durante 2 meses a una ración de 70% cebada – 30% soya (300 g/cabeza/día) que contenía cantidades crecientes de "sagebrush" (1 a 20%). Los corderos del tratamiento control recibieron grano sin "sagebrush". Todos los corderos tenían libre acceso a heno y pelets de alfalfa. Cuando los corderos fueron evaluados a los 6 meses de edad. la exposición previa no tuvo efecto en el consumo de "sagebrush" después de los primeros 4 días del ensayo. Cuando el "Sagebrush" constituyó el 20% de la ración alfalfa/cebada, los corderos comieron fácilmente la ración de "Sagebrush", aun cuando se ofrecieron alternativas nutritivas, lo que indica que el sabor del "Sagebrush" no evita que los corderos se alimenten. El aumento de la cantidad de "Sagebrush" en la ración de 50% a 75% resultó en que los corderos comieron menos de la ración alfalfa/cebada, pero el consumo diario de "Sagebrush" permaneció constante hasta el cuarto día del estudio, presumiblemente porque las toxinas (terpenos), limitaron el consumo de "Sagebrush". En la segunda parte de nuestro estudio, los corderos que experimentaron con "Sagebrush" fueron alimentados con 250 g/cabeza/día de cebada, y el estado nutricional se varió ofreciendo pelets de alfalfa a un 33% o 80% del consumo libre (1.2 y 2.7 veces el mantenimiento respectivamente) para determinar si los niveles de energía dietaria afectaron el consumo de "Sagebrush". Cada día los corderos recibieron, a libre acceso durante una hora, un suplemento de 50/50 de "Sagebrush"/cebada. Los corderos alimentados con un 33% del consumo libre comieron mas del suplemento "Sagebrush/"cebada que los corderos alimentados al 80% del consumo libre. Así, la energía adicional no induce a los corderos a comer mas "Sagebrush". En el ultimo ensayo, los corderos en ambos tratamientos se alimentaron con una ración basal de pelets de alfalfa al 50% del consumo libre. Cada mañana, durante una hora. se les ofreció a los corderos suplementos de micronutrientes conteniendo 50% cebada / 50% "Sagebrush" (alta energía) o 25% cebada / 25% soya / 50% "Sagebrush" (alta energía y proteína). Los corderos consumieron la misma cantidad de "Sagebrush " independientemente del suplemento. Como resultado, la suplementación protéica no mejoro el consumo de "Sagebrush". Concluimos que los corderos consumieron fácilmente una ración alta en energía que contenia "Sagebrush, esto sin importar la exposición al "sagebrush" al que se sometieron a la edad temprana, sugiriendo que las toxinas, y no el sabor, controlan el consumo de "sagebrush. Además, el suplementar los corderos con energía y proteína fracasó en mejorar el consumo de "sagebrush", lo que sugiere que estos micronutrientes no aumentan la detoxificacion de ‘sagebrush"

Sagebrush (*Artemisia tridentata* ssp.) is a dominant species on millions of hectares of rangeland in the western United States. As a forage, it generally is not preferred by either sheep or cattle, especially during the growing season. Low use of sagebrush is often attributed to its monoterpenoid content (Yabann et al. 1986). Terpenoids depress in vitro digestion of sagebrush (Striby et al. 1987) and wethers fed grass/sagebrush diets exhibit marked depression in in vivo digestibility (Ngugi et al. 1995). Sagebrush can also be lethal to sheep (Johnson et al. 1976).

Exposure to sagebrush early in life may increase preference for sagebrush. Sheep with experience eating sagebrush consume more of the shrub than inexperienced sheep when alternative forages are lacking (Narjisse 1981). The degree to which exposure can increase a food's acceptability depends on the food's toxicological and nutritional properties. It is unlikely that herbivores can ever be conditioned to consume large amounts of foods high in toxins (Distel and Provenza 1991) because toxins set a limit on the amount of nutritious foods herbivores can ingest (Wang and Provenza 1997). On the other hand, exposure early in life can enhance preference for foods that are low (Distel and Provenza 1991) or high (Villalba and Provenza 1997a) in macronutrients, provided foods are not toxic.

An animal's nutritional state may also affect its ability to consume plants such as sagebrush that contain toxins (terpenes). Toxins are absorbed, biotransformed and metabolized by mammals to form organic acids that must be buffered and excreted from the body (Foley et al. 1995, McArthur et al. 1991). Illius and Jessop (1995) propose detoxification requires additional expenditures of amino acids and glucose to conjugate with toxins and maintain an animal's acid-base balance. Thus, a diet low in energy and protein may provide inadequate levels of substrate for terpene detoxification and limit the amount of sagebrush animals can eat.

Our objectives were to investigate how experience early in life and macronutrient content of the diet influenced intake of sagebrush by sheep. In the first study, we hypothesized lambs exposed to sagebrush early in life would have a higher preference for sagebrush later in life than lambs without exposure to sagebrush. In the second experiment, we speculated lambs consuming more macronutrients would have more nutrients available to detoxify terpenes and would consume more sagebrush than lambs on a poorer nutritional plane.

Materials and Methods

Sagebrush

We conducted 5 trials. Sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle) used in Trials 1, 2 and 3 was vegetative growth with a maximum twig size of 3.5 mm and was hand-harvested from 22 March to 15 April 1996 approximately one-half mile southeast of Paradise, Utah. Sagebrush was placed in the freezer within 2 hours of collection; several days later the frozen sagebrush was passed through a garden chipper-shredder (chipped to 1–2 cm lengths) and immediately returned to the freezer until thawed and fed. Sagebrush contained about 50% moisture. Sagebrush used in Trials 4 and 5 was vegetative and reproductive growth with a maximum twig size of 3.5 mm, collected during September at the Green Canyon Ecology Center, North Logan, Utah. It was hand-harvested each morning and immediately passed through a garden chipper-shredder, mixed with ground food and fed fresh.

Sheep

Lambs used in Trials 1, 2, and 3 were orphans (crossbred Suffolk), reared on milk replacer until 4 weeks of age. At weaning they were offered free choice a soybean meal/corn/barley ration, alfalfa hay and pellets. When lambs were 2-months-old they were weighed and randomly assigned (by weight) to 2 treatments and placed in 2 separate pens. For 2 months, half of the lambs (n=12) received sagebrush in their grain ration (70% barley, 30% soybean meal, 300 g/hd/day of the sagebrush/barley/soybean meal ration). The amount of sagebrush in the ration was initially 1% and was increased 1% every 5 days until it reached 4%, then increased 4% every 5 days until it reached 20%; the amount of sagebrush in the ration remained at 20% for 25 days. The other group of lambs (n=12) received the same foods without sagebrush. In addition to the grain ration, lambs also had access to alfalfa pellets and alfalfa hay ad libitum. Following the 60-day exposure, all lambs grazed a common grass pasture for 2 months. When lambs were 6-months-old, they were placed in individual pens so we could measure intake of sagebrush. Throughout the trials, lambs had access to trace mineralized salt blocks and water ad libitum.

Lambs used in Trials 4 and 5 were 3-mo-old wethers (white-faced commercial crossbred lambs). They were reared on alfalfa hay and pellets and weaned at 60 days of age. Lambs were placed in individual pens prior to the onset of the trials. They were exposed to increasing levels of sagebrush (10% to 50%) mixed with ground alfalfa for 1 hour each day for 30 days. They had access to water and mineral blocks ad libitum during conditioning and trials.

Exposure early in life
Trial 1

The objective of Trial 1 was to determine if lambs exposed to sagebrush early in life had a higher preference for a sagebrush ration than control lambs (naive to sagebrush). In this trial, the sagebrush ration contained 15% more energy than the alternative ration (2.3 vs. 2.0 Mcal ME/kg dry matter basis (dmb)(NRC 1985)). Each morning at 0900 hours lambs were offered a choice between a mixture of 50% ground alfalfa/30% ground barley/20% ground sagebrush and 100% ground alfalfa. Food refusals were collected and weighed at the end of an hour and intake calculated on an as-fed basis. Lambs had access to alfalfa pellets ad libitum until 1700 hours, when food boxes were removed and emptied. The trial lasted 5 days. Lambs received 200 g of each food on day 1, 250 g of each food on day 2, and they had ad libitum access to each food on days 3–5. On days 1 and 2 of the trial, food boxes were removed before the end of the hour, if lambs consumed all of 1 of the 2 foods offered.

Trial 2

The objective of Trial 2 was to determine if lambs with early exposure to sagebrush would consume more sagebrush than control lambs when the 2 rations offered had similar energy contents (2.3 Mcal ME/kg dmb (NRC 1985)). In other words, would lambs continue to eat the sagebrush ration if it no longer contained more energy than the alternative ration? Each morning at 0900 hours lambs were offered a choice of a mixture of 70% ground alfalfa/30% ground barley and a mixture of 50% ground alfalfa/30% ground barley/20% ground sagebrush for 1 hour. During the trial, foods were offered ad libitum. Food refusals were collected and weighed at the end of the hour and intake calculated on an as-fed basis. Lambs then received alfalfa pellets ad libitum until 1700 hours when food boxes were removed and emptied. The trial lasted 4 days.

In Trials 1 and 2 intake was calculated on a dry matter basis and expressed as percent sagebrush-ration in the diet. When the percent of sagebrush-ration in the diet was above 50% it was preferred and below 50% it was avoided.

Trial 3

The objective of Trial 3 was to determine if lambs exposed to sagebrush early in life consumed more sagebrush than lambs naive to sagebrush when no alternative food was available. Each morning at 0900 hours lambs had ad libitum access to a mixture of 50% sagebrush/50% ground barley for 1 hour. Food refusals were collected and weighed at the end of 1 hour and intake calculated on an as-fed basis. Lambs then received alfalfa pellets ad libitum until 1700 hours when food boxes were removed and emptied. The trial lasted 4 days. Finally, sagebrush concentration was increased to 75% and lambs had ad libitum access to the ration for 1 hour/day for 2 days more.

Nutritional state

Trial 4

The objective of Trial 4 was to determine if lambs' macronutrient status affected sagebrush consumption. Lambs (n=12/treatment) were offered a basal ration of 250 g of barley, and nutritional status was varied by offering alfalfa pellets at either 33% or 80% of ad libitum intake (1.2 and 2.7 times NE_m, respectively). Levels of intake (33% and 80% of ad libitum) were chosen so we could compare our results to those of Wang and Provenza (1996). To determine ad libitum intake, lambs were offered 250 g of ground barley each morning followed by alfalfa pellets for 24 hour/day for 4 days and intake was recorded each day. Barley was fed prior to offering alfalfa pellets because a barley/sagebrush ration was to be fed to lambs during the subsequent trial, and we estimated lambs would consume about 250 g of a 50/50 sagebrush/barley ration in 1 hour based on earlier feeding trials. Lambs were ranked by level of intake and assigned to the 2 treatments alternatively from highest to lowest intake. Lambs were fed treatment rations for 2 days before the onset of the trial and throughout the 5-day trial. Each morning during the trial, lambs were offered a 50/50 mix of ground barley and sagebrush (2.6 Mcal ME/kg; 12% CP dmb (NRC 1985)) ad libitum from 0800 to 0900 hours. On days when lambs ate less than 250 g of the sagebrush/grain mix, we provided additional barley to ensure that all lambs received the same amount of macronutrients from their supplement each day. Lambs then received alfalfa pellets.

Trial 5

The objective of Trial 5 was to determine if lambs consuming adequate levels of protein for maintenance and growth consumed more sagebrush if they were offered additional dietary protein. All lambs were fed alfalfa pellets at 50% ad libitum prior to (2 days) and during (5 days) the trial. Lambs received either a 50/50 mixture of barley and sagebrush (2.6 Mcal ME/kg and 12% CP dmb (NRC 1985)), or a 25/25/50 mixture of soybean meal, barley and sagebrush (2.7 Mcal ME/kg and 24% CP dmb (NRC 1985)). Each morning lambs received the sagebrush/concentrate supplement ad libitum for 1 hour. Lambs then received alfalfa pellets. Assignment to treatments in Trial 5 was such that lambs from different treatments in Trial 4 occurred equally in both treatments in Trial 5.

Statistical analyses

To test if exposure early in life affected intake of sagebrush in Trials 1, 2 and 3, we used a repeated measures analysis of variance with 2 treatments (early-exposure to sagebrush and control); lambs (n=12) nested within treatments was the error term to test differences between treatments. Day was the repeated measure. Several additional analyses of variance were also conducted; for control lambs in Trial 1 and all lambs in Trial 2, we tested if intake of the ration with sagebrush differed from intake of the ration without sagebrush. There were 2 treatments (sagebrush vs. no sagebrush) and lambs crossed with treatments was the error term. Day was the repeated measure. For Trial 3, two additional analyses were run to test the effect of increasing the proportion of sagebrush in the ration on intake of the sagebrush/barley ration and on sagebrush alone. Data from days 1 and 2 of the trial were omitted from these analyses so that we had an equal number of days when sagebrush was fed as 50% and 75% of the ration (2 days at each level). In both analyses day (n=4, 2 days at 50% and 2 days at 75% sagebrush) was the treatment and lambs (n=24) crossed with day was the error term to test for differences between days. In Trials 4 and 5, the repeated measure analysis of variance had 2 treatments (Trial 4–33% and 80% ad libitum; Trial 5 –soybean meal and no soybean meal) and lambs nested within treatments was the error term to test differences between treatment means. Day was the repeated measure. For all analyses, when F-ratios for main effects and interactions were significant ($P<0.05$), multiple mean comparisons using LSD were used to test differences among treatment means.

Results

Exposure early in life

During Trial 1, lambs with early exposure to sagebrush and control lambs were offered 2 rations, one with and the other without sagebrush (the sagebrush ration contained 15% more energy). Lambs with early exposure to sagebrush had a higher preference for the sagebrush/barley/alfalfa ration compared with control lambs, but the differences between treatments persisted only for the first 4 days of the trial (trt x day interaction $P<0.001$; Fig. 1). Lambs with early exposure to sagebrush consumed the same amount of each ration regardless of sagebrush content (144 g/hd/day for both rations, SEM=12, P=.96).

During Trial 2, when lambs were offered 2 rations equal in energy, 1 with sagebrush and 1 without sagebrush, lambs did not differ in their preference for the sagebrush ration (45% control vs 42% early exposure, SEM=2.2, P=0.41). Regardless of prior experience, lambs preferred the ration without sagebrush to the ration with sagebrush (207 g vs. 153 g, respectively, SEM=7.0, $P<0.001$).

During Trial 3, when lambs were offered only 1 ration (either 50/50 or 75/25 sagebrush/barley), lambs with early exposure to sagebrush and control lambs

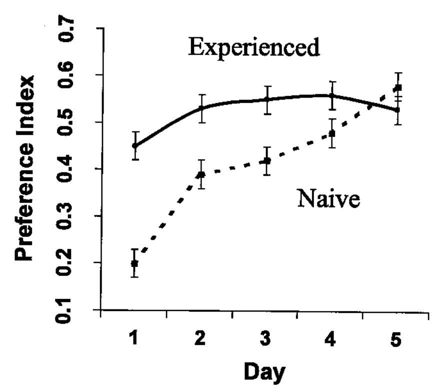

Fig. 1. Percent of a 20/30/50 sagebrush/barley/alfalfa ration in the total diet consumed by lambs with and without prior exposure to sagebrush. The alternative food offered during Trial 1 was 100% ground alfalfa. Bars represent standard errors of the mean. $LSD_{.05} = 6.1$.

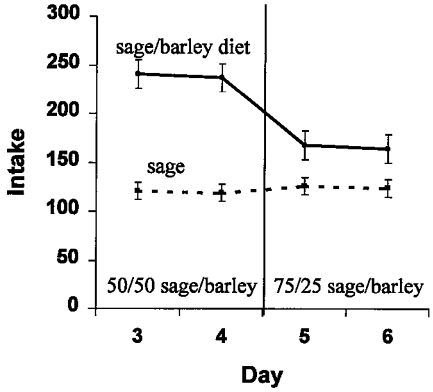

Fig. 2. Intake by all lambs fed a 50/50 sagebrush/barley ration (days 3 and 4) and a 75/25 sagebrush/barley ration (days 5 and 6). Solid line is intake of the sage/barley rations; dashed line is intake of sagebrush in those rations. Comparisons between means are made across days. Bars represent standard errors of the mean. $LSD_{.05}$ = 29 for the sagebrush/barley diets.

ingested similar amounts of sagebrush (126 g control vs. 117 g early exposure, SEM = 11.0, P=0.57). When the amount of sagebrush in the sagebrush/barley ration was increased from 50% to 75%, lambs ingested less of the 75% sagebrush/25% barley ration than the 50/50 ration, but total daily sagebrush intake remained constant throughout the 4-day trial (Fig. 2).

Individual lambs varied in their consumption of sagebrush. Some lambs ingested as little as 60 g/hour, whereas others consistently ate as much as 180 g/hour (SEM=8.9).

Nutritional state

In Trial 4, lambs that received a basal ration of 33% ad libitum consumed more of the sagebrush/barley ration than lambs that received 80% of ad libitum intake (205 g vs. 151 g respectively; P=0.056). The difference became more pronounced as the trial progressed (trt x day interaction P=0.008; Fig. 3). In Trial 5, lambs that received the soybean meal/barley/sagebrush ration and lambs that received the barley/sagebrush ration consumed similar amounts of the grain/sagebrush mixtures throughout the 5-day trial (soybean meal= 251 g; no soybean meal=256 g; SEM=21.5, P=0.86).

Discussion

Exposure early in life

Lambs with prior exposure to sagebrush did not eat more sagebrush than control lambs except during the first 4 days of Trial 1. The gradual increase in intake of the sagebrush ration by control lambs is comparable to the intake pattern of lambs introduced to any (non-toxic nutritious) novel food or flavor (Provenza et al. 1995). In Trial 2, lambs ate sagebrush readily regardless of prior exposure, even when a nutritious alternative was available. In other studies, experience with sagebrush did not increase sagebrush intake by mature sheep (Narjisse 1981) or goats (Richman et al. 1994) when alternative forages were available. In Trial 3, prior exposure continued to have no effect on intake when a sagebrush/barley ration was the only food available. Narjisse (1981) observed that sheep experienced with sagebrush only consumed more sagebrush than naive sheep when alternative foods were limited. However, Pritz et al. (1997) observed a slight decrease in intake of redberry juniper by goats given juniper essential oils early in life.

During Trial 3, lambs in both groups consumed more of the barley/sagebrush ration containing 50% sagebrush than the ration containing 75% sagebrush, but they ate the same amount of sagebrush regardless of the amount of barley mixed with sagebrush. These findings suggest toxic compounds in sagebrush limited the amount of sagebrush lambs could consume. Sagebrush contains a diverse array of terpenes (Kelsey et al. 1982, Bray et al. 1991) that are potentially toxic (Johnson et al. 1976). Thus, we hypothesize terpenes set a limit on the amount of food lambs consumed (i.e., toxin satiation). This hypothesis is consistent with the observation that lambs eating sagebrush/grass diets limited terpenoid ingestion to 170 mg/kg metabolic weight/day (Ngugi et al. 1995) and that toxins can limit the amount of foods lambs can ingest (Launchbaugh et al. 1993, Wang and Provenza 1997).

In our study, experienced lambs did not eat more sagebrush than inexperienced lambs, but the reverse was true in other studies with goats (Distel and Provenza 1991) and sheep (Distel et al. 1996). The nutrient and toxin content of the food likely determines whether exposure early in life will increase preference. If a food is low in macronutrients, but not toxic, then exposure early in life can increase preference by causing various neurological, morphological and physiological changes in animals (Distel et al. 1994, 1996). On the other hand, if a food is toxic, no amount of exposure is likely to increase intake beyond the level of toxin satiation (Distel and Provenza 1991), unless exposure enhances detoxification. Exposure can decrease the lethal effects of a toxin (Cheeke and Shull 1985, Johnson et al. 1976) by improving a ruminant's ability to detoxify a compound (Frutos et al. 1999), but it is not clear whether these adaptations always lead to an increase in intake of a toxic food. For example, Frutos et al. (1999) reported that goats adapted to oxalate, detoxified oxalate to a greater extent than non-adapted goats, but adapted goats did not eat more of an oxalate-containing diet than non-adapted goats. Our data suggest that toxins (terpenes) limit intake of sagebrush by lambs and early exposure is not likely to enhance sagebrush consumption beyond the limit of toxin satiation.

Our data suggest that the flavor of sagebrush had little effect on the consumption of sagebrush by lambs. Experienced lambs in Trial 1 ate the same amount of each ration regardless of sagebrush content. When the ration containing sagebrush and the alternative ration had similar energy contents (Trial 2), both groups of lambs showed only a modest preference for the diet without sagebrush. Evidently, the flavor of sagebrush did not prevent lambs from eating the ration containing sagebrush because lambs consumed both rations instead of solely eating the ration without sagebrush.

Nutritional state

Illius and Jessop (1995) hypothesize that animals limit consumption of toxins when nutritional stress reduces their tolerance to allelochemicals. According to their mathematical model, animals that consume energy at twice maintenance should be able to

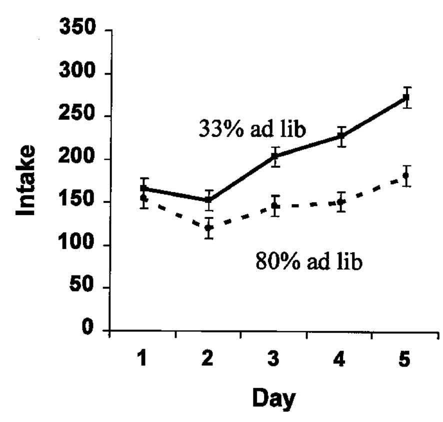

Fig. 3. Consumption of a 50/50 sagebrush/barley ration by lambs maintained at either 33% or 80% ad libitum. Bars represent standard errors of the mean. $LSD_{.05}$ = 23.

tolerate the maximum concentration of allelochemicals.

Wang and Provenza (1996) reported energy affected the amount of lithium chloride (LiCl) lambs could ingest. Lambs fed a barley-based ration at 1/3 ad libitum ingested less LiCl than lambs fed at 2/3 ad libitum or ad libitum. They speculated lambs on restricted rations may limit intake of LiCl because it causes hypoglycemia, which is attenuated by energy in supplemental barley. In contrast, lambs in our study (Trial 4) fed at 33% ad libitum (1.2 times maintenance) ate more sagebrush than lambs fed at 80% ad libitum (2.7 times maintenance). Thus, our results are not consistent with the hypothesis animals consuming more energy in their basal ration ingest more toxins, evidently because lambs fed at 33% ad libitum had a greater need for nutrients that was not offset by aversive effects of terpenes. Our results differ from those of Wang and Provenza (1996), perhaps because LiCl and terpenes have different physiological effects. Lambs in their study also could consume foods with or without LiCl, whereas in our study lambs could either eat a supplement containing sagebrush or not eat.

The source of the energy and when it is ingested in relation to sagebrush consumption may also have an impact on intake of sagebrush. Banner et al. (1999) found that lambs fed barley immediately prior to eating sagebrush ate more sagebrush than lambs fed no barley. In our study, barley was mixed with sagebrush so lambs in both groups ate a readily fermentable source of energy with sagebrush. Banner et al. (1999) also found, as we did, that lambs fed an adequate basal ration - and a high-energy supplement - did not eat nearly as much sagebrush as food-deprived lambs fed the same high-energy supplement. Collectively, these data suggest that intake of sagebrush is likely to be highest when lambs are concurrently supplemented with a readily available source of energy and when lambs are somewhat food deprived.

The deterrent nature of allelochemicals may also be caused by the body's increased demand for nitrogen and amino acids during allelochemical detoxification; thus, increasing protein ingestion may increase allelochemical consumption (Illius and Jessop 1995). All lambs in Trial 5 received adequate protein for maintenance and growth (181 g/day, the requirement is 185 g/day for a 40 kg lamb gaining 275 g/day (NRC 1985)) from their basal ration of alfalfa pellets. Lambs fed the barley/soybean meal/sagebrush ration consumed twice as much additional protein (42 g) from their supplement as lambs fed the barley/sagebrush ration (21 g). Illius and Jessop (1995) predict animals may consume a food high in toxins if it provides sufficient nutrients for detoxification. They further speculate when animals consume protein over their requirement for net protein synthesis, the excess amino acids can be used for synthesis of glucose, which can be used for conjugation with toxins. In our study, increasing the amount of dietary protein in the supplement did not affect the amount of sagebrush consumed by lambs.

Foley et al. (1995) propose ingestion of forages high in secondary metabolites leads to increases in acidemia when their capacity to biotransform and eliminate secondary metabolites is exceeded. They speculate when this system is exceeded, postingestive feedback causes mammals to decrease intake of forages high in secondary metabolites. To date no feedback signal has been found from the biotransformation system that regulates intake. Another possibility is that the toxins in sagebrush stimulate the emetic system after the onset of eating and quickly cause a decrease in preference for sagebrush (Provenza 1995). Such an immediate response to toxins may be necessary to prevent animals from overingesting toxins (Provenza et al. 1994).

Sagebrush may also limit intake because terpenes are toxic to rumen microbes (Nagy et al. 1964, Oh et al. 1968). Animals forced to eat a ration of 30% sagebrush show marked depression in in vivo dry matter digestibility (Ngugi et al. 1995). Reduced microbial activity decreases digestibility of macronutrients and byproducts of fermentation (i.e., volatile fatty acids), all of which affect food preferences of sheep (Villalba and Provenza 1996, 1997a, 1997b, 1997c).

Conclusions

Some species (as well as subspecies and ecotypes) of sagebrush are more palatable to than others to sheep and mule deer, evidently because of differences in concentrations of terpenes (Welch et al. 1983, 1987, Personius et al. 1987). Neither exposure early in life, nor supplemental energy or protein caused a greater intake of sagebrush by lambs. The flavor of sagebrush did not prevent lambs from eating rations that contained sagebrush. Sagebrush intake was highly variable for individual lambs. Terpene levels in sagebrush vary seasonally (Kelsey et al. 1982), and sheep are most likely to use sagebrush when terpene concentrations are low and alternative forages are scarce (e.g. winter; Gade and Provenza 1986). Increasing use of sagebrush by livestock beyond the level of toxin satiation is unlikely unless the toxic compounds in sagebrush can be rendered inactive.

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Livestock grazing effects on forage quality of elk winter range

PATRICK E. CLARK, WILLIAM C. KRUEGER, LARRY D. BRYANT, AND DAVID R. THOMAS

Authors are range scientist, USDA Agricultural Research Service, 800 Park Blvd., Plaza IV, Suite 105, Boise, Ida. 83712; professor, Department of Rangeland Resources, Oregon State University, Corvallis, Ore. 97331; range ecologist, USDA Forest Service, Washington, D.C. 20250; and professor, Department of Statistics,Oregon State University, Corvallis, Ore. 97331. At the time of the research, Clark was graduate research assistant, Department of Rangeland Resources, Oregon State University, Corvallis, Ore. 97331 and Bryant was wildlife biologist, USDA Forest Service, Pacific Northwest Research Station, La Grande, Ore. 97850.

Abstract

Carefully-managed livestock grazing has been offered as a tool to improve the forage quality of graminoids on big game winter range. Formal testing of this theory has thus far been done using hand clippers rather than livestock grazing. We report winter standing reproductive culm, crude protein, in vitro dry matter digestibility, and standing crop responses of bluebunch wheatgrass (*Agropyron spicatum* [Pursh] Scribn. & Smith), Idaho fescue (*Festuca idahoensis* Elmer), and elk sedge (*Carex geyeri* Boott) to late-spring domestic sheep grazing. The study was conducted in 1993 and 1994 on a big game winter range in the Blue Mountains of northeastern Oregon. Sheep grazing and exclusion treatments were applied to 20-ha plots at 3 sites on the study area. Targeted utilization for grazed plots was 50% graminoid standing crop removal during the boot stage of bluebunch wheatgrass. Grazing did not influence the number of standing reproductive culms per plant in bluebunch wheatgrass. Crude protein and in vitro dry matter digestibility of bluebunch wheatgrass in grazed plots increased by 1.0 and 4.3 percentage points, respectively, over ungrazed plots. Grazing reduced the standing crop of bluebunch wheatgrass by 116.9 kg ha^{-1} DM. Standing Idaho fescue reproductive culms decreased by 0.7 culms plant^{-1} under grazing. Crude protein of Idaho fescue in grazed plots was 1.3 percentage points greater than in ungrazed plots. Crude protein and in vitro dry matter digestibility responses of elk sedge were inconsistent between years and may be related to utilization or growth differences between years. The levels of forage quality improvement in bluebunch wheatgrass and Idaho fescue obtained in this study could benefit the nutritional status of wintering Rocky Mountain elk (*Cervus elaphus nelsoni* Bailey). More research is needed regarding the effects of grazing on the winter forage quality of elk sedge.

Key Words: *Agropyron spicatum*, bluebunch wheatgrass, *Carex geyeri*, *Cervus elaphus*, elk sedge, *Festuca idahoensis*, forage conditioning, Idaho fescue, nutrition, phenology, reproductive culms.

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Two native perennial bunchgrasses, bluebunch wheatgrass (*Agropyron spicatum* [Pursh] Scribn. & Smith) and Idaho fescue (*Festuca idahoensis* Elmer) dominate the grasslands of big game winter ranges in northeastern Oregon. Anderson and Scherzinger (1975) suggested spring livestock grazing of bluebunch wheatgrass and Idaho fescue may enhance the forage quality and palatability of these bunchgrasses for wintering elk. On a state wildlife management area in northeastern Oregon, where livestock grazing had initially been prohibited, Anderson and Scherzinger (1975) reported wintering elk numbers had increased from 320 to 1,191 head during a 10-year period when a rest-rotation cattle grazing management system was used to condition forages. Other researchers have also witnessed increased winter elk use following cattle grazing treatments on bluebunch wheatgrass and Idaho fescue (Jourdonnais 1985, Jourdonnais and Bedunah 1990, Frisina and Morin 1991).

Anderson and Scherzinger (1975) hypothesized grazing bluebunch wheatgrass and Idaho fescue in the late spring would delay the phenological development of grazed plants and cause them to cure at a younger, more nutritious phenological stage providing higher quality forage than ungrazed plants. Late-spring grazing should also reduce reproductive culm densities of bunchgrasses (Anderson and Scherzinger 1975), and enhance their palatability (Murray 1984, Ganskopp et al. 1992). Clipping treatments have been used to test this hypothesis for bluebunch wheatgrass (Pitt 1986, Bryant 1993, Westenskow-Wall et al. 1994, Clark et al. 1998) but there are no data on the winter forage quality responses of bluebunch wheatgrass and Idaho fescue to late-spring livestock grazing. Elk sedge *(Carex geyeri* Boott), another prevalent forage in the region, often contributes substantially to the winter diet of elk (Skovlin and Vavra 1979, Sheehy 1987). The effects of spring defoliation on the forage quality of elk sedge have not been studied.

Our objective was to test the forage conditioning hypothesis of Anderson and Scherzinger (1975) by measuring the reproductive culm response of bluebunch wheatgrass and Idaho fescue and the winter forage quality and quantity responses of bluebunch wheatgrass, Idaho fescue, and elk sedge grazed by domestic sheep in the late spring.

Materials and Methods

Study Area

The 2,073 ha study area was located within the McCarty Spring Big Game Winter Range Management Area on the USDA-Forest Service McCarty Spring Sheep Allotment in the Blue Mountains of northeastern Oregon approximately 45 km southwest of La Grande. The area is typical of foothill rangelands occurring at the interface of the bunchgrass steppe vegetation of the Columbia Basin Geological Province and the forest vegetation of the Blue Mountain Geological Province (Franklin and Dryness 1973).

Several shallow, nearly-parallel drainages oriented in a northerly or northeasterly direction dissect the area forming a series of broad, gently sloping ridges. Elevation ranges from 1,170 m to 1,536 m. Vegetation on the open ridges is a bunchgrass grassland dominated by bluebunch wheatgrass, Idaho fescue, Sandberg bluegrass (*Poa sandbergii* Vasey), and western yarrow (*Achillea millefolium* L.) (See Hall 1973: GB-49-11). Vegetation in the shallow drainages is a mixed-conifer forest of ponderosa pine (*Pinus ponderosa* Dougl.), Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco.), and grand fir (*Abies grandis* [Douglas] Forbes) with a shrub layer of mallow ninebark (*Physocarpus malvaceus* [Greene] Kuntze), common snowberry (*Symphoricarpos albus* [L.] Blake), and oceanspray (*Holodiscus discolor* [Pursh] Maxim.) and a herbaceous layer of elk sedge and pinegrass (*Calamagrostis rubescens* Buckl.) (See Hall 1973: CD-S7-11). Vegetation in the ecotone between the ridgetop grasslands and forested drainages is a pine-bunchgrass savanna containing a ponderosa pine overstory and an understory of Idaho fescue, elk sedge, and bluebunch wheatgrass (see Hall 1973: CP-G1-12). Soils on the ridgetops and droughty exposures are shallow, extremely stony to very cobbly, loams and silt-loams of the Anatone-Bocker complex (Dysterhuis and High 1985, Bryant 1993). Soils on the mesic exposures are probably Klicker stony silt loam.

Mean annual temperature (1989-1995) at Starkey Experimental Forest and Range, less than 4 km from the study area, was 6.6°C (Unpubl. data, on file at USDA Forest Service, Forestry and Range Sciences Laboratory, La Grande, Oregon). Mean annual maximum (August) and minimum (December) temperatures (1989–1995) at Starkey Experimental Forest and Range were 25.4 and –7.2°C, respectively. Maximum, minimum, and mean annual precipitation (1986 to 1995) at Starkey Experimental Forest and Range were 72.0, 36.2, and 54.8 cm, respectively. Approximately 60% of the annual precipitation occurred between 1 December and 31 May as winter snow and spring rain. The amount and timing of late summer and fall rain is unpredictable, but it can promote additional growth in perennial grasses. Annual precipitation totals for 1993 and 1994 at Starkey Experimental Forest and Range were 56.6 cm and 54.4 cm, respectively (Fig. 1).

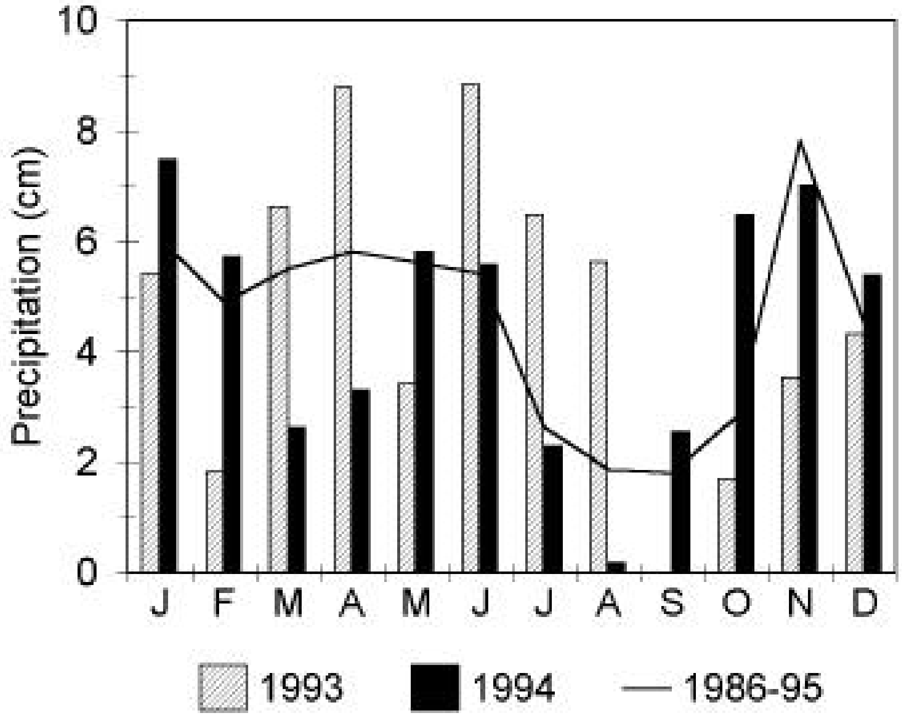

Fig. 1. Monthly precipitation at Starkey Experimental Forest and Range near La Grande, Ore. for 1993, 1994, and a 10-year average (1986 to 1995).

Light to moderate levels of sheep grazing has occurred on the study area from early June until early October since 1950. Prior to 1950 the area had received moderate to heavy cattle grazing. Typically, 300 to 400 elk winter on or near the study area (Unpub. data, on file at Oregon Department of Fish and Wildlife, Northeast Region, La Grande, Ore.).

Experimental Design

A split plot experimental design was used. Three blocks containing 2 main plots each were established along selected ridges and associated drainages within the study area. These 3 blocks represented 3 different locations within the study area; Tybow Canyon, McCarty Spring, and Cabbage Spring. Each main plot was 250 m by 800 m and oriented with its long axis parallel to the drainage. Elevation and aspect of main plot pairs were similar. Three plant communities, occupying roughly equal areas, occured in each main plot:

1) Bunchgrass grassland dominated by bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass (ridgetops and large openings on droughty exposures).
2) Pine-bunchgrass savanna consisting of a ponderosa pine overstory and an Idaho fescue/elk sedge/bluebunch wheatgrass understory (mid-slope grassland-forest ecotone).
3) Mixed-conifer forest with a ponderosa pine/Douglas-fir/grand fir overstory, a ninebark/common snowberry/oceanspray shrub layer, and an elk sedge/pinegrass herbaceous layer (drainage bottoms and lower slopes).

Plant communities were treated as subplots within each main plot. The savanna and forest comminities were further divided into areas with tree canopy (i.e., areas under trees greater than 25 cm d.b.h.) and areas without tree canopy (i.e., open areas or areas under trees of 25 cm d.b.h. or less).

Treatment Applications

Main plots within each block were randomly assigned to 1 of 2 treatments: (1) sheep grazing during the boot stage of bluebunch wheatgrass, or (2) exclusion of sheep grazing. Sheep grazing, at a stocking rate of 52 ewe-lamb pairs ha^{-1} , was applied for either a maximum of 3 days main $plot^{-1}$ or until approximately 50% utilization was reached on at least 1 of the 3 targeted forages. Electric fences kept sheep in the plots during treatment application and excluded them after treatment. Big game had open access to the plots. To simulate a rest-rotation grazing system, treatments within each block was reversed during the second year (1994).

In the first year of grazing, sheep accidently entered our exclusion main plot in Block 2 (McCarty Spring). The resulting forage use precluded its service as a control, consequently, Block 2 was dropped from the study.

Logistical problems prevented us from using sheep familiar with the study area in 1993. The ewe-lamb band used in 1993 was too agitated to graze effectively in the plots, and prevented us from reaching 50% utilization on any of the targeted forages within the 3-day limit. The ewe-lamb band used in 1994 was familiar with the study area, actively foraged in the plots, and our 50% utilization level was easily accomplished.

During late spring 1993, slight utilization of bluebunch wheatgrass (0.9 to 1.6%), Idaho fescue (0.1 to 0.9%), and elk sedge (1.8 to 3.1%) by elk occurred in the grazing exclusion main plots of Block 1 and Block 3. We assumed this slight utilization would not confound the statistical analyses of treatment effects.

Sampling Protocol

Forage utilization and the number of standing reproductive culms per plant were assessed after treatment. Five, 150-m pace transects were randomly located in each plant community of each plot. Six sampling points were located at 25 m intervals along each transect. A 0.5-m^2 circular frame was positioned at each point, and forage utilization was estimated using an ocular estimate method (Pechanec and Pickford 1937). Within the same frame, the number of standing reproductive culms per species were counted and the total for each species was divided by the respective number of plants found in the frame. In the grassland community, 30 frames were sampled for utilization and number of reproductive culms in bluebunch wheatgrass and Idaho fescue. In the savanna, utilization of bluebunch wheatgrass, Idaho fescue, and elk sedge, and number of reproductive culms in bluebunch wheatgrass and Idaho fescue were estimated in 60 frames, with 30 frames under tree canopy and 30 frames in openings. In the forest community, 30 frames under tree canopy and 30 frames in openings were read for utilization of elk sedge. Transect means were treated as subsamples. Plot means for each species/community/canopy combination were treated as samples.

In early November, the number of reproductive culms per plant for bluebunch wheatgrass and Idaho fescue in the grassland and savanna types were resampled along 5 new transects per type. Forage samples were collected at 2 randomly selected points along transects in all 3 types. All the bluebunch wheatgrass, Idaho fescue or elk sedge within the 0.5-m^2 frame were clipped to a 2.5 cm stubble height and sorted by species. Forage samples were also collected in early March of both years along new transects.

Forages were oven dried at 50°C, ground to pass a 1-mm screen, and stored in airtight bags. Samples were analyzed for percentage crude protein (CP) (AOAC 1980), percentage in vitro dry matter digestibility (IVDMD) (Tilley and Terry 1963), and kg ha^{-1} of dry matter standing crop.

Statistical Analysis

Tests for treatment, period, canopy, sequence, and year effects on number of reproductive culms per plant, CP, IVDMD, and standing crop were conducted with General Linear Model (GLM) procedures (SAS 1988). Because treatments were reversed in 1994, a cross-over analysis was used to examine sequence effect. The sequence variable describes the order of treatment application. Sequence 1 represents plots ungrazed in 1993 and grazed in 1994 and Sequence 2 represents plots grazed in 1993 and ungrazed in 1994. Treatment, canopy, period, and sequence were analyzed as fixed effects, and year was analyzed as a random effect. Interactions between fixed effects and between fixed effects and year were analyzed and tested. Separate reduced models were developed for each species/plant community combination by systematically dropping non-significant, fixed-random effect interactions from the full models. Where significant effects were detected, Fisher's Least Significant Difference (LSD) procedure was used for mean separations (SAS 1988). All differences reported are significant at $P<0.05$ unless stated otherwise.

Results

Bluebunch Wheatgrass-Grassland Community

Utilization of bluebunch wheatgrass in the grassland community was affected by treatment, sequence, and year (Table 1). Grazed plots received 38.9% utilization while ungrazed plots received 0.8% utilization. Utilization under Sequence 1 (i.e., ungrazed in 1993 and grazed in 1994) ($\bar{x}$=28.8%) was greater than under Sequence 2 (i.e., grazed in 1993 and ungrazed in 1994) ($\bar{x}$=10.9), and utilization was higher in 1994 ($\bar{x}$=28.0%) than in 1993 ($\bar{x}$=11.7%).

Number of standing reproductive culms per bluebunch wheatgrass plant was not

Table 1. Main effects and interactions, with their respective p-values, for response variables of bluebunch wheatgrass occurring in bunchgrass grasslands on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Number of Reproductive Culms per Plant	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
		(P-Values)				
T[1]	1	**0.0094**[2]	0.1641	**0.0097**	**0.0021**	**0.0099**
P	1	NA	**0.0438**	0.0714	0.1381	0.7727
T*P	1	NA	0.2535	0.8592	0.9691	0.5840
S	1	**0.0407**	0.4942	0.3059	**0.0426**	0.0755
S*P	1	NA	0.8379	0.3508	0.2593	0.9325
Y	1	**0.0485**	**0.0184**	**0.0018**	**0.0008**	0.8332

[1]T = Treatment (grazed or ungrazed), P = Sampling period (June or November for reproductive culms and November or March for forage quality and quantity variables), S = Sequence or order of treatment application on a plot (ungrazed/grazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face.

Table 2. Main effects and interactions, with their respective p-values, for response variables of bluebunch wheatgrass occurring in grazed and ungrazed pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Number of Reproductive Culms per Plant	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
		(P-Values)				
T[1]	1	**0.0001**[2]	0.1271	**0.0001**	**0.0036**	0.4414
P	1	NA	0.0862	**0.0118**	0.1378	0.5957
C	1	0.0559	**0.0235**	0.0816	0.4666	**0.0002**
T*P	1	NA	0.7351	0.9855	0.2273	0.4848
T*C	1	**0.0453**	0.9121	0.2484	0.9838	0.5035
P*C	1	NA	0.4388	0.2775	**0.0242**	0.9120
T*P*C	1	NA	0.4629	0.5019	0.1450	0.7494
S	1	**0.0001**	0.8274	0.3571	0.7519	0.7217
S*P	1	NA	0.4699	0.8516	0.2457	0.6264
S*C	1	0.3303	0.7297	0.0809	0.4646	0.8967
S*P*C	1	NA	0.5110	0.7133	0.2397	0.8896
Y	1	**0.0001**	**0.0127**	**0.0019**	0.0944	**0.0053**

[1]T = Treatment (grazed or ungrazed), P = Sampling period (June or November for reproductive culms and November or March for forage quality and quantity variables), C = Canopy (present or absent), S = Sequence or order of treatment application on a plot (ungrazed/grazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face.

affected by grazing, however, significant sampling period and year effects were detected (Table 1). More reproductive culms were present in June ($\bar{x}$=3.7) than in November ($\bar{x}$=1.9), and more reproductive culms occured in 1993 ($\bar{x}$=3.9) than in 1994 ($\bar{x}$=1.6).

Crude protein of bluebunch wheatgrass was affected by treatment and year (Table 1). Crude protein was higher in grazed ($\bar{x}$=4.2%) than in ungrazed plots ($\bar{x}$=3.2%). Crude protein was also higher in 1994 ($\bar{x}$=4.4%) than in 1993 ($\bar{x}$=3.0%).

Significant treatment, sequence, and year effects were detected for IVDMD of bluebunch wheatgrass (Table 1). In vitro dry matter digestibility was greater in grazed ($\bar{x}$=42.2%) than in ungrazed plots ($\bar{x}$=37.9%). In vitro dry matter digestibility was higher under Sequence 1 ($\bar{x}$=41.2%) than under Sequence 2 ($\bar{x}$=38.9%), and IVDMD was greater in 1994 ($\bar{x}$=42.6%) than in 1993 ($\bar{x}$=37.5%).

Standing crop of bluebunch wheatgrass in the grassland community was affected by treatment (Table 1). Grazing reduced the standing crop ($\bar{x}$=135.0 kg ha^{-1} DM) relative to grazing exclusion ($\bar{x}$=251.9 kg ha^{-1} DM).

Bluebunch Wheatgrasss-Savanna Community

Significant treatment, sequence, year, and treatment by canopy effects were detected for utilization of bluebunch wheatgrass in the savanna community (Table 2 and 3). Canopy and year affected the number of reproductive culms per plant (Table 2). More reproductive culms were present in the openings ($\bar{x}$=1.3) than under the tree canopy ($\bar{x}$=0.5), and more culms occured in 1993 ($\bar{x}$=1.4) than in 1994($\bar{x}$=0.5).

Treatment, period, and year effects were detected for CP of bluebunch wheatgrass (Table 2). Grazing increased CP ($\bar{x}$=4.2%) relative to grazing exclusion ($\bar{x}$=3.3%). Crude protein increased between the November ($\bar{x}$=3.5%) and March sampling periods ($\bar{x}$=4.0%), and CP was higher in 1994 ($\bar{x}$=4.0%) than in 1993 ($\bar{x}$=3.4%). Treatment and the interaction of period by canopy affected IVDMD of bluebunch wheatgrass (Tables 2 and 4).

Table 3. Mean levels of utilization (percent plant weight) on bluebunch wheatgrass as affected by treatment, sequence, year, and the interaction of treatment and canopy presence in pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

	Treatment	Sequence		Year		Canopy	
		Ungrazed-Grazed	Grazed-Ungrazed	1993	1994	Absent	Present
	(%)						
Ungrazed	0.6a[1]	0.0	1.1	1.1	0.0	0.4a	0.7a
Grazed	26.8b	6.6	46.9	6.6	46.9	31.2b	22.3c
Mean	13.7	3.3a	24.0b	3.9a	23.4b	17.8	11.5

[1]Means for main effects or treatment by canopy interactions which share a common letter are not significantly different (P>0.05).

Canopy and year affected the standing crop of bluebunch wheatgrass (Table 2). More standing crop was present in the openings ($\bar{x}$=109.5 kg ha DM) than under the tree canopy ($\bar{x}$=38.1 kg ha^{-1} DM). Standing crop was greater in 1993 ($\bar{x}$=98.1 kg ha^{-1} DM) than in 1994 ($\bar{x}$=49.5 kg ha^{-1} DM).

Idaho Fescue-Grassland Community

Utilization of Idaho fescue by sheep in the grassland community was influenced by treatment, sequence, and year effects (Table 5). Idaho fescue in grazed plots received 31.5% utilization while 0.1% utilization occurred in ungrazed plots. Utilization was heavier under Sequence 1 ($\bar{x}$=26.3%) than under Sequence 2 ($\bar{x}$=5.2%), and utilization was greater in 1994 ($\bar{x}$=26.2%) than in 1993 ($\bar{x}$=5.3%).

Number of reproductive culms per Idaho fescue plant was not affected by grazing, however, a year effect was detected (Table 5). Number of reproductive culms per plant was higher in 1993 ($\bar{x}$=4.0) than in 1994 ($\bar{x}$=1.0)

Significant treatment, sequence, and year effects were detected for CP of Idaho fescue (Table 5). Idaho fescue in grazed plots was higher in CP ($\bar{x}$=6.2%) than in ungrazed plots ($\bar{x}$=4.9%). Crude protein was greater under Sequence 1 ($\bar{x}$=5.9%) than under Sequence 2 ($\bar{x}$=5.2%), and CP was higher in 1994 ($\bar{x}$=6.5%) than in 1993 ($\bar{x}$=4.6%).

In vitro dry matter digestibility of Idaho fescue was not affected by grazing but a period effect was detected (Table 5). In vitro dry matter digestibility declined between November ($\bar{x}$=47.1%) and March ($\bar{x}$=42.5%). The standing crop of Idaho

Table 4. Mean levels of in vitro dry matter digestibility for bluebunch wheatgrass as affected by grazing treatment and the interaction of sampling period and canopy presence in pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

	Period	Treatment		Canopy	
		Ungrazed	Grazed	Absent	Present
	– – – – – – – – – –	– – – – – – – –	(%)	– – – – – – – –	– – – – – – – –
Early	40.0	38.1	41.8	40.7a	39.3b
Late	38.8	38.0	39.6	37.5c	40.0a
Mean	39.4	38.1a[1]	40.7b	39.1	39.7

[1]Means for main effects or period by canopy interactions which share a common letter are not significantly different (P>0.05).

fescue in the grassland community was not affected by any of the variables measured (Table 5).

Idaho Fescue-Savanna Community

Treatment, sequence, and year also affected utilization of Idaho fescue in the savanna community (Table 6). Idaho fescue in grazed plots received 19.3% utilization while 0.4% utilization occurred in ungrazed plots. Utilization was heavier under Sequence 1 ($\bar{x}$=16.4%) than under Sequence 2 ($\bar{x}$=3.2%), and utilization was greater in 1994 ($\bar{x}$=16.1%) than in 1993 ($\bar{x}$=3.6%).

Treatment, period, and year effects influenced the number of reproductive culms per Idaho fescue plant (Table 6). Grazing ($\bar{x}$=1.6) reduced reproductive culms per plant relative to grazing exclusion ($\bar{x}$=2.3). Number of reproductive culms per plant declined between June ($\bar{x}$=2.4) and November ($\bar{x}$=1.5), and more reproductive culms occured in 1993 ($\bar{x}$=2.9) than in 1994 ($\bar{x}$=1.1).

Significant treatment, period, and year effects were detected for CP of Idaho fescue (Table 6). Grazing increased CP of Idaho fescue ($\bar{x}$=5.8%) relative to grazing exclusion ($\bar{x}$=4.8%). Crude protein increased between November ($\bar{x}$=5.0%) and March ($\bar{x}$=5.6%), and CP was higher in 1994 ($\bar{x}$=6.0%) than in 1993 ($\bar{x}$=4.6%).

Period also affected in vitro dry matter digestibility of Idaho fescue (Table 6). In vitro dry matter digestibility declined between November ($\bar{x}$=44.3%) and March ($\bar{x}$=41.8%).

A year effect was detected for the standing crop of Idaho fescue (Table 6). The standing crop was greater in 1993 ($\bar{x}$=136.2 kg ha^{-1} DM) than in 1994 ($\bar{x}$=101.9 kg ha^{-1} DM).

Elk Sedge-Savanna Community

Utilization of elk sedge in the savanna community was affected by treatment, canopy, sequence, year, and the interaction of treatment by canopy (Tables 7 and 8). Crude protein of elk sedge was influenced by canopy and sequence effect (Table 7). Crude protein was higher under the tree canopy ($\bar{x}$=5.3%) than in openings ($\bar{x}$=4.8%). Crude protein was greater under Sequence 2 ($\bar{x}$=5.2%) than under Sequence 1 ($\bar{x}$=4.9%).

Significant treatment, sequence, and year effects were detected for IVDMD of elk sedge (Table 7). Grazing produced an IVDMD response in elk sedge opposite of that in bluebunch wheatgrass. In vitro dry matter digestibility of elk sedge in ungrazed plots was higher ($\bar{x}$=53.7%) than in grazed plots ($\bar{x}$=51.4%). Elk sedge under Sequence 2 ($\bar{x}$=53.6%) was more digestibility than under Sequence 1 (x=51.5%), and IVDMD of elk sedge was greater in 1993 (x=53.7%) than in 1994 ($\bar{x}$=51.4%). The standing crop of elk sedge in the savanna community was not affected by any of the variables measured (Table 7).

Elk Sedge- Forest Community

Utilization of elk sedge in the forest community was affected by treatment, sequence, and year (Table 9). Elk sedge in grazed plots received 12.7% utilization while 1.3% utilization occurred ungrazed plots. Utilization was greater under Sequence 1 ($\bar{x}$=13.3%) than under Sequence 2 ($\bar{x}$=0.8%), and utilization was higher in 1994 ($\bar{x}$=11.9%) than in 1993 ($\bar{x}$=2.2%).

Treatment and sequence effects were detected for CP of elk sedge (Table 9). Grazing increased CP ($\bar{x}$=6.3%) relative to grazing exclusion ($\bar{x}$=5.8%). Crude protein was greater under Sequence 2 ($\bar{x}$=6.7%) than under Sequence 1 ($\bar{x}$=5.5%).

Period, sequence, and year affected IVDMD of elk sedge (Table 9). In vitro dry matter digestibility declined between the November ($\bar{x}$=55.0%) and March ($\bar{x}$=52.3%) sampling periods. In vitro dry matter digestibility was greater under Sequence 2 ($\bar{x}$=55.6%) than under Sequence 1 ($\bar{x}$=51.7%), and IVDMD was higher in 1993 ($\bar{x}$=54.6%) than in 1994 ($\bar{x}$=52.7%). A sequence by canopy interaction was detected for the standing crop of elk sedge in the forest community (Table 9 and 10).

Discussion

Forage Utilization

Sequence and year effects detected for utilization on all 3 forage species likely

Table 5. Main effects and interactions, with their respective p-values, for response variables of Idaho fescue occurring in bunchgrass grasslands on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Number of Reproductive Culms per Plant	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
		- - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	(P-Values)	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
T[1]	1	**0.0112**[2]	0.1261	**0.0019**	0.1101	0.4154
P	1	NA	0.4011	0.1041	**0.0068**	0.7508
T*P	1	NA	0.9402	0.8891	0.1579	0.4462
S	1	**0.0245**	0.1276	**0.0280**	0.2073	0.1587
S*P	1	NA	0.1596	0.0738	0.7648	0.8674
Y	1	**0.0248**	**0.0004**	**0.0001**	0.2820	0.3255

[1]T = Treatment (grazed or ungrazed), P = Sampling period (June or November for reproductive culms and November or March for forage quality and quantity variables), S = Sequence or order of treatment application on a plot (ungrazed/grazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face.

Table 6. Main effects and interactions, with their respective p-values, for response variables of Idaho fescue occurring in pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Number of Reproductive Culms per Plant	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
		(P-Values)				
T[1]	1	**0.0005**[2]	**0.0249**	**0.0005**	0.6024	0.3460
P	1	NA	**0.0079**	**0.0218**	**0.0023**	0.0871
C	1	0.9641	0.8037	0.3318	0.3952	0.0904
T*P	1	NA	0.5253	0.7177	0.9034	0.6250
T*C	1	0.9290	0.9863	0.2310	0.0981	0.6987
P*C	1	NA	0.6064	0.3595	0.3099	0.4716
T*P*C	1	NA	0.3960	0.6626	0.6993	0.7891
S	1	**0.0036**	0.9791	0.1020	0.1262	0.9579
S*P	1	NA	0.1993	0.4220	0.1578	0.9757
S*C	1	0.6276	0.8219	0.3682	0.3108	0.1311
S*P*C	1	NA	0.4692	0.2442	0.2094	0.1714
Y	1	**0.0048**	**0.0001**	**0.0001**	0.0801	**0.0364**

[1]T = Treatment (grazed or ungrazed), P = Sampling period (June or November for reproductive culms and November or March for forage quality and quantity variables), C = Canopy (present or absent), S = Sequence or order of treatment application on a plot (ungrazed/grazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face.

arose from differences in experience and foraging behavior between the 2 ewe-lamb bands. The band used in 1993, had no prior experience on the study area, remained agitated and alert, and tended to trail rather than forage through the grassland and savanna communities. They rarely ventured into the forest community. The sheep used in 1994 were well-experienced with the area and actively foraged in all 3 plant communities. These inherent differences between bands may have been compounded by higher reproductive culm production in 1993. An increase in reproductive culm density tends to reduce utilization of grasses by sheep (Murray 1984). The high density of reproductive culms present in 1993 likely reduced sheep utilization of bluebunch wheatgrass and Idaho fescue during that year. Both bands of sheep tended to forage in the openings and rest and ruminant under trees in the savanna community. This probably contributed to the canopy effects observed in utilization of elk sedge and treatment by canopy interactions that affected utilization of bluebunch wheatgrass (Tables 2 and 3) and elk sedge (Tables 7 and 8). It is unclear why the utilization of Idaho fescue was not affected by canopy or treatment by canopy interactions.

Reproductive Culms

Although late-spring grazing generally appeared to reduce numbers of reproductive culms in bluebunch wheatgrass and Idaho fescue, significant treatment effects were only observed for Idaho fescue in the savanna community (Table 6). Period effects on numbers of reproductive culms in bluebunch wheatgrass in grassland community (Table 1) and Idaho fescue in savanna community (Table 6) were likely a product of natural attrition caused by wind, early-season snowfall, and grazing by wild ungulates between June and November. Reproductive culm production is commonly used as an index of vigor for bluebunch wheatgrass. The occurrence of more reproductive culms in bluebunch wheatgrass in openings than under the tree canopy suggests bluebunch wheatgrass may endure more competition in open environments than under trees (Table 2).

Year was the most notable factor affecting numbers of reproductive culms in bluebunch wheatgrass (Tables 1 and 2) and Idaho fescue (Tables 5 and 6). Growing season precipitation was higher in 1993 than in 1994 (Fig. 1), this probably contributed to greater reproductive culm production in these species during 1993.

Forage Quality and Quantity

The levels of improvement in CP of bluebunch wheatgrass and Idaho fescue and IVDMD of bluebunch wheatgrass obtained with late-spring grazing could have substantial impact on the nutritional status of wintering elk (see Clark et al. 1998). The heavier utilization that occurred under Sequence 1 probably removed a larger proportion of apical meristems and foliage from bluebunch wheatgrass and Idaho fescue than did the

Table 7. Main effects and interactions, with their respective p-values, for response variables of elk sedge occurring in pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
		(%)			
T[1]	1	**0.0001**[2]	0.9036	**0.0125**	0.6499
P	1	NA	0.7222	0.0613	0.0942
C	1	**0.0132**	**0.0018**	0.1627	0.1587
T*P	1	NA	0.6705	0.6751	0.1549
T*C	1	**0.0128**	0.1620	0.6471	0.8118
P*C	1	NA	0.0608	0.1400	0.7267
T*P*C	1	NA	0.2379	0.3264	0.9692
S	1	**0.0055**	**0.0246**	**0.0200**	0.5320
S*P	1	NA	0.5878	0.5300	0.7231
S*C	1	0.1540	0.7700	0.6723	0.6933
S*P*C	1	NA	0.4447	0.3467	0.6729
Y	1	**0.0115**	0.1174	**0.0133**	0.3235

[1]T = Treatment (grazed or ungrazed), P = Sampling period (November or March), C = Canopy (present or absent), S = Sequence or order of treatment application on a plot (ungrazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face..

Table 8. Mean levels of utilization (percent plant weight) on elk sedge as affected by treatment, sequence, year, and the interaction of treatment and canopy presence in pine-bunchgrass savannas on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

		Sequence		Year		Canopy	
	Treatment	Ungrazed-Grazed	Grazed-Ungrazed	1993	1994	Absent	Present
	(%)						
Ungrazed	0.9a[1]	1.8	0.1	1.8	0.1	0.9a	0.9a
Grazed	23.8b	35.0	12.7	12.7	35.0	33.9b	13.8c
Mean	12.4	18.4a	6.4b	7.2a	17.5b	17.4a	7.4b

[1]Means for main effects or treatment by canopy interactions which share a common letter are not significantly different (P>0.05).

lighter grazing that occurred under Sequence 2. This may explain the higher CP of Idaho fescue (Table 5) and IVDMD of bluebunch wheatgrass (Table 1) detected under Sequence 1. If the apical meristems are left intact following defoliation, grazed tillers continue to develop leaves and elongate. Consequently, light grazing of bluebunch wheatgrass and Idaho fescue may have had little effect on the phenological development or forage quality relative to grazing exclusion (Stoddart 1946). Removal of apical meristems and foliage by heavier grazing stimulates regrowth from axillary buds (Mueller and Richards 1986, Richards et al. 1998), effectively delaying plant development and potentially allowing plants to cure at a younger phenological stage.

Given a lack of information on the physiology of elk sedge, its forage quality responses are difficult to interpret. Additional research is needed to improve our understanding of elk sedge and its responses to grazing.

Bluebunch wheatgrass in the grassland community was the only case where utilization was heavy enough to cause significant declines in the standing crop (Table 1). Winter ranges in northeastern Oregon are forage quality- rather than quantity-limited. Even in March, when the standing crop of bluebunch wheatgrass in the grassland community of grazed plots was the lowest (=87.6 kg ha^{-1} DM), bluebunch wheatgrass forage from only 17 ha of grassland would supply the daily dry matter needs of 300 adult cow elk, the typical winter population on the study area (i.e., assuming 5 kg DM each or 2.5% of 200 kg body weight) (see Hobbs et al. 1982 and Clark et al. 1998). Consequently, it is unlikely the reduced standing crop observed in this study would limit forage availability for wintering elk.

Increases in CP of bluebunch wheatgrass (Table 2) and Idaho fescue (Table 6) between the November and March sampling periods were probably due to proportionately lower standing litter content and higher live tissue content in March samples. Forage quality of standing litter is typically lower than that of live tissue. Given the significant period effects detected for numbers of reproduction culms in bluebunch wheatgrass and Idaho fescue, it is likely total standing litter in these species continued to decline (particularly older, degraded litter of low forage quality) between November and March. This probably reduced the standing litter content and increased the forage quality of March samples. Additionally, under favorable winter and early spring conditions, bluebunch wheatgrass may resume growth of tillers initiated during the previous fall (Blaisdell and Pechanec 1949). This would increase the amount of live tissue in March relative to November samples. Both bluebunch wheatgrass (McIlvanie 1942, Evans and Tisdale 1972, Wilson et al. 1966) and Idaho fescue (Borman 1990) may initiate spring growth in early March. Given the assumptions above, one might expect both CP and IVDMD of bluebunch wheatgrass and Idaho fescue to increase between November and March. Consequently, it is unclear why IVDMD of bluebunch wheatgrass under the tree canopy increased between November and March but declined in the openings (Table 2 and 4). A possibility is that the openings of the savanna tended to remain snow-covered while areas under the canopy remained snow-free. Winter and early spring growth may have occurred under the canopy but not in the openings, and this resulted in more live tissue in samples from under the canopy. It is also unclear why IVDMD of Idaho fescue (Tables 5 and 6) actually decreased between November and March. Declines in IVDMD of elk sedge in the forest community between November and March were probably due to death and weathering of leaf tips and consumption of the higher quality portions of leaves by wintering elk (Table 9).

Canopy effects on CP of elk sedge may be related to differences in plant vigor (Table 7). Elk sedge in the openings appeared to be stressed, with short, light green leaves and dead tips, compared to elk sedge under the canopy which had long, dark green leaves. Elk sedge in the openings likely endured more intense solar radiation and competition from bunchgrasses than elk sedge under the canopy. Conversely, bluebunch wheatgrass in the openings of the savanna community exhibited more standing crop than under the canopy. This suggests again, that bluebunch wheatgrass is more competitive and vigorous in the openings than under the tree canopy (Table 2).

It is difficult to interpret the canopy by sequence interaction affecting the standing crop of elk sedge in the forest community (Tables 9 and 10). Additional research is

Table 9. Main effects and interactions, with their respective p-values, for response variables of elk sedge occurring in mixed-conifer forests on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

Main Effects and Interactions	Degrees of Freedom	Forage Utilization	Crude Protein	In Vitro Dry Matter Digestibility	Standing Crop
	(P-Values)				
T[1]	1	**0.0006**[2]	**0.0495**	0.1320	0.2855
P	1	NA	0.2513	**0.0023**	0.3995
C	1	0.0598	0.1910	0.6826	0.7470
T*P	1	NA	0.5891	0.5772	0.7968
T*C	1	0.0805	0.8481	0.9871	0.4169
P*C	1	NA	0.8052	0.8545	0.4401
T*P*C	1	NA	0.8028	0.8209	0.7583
S	1	**0.0004**	**0.0001**	**0.0001**	0.1215
S*P	1	NA	0.2530	0.8806	0.1257
S*C	1	0.1053	0.4137	0.9932	**0.0451**
S*P*C	1	NA	0.6000	0.8453	0.2765
Y	1	**0.0016**	0.3731	**0.0176**	0.8591

[1]T = Treatment (grazed or ungrazed), P = Sampling period (June or November for reproductive culms and November or March for forage quality and quantity variables), C = Canopy (present or absent), S = Sequence or order of treatment application on a plot (ungrazed/grazed or grazed/ungrazed), and Y = Year (1993 or 1994).
[2]P-values <0.05 are printed in bold face.

Table 10. Mean levels of standing crop for elk sedge as affected by the interaction of canopy presence and sequence or order of treatment application in mixed-conifer forests on the McCarty Spring Big Game Winter Range Management Area in northeastern Oregon during 1993 and 1994.

	Canopy	Sequence	
		Ungrazed-Grazed	Grazed-Ungrazed
	-----------------	(kg ha^{-1} DM)	-----------------
Absent	124.9	119.8a[1]	129.9a
Present	131.1	167.3b	94.9c
Mean	128.0	143.5	112.4

[1]Means for canopy by sequence interactions which share a common letter are not significantly different (p>0.05).

needed to improve our understanding of how elk sedge responds to defoliation and tree canopy presence.

Year effects on CP and IVDMD of bluebunch wheatgrass (Tables 1 and 2) and on CP of Idaho fescue (Tables 5 and 6) were probably due to a higher reproductive culm presence in 1993 and the occurrence of fall regrowth in 1994. Bryant (1993) reported CP and IVDMD of the reproductive culms and inflorescences of cured bluebunch wheatgrass forage were lower than leaf material. A similar relationship is likely for Idaho fescue. Higher fall precipitation in 1994 (Fig. 1) may have stimulated fall regrowth elevating the live tissue content in 1994 samples.

Year effects on IVDMD of elk sedge (Tables 7 and 9) were probably related to differences in spring precipitation between years (Fig. 1). Increased precipitation in 1993 may have enhanced elk sedge production. Samples collected in 1993 would then contain proportionately more current year growth which is probably more digestible than older material. If more production occurred in 1993, it apparently was not great enough to produce a year effect on the standing crop of elk sedge. Differences in growth season precipitation probably caused the year effects detected for the standing crop of bluebunch wheatgrass (Table 2) and Idaho fescue (Table 6) in the savanna community.

Conclusions

Experience of livestock can strongly influence their effectiveness as forage conditioning agents. Moderate levels of late-spring sheep grazing can decrease numbers of reproductive culms in Idaho fescue. Numbers of reproductive culms present in bluebunch wheatgrass and Idaho fescue plants decline from June to November. Above-normal precipitation can increase reproductive culm production in bluebunch wheatgrass and Idaho fescue. Late-spring grazing can enhance winter CP levels in bluebunch wheatgrass, Idaho fescue, and elk sedge and IVDMD of bluebunch wheatgrass. Forage quality of bluebunch wheatgrass and Idaho fescue is more responsive to moderate than light levels of late-spring grazing. Crude protein in bluebunch wheatgrass and Idaho fescue can increase between November and March while IVDMD of Idaho fescue and elk sedge may decrease. Winter levels of CP in elk sedge can improve under light spring grazing but grazing may cause declines in IVDMD of elk sedge. The winter standing crops of bluebunch wheatgrass, Idaho fescue, and elk sedge are not affected by light to moderate utilization during late spring.

Carefully-managed, late-spring grazing can be an effective means for improving the winter forage quality of bluebunch wheatgrass and Idaho fescue on big game winter range. Further research is needed to evaluate grazing as a tool for improving the winter forage quality of elk sedge. Although, the percentage point changes in CP and IVDMD obtained in this study appear small, these changes are actually quite substantial when compared to the low basal forage quality levels common to grassland winter range. These forage quality improvements can also be obtained at relatively low cost, applied to different portions of the winter range in subsequent years, and have a positive influence on the nutritional status of wintering elk. Late-spring grazing could also improve the quality of livestock winter pasture and reduce supplementation costs for livestock producers. With some careful thought, a forage conditioning program could be integrated into existing rotation grazing systems.

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Reassessment of revegetation strategies for Kaho‘olawe Island, Hawai‘i

ALAN D. ZIEGLER, STEVEN D. WARREN, J. LYMAN PERRY AND THOMAS W. GIAMBELLUCA

Alan Ziegler is a doctoral candidate in the Department of Geography, 2424 Maile Way, 445 Porteus Hall, University of Hawai‘i, Honolulu, Hawai‘i 96822; Steven Warren is a research scientist, Land Management Laboratory, US Army Construction Engineering Research Laboratories, Box 9005, Champaign, Ill. 61826-9005; Lyman Perry is State Forester, Division of Forestry and Wildlife, State of Hawai‘i, Box 4849, Hilo Hawai‘i, 96720; Thomas Giambelluca is a professor of Geography at the University of Hawai‘i, Honolulu, Hawai‘i 96822.

Abstract

This work investigates 2 US Army Construction Engineering Research Laboratory revegetation experiment sites (Phase I and II) on Kaho‘olawe Island, Hawai‘i (USA) to determine the long-term success of several revegetation strategies and to identify species that are best suited for future restoration activities in the highly eroded central plateau region of the island. Only the Phase I treatments receiving the highest rates of phosphorus and nitrogen fertilizer and the Phase II strategy (moderately high fertilizion, and landscaping) produced enough cover to begin providing protection from erosion processes. Buffelgrass (*Cenchrus ciliaris* L.), glycine (*Neonotonia wightii* (Wight & Arnott) Verdc.), Natal redtop (*Rhynchelytrum repens* (Willd.) Hubb.), and siratro (*Macroptilium atropurpureum* (DC) Urb.) appear to be resilient to the harsh island conditions, which include strong winds, low annual rainfall, acute erosion, and a nutrient-depleted soil profile. Although all 4 species offer some protection against erosional processes, none are particularly desirable for long-term restoration of the island. Glycine and siratro, both of which volunteer readily in planting sites, are considered invasive in that they may smother other more desirable species, particularly less competitive natives. Finally, native woody species are shown to have difficulty in surviving on the island without special attention to planting and maintenance.

Key Words: Island restoration, long-term monitoring, ecology

Resumen

Este trabajo investiga 2 sitios experimentales de revegetación del Laboratorio de Investigación e Ingeniería de Construcción del Ejercito de E.U.A. (fase I y II) localizados en Kaho‘olawe Island Hawai‘i (E.U.A.). El objetivo fue determinar el éxito a largo plazo de varias estrategias de revegetación e identificar las especies mas apropiadas para actividades futuras de revegetación en regiones altamente erosionadas de las mesetas centrales de la isla. Solo los tratamientos de la fase I que recibieron altas cantidades de fertilización fosforada y nitrogenada, y las estrategias de la fase II, fertilización moderadamente alta y manejo del paisaje produjeron cobertura suficiente para iniciar la protección contra el proceso de erosión. El "Buffelgrass" (*Cechurus ciliaris* L.),"Glycine" (*Neonotonia wightii* (Wight & Arnott) Verde) "Natal redtop" (*Rhynchelytrum repens* (Willd) Hubb.) y "Siratro" (*Macroptilium atropurpureum* (DC) Urb.) parecen ser resistentes a las condiciones adversas de la isla, las cuales incluyen fuertes vientos, baja precipitacion anual, erosión aguda y un perfil de suelo pobre en nutrientes. Aunque las 4 especies ofrecen algo de protección contra el proceso de erosivo, ninguna es particularmente deseable para una recuperación a largo plazo de la isla. "Glycine" y "Siratro", ambas colonizan rápidamente los sitios de plantación, y son consideradas invasivas, ellas pueden suprimir otras especies más deseables, particularmente las nativas menos competitivas. Finalmente las especies leñosas muestran tener dificultad para sobrevivir en la isla sin atención especial para plantarlas y mantenerlas.

Prior to European contact, the Hawaiian island of Kaho‘olawe (Fig. 1) had become important to native Hawaiians as a site for religious practices, astronomical and navigational training, tool making, fishing, and agriculture as early as 1000 A.D. (Kaho‘olawe Island Conveyance Commission 1993). Original dry scrub forest vegetation of the island may have given way to a grassland in some areas as a result of agricultural practices of Hawaiians, especially burning. Substantial erosion may have occurred on the island as early as the 1500s (Kirch 1982). Severe vegetation loss and soil loss were greatly enhanced following the introduction of goats in 1793. Following the onset of western style ranching in the 1850s, the 1880s overgrazing by large herds of goats and sheep had led to significant wind and gully erosion. At about that time, kiawe (*Prosopis pallida* (Humb. & Bonpl. ex Willd.) Kunth) was introduced by ranchers to check soil loss, but erosion problems continued to worsen throughout a period during which Kaho‘olawe was designated a forest reserve (1910–1918) and during the subsequent return to ranching. Although ranching was discontinued when the U.S. Navy took control of the island for training purposes in 1941, feral goats remained, continuing to thwart restoration efforts until they were finally eradicated in the early 1990s (cf., Giambelluca et al. 1997). By this time, the

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cumulative effects of ranching, decades of uncontrolled grazing by feral goats, and military use had left one third of the island barren, with large areas completely without topsoil (cf. Loague et al. 1996, Nakamura and Smith 1995). Today, this largely barren plateau is commonly referred to as the "hardpan". Hardpan vegetation consists mainly of introduced species including kiawe, tamarisk (*Tamarix aphylla* (L.) H. Karst.), buffelgrass (*Cenchrus ciliaris* L.), Natal redtop (*Rhynchelytrum repens* (Willd.) Hubb.), lantana (*Lantana camara* L.), koa haole (*Leucaena leucocephala* (Lam.) de Wit), and pitted beardgrass (*Bothriochloa pertusa* (L.) *A. Camus*). Additionally, native pili or twisted beardgrass (*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult.), ‘ilima (*Sida fallax* Walp.), and indigenous (status uncertain) ‘uhaloa (*Waltheria indica* L.) are moderately abundant.

Restoration of soil and vegetation, especially native species, is a prerequisite for the Kaho‘olawe Island Reserve Commission's (1995) vision for the future of Kaho‘olawe. During the past few decades, various entities have initiated projects on Kaho‘olawe, including research-oriented or pilot studies, and other direct attempts at improving the vegetative cover or arresting soil erosion. Two studies undertaken in 1988 and 1990 by the U.S. Army Construction Engineering Research Laboratories (CERL) investigated the use of exotic grass seeding, various treatments of fertilizer, windbreak fencing, and jute netting (Warren and Aschmann 1993). In this work, we reassess the CERL plantings to determine: (i) changes in individual species coverage and overall species composition among various treatments and planting blocks since the initial assessment; and (ii) native and exotic species most capable of persisting on this barren windswept area, following revegetation efforts.

Materials and Methods

1988–1991 Investigations

The CERL vegetation trials were initiated at 2 sites on the hardpan in 1988 to identify effective, economical techniques for revegetation. Scarcity of hardpan vegetation (< 2% at time of planting) results in part from low annual rainfall totaling only approximately 370 mm (Ziegler and Giambelluca 1997). More importantly, the paucity of vegetation cover results from significant overgrazing by feral goats and the ensuing large-scale erosion. Today the soil surface, which is probably lower than the original by > 2 m, is best described as the Bw horizon of the Kaneloa and Puu Moiwi Oxisol soil series (cf. Nakamura and Smith 1995). Soil in this general area is slightly acidic, and low in phosphorous, calcium, and zinc (Table 1). Salinity is not problematic; calcium and magnesium levels are high. Total nitrogen is low for ideal plant growth. Bulk density of the disturbed barren soils is high (1.2 g cm^{-3}), and partly as a result, saturated hydraulic conductivity is only about 120 mm $hour^{-1}$. This area is the source area of significant overland flow eroding large gullies on the slopes extending down the plateau to the coastline (Loague et al. 1996).

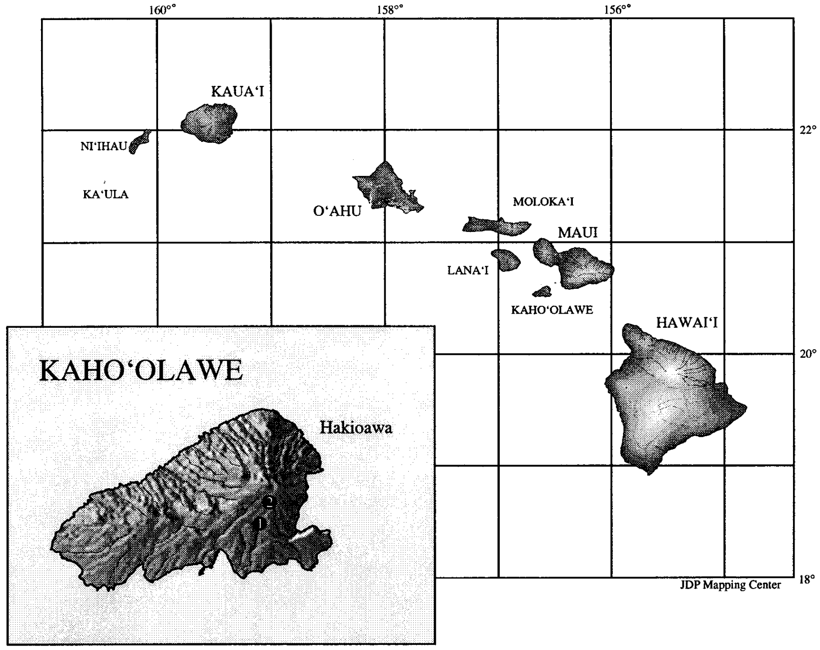

Fig. 1. Kaho‘olawe, the 8th largest island in the Hawaiian archipelago, rests in the rainshadow of Mt. Haleakalā on Maui Island to the northeast. Research was conducted within two areas associated with the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) planting Phases I and II.

During Phase I, a seed mixture of one legume (glycine [*Neonotonia wightii* (Wight & Arnott) Verdc.]) and 6 exotic grasses (buffelgrass, yellow bluestem [*Bothriocloa ischaemum* (L.) Keng], plains bristlegrass [*Setaria leucopila* (Scribn. & Merr.) K. Schum.], buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.], common bermudagrass [*Cynodon dactylon* (L.) Pers.], and Guinea grass [*Panicum maximum* Jacq.]) was sown. The choice of exotic species was necessitated by the absence of commercial sources of adequate quantities of native

Table 1. Chemical and physical characteristics of surface soils within the general area of the Phase I and II planting sites on Kaho‘olawe.

Soil Characteristics[1]	Units	Value
pH		6.8
P	ppm	15
K	ppm	325
Ca	ppm	839
Mg	ppm	543
Total N (TN)	%	0.1
Organic carbon (OC)	%	1.2
OC/TN	—	9.7
Zn	ppm	0.3
Electrical conductivity (EC)	mmhos cm^{-1}	0.3
Saturated hydraulic conductivity	mm $hour^{-1}$	117.5
Field bulk density	g cm^{-3}	1.16
Soil moisture at saturation	g g^{-1}	0.47

[1]pH, P, K, Ca, Mg, TN, OC, Zn, and EC data are means of 32 surface (0–10 cm) samples (from Ziegler and Smith 1998). All other values were determined as a weighted mean of CERL O-group and V-group lands in the Giambelluca et al. 1997.

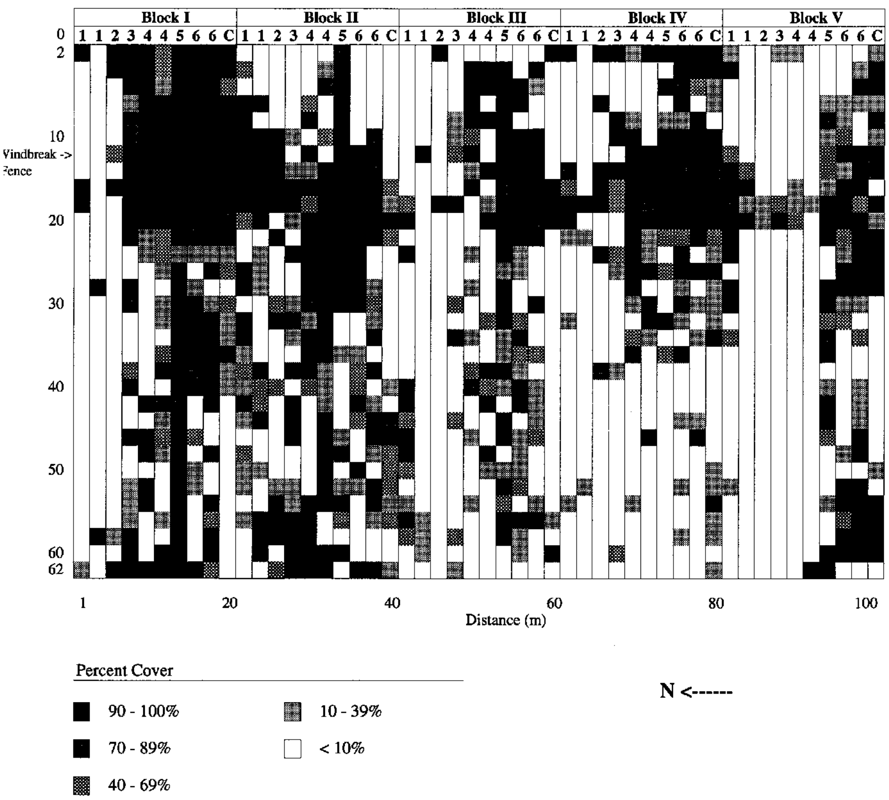

Fig. 2. Spatial distribution of ground cover in the Phase I planting area. The darkest squares correspond to areas of highest cover. Treatment planting strips and treatment blocks are labeled at the top of the diagram. Treatments are described in Table 2.

Table 2. Six treatments and control associated with the CERL Phase I planting.

Identifier	Treatment[1]
T1	Seed only
T2	Seed and jute netting
T3	Seed and fertilizer rate 1
T4	Seed and fertilizer rate 2
T5	Seed, fertilizer rate 2, and jute netting
T6	Seed and fertilizer rate 3
C	Control

[1]Fertilizer rate 1 = 3.6 kg ha^{-1} N plus 17.1 kg ha^{-1} P_2O_5; Rate 2 = 62 kg ha^{-1} N plus 291 kg ha^{-1} P_2O_5; and Rate 3 = 123 kg ha^{-1} N plus 582 kg ha^{-1} P_2O_5 (Warren and Aschmann 1993).

seed for the state of Hawai‘i. Buffelgrass, bermudagrass, Guinea grass and glycine were used because of apparent success during the 1970s. Yellow bluestem, plains bristlegrass and buffalograss were selected for their drought tolerance on the mainland United States. Fifty strips (2 x 62 m) were treated with various combinations of fertilizer, jute netting, and seed. Fertilizer selection was based on an earlier study that determined phosphorus to be a major limiting nutrient on the island (Warren et al. 1988) and evidence that tropical soils in general are often low in nitrogen (Manrique 1993). The use of a high concentration of phosphorus was due to the abundance of iron and aluminum oxides and hydroxides, which are well known for their propensity to bind phosphorus and make it unavailable to plants. The treatments are summarized in Table 2.

The plantings were conducted in 5 adjacent, identical blocks, with treatments 1, 4, and 6 repeated within each block (Fig. 2). Therefore, these 3 treatments were replicated 10 times; all other treatments and the control, 5 times. The planting strips were laid out parallel to the prevailing wind direction. A windbreak fence was constructed perpendicular to the strips about 12 m from the windward end. Initial assessment of Phase I, about 15 months following planting (Warren and Aschmann 1993), revealed: (i) treatments consisting of moderate and high fertilizer rates (i.e., T4, T5, and T6 in Table 2) were the most effective; (ii) jute netting and windbreak fencing significantly enhanced plant coverage, but may be prohibitively expensive; (iii) buffelgrass, common bermudagrass, and weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees, probably a contaminant in one of the other grass seed stocks) were the most successful ‘planted’ species in becoming established; and (iv) Australian creeping saltbush (*Atriplex semibaccata* R. Br.), although not planted, responded favorably to seedbed preparation and fertilization. The windbreak fence ruptured a short time after planting, thus contributing less protection to the restoration sites than intended, particularly for Blocks II and III.

Additionally, within the CERL Phase I project area, 310 native woody plants (Table 3) were planted in 3 rows, perpendicular to the treatment strips, at 0, 12.3, and 60 m from the beginning of the planting area (Warren and Riggins 1991). This planting was conducted in December 1988. One hundred plants were planted at equal intervals in the first row; 100 and 110, in rows 2 and 3, respectively (Table 3). Row 2 is located ≈ 0.3m leeward of the windbreak fence. Monoammonium phosphate fertilizer was added to approximately half the plants in each row. No formal investigation has been made of the survivorship of these plants.

Phase II was a larger-scale revegetation effort, conducted in January and November 1990, utilizing a chisel plow seeder to scarify and plant an 8-ha watershed, having a pre-planting vegetative cover of 1.4% (Warren and Riggins 1991). The seeding mixture included buffelgrass, common bermudagrass, weeping lovegrass, and Italian ryegrass (*Lolium multiflorum* Lam.). Fertilization at a rate of 70 kg ha^{-1} N plus 179 kg ha^{-1} P_2O_5 was applied to the furrows created by the chisel plow (Warren and Aschmann 1993). The initial

Table 3. Native woody species planted in CERL Phase I (from Warren and Riggins 1991). Numbers reflect total species planted only; they do not indicate planting order.

Species	Row 1[1]	Row 2	Row 3
wiliwili (*Erythrina sandwicensis* Degener)	21	22	59
‘ūlei (*Osteomeles anthyllidifolia* (Sm.) Lindl.)	10	10	9
‘a‘ali‘i (*Dodonea eriocarpa* Sm.)	20	20	19
koa (*Acacia koa* A. Gray)	20	20	5
ko‘oloa‘ula (*Abutilon menziesii* Seem.)	19	10	6
ma‘o (*Gossypium tomentosum* Nutt. ex Seem.)	10	18	12
TOTAL	100	100	110

[1]Rows 1, 2, and 3 are located at 0, 12.3, and 60 m respectively from the beginning of the planting area (shown in Fig. 2).

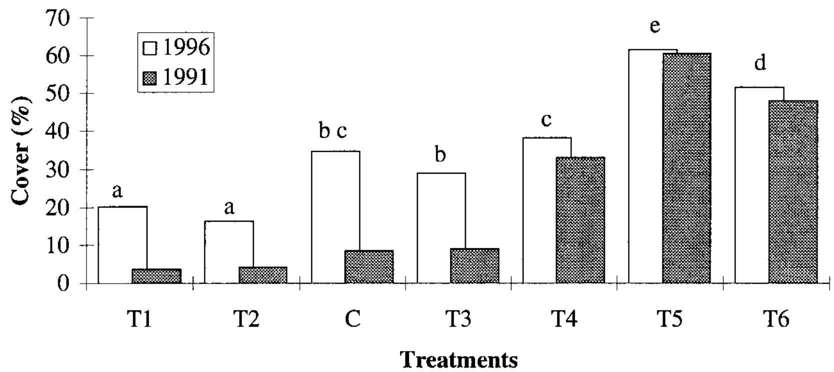

Fig. 3. Percent cover within the 6 treatments and the control in the Phase I area for the 1991 assessment (Warren and Aschmann 1993) and the study reported herein. For the 1996 values, similar letters indicate cover values are not statistically different (ANOVA, $\alpha = 0.05$). Treatments are described in Table 2. Increases since 1991 for Treatments T1, T2, T3, and the control are significant (t-test, $\alpha = 0.05$).

results of a field survey conducted in January 1992 revealed the following: (i) average foliar coverage was 55% compared to 6% in outside control areas; (ii) weeping lovegrass contributed 31% of the total foliar coverage; and (iii) success of the project, relative to Phase I, was attributed, at least in part, to an increased ratio of N to P_2O_5 in the fertilizer and the use of Italian ryegrass to provide a fast-growing protective vegetation cover (Warren and Aschmann 1993). The success of Phase II compared with Phase I might be attributed to better growing conditions at the former, such as better wind protection or more rainfall. Furthermore the landscaping conducted at the Phase II site prior to planting may have influenced soil moisture by damming overland flow, thus retaining more water on-site for plant use. Plowing also breaks up the hard surface crust, decreases the soil bulk density, increases porosity (especially macroporosity), thus leading to increased infiltration and more favorable conditions for root growth.

1996 Measurements

At the Phase I site, vegetative cover of all plant species was measured in June and August 1996 using the relevé sampling method (Mueller-Dombois and Ellenberg 1974). This methodology follows that of Warren et al. (1988) who surveyed the site initially in 1988 and then again in 1991, 25 months after planting (Warren and Aschmann 1993). For the 1996 survey, 50 transects (62 m in length) were established along the central axis of each treatment strip and sampled using a 0.25 m^2 frame. At 2-m intervals along each transect individual species coverage and bare ground was visually estimated within the sampling frame using the Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974). Briefly, with this technique, numbers from 1 to 10 are assigned for each species and bare ground. The Braun-Blanquet values correspond to ranges of cover values. Coverages were quantified by assigning the midpoint values of cover ranges (i.e., 1 = 0.5%, 2 = 3.0%, 3 = 7.5 %, 4 = 17.5%, 5 = 37.5%, 6 = 62.5%, 7 = 82.5%, 8 = 92.5%, 9 = 97.0%, and 10 = 99.5%). Individual species coverage within a given treatment strip was computed as the mean of 31 sampling locations. Because Braun-Blanquet values are not additive, total foliar coverage within a treatment strip was computed as the residual of the bare cover values (i.e., 100% - percent bare ground).

For sampling in the Phase II site, we utilized the boot-step method (Cook and Stubbendieck 1986), which was employed in surveys conducted in 1987 and 1991 (Warren et al. 1988). Briefly, this method involves identifying the plant species present at the tip of the toe of each "boot step" on a randomly walked path through the study area. Species coverage is computed as the percentage of times the species was encountered. To increase comparability with the prior assessment, we attempted to follow the route sampled by Warren et al. (1988) between specified markers.

The depth of "soft soil" above the hardpan surface was measured as an indicator for sediment depth on the Phase I site. This measurement involved recording the depth a 0.01 m diameter rod could be pushed into the soil surface before reaching the resistant hardpan below. Sediment depth was sampled at 2 m intervals on 12 transects, running parallel to the planting strips. The transects were established every 5 m, beginning from the northern end of the planting site. This measurement was used to ascertain how the windbreak fence may have contributed to sediment accumulation within the planting area and to investigate correlations between sediment depth and vegetation cover.

Three-factor analysis of variance (ANOVA) was used to assess the effects of (1) planting treatments, (2) treatment block location, and (3) location with respect to the windbreak fence on total vegetation cover in the experiment area. If ANOVA tied-P values were less than 0.05 during testing of each individual factor, 1-factor ANOVA followed by post-hoc testing with Fisher's Protected Least Square Difference test (FPLSD) was employed to identify groups that were statistically indistinguishable. The one sample t-test was used to evaluate changes since the initial assessment in percent cover for the 7 treatments and the 5 blocks. Finally, the nonparametric Spearman Rank Correlation Coefficient was computed to show the influence of sediment depth and fertilizer application rates on percent cover.

Results and Discussion

CERL Phase I

Total foliar coverage in the Phase I planting area was 36%, compared with 24% cover determined in 1991 by Warren and Aschmann (1993). Fig. 2 depicts the current distribution of vegetative cover within the 6,200 m^2 planting area. A total of 20 species (6 sown; 14 volunteer) were present, with buffelgrass, glycine, Natal redtop, and siratro (*Macroptilium atropurpureum* (DC) Urb.) having the greatest coverages (Table 4). The 16 other species present had cover values ≤1%. Each of the 4 most common species in our survey increased in coverage since 1991. Only 2 species, common bermudagrass and Australia creeping saltbush, decreased substantially since 1991. Australian creeping saltbush is a pioneer species on Kahoʻolawe that dies back after producing seed (approximately 2 years). The decline of this species between 1991 and 1996 suggests competition may be preventing propagation of new saltbush plants. Buffalograss and plains bristlegrass, which were originally planted in 1988 and present in the 1991 assessment, were absent in our survey. Buffelgrass and glycine, and 2 volunteer species, Natal redtop and siratro, demonstrate the greatest ability to persist on the hardpan for periods of several years.

In general, treatments with the highest fertilizer rates (i.e., T4, T5, and T6) still had the highest cover values since the initial assessment (Fig. 3). Total plant cover for these 3 treatments increased only slightly since 1991, while cover for the control and treatments T1, T2, and T3 increased significantly (t-test, $\alpha = 0.05$). Cover for the lowest fertilizer treatment (T3) was not statistically different from the control—nor was the higher fertilizer T4 treatment. Cover for the 2 non-fertilizer treatments (T1 and T2), however, was significantly less (ANOVA, $\alpha = 0.05$), perhaps because the control plots were located adjacent to, and thus influenced by, the high fertilizer plots (i.e., T6, see Fig. 2). In general, buffelgrass appeared to respond favorably to all levels of fertilizer treatments (T3-6, Table 4); and glycine responded well to the highest levels of fertilization and jute netting (T5 and T6).

Jute netting (T2) alone did not produce significant cover increases, demonstrating the importance of fertilizing the nutrient-poor soil of this area. The fertilizer treatments contained various application rates (also various ratios) of P- and N-based fertilizer (Table 2). The general trend was as total application rate increased vegetative cover increased—and there was no indication that a threshold had been reached such that increasing N and P would not promote greater cover. Nor were important limiting micronutrients, such as zinc, included in the tested fertilizer mixtures.

Prior laboratory and field studies suggest a ground cover of approximately 40 to 60% is needed to provide significant protection from erosion detachment and transport processes (e.g. DePloey et al. 1976, Morgan et al. 1986, Rogers and Schumm 1991). This threshold varies depending on soil hydrological/physical properties, rainfall characteristics, slope, and vegetation type. As a rough estimate of the erosion control effectiveness of the various treatments, the nonlinear relationship between groundcover and sediment transport by runoff reported by Dadkhah and Gifford (1980) is useful. This relationship suggests that treatments T4, T5, and

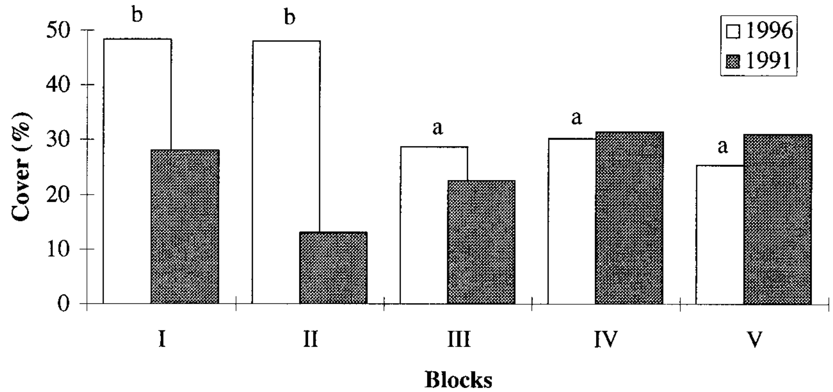

Fig. 4. Percent cover in the 5 planting blocks in the Phase I area for the 1991 assessment (Warren and Riggins 1991) and the study reported herein. For the 1996 values, similar letters indicate cover values are not statistically different (ANOVA, $\alpha = 0.05$). Changes for all Blocks, except IV, since 1991 are significant (t-test, $\alpha = 0.05$).

Table 4. CERL Phase I total ground coverage (%) of plant species for the initial assessment (1991) and this study (1996); and coverage within the seven fertilizer treatments for 1996.

N/E[1]	Species	Common Name	Total Coverage 1991	Total Coverage 1996	1996 Coverage by Treatments[2] T1	T2	T3	T4	T5	T6	C
	PLANTED		(%)								
E	*Bothriochloa ischaemum* (L.) Keng	yellow bluestem	t	t				t			
E	*Buchloë dactyloides* (Nutt.) Engelm.	buffalograss	t								
E	*Cenchrus ciliaris* L.	buffelgrass	7	9	4	4	12	10	12	12	4
E	*Cynodon dactylon* (L.) Pers.	common bermudagrass	4	t	t	t	t		t	t	tr
E	*Eragrostis curvula* (Schrad.) Nees[3]	weeping lovegrass	1	t	t	t	t	t	2	t	tr
E	*Neonotonia wightii* (Wight & Arnott) Verdc.	glycine	2	8	2	3	6	9	17	12	7
E	*Panicum maximum* Jacq.	Guinea grass	t	t	t			t	t	1	tr
E	*Setaria leucopila* (Scribn. & Merr.) K. Schum.	plains bristlegrass	t								
	NOT PLANTED										
E	*Atriplex semibaccata* R. Br.	Australian creeping saltbush	8	t		t	t	t	t	t	tr
E	*Chamaecrista nictitans* (L.) Moench	partridge pea		t			t	t			
E	*Conyza bonariensis* (L.) Cronq.	hairy horseweed		t						t	
E	*Digitaria pentzii* Stent	pangola grass		t	t		t	t		t	tr
E	*Emilia fosbergii* Nicolson	pualele		t	t		t	t	t	t	tr
E	*Macroptilium atropurpureum* (DC) Urb.	siratro		3	4	1	1	2	1	3	4
E	*Nicotiana glauca* R.C. Graham	tree tobacco		t				t			
E	*Rhynchelytrum repens* (Willd.) Hubb.	Natal redtop		4	2	3	2	5	8	5	4
E	*Sonchus oleraceus* L.	pualele		t			t				t
E	*Tridax procumbens* L.	coat buttons		t	t						
N	*Waltheria indica* L.	‘uhaloa		t	t	t	t	t	t		tr
E	*Asclepias physocarpa* (E. Mey.) Schlechter	balloon plant		t		t		t		t	
E	*Bothriochloa pertusa* (L.) A. Camus	pitted beardgrass		t			t				
E	*Xanthium strumarium* L. var *canadense* (Mille.) Torr. & A. Gray	cocklebur		‘t’			t	t	t		
TOTAL[4]			24	36	20	16	29	38	61	52	36

[1]N is native; E is exotic; ‘t’ (trace) means present at less than 1%.
[2]Treatments are described in Table 1.
[3]This species was accidently present in the seeding mixture.
[4]Total values are computed as 100% - percent bare ground.

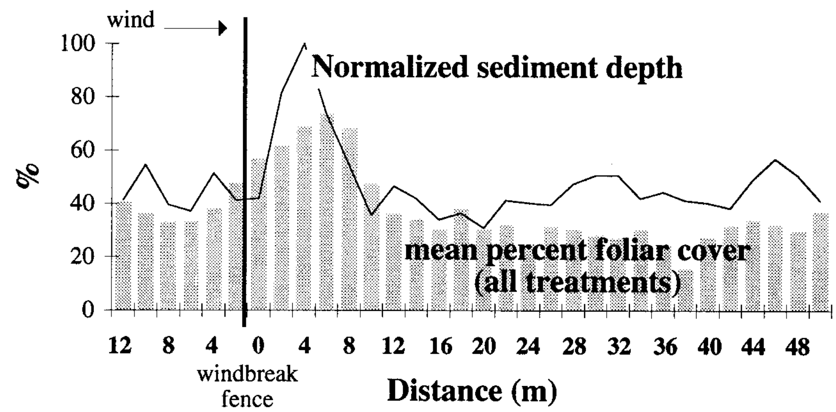

Fig. 5. Mean percent cover and mean normalized sediment depth (expressed as a percent) within the Phase I area. The Y-axis is percent for both cover and normalized sediment depth. A windbreak fence was originally constructed at 12 m.

T6 would reduce sediment output by 65, 79, and 75%, respectively. All other treatments would reduce output by ≤ 60%.

Blocks I and II had significantly higher cover than Blocks III, IV, and V (Fig. 4; ANOVA, $\alpha = 0.05$). In a prior assessment, Warren and Riggins (1991) reported that Blocks II and III, which were badly damaged by water erosion, had significantly lower foliar cover than the remaining blocks. Blocks II and III have largely recovered from the initial erosion damage. There is a slight increase in elevation across the study area from north to south (from Block I to V). The additional runoff that originally damaged Blocks II and III may now be contributing to their vegetative cover. Additionally, runoff water could be transporting P from treatments 3, 4, and 5 downslope, and thus contributing to the success of the other treatments and the control.

Three factor ANOVA indicated that differences in total vegetative cover are not independent of: (1) treatment, (2) planting block, or (3) distance from the windbreak fence; and differences in cover among treatments (or blocks, or distances) are not independent of the other 2 factors. With respect to distance, for 1-factor ANOVA, distances before and after the windbreak fence were classified into 5 groups: (1) 0 to 12 m windward of the fence; (2) 0 to 12 m leeward; (3) 13 to 24 m leeward; (4) 25 to 36 m leeward; and (5) 37 to 48 m leeward. Three statistically indistinguishable groups were identified, with {0 to 12 m leeward (64%)} > {windward (38%)} > {13 to 24 m, 25 to 36 m , 37 to 48 m leeward (27%, average of three groups)}. This relationship, which is apparent in Fig. 5, suggests the windbreak fence had a positive influence on promoting vegetative growth, probably by decreasing strong winds and creating sediment deposition areas where seeds could germinate.

In support, sediment depth was greatest 4 to 8 m leeward of the fence. The small peak at approximately 4 m windward of the fence is probably also related to deposition by wind. These distances are in reasonable agreement with literature values for sediment deposition both windward and leeward of a 1.2 m fence (cf., Morgan 1995). The sediment peak near the beginning of the planting area (10 m windward) may be that deposited leeward of a row of tamarisk trees (another revegetation project, cf., Giambelluca et al. 1997). Figure 5 shows the spatial relationship between sediment cover and sediment depth (normalized by dividing all values by the maximum depth, 11.5 cm; expressed as a percent). The 2 are positively correlated (tied-P value = 0.10; Spearman Rank Correlation). In Fig. 6, higher application rates of fertilizer are also shown to produce higher vegetative cover. Thus, sediment depth and fertilizer application rate both have a positive influence on cover. Figure 6 additionally shows that as fertilizer application rate increases the correlation between sediment depth and cover decreases (i.e., tied-P values increase toward one). This trend suggests fertilization is critical. Entrapment of windblown sediments may be beneficial for plant establishment, but this benefit pales in comparison to fertilization, particularly at higher rates.

Survival of Native Species in Phase I

Of the 310 native woody species planted in the Phase I site, only 14 (of 103 planted) wiliwili trees survive today. Nine are located immediately in the lee of the windbreak fence line (Row 2; Blocks I and IV); the remaining 5, in Row 3 (Blocks I and II), 60 m from the beginning of the planting area. These data reflect the difficulty of establishing native woody species on some parts of the island without careful attention to planting and maintenance, especially for plants other than wiliwili. The marginal success within Row 2 indicates that windbreak fencing may be beneficial for the establishment of some tree species.

Table 5. CERL Phase II species cover (%) for the planting year and at the time of this study.

N/E[1]	Species	Common Name	1988[2]	1996
			- - - - (%)	- - - -
	PLANTED			
E	*Cenchrus ciliaris* L.	buffelgrass		18
E	*Cynodon dactylon* (L.) Pers.	common bermudagrass		
E	*Eragrostis curvula* (Schrad.) Nees[3]	weeping lovegrass		17
E	*Lolium multiflorum* Lam.	Italian ryegrass		
	NOT PLANTED			
E	*Atriplex semibaccata* R. Br.	Australian creeping saltbush	1	2
E	*Asclepias physocarpa* (E. Mey.) Schlechter	balloon plant		t
E	*Bothriochloa pertusa* (L.) A. Camus	pitted beardgrass	't'	
E	*Casuarina equisetifolia* L.	common ironwood		t
E	*Chamaecrista nictitans* (L.) Moench	partridge pea		5
E	*Conyza bonariensis* (L.) Cronq.	hairy horseweed		t
E	*Emilia fosbergii* Nicolson	pualele		t
E	*Neonotonia wightii* (Wight & Arnott) Verdc.	glycine		12
E	*Lantana camara* L.	lantana		t
E	*Leucaena leucocephala* (Lam.) de Wit	koa haole		1
E	*Rhynchelytrum repens* (Willd.) Hubb.	Natal redtop		16
N	*Waltheria indica* L.	'uhaloa		1
	TOTAL		1	73

[1]N is native; E is exotic; 't' (trace) means present at less than 1%.
[2]1988 is at the time of planting; total cover was determined to be 55% in 1992 (individual species data are not available).

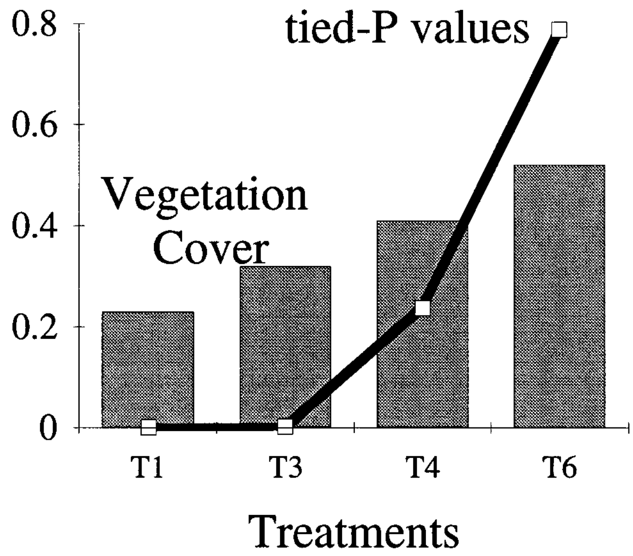

Fig. 6. The influence of fertilizer application rate on (1) total vegetation cover (expressed as a fraction) within a treatment (bars), and (2) the tied-P values for the Spearman Rank Correlation Coefficient (line) for total cover and sediment depth. The Y-axis contains values ranging from 0 to 1 for both cover and tied-P values. As fertilizer application rate increases cover increases. Meanwhile the correlation between sediment depth and cover decreases (i.e., tied-P value increase), indicating fertilizer application rate is more important in determining cover than is sediment depth. Treatments are described in Table 2.

Finally, ‘uhaloa (*Waltheria indica* L.) was the only woody native species to volunteer in either planting phase (Table 4, 5), demonstrating a lack of native seed sources to foster germination of new plants.

CERL Phase II

Total foliar coverage in the Phase II planting watershed has increased from 1% at planting in 1988 to 55% in January 1992, and finally to 73% in August 1996 (Table 5). Exotic grasses buffelgrass, weeping lovegrass, and Natal redtop, and the exotic viney legume glycine are now the most abundant species (18, 17, 16, and 12%, respectively). The latter 2 species were not sown. Glycine appears to have been a contaminant in the hay mulch used to stabilize terraces that were constructed across the site. In addition, 7 species absent in the 1992 survey were volunteers. Two species planted during Phase II, common bermudagrass and Italian ryegrass, were absent from our survey. Common burmudagrass similarly decreased at the Phase I site from 4% in 1991 to <1% in 1996, suggesting it is not suitable for revegetation. The inclusion of Italian ryegrass was credited in an earlier study (Warren and Aschmann 1993) for contributing to the success of Phase II because it established a fast-growing protective cover. Its disappearance in 1996 suggests it is not resilient to the harsh conditions and/or was outcompeted by one of the more dominant volunteers. Buffelgrass, the most abundant species in the Phase I site, was also the most abundant in the Phase II planting area. Weeping lovegrass, accidentally introduced in small quantities during Phase I, but intentionally planted during Phase II, was the second most abundant species (17%). Additionally, glycine and Natal redtop were more abundant in Phase II than Phase I; siratro however, one of the most abundant Phase I species, was not found in the Phase II area.

Conclusion

Vegetation within planting strips receiving large fertilizer inputs had the highest cover, demonstrating the benefits of phosphorus and nitrogen fertilization. However, there was no indication that appropriate fertilizer rates and combinations have been achieved to promote the greatest cover. The significant cover increases in the strips receiving little or no fertilizer may be artifacts of: (i) vegetation spreading from several large clumps centered around strips with high fertilizer application rates; (ii) enhanced plant growth in sediment deposition areas created by the presence of the windbreak fence; or (iii) growth promoted by run-on water transporting nutrients from treatments strips with higher fertilizer rates. In terms of providing adequate cover to reduce surface erosion processes, only treatments T4, T5, and T6 in Phase I and the Phase II strategy are potentially effective.

Four species, buffelgrass, glycine, Natal redtop, and siratro appear resilient to the harsh conditions on the windswept hardpan. Glycine and buffelgrass respond well to high rates of fertilization. Glycine, which was intentionally excluded from the planting mixture in Phase II because it was believed to smother other species, was still one of the most abundant species in the Phase II survey. The presence of glycine may result from contamination in the seed mixture, and/or dispersal, from on-island sources, including the Phase I site. Siratro, because it is similar to glycine in habit, is probably not a desirable revegetation species for Kaho‘olawe, despite its ability to volunteer and persist on the hardpan. Italian ryegrass and common bermudagrass do not appear to be successful long-term revegetation species. However, Italian ryegrass may be useful as a starter that will yield to more desirable species once growing conditions become more favorable (i.e., wind protection established, increased infiltration, increased organic matter). Survival of native woody species can be very low without the combination of other revegetation strategies such as rhizobial inoculation, windbreak fencing, protective vegetative cover, and/or carefully applied fertilization.

Future work should focus first on identifying appropriate species for island restoration. This should involve finding both fast starters and persistent long-term survivors. If nonnative species are to be used, care should be taken to select non-invasive species. Finally, planting strategies and fertilizer mixtures, determined from plant nutrient/rhizobial requirements of selected revegetation species and soil nutrient data, should be determined to promote quick establishment of pioneer species and long-term growth of other species resilient to the harsh climate conditions.

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Seedbank diversity in grazing lands of the Northeast United States

BENJAMIN F. TRACY AND MATT A. SANDERSON

Authors are Postdoctoral Research Associate and Research Agronomist, USDA Agricultural Research Service, Pasture Systems and Watershed Management Research Lab, Curtin Rd., University Park, Penn. 16802.

Abstract

We evaluated the species composition of soil seed banks from 9 farms (36 pastures total) located in the northeast United States. Our objective was to quantify the soil seed bank composition of pastures managed for intensive grazing and hay production. Seeds from pasture soils were allowed to germinate in a greenhouse under natural light conditions. Seedlings were identified as they germinated, and the experiment was concluded after 4 months. Germinable seed was dominated by annual (40%) and perennial (23%) forbs most of which contributed little useful forage for cattle. Perennial grasses (11%), except for bluegrass (*Poa pratensis* L.), were largely absent from the germinable seed bank, while legumes (19%) were more abundant. Seed bank species composition showed little similarity (44%) to the existing vegetation. Exceptions were bluegrass, white clover (*Trifolium repens* L.), and common dandelion (*Taraxacum officinale* Weber ex Wiggers). These species were abundant in both the germinable seed bank and existing vegetation on most pastures. Overall, our study suggests that seed banks in these northeast pastures support abundant white clover and bluegrass seed, both of which are important forages for cattle. Soil seed banks, however, will not supply a diverse assemblage of useful forages. If a manager seeks to establish diverse, mixed-species pasture, then re-seeding pastures with desired mixes may be the best option.

Key Words: management-intensive grazing, viable seed, aboveground vegetation, temperate grasslands

Resumen

Evaluamos la composición de especies del banco de semillas del suelo de 9 granjas (36 potreros en total) localizadas en el noreste de Estados Unidos. Nuestro objetivo fue cuantificar la composición del banco de semillas del suelo de potreros manejados con apacentamiento intensivo y producción de heno. Las semillas de los potreros se germinaron en invernadero bajo condiciones de luz natural. Las plántulas se identificaron conforme germinaron y el experimento terminó en 4 meses. La semilla que germinó estuvo dominada por hierbas anuales (40%) y hierbas perennes (23%), muchas de las cuales contribuyen con poco forraje útil para el ganado. Los zacates perennes (11%), excepto "Bluegrass" (*Poa pratensis* L.), estuvieron ausentes en el banco de semilla, mientras las leguminosas (19%) fueron más abundantes. La composición de especies del banco de semillas mostró poca similitud (44%) con la vegetación existente. Las excepciones fueron "Bluegrass", "White clover" (*Trifolium repens* L.) y "Common dendelion" (*Taraxacum officinale* Weber ex Wiggers). Estas especies abundaron tanto en el banco de semillas germinables como en la vegetación existente en el potrero. En general, nuestro estudio sugiere que los bancos de semilla en estos potreros del noreste poseen abundante semilla de "white clover" y "Bluegrass", las cuales son especies importantes para el ganado. Sin embargo, los bancos de semilla no suministran un ensamble diverso de especies forrajeras útiles. Si el manejador busca establecer un potrero con diversas especies, entonces la resiembra de potreros con mezclas de especies deseables puede ser la mejor opción.

The species composition of buried seed in a plant community depends on seed inputs from present and previous vegetation and the longevity of viable seed under local conditions (Roberts 1981). Knowledge of this seed bank is essential to achieve a more complete understanding of local vegetation dynamics, since composition of the soil seed bank may predict what species dominate a plant community after disturbance (Nobel and Slatyer 1980). If a land manager wishes to promote recruitment of desirable species from existing seed banks, then it is first crucial to determine its composition. Although not often used in terrestrial plant communities, seed-bank resources can be effectively managed to recruit useful plants into the community. Successful management based on seed bank exploitation requires 3 conditions be met: 1) seeds of desirable species are present in the soil, 2) seeds of undesirable species are rare and 3) conditions are suitable for germination and establishment of preferred species (van der Valk and Pederson 1989).

Pasture represents approximately 8% (~3.5 million hectares) of the non federal, rural land use in the 12 state region of the northeast with crop land and forest occupying significantly more (USDA 1994). Although some work has evaluated seed bank composition of abandoned agricultural fields in the northeast US (Leck and Leck 1998), little recent research has assessed seed bank resources of pasture lands in this region. Prince and Hodgdon (1946) studied seed bank species composition in 21 New Hampshire pastures, but no work has been published since then.

The objective of this study was to quantify the soil seed bank composition of pastures managed for intensive grazing and hay production across the northeast US. The focus of the survey was to determine the relative abundance of useful forage species for cattle and hay production (e.g. perennial grasses and legumes)

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present in the seed bank and relate the composition of the seed bank to existing vegetation on these pastures.

Material sand Methods

A total of 36 pastures from 9 farms were sampled in this study. Four farms were located in New York, 4 in Vermont and 1 in Pennsylvania. These farms lie in the region between 40 and 45°N and 72 and 77° W in the northeast United States. This is a cool, humid region of plateaus, plains, and mountains. Average annual temperatures in this region range from 4–13°C, with average annual precipitation ranging from 750–1,325 mm (USDA 1981). In most of the region, one half of the precipitation falls in the freeze-free season, which ranges from 110–170 days (USDA 1981). Soils in the study region are dominated by Ochrepts, Orthods and Aqualfs (USDA 1981). Farms were selected because they either relied on management-intensive grazing (MIG) to supply feed for cattle or were about to be converted to management-intensive grazing (MIG). Management-intensive grazing is characterized by applying a high stocking density to a small paddock (0.5^{-1} ha) for a short (12–48 hr) period then moving cattle to fresh pasture. Seven of the 9 farms were dairy operations that relied on management-intensive grazing as the primary feed for cattle. Although these pastures were primarily managed for grazing, farmers also took 1 or 2 cuttings of hay from these pastures each year. Two farms had not been grazed in the last 5 years but were about to be converted to MIG systems. These 2 farms were sporadically used for hay production, however, so old field succession to woodland was not allowed to progress during the years pastures were not grazed. One of these had been plowed and left fallow for several months before sampling. To our knowledge, none of the pastures had been seeded within the last 5 years.

We randomly selected four pastures on each farm for sampling. Pasture size varied from 2–10 ha with a median of 4 ha. Sampling occurred in July and August 1997. Vegetation composition was assessed by noting the species present in 15, randomly positioned 1 m^2 quadrats. Five soil cores were taken from random locations in each pasture for subsequent seed bank analyses. Cores were 10 cm in diameter and taken to a 10 cm depth.

Soil cores were stored in a dark freezer (~ 0 °C)for 3 months. Cores were then air dried at 20°C and sieved (1 dm mesh) to remove large rocks and roots. Soil from the 5 cores from each pasture were pooled and spread into plastic trays (25 by 50 by 6 cm) to a depth of 2 cm over 2 cm of sterile potting soil. Trays were placed in a greenhouse (temperature 18 ± 4°C) and allowed to germinate under natural light conditions. Soils were watered once or twice daily with tap water. As seedlings germinated they were identified and removed from trays. Seedlings that could not be identified were transplated to pots. Soils in each tray were mixed regularly with a small trowel to increase germination. Germination trials lasted approximately 4 months (15 December 1997- 16 April 1998).

The relative frequency of plant species in aboveground vegetation was compared to germinable seed using linear regression. The number of plant species (species richness S) was calculated for each pasture. Sorensenís coefficient of community (CC) (Magurran 1988) was calculated to index similarities between the seed bank and vegetation.

$$CC = 2(c)/ s1+s2$$

Where (c) is the number of species common to both seed bank and vegetation and (s1) and (s2) are the respective number of species detected in the plant community and its associated seed bank. Farms were considered the experimental unit and t-tests were used to compare variables between the grazed (n=7) and hayed farms (n=2). We considered $p<0.10$ as statistically significant.

Results

Aboveground vegetation cover on most farms was dominated by bluegrass (*Poa pratensis* L.), white clover (*Trifolium repens* L.) and common dandelion (*Taraxacum officinale* Weber ex Wiggers). Orchard grass (*Dactylis glomerata* L.) and English plantain (*Plantago lanceolata* L.) were also abundant on many of the pastures. A total of 54 species germinated from soil seed banks of the nine farms. Across farms, the number of species in the germinated seed ranged from 4 to 18, while mean species richness of vegetation ranged from 10–18 (Table 1). Overall, the number of species in seed banks was unrelated to the number of species in existing vegetation (linear regression, r = 0.14, p>0.10). Pastures on farms that had not been grazed in the last 5 years (Farms 1 and 2) contained more species in their seed banks than pastures that had been in continuous grazing (t = 3.92, p = 0.005, df = 7).

Annual and perennial forbs constituted more than 50 % of the seed bank species composition on 8 of 9 farms (Fig. 1a). On farm 9, the seed bank was primarily white clover, a legume (Fig. 1b). Annual forbs made up a greater proportion of the seed bank from ungrazed farms than grazed farms (t=3.21, p=0.01, df=7). Functional groups important for cattle forage, perennial grasses and legumes, accounted for less than 50% of the seed bank species composition on 8 of 9 farms. More perennial grasses germinated from soils taken on ungrazed farms compared with grazed farms (t=2.16, p=0.06, df=7). While not statistically significant, legumes were generally more abundant in cores taken from grazed farms (Fig. 1b). On farm 7, only 3% of the germinable seed was white clover. This low value primarily accounted for the lack of statistical difference between legume density on grazed and ungrazed farms. Seedlings of annual grasses were abundant on only 2 farms (# 2 and 6) (Table 2).

Four species were common to the seed banks of all nine farms: white clover, yel-

Table 1. Mean species richness (S) in vegetation and seedbank for 9 farms where pastures were either hayed or intensively grazed. Farms were sampled across the northeast US in July and August 1997. Values are means with 1 SE () calculated from 4 pastures on each farm (n=4).

	Species Richness (S)	
Farm	Vegetation	Seedbank
Hayed Pastures		
1	13(1)	18(1)
2	15 (2)	15 (3)
Grazed Pastures		
3	11(1)	12(1)
4	10(0)	7(1)
5	11(1)	8(0)
6	12(1)	10(3)
7	18(3)	10(1)
8	14(1)	6(1)
9	15(2)	4(1)

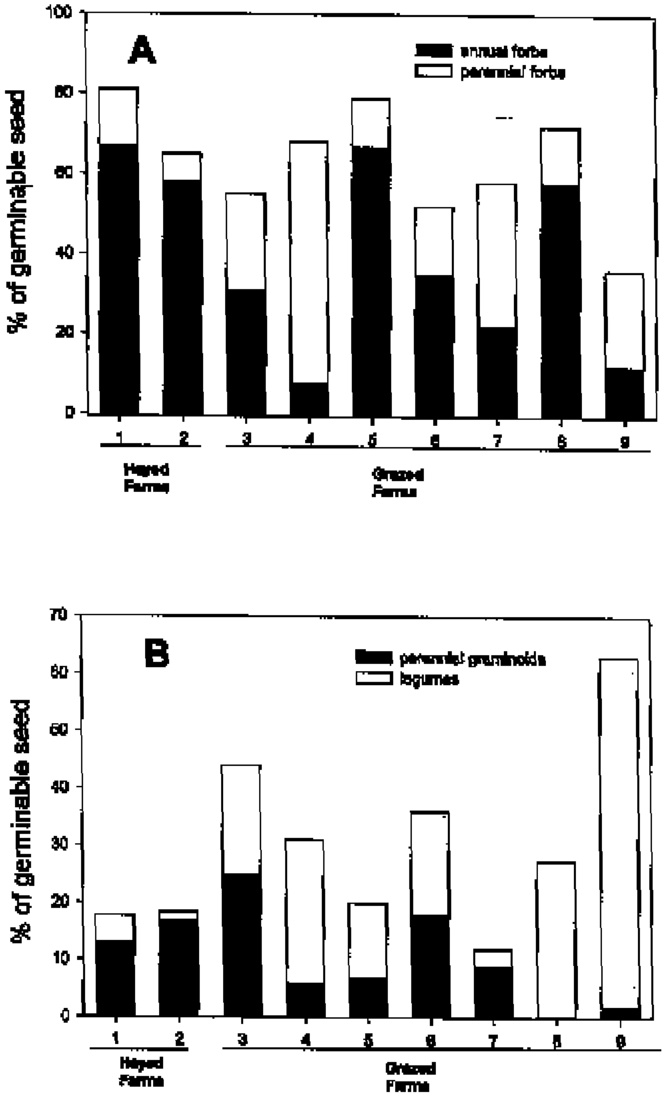

Fig. 1. Percent of the total germinable seed that were (A) annual and perennial forbs and (B) perennial grasses and legumes. Farms 1 and 2 were hayed in the last five years while farms 3–9 were in continuous rotational grazing.

low wood sorrel (*Oxalis stricta* L.), common dandelion and bluegrass (Table 2). Among the annual forbs, yellow rocket (*Barbarea vulgaris* R. Br.) and lamb's quarters (*Chenopodium album* L.) attained the highest densities on 7 of the 9 farms. Among annual grasses, yellow foxtail (*Setaria glauca* P. Beauv.) yielded the highest density of seedlings, but it was only found on 2 farms. Chess grass *(Bromus secalinus* L.) was more common across farms. Seedlings of white clover, dandelion, and bluegrass were the most abundant legume, perennial forb and perennial grass, respectively.

Sorensen's coefficient of community (CC) was calculated to index similarities between seed bank and vegetation species on respective farms (Fig. 2). Seed bank species and existing vegetation were more similar on ungrazed farms (60±3) while the coefficient of community on grazed farms averaged (39±11) ($t=2.47$, $p= 0.042$, $df=7$). Four of 9 farms showed positive correlations between species composition in the seed bank and standing crop: Farm 3: $r=0.52$, $p=0.003$, $df= 28$, Farm 4: $r=0.60$, $p=0.0014$ $df= 23$, Farm 6: $r=0.54$, $p=0.004$ $df=23$ and Farm 9: $r=0.56$, $p=0.0017$, $df=26$. Three species primarily were responsible for these positive relationships. If farms had abundant seedlings of either bluegrass, dandelion, or white clover in their seed bank these species were usually common in the existing vegetation. Yellow rocket, lamb's quarters and common chick weed (*Stellaria media* (L.)Villars.) were abundant in the seed bank, but usually rare in the vegetation.

Discussion

Our findings suggest that seed banks in northeast pastures may not supply a diverse assemblage of useful forage species for cattle. With the exception of bluegrass, perennial grasses, were essentially absent from the germinable seed bank. Prince and Hodgdon (1946) also found abundant germination of bluegrass, and detected few economically useful species in their survey of 21 pastures in New Hampshire. Although dominant in the vegetation, perennial grasses are almost universally under represented in the germinable seed bank (Chippindale and Milton 1934, Prince and Hodgdon 1946, Champness and Morris 1948, Major and Pyott 1966, Archibold 1981, Rabinowitz 1981, Hassan and West 1986, Rice 1989, Perez et al. 1998). Unlike annual and perennial forbs, most perennial grasses rely on vegetative reproduction and have not evolved seed that remains viable for long periods in soil (Roberts 1981). Unless germination conditions are immediately optimal for perennial grasses, much of this seed will be lost from the seed bank through decomposition or predation. Bluegrass is an exception to most perennial grasses because it forms substantial reserves of viable seed (Chippindale and Milton 1934, Champness and Morris 1948, Jalloq 1975, Roberts 1981). Of course, grazing can also affect seed bank composition (Major and Pyott 1966, Jalloq 1975, Iverson and Wali 1982, Kinucan and Smeins 1992, Bertiller 1992) especially if defoliation interrupts sexual reproduction.

Legumes were more abundant than perennial grasses in seed banks, particularly on farms that used management-intensive grazing. Compared with most perennial grasses, legumes produce large numbers of durable seed that maintain viability for long periods (Beale 1974, Jalloq 1975, Jones and Evans 1977, Rice 1989). Furthermore, some legumes like white clover have no specific germination requirements, so their seeds may germinate readily under many different conditions particularly if the population has a low abundance of hard seed genotypes (Turkington and Burdon 1983). Grazing by cattle may also increase seed production of white clover and indirectly raise seed bank stores. Because grazing reduces the height of tall grasses and increases light availability for more prostrate white clover plants, grazing may indirectly promote clover growth and reproduction.

Table 2. Mean density of germinated seedlings (m^{-2}) for the 9 farms surveyed and the number of farms where the respective species were found. Values are means and 1 SE from the 9 farms. Nomenclature follows (Gleason and Cronquist 1991).

	Mean	SE	# of farms		Mean	SE	# of farms
	(m^{-2})				(m^{-2})		
Annual/Biennial Forbs	**1019**	**386**	**9**	**Legumes**	**224**	**51**	**9**
Abutilon theophrasti	75	29	3	*Baptista tinctoria*	6		1
Amaranthus blitoides	9	1	3	*Medicago lupulina*	33	18	6
Amaranthus retroflexus	6	0	2	*Trifolium pratense*	6		1
Ambrosia artemisiifolia	22	3	4	*Trifolium repens*	201	48	9
Anthemis arvensis	35	19	4				
Arabis lyrata	64		1	**Perennial Forbs**	**330**	**47**	**9**
Barbarea vulgaris	462	192	7	*Allium canadense*	13		1
Brassica kaber	241	136	3	*Cerastium vulgatum*	39	12	8
Capsella bursa-pastoris	96	34	6	*Cichorium intybus*	26		1
Cardamine hirsuta	19		1	*Glechoma hederacea*	13		1
Cardamine parviflora	13		1	*Oxalis stricta*	56	15	9
Chenopodium album	319	122	7	*Plantago major*	78	21	6
Cirsium vulgare	6		1	*Potentilla norvegica*	21	6	6
Daucus carota	34	13	2	*Rubus* spp.	6	0	2
Erigeron annuus	19	0	2	*Rumex crispus*	49	17	2
Erysimum cheiranthoides	13		1	*Taraxacum officinale*	150	39	9
Euphorbia nutans	32	6	2	*Veronica serpyllifolia*	15	3	3
Malva neglecta	13		1				
Oenothera biennis	64	17	3	**Perennial Grasses**	292	122	9
Polygonum aviculare	28	3	3	*Cyperus* spp.	16	5	2
Polygonum convolvulus	6		1	*Dactylis glomerata*	26	7	3
Polygonum pensylvanicum	21	4	3	*Elytrigia repens*	19	3	2
Sonchus asper	38	15	2	*Festuca arundinacea*	10		1
Stellaria media	77	38	6	*Juncus tenuis*	53		1
Urtica dioica	33	9	5	*Phalaris arundinacea*	37	11	4
Veronica arvensis	41	13	2	*Poa pratensis*	252	118	9
Veronica peregrina	483		1				
Annual Grasses	**273**	**147**	**5**				
Bromus secalinus	8	1	4				
Echinochloa crusgalli	58		1				
Panicum dichotomiflorum	10	2	2				
Poa annua	269		1				
Setaria glauca	494	221	2				

Most studies report striking differences between the species composition of grassland seed banks and standing vegetation (Major and Pyott 1966, Rabinowitz 1981, Hassan and West 1986, Bertiller 1992, Kinucan and Smeins 1992). In our survey, several species, (e.g. yellow rocket, lamb's quarters and chick weed) were abundant in the seed bank but rare in the vegetation. Such species likely represent past ecological conditions, have pulsed seed input, possess long-lived seed, and may only emerge from the seed bank under specific conditions (Rabinowitz 1981). These species probably become more important in the community after severe disturbance, and their identification in the seed bank may be important to predict vegetation dynamics in these pastures.

Positive correlations between seed bank species composition and the composition of aboveground vegetation suggests that either a large proportion of the seed recently entered the seed bank or, in the case of a more persistent seed bank, species abundance in the seed bank is more continuous where it is present in the vegetation (Kirkham and Kent 1997). Bluegrass, white clover, and dandelion were abundant in both the germinable seed bank and existing vegetation on the majority of pastures. This finding suggests that these 3 species may perpetuate their dominance in grazed pastures through recruit-

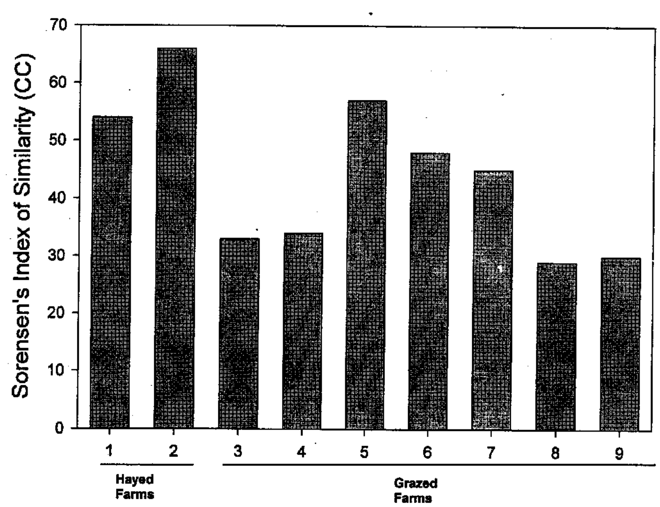

Fig. 2. Sorensen's index for community similarity (Magurran 1988) comparing seed bank species and standing crop in pastures. Higher values indicate greater similarity between the germinable seed bank and existing vegetation.

ment of seed bank individuals. Although dandelion was abundant in both the seed bank and vegetation on most farms, this species does not produce seed that remains viable in the soil for long periods (Grime et al. 1988). The abundance of dandelion in the germinable seed bank likely reflects recent seed input during the spring before soil cores were collected (August). To reduce dandelion abundance, eradication measures should be applied early in the spring before most individuals set seed.

In our study, ungrazed pastures showed higher similarity in species composition between their seed bank and aboveground vegetation than did grazed pastures, especially for annual and perennial forbs. In general though, our findings differ from those of Kinucan and Smeins (1992) who found weedy dicots more prevalent in the seed banks of grazed areas compared with ungrazed areas. Possibly, grazing intensity was lower on our pastures and thus did not promote extensive recruitment of weedy species from the seed bank. A better explanation is that annual forbs were competitively excluded by either bluegrass, white clover or dandelion that became established in gaps created by grazing. Our data suggests that existing seed banks or inputs from seed rain can supply these species to fill gaps created in the grassland canopy. Other than white clover, however, we find no evidence that grazing increases the density of desirable forage species in seed banks.

Conclusions

Findings from this study showed that seed banks from northeast pastures contain an abundance of viable bluegrass and white clover seed, but few other useful forage species. Frequent recruitment of bluegrass and white clover seedlings into the aboveground vegetation probably helps maintain a stable forage base in response to frequent disturbance in these pastures. Nevertheless, more research is needed to develop management strategies or new seed types that will increase the diversity of viable forage seed in pastures. A diverse and viable seed bank of forages may allow farmers to depend less on replanting or frequently over seeding pastures to attain desired pasture mixes for specific operational needs.

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Understory dynamics in cut and uncut western juniper woodlands

JON D. BATES, RICHARD F. MILLER, AND TONY J. SVEJCAR

Authors are research associate, Oregon State University, Eastern Oregon Agricultural Research Center, Burns, Ore. 97720; professor, Rangeland Resources Department, Oregon State University, Eastern Oregon Agricultural Research Center, Burns, Ore.; and research leader, USDA-ARS, Eastern Oregon Agricultural Research Center, Burns, Ore. At the time of the research, the senior author was a research assistant, Rangeland Resources Department, Oregon State University, Eastern Oregon Agricultural Research Center.

Abstract

Expansion of western juniper (*Juniperus occidentalis* spp. *occi - dentalis* Hook.) woodlands in the sagebrush steppe has the potential to change composition, structure, and productivity of understory vegetation. Cutting of western juniper woodland can potentially restore understory productivity and diversity. Understory responses were assessed after cutting a juniper woodland in southeastern Oregon in 1991. The experimental design was a randomized complete block with eight, 0.8 ha sized blocks and 2 treatments, cut and uncut woodland. Understory cover, density, diversity, biomass, and nitrogen (N) status were compared between treatments after cutting. Plants were separated into 5 functional groups: bluegrass (*Poa* spp.), perennial bunchgrass, perennial forb, annual forb, and annual grass. Cutting of juniper reduced belowground interference for soil water and N. Leaf water potentials were less negative (P<0.01) and understory N concentration and biomass N were greater (P<0.05) in the cut versus woodland treatment. Cutting of juniper trees was effective in increasing total understory biomass, cover, and diversity. In the second year post-cutting total understory biomass and N uptake were nearly 9 times greater in cut versus woodland treatments. Perennial plant basal cover was 3 times greater and plant diversity was 1.6 times greater in the cut versus woodland treatments. In the cut, perennial bunchgrass density increased by 1 plant m^{-2} in both duff and interspace zones and bluegrass increased by 3 plants m^{-2} in interspaces. Plant succession was dominated by plants present on the site prior to juniper cutting suggesting that pre-treatment floristics may be useful in predicting early successional understory response. Early plant dynamics on this site supports the multiple entrance point model of succession as perennial grasses and bluegrass made up the majority of total herbaceous biomass and cover.

Key Words: interference, water potential, nitrogen content, diversity, restoration, tree cutting.

Resumen

La expansión del "Western juniper" (*Juniperus occidentalis* spp. *Occidentalis* Hook) en las estepas de "Sagebrush" tiene el potencial de cambiar la composición, estructura y productividad de la vegetación herbácea. La tala de bosques de "Western juniper" puede potencialmente restaurar la productividad y diversidad de la vegetación herbácea. Se evaluó la repuesta de la vegetación herbácea después de cortar en 1991 un bosque de "Western juniper" en el sudeste de Oregon. El diseño experimental utilizado fue el de bloques completos al azar con 8 bloques de 0.8 ha y dos tratamientos, con corte y sin corte. Se comparó entre tratamientos la cobertura, densidad, diversidad, biomasa y el contenido de nitrógeno de la vegetación herbácea después de la tala. Las plantas fueron separadas en 5 grupos funcionales: "Bluegrass" (*Poa*. spp.), "Bunchgrass perenne", hierbas perennes, hierbas anuales y zacates anuales. El corte de "Western juniper" redujo la interferencia en el subsuelo del agua y el nitrógeno del suelo. Los potenciales de agua de las hojas fueron menos negativos (p<0.01) y la concentración de N de la biomasa de la vegetación herbácea fue mayor (p<0.05) en el tratamiento con corte de "Western juniper". El corte de árboles de 'Western juniper" fue efectivo para incrementar la biomasa total, cobertura y diversidad de la vegetación herbácea. En el segundo año después del corte, la biomasa de la vegetación herbácea y la absorción de nitrógeno fueron casi 9 veces mayores en el tratamiento con corte que en el tratamiento sin corte. La cobertura de plantas perennes fue 3 veces mayor y la diversidad de plantas fue 1.6 veces mas en las áreas con corte que en las intactas. En las parcelas con corte, la densidad de "Bunchgrass" perenne se incremento a razón de 1 planta m^{-2} en los interespacios y el "Bluegrass" aumentó en 3 plantas m^{-2}. La sucesión vegetal fue dominada por plantas que estaban presentes en el sitio antes de cortar el "juniper", sugiriendo que la composición florista pre-tratamiento puede ser útil para predecir la respuesta sucesional inicial de la vegetación herbácea. La dinámica inicial de las plantas en este sitio sostiene el modelo de sucesión de punto de entrada múltiple conforme los zacates perennes y el "bluegrass" constituyen la mayoría de la biomasa y cobertura total de la vegetación herbácea.

Displacement of sagebrush steppe communities by the recent expansion of western juniper (*Juniperus occidentalis* spp. *occi - dentalis* Hook.) woodlands has raised concerns over the effects of tree canopy development on plant community structure, composition, and diversity. Since the late 1800's western juniper has increased in density and spatial extent in central and eastern Oregon, northeastern California, and southwestern Idaho (Miller and Wigand 1994). Prior to Euro-American settlement, western juniper was largely confined to areas with shallow rocky soils underlain by fractured bedrock (Burkhardt and Tisdale 1969, Miller and Wigand 1994, Miller and Rose 1995). Recent juniper expansion has occurred in deeper more productive soils occupied

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by mountain big sagebrush [*Artemisia tridentata* spp. vaseyana Nutt.] grasslands, riparian zones, and quaking aspen [*Populus tremuloides* Michx.] woodlands (Burkhardt and Tisdale 1969, Eddleman 1987, Miller and Rose 1995). Reduced fire frequency is the main causal factor attributed to the expansion of juniper (Burkhardt and Tisdale 1976, Evans and Young 1985). The decrease in fire frequency began in the late 1800's with the suspension of fires set by Native-Americans (Miller and Wigand 1994). Reductions in fine fuel loads as a result of heavy livestock grazing at the turn of the century and additional fire suppression have further reduced fire frequency in shrub steppe communities (Burkhardt and Tisdale 1976, Miller and Wigand 1994). Succession to juniper-dominated communities is accompanied by reductions in understory productivity (West 1984, Vaitkus and Eddleman 1987), cover (Driscoll 1964), and diversity (Burkhardt and Tisdale 1969), increased site aridity (Angell and Miller 1994), and accelerated soil erosion (Buckhouse and Mattison 1980).

Juniper dominated communities are relatively stable and resistant to all but the most severe fire disturbances (Miller and Wigand 1994). Natural or prescribed fire is largely eliminated as a management tool for restoring understory vegetation in woodlands because of lack of fuels necessary to carry fires through juniper stands. Consequently, understory restoration in many juniper dominated communities is limited to mechanical treatments such as tree cutting or chaining.

Tree cutting is commonly used to restore understory productivity in areas occupied by western juniper. Cutting of trees in western juniper woodlands (Vaitkus and Eddleman 1987, Rose and Eddleman 1994) and *Pinus monophylla* Torr. & Frem.—*Juniperus osteosperma* (Torr.) Little woodlands in Nevada (Everett and Sharrow 1985a) removes overstory interference and leads to greater understory biomass and cover. Nonetheless, there is insufficient quantitative and qualitative evidence documenting impacts of cutting in western juniper woodlands on plant community structure, composition, and diversity. It will be important to understand the effects of tree cutting in the juniper ecosystem because cutting is likely to increase in the near future as juniper may be used in a variety of wood products. There is concern that lack of a good ecological data base will hamper or misdirect decision making for understory restoration and commercial use of western juniper woodlands.

Understory dynamics after tree cutting in a western juniper woodland were assessed in this study. We hypothesized that cutting of juniper would reduce belowground interference for water and nitrogen, which would result in increased cover, biomass, density, and diversity of understory plants.

Materials and Methods

Study Site

The study site was on Steens Mountain in southeast Oregon (118°36' E, 42°55' N). Elevation at the site is 1,525 m. Aspect is west facing with a 22% slope. The site was dominated by an 80-year-old juniper woodland (Bates 1996). Full occupancy of the site by juniper was indicated by the limited leader growth on juniper trees, low herbaceous cover, and the majority of mountain big sagebrush shrubs being dead. Juniper canopy cover averaged 24% and tree density averaged 228 trees/ha. Bare ground accounted for 74% of the area and rill erosion was evident throughout the site. Basal cover of understory perennials averaged less than 2.3% across the site (Bates 1996). In the early 1900's this site was used as wintering grounds for domestic sheep. Since the late 1940's the site has been moderately grazed by cattle in the early spring.

The understory was dominated by Sandberg's bluegrass (*Poa sandbergii* Vasey). Sandberg's comprised about 75% of the total understory perennial plant basal cover. Other species characteristic of the site were bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) Smith), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith (syn. *Pseudoroegenaria spicata* (Pursh) A. Löve)), Thurber's needlegrass (*Stipa thurberiana* Piper), basalt milkvetch (*Astragalus filipes* Torr.), and pale alyssum (*Alyssum alyssoides* L.). Based on remnant plants, soils, elevation, and aspect, we judged the plant community prior to juniper encroachment to be a Mountain big sagebrush-Thurber's needlegrass association.

Climate in southeast Oregon is typically cool and moist during winter and spring periods, while summers are warm and dry. The majority of annual precipitation falls between November and late May. Water year (October 1–Sept. 30) precipitation at Malheur National Wildlife Refuge weather stations located 27 km southwest (elev. 1,300 m) and 30 km northwest (1,250 m) of the site averaged 282 mm and 249 mm, respectively, over the past 30 years.

Soils on the site are rocky, 40 to 50 cm deep, and clay loam in texture. Soils are underlain by a welded ash tuff of rhyolite/rhyodacite composition, which restricts root penetration. Soils were classified as clayey-skeletal, smectitic, frigid, Lithic Argixerolls.

Experimental Design

Experimental design was a randomized complete block with 8 blocks and 2 treatments, cut and uncut juniper woodland. Blocks were 0.8 ha in size and were selected for their similarities in soil type, slope, and aspect, and overstory/understory density and cover characteristics. Measurements of baseline vegetation characteristics were recorded prior to tree cutting in July 1991. Half of each block was cut with chainsaws in August 1991. All cut juniper trees were left in place. Leaving cut trees on site is a standard practice in eastern Oregon. Three small juniper trees (<3 m) were left in each cut block for measurement of leaf water potentials (Ψ_l). Post-treatment measurements of understory characteristics, Ψ_l, and soil water content began in April 1992 and were concluded in September 1993. Livestock were excluded during the study.

Understory Sampling Procedures

Understory measurements were basal cover (perennial plants), canopy cover, density, diversity, biomass, and nitrogen (N) content. Understory plants were measured by species but are organized into 5 functional groups to simplify presentation of results (Table 1). The functional groups are: (1) bluegrass (Sandberg's bluegrass); (2) perennial grasses; (3) perennial forbs; (4) annual grasses; and (5) annual/biennial forbs. Sandberg's bluegrass is perennial but differs from the other bunchgrasses morphologically and phenologically. Sandberg's is of lower stature, with shallow roots, and grows and develops earlier in the spring than other bunchgrass species (Rickard and Vaughn 1988, Link et al. 1990).

Understory biomass was sampled at peak standing crop for perennial grass, bluegrass, perennial forb, and annual grass in 1992 and 1993. Biomass was sampled at 3-m intervals with 1-m^2 quadrats along two, 45-m randomly selected transects in cut and uncut woodland blocks. Vegetation was clipped to a 1-cm stubble height. Clipped herbage was dried at 60°C for 48 hours prior to weighing. In 1993, subsamples of each plant group were ground to pass a 0.1-mm screen and ana-

Table 1. Understory functional groups showing common species identified in cut and uncut western juniper woodland. Nomenclature of plant species follows Hitchcock and Cronquist (1973).

Bluegrass	
Pine bluegrass	*Poa scrabella* Vasey
Sandberg's bluegrass	*Poa sandbergii* Vasey
Perennial Grasses	
Bluebunch wheatgrass	*Agropyron spicatum* (Pursh) Scribn. & Smith
Basin wildrye	*Elymus cinereus* Scribn. & Smith
Prairie junegrass	*Koeleria cristata* Pers.
Indian ricegrass	*Oryzopsis hymenoides* (R. & S.) Ricker
Bottlebrush squirreltail	*Sitanion hystrix* (Nutt.) Smith
Thurber's needlegrass	*Stipa thurberiana* Piper
Perennial Forbs	
Pale agoseris	*Agoseris glauca* (Pursh) Raf.
Basalt milkvetch	*Astragalus filipes* Torr.
Mariposa lily	*Calochortus macrocarpus* Dougl.
Western hawksbeard	*Crepis occidentalis* (Hook.) H. & A.
Desert yellow daisy	*Erigeron linearis* (Hook.) Piper
Donnell's lomatium	*Lomatium donnelli* Coult & Rose
Tailcup lupine	*Lupinus caudatus* Kell.
Showy penstemon	*Penstemon speciosus* Dougl.
Silverleaf phacelia	*Phacelia hastata* Dougl.
Hood's phlox	*Phlox hoodii* Rich.
Annual Grasses	
Japanese Brome	*Bromus japonicus* Thunb.
Cheatgrass	*Bromus tectorum* L.
Pale alyssum	*Alyssum allyoides* L.
Blepharipappus	*Blepharipappus scaber* Hook.
Utah thistle	*Cirsium utahense* Petr.
Watson's crypthantha	*Crypthantha watsonii* (Gray) Greene
Tanseymustard	*Descurainia pinnata* (Walt.) Britt.
Autumn willoweed	*Epilobium paniculatum* Nutt.
Prickley lettuce	*Latuca serriola* L.
Hoary aster	*Machaeranthera canascens* (Pursh) Gray
Microsteris	*Microsteris gracilis* (Hook.) Cronq
Threadleaf phacelia	*Phacelia linearis* (Pursh) Holz.
Burr buttercup	*Ranunculus testiculatus* Crantz

lyzed for N concentration using a PE 2400 II CHNS analyzer (Perkin-Elmer Corp. Norwalk, Connecticut)[1]. Biomass N content was estimated by multiplying N concentration by understory biomass values.

Understory plant density was measured using 30.5 x 61-cm quadrats in duff and interspace zones. Duff zones were defined as: 1) areas beneath existing juniper canopies in uncut woodlands and 2) areas previously under juniper canopies in cut plots. Quadrats were placed in the outer third of the duff area. Interspace zones were defined as open areas not influenced by juniper litter. Subsampling for the interspace zone occurred approximately 3 m from the edge of duff zones. Density was measured in 4 cardinal directions around 12 randomly selected trees in each cut and woodland plot (48 quadrats per zone in each plot). Statistical analysis showed cardinal direction was not a significant factor in explaining treatment or zonal differences.

[1]Mention of trade names does not imply endorsement by Oregon State University or USDA-ARS.

Basal cover of perennial plants was measured along five, 30.5-m line transects (Canfield 1941) in each cut and woodland plot in 1991, 1992, and 1993. Basal cover was separated into interspace and duff zones. Along transects ground cover provided by trees, litter zones (duff and cut trees), and canopy cover provided by herbaceous plants was estimated.

Soil Water Availability and Plant Phenology

Soil water availability was determined from gravimetric soil water content and leaf water potentials (Ψ_l) of junipers during the 1992 and 1993 growing seasons (April–September). Soil water samples were collected the day preceding measurement of Ψ_l. Soil samples were collected at 2 depths, 0–20 cm and 20–40 cm, in interspace soils of cut and woodland treatments. Five samples, randomly placed, were collected for each depth in each treatment plot. Soils water was determined gravimetrically after drying at 106°C for 48 hours. Soil water potentials and release curves (–0.03 to –1.5 MPa) were developed using a pressure plate apparatus.

Leaf water potential of juniper was measured with a pressure chamber using methods described by Turner (1981). Predawn and midday Ψ_l were collected every other week on 12 dates in 1992 and on 13 dates in 1993. Junipers were used because their root system explored the soil at all depths thus indicating the availability of water through the entire soil profile. Because soils were shallow (≤45 cm) we felt that juniper Ψ_l would approximate herbaceous Ψ_l , at least during the spring growth period. Observation of understory phenology and growth characteristics (e.g. tillering, duration of the growth period) also served as indicators of soil water availability.

Statistical Analysis

Understory data were compared between treatments over time using ANOVA techniques for a randomized block design. Main effects for understory biomass and biomass N were year and treatment. Main effects for density and cover were year, treatment, and zone. Soil water content and leaf water potentials were analyzed using repeated measures ANOVA's for a randomized block design. Main effects for soil water content were treatment, soil depth, and time. All statistical analyses were performed using the Statistical Analysis System (SAS Institute 1988). Data was tested for normality using the SAS univariate procedure. Data not normally distributed were log transformed to stabilize variance. When interactions were significant means were separated using Fisher's protected LSD procedure. Statistical significance of all tests was assumed at $P<0.05$.

Hill's (1973) N1 and N2 indices were used as indicators of plant diversity. Hill's N2 index is a measure of very abundant species and Hill's N1 index is a measure of abundant species. Hill's modified evenness ratio was used to compare relative abundances of species between zones (Ludwig and Reynolds 1988).

Results and Discussion

Precutting Understory Characteristics

Baseline measurements made before juniper cutting in 1991 indicated there were no differences in basal cover (Table 2) of herbaceous perennials or in understory plant density (Table 3), (except perennial forbs), between plots that were left as woodlands and plots selected to be cut.

Table 2. Understory basal cover (%) means (±SE) by year, zone, treatment and functional group. Column means sharing the same lower case letter are not significantly different (P>0.05).

Parameter	Year	Zone	Treatment	*POA*	*PG*	*PF*	Total
Basal Cover	1991	Interspace	Cut	1.1 ± 0.2 a	0.8 ± 0.2 c	0.2 ± 0.1	2.1 ± 0.5 ab
(%)			Woodland	1.3 ± 0.2 a	0.7 ± 0.1 bc	0.3 ± 0.1	2.3 ± 0.2 b
		Duff	Cut	2.0 ± 0.4 b	0.6 ± 0.1 bc	0.2 ± 0.1	2.8 ± 0.5 b
			Woodland	1.6 ± 0.2 b	0.7 ± 0.2 bc	0.3 ± 0.1	2.4 ± 0.5 b
	1992	Interspace	Cut	1.0 ± 0.2 a	0.9 ± 0.2 c	0.4 ± 0.1	2.3 ± 0.3 b
			Woodland	0.9 ± 0.2 a	0.4 ± 0.1 ab	0.2 ± 0.1	1.4 ± 0.2 a
		Duff	Cut	1.7 ± 0.5 b	0.4 ± 0.2 ab	0.3 ± 0.2	2.4 ± 0.7 b
			Woodland	1.4 ± 0.2 b	0.2 ± 0.1 a	0.1 ± 0.0	1.5 ± 0.2 a
	1993	Interspace	Cut	1.7 ± 0.3 b	2.2 ± 0.4 d	0.4 ± 0.2	4.3 ± 0.7 c
			Woodland	0.9 ± 0.1 a	0.3 ± 0.1 ab	0.2 ± 0.1	1.4 ± 0.2 a
		Duff	Cut	2.8 ± 0.4 c	1.9 ± 0.5 d	0.2 ± 0.1	4.8 ± 0.9 c
			Woodland	1.3 ± 0.1 ab	0.1 ± 0.1 a	0.1 ± 0.0	1.5 ± 0.2a

Perennial forb density was significantly less in cut interspaces than in other zones. Precutting analysis indicated density and cover of bluegrass was greater in duff zones than in interspaces (P<0.001). These zonal relationships for the functional groups did not change after tree cutting. Thus, post-cutting results for 1992 and 1993 will focus on treatment differences. Annual forb densities were probably under estimated in 1991. Annual forbs completed their growth phases by July when measurements were made, thus, many plants had deteriorated to the point where a complete count was no longer possible.

Post-Cutting; Resource Availability

Removal of juniper reduced belowground interference, thus increasing availability of soil water in 1992 and 1993. However, growing conditions and soil water availability differed markedly between years. The 1992 growing season was warmer and dryer than local and regional averages. Water year precipitation at nearby weather stations was 25% below average. Study site precipitation in the 1992 water year totaled 213 mm, half of which was received late in the growing season in June and July. Despite a dry year, soil water content was significantly greater (P<0.01) at both depths in cut plots versus woodland plots throughout the growing season (April–September) (Fig. 1A and 1B). As a result of greater available soil water, juniper predawn and midday Yl were less negative (P<0.001) in the cut versus woodland treatment (Figs. 2A and 2B). In both treatments Ψ_l became more negative over time as soil water decreased during the growing season (P<0.001).

In 1993 eastern Oregon received record amounts of moisture. Precipitation at the Malheur Wildlife Refuge weather stations were 140% and 149% of long term averages. Precipitation on the study site totaled 418 mm. Due to the wet spring, soil water content did not differ between treatments until late June (Fig 1A and 1B). Despite similar soil moisture conditions between March and June, juniper predawn and midday Ψ_l were significantly less negative (P<0.001) in cut versus woodland plots (Figs. 2A and 2B). Differences in Ψ_l between treatments increased after late June as available soil water was depleted more rapidly in woodland plots.

Juniper interference with N uptake by the understory was evident in 1993. Nitrogen concentration in biomass was greater (P<0.05) in the cut versus woodland plots, with the exception of bluegrass (Table 4). The lower N concentration in bluegrass in the cut versus the woodland may have been due to a dilution effect (Mislevy and Everett 1981) resulting from greater bluegrass biomass in the cut treatment (Table 4). Total bluegrass biomass N was 5 times greater in cut versus the woodland plots. The combination of increased biomass production and greater N concentration in the other functional groups resulted in greater total aboveground understory N content in the cut plots (Table 4). We concluded that juniper interfered with understory N uptake in the woodlands because soil N availability and mineralization did not differ between the 2 treatments in 1993 (Bates 1996). Increased understory N content has also been measured after cutting pinyon-juniper woodlands in Nevada (Everett and Sharrow 1985b).

Table 3. Understory density (plants m^{-2}) means (±SE) by year, zone, treatment, and functional group. Column means sharing the same lower cowe letter are not significantly different (P<0.05).

Parameter	Year	Zone	Treatment	Bluegrass	Perennial Grass	Perennial Forb	Annual Grass	Annual Forb
Density	1991	Interspace	Cut	5.6 ± 0.6 a	2.9 ± 0.5 bc	0.4 ± 0.1 a	0.3 ± 0.2 a	6.2 ± 5.2 a
(Plants/m^2)			Woodland	6.1 ± 0.6 ab	2.9 ± 0.4 bc	1.0 ± 0.4 b	1.5 ± 1.4 ab	7.9 ± 6.2 a
		Duff	Cut	12.7 ± 1.2 c	2.8 ± 0.3 bc	1.0 ± 0.2 b	1.2 ± 0.3 b	5.6 ± 4.7 a
			Woodland	12.0 ± 1.9 c	2.2 ± 0.3 b	1.2 ± 0.2 b	1.8 ± 0.7 b	5.4 ± 4.9 a
	1992	Interspace	Cut	7.5 ± 0.8 b	3.2 ± 0.3 c	1.9 ± 0.4 c	0.4 ± 0.1 a	85.6 ± 16.4 cd
			Woodland	6.3 ± 0.6 ab	1.7 ± 0.3 a	2.1 ± 0.4 c	6.7 ± 3.4 d	263.0 ± 49.4 d
		Duff	Cut	14.7 ± 1.9 c	2.5 ± 0.3 b	2.0 ± 0.3 c	7.3 ± 1.4 d	21.1 ± 3.1 b
			Woodland	13.0 ± 1.8 c	1.6 ± 0.3 a	1.7 ± 0.4 bc	5.0 ± 1.9 cd	3.6 ± 0.9 a
	1993	Interspace	Cut	8.4 ± 0.6 b	4.3 ± 0.3 d	3.6 ± 0.6 d	2.6 ± 0.6 d	104.6 ± 15.4 d
			Woodland	6.9 ± 0.7 ab	1.6 ± 0.3 a	1.8 ± 0.2 c	4.4 ± 2.1 cd	242.9 ± 37.0 e
		Duff	Cut	15.4 ± 1.6 c	4.3 ± 0.3 d	2.8 ± 0.3 d	16.7 ± 3.6 e	79.3 ± 5.4 c
			Woodland	13.9 ± 1.7 c	1.6 ± 0.3 a	3.1 ± 0.5 d	7.1 ± 2.8 d	101.4 ± 15.9 d

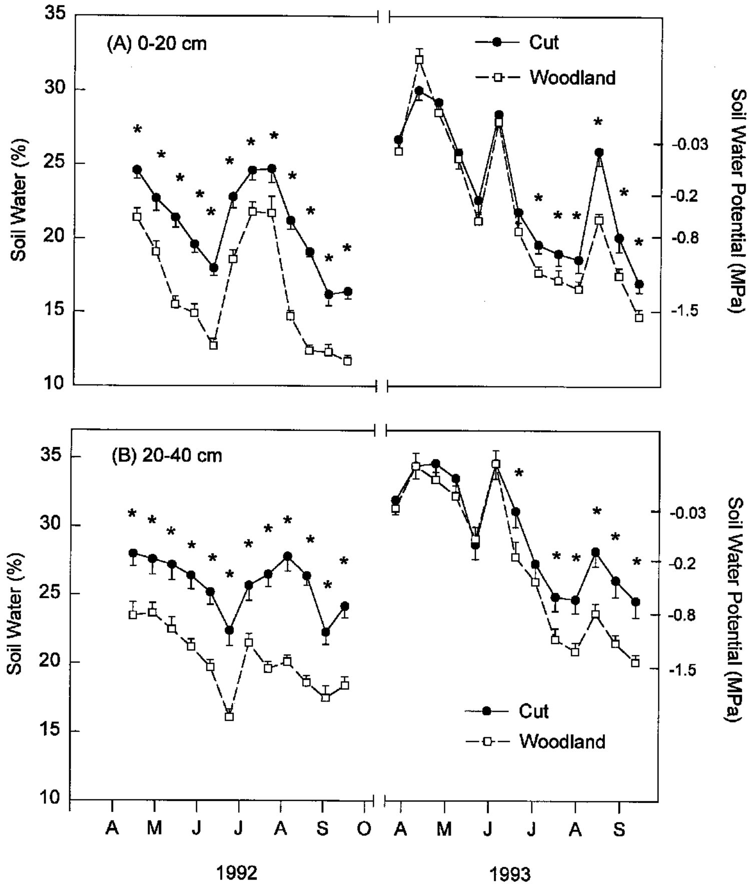

Fig 1. Volumetric soil water content and soil water potential in interspace soils from: (A) 0–20 cm; and (B) 20–40 cm. Data points are means + one standard error. Asterisks indicate significant treatment differences on that sampling date (P<0.05).

Post-Cutting; 1992 Understory Response

Understory response to juniper cutting and the differing growth conditions in 1992 and 1993 produced both expected and unexpected results. In 1992, treatment differences for understory parameters were small and limited to perennial bunchgrass, perennial forb, and annual forb functional groups. Total understory biomass was 2 times greater ($P<0.05$) in the cut compared to the woodland treatment because of greater perennial bunchgrass and perennial forb production (Table 4). Basal cover (Table 2) and density (Table 3) of perennial bunchgrasses were also greater ($P<0.05$) in cut plots.

Differences between treatments for perennial bunchgrasses resulted from a decline ($P<0.05$) in bunchgrass cover (Table 2) and density (Table 3) in the woodlands between 1991 and 1992. The drier soil conditions in the woodlands (Figs. 1 and 2) was probably the main factor contributing to reductions in perennial bunchgrass cover and density. In cut plots bunchgrass density and basal cover showed no significant changes between 1991 and 1992 (Tables 2 and 3). Removal of juniper competition in the cut plots was therefore important in maintaining perennial grass cover and density in the dry year.

An unexpected result was the significantly higher densities ($P<0.01$) of annual forbs in the interspaces of the woodlands versus the cut (Table 3). This difference was a result of higher densities of pale alyssum, an early season annual in woodlands. Interspace density of pale alyssum averaged 218 plants m^{-2} in woodland plots versus only 72 plants m^{-2} in cut plots. We are unsure why interspace annual forb (i.e. pale alyssum) densities were lower in the cut versus woodland treatment considering that soil moisture availability was greater in the cut. Changes in micro-climate, which was not tested, could have negatively affected germination and establishment of pale alyssum, a winter annual, in cut treatment interspaces.

An important advantage to understory plants in the cut plots was their ability to respond to late growing season moisture in 1992. The site received about 90 mm of rain between late June and mid July. Understory plants in the woodland treatment did not respond to the additional moisture and were dormant by early late June. In the cut plots we observed that perennial grasses and forbs, and annual forbs remained active into early September 1992. In July and August, perennial bunchgrasses and bluegrass tillered proficiently, and squirreltail and bluegrass produced a second set of reproductive structures. These basal tillers, initiated in summer 1992, were an important factor in increasing the potential for a significant perennial grass and bluegrass growth response in 1993.

Post-Cutting; 1993 Understory Response

Differences between treatments increased in magnitude in 1993. Total biomass production increased in both cut and woodland treatments (Table 4). However, total biomass increase was nearly 9 times greater in cut plots. Biomass of all the plant groups in the cut plots were greater ($P<0.001$) in 1993 than in 1992 and all were greater ($P<0.001$) in the cut versus the woodland treatment. In the woodlands, bluegrass was the only understory group with significantly more biomass in 1993 compared to 1992. Perennial grasses in woodlands showed no changes in biomass production (Table 4) and cover (Table 2) from 1992 to 1993, although soil moisture availability in the woodlands was similar to that in cut plots during spring 1993 (Figs. 1 and 2).

Total basal cover was 3 times greater in duff and interspace zones of cut plots compared to woodland plots (Table 2). Basal cover differences resulted from increased ($P<0.01$) perennial bunchgrass and bluegrass cover in cut plots between 1991 and 1993. Total ground cover was nearly twice as great ($P<0.01$) in the cut compared to the woodland treatment. Ground cover in the cut plots totaled 56% (juniper debris, 18%; duff and other litter, 20%; interspace herbaceous canopy cover, 18%) compared to 29% in the woodland treatment (juniper trees and duff, 24.5%; interspace herbaceous canopy cover, 4.5%). The increase in herbaceous cover in the cut interspaces is important from a hydrologic standpoint. Erosion rates in semiarid systems are greatest in interspace zones (Wilcox and Breshears 1994). Research in New Mexico suggests that herbaceous ground cover is more effective at reducing erosion rates than is cover of woody vegetation (Wilcox and Breshears 1994). In the western juniper system, Buckhouse and Mattison (1980) measured greater soil ero-

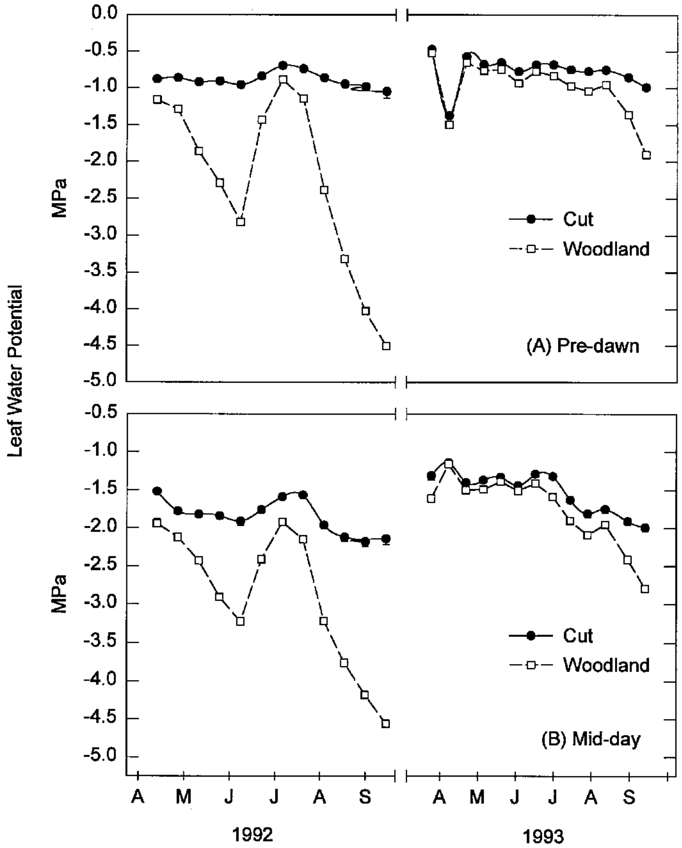

Fig 2. Juniper water potentials for: (A) pre-dawn and; (B) mid day measurements. Data points are means + one standard error. All data points show highly significant differences between treatments (P<0.001).

sion potential in woodland dominated sites than in sagebrush grasslands.

Densities of perennial bunchgrasses remained greater (P<0.05) in both duff and interspace zones of cut plots compared to woodland plots (Table 3). In cut plots perennial bunchgrass density increased by about 1 plant m^{-2} in both duff and interspace zones, and bluegrass increased by about 3 plants m^{-2} in interspaces from 1992. The majority of the increase in perennial grass density can be attributed to squirreltail (Bates et al. 1998). This suggest's squirreltail and bluegrass may, initially, colonize open sites more rapidly than other perennial grasses in this system.

Annual forb densities were greater in woodlands than cut plots in both duff and interspace locations in 1993 (Table 3). The lower annual forb densities in both locations of cut plots was a result of lower densities of pale alyssum compared to woodland plots (Bates 1996). As a result of higher spring moisture conditions annual and perennial forb densities increased significantly between 1992 and 1993 in woodland and cut duff locations, and cut interspace locations. Annual and perennial forbs in woodland interspaces did not respond with higher plant densities in the wet year.

In woodland plots the limited understory biomass response (Table 4) and lack of any cover changes (Table 2) in 1993 indicates that juniper interference of understory plants remains strong during wet years. We do not know how the understory on these shallow soil sites would respond to several additional years of above average soil moisture. Other resources, such as N may limit understory plant growth in high moisture years. Juniper appears to have interfered with understory N uptake (Table 4), which may have limited understory growth in woodlands in 1993. Vaitkus and Eddleman (1987) also measured only small changes in understory biomass production in western juniper dominated communities when precipitation during a 2-year period was double the 30-year average. Additional research is needed to isolate competitive interactions between the understory and overstory in juniper woodlands in wet and dry years.

It has been suggested that junipers may restrict plant growth via the release of allelopathic compounds from litter (Jameson 1966, Gehring and Bragg 1992). Allelopathic effects should not be discounted, but seem unlikely given growth patterns of plants established in litter zones (duff and juniper debris areas) of cut plots. Individual plants that were established or became established in litter zones grew larger than their species counterparts in the interspace, particularly annual grasses and forbs (Bates et al. 1998).

Table 4. Means (±SE) of understory biomass, N concentration, and N content parameters. Column means sharing the same lower case letter are not significantly different (P>0.05).

Parameter	Year	TRT	Bluegrass	Bunchgrass	Perennial Forb	Annual Grass	Total Biomass
Biomass	1992	Cut	12.2 ± 1.1 a	18.9 ± 2.1 b	12.8 ± 3.1 b	1.8 ± 0.9 b	45.7 ± 3.2 b
(kg/ha)		Woodland	12.2 ± 1.6 a	5.8 ± 1.6 a	2.8 ± 1.1 a	0.1 ± 0.1 a	20.9 ± 1.6 a
	1993	Cut	141. ± 20.1 b	154.3 ± 16.2 c	25.8 ± 4.2 c	7.8 ± 2.3 c	329.0 ± 35.2 c
		Woodland	24.7 ± 3.0 c	7.8 ± 1.6 a	4.5 ± 1.0 a	0.8 ± 0.5 ab	37.9 ± 4.1 b
N Concentration							
(%)	1993	Cut	1.33 ± 0.05 g	2.13 ± 0.05 h	3.39 ± 0.15 h	2.10 ± 0.11 h	———
		Woodland	1.66 ± 0.08 h	1.56 ± 0.07 g	2.38 ± 0.18 g	1.60 ± 0.16 g	———
		Duff	Cut	1.7 ± 0.5 b	0.4 ± 0.2 ab	0.3 ± 0.2	2.4 ± 0.7 b
		Woodland	1.4 ± 0.2 b	0.2 ± 0.1 a	0.1 ± 0.0	1.5 ± 0.2 a	
Biomass N							
(kg N/ha)	1993	Cut	1.88 ± 0.07 z	3.27 ± 0.06 z	0.87 ± 0.12 z	0.16 ± 0.09 z	6.19 ± 0.21 z
		Woodland	0.38 ± 0.11 y	0.12 ± 0.04 y	0.12 ± 0.13 y	0.01 ± 0.12 y	0.59 ± 0.12 y

Table 5. Plant diversity (Hill's N1 and N2) indices and eveness ratio (Hill's modified evenness ratio) in duff and interspace locations for cut and woodland treatments. Column means sharing the same lower case letter are not significantly different (P>0.05). N1[1]

Year, Location Treatment	N1[1]	N2[2]	Evenness
1992			
Interspace			
Cut	5.0 b	3.5 b	0.63 ab
Woodland	3.2 a	2.5 a	0.68 b
Duff			
Cut	7.0 d	4.9 d	0.65 ab
Woodland	3.6 a	2.5 a	0.58 a
1993			
Interspace			
Cut	5.9 c	4.0 c	0.61 a
Woodland	3.5 a	2.6 a	0.64 ab
Duff			
Cut	8.5 c	6.2 e	0.69 b
Woodland	4.6 b	3.1 ab	0.58 a

[1]N1–is a measure of the number of abundant species.
[2]N2–is a measure of very abundant species.

Post-Cutting: Succession

Understory response was largely determined by species present on the site prior to juniper cutting. About 70% of the species observed in 1992 and 1993 were present in the study area in 1991. Everett and Ward (1984) estimate that 60 to 80% of predisturbance species return within 1–5 years after burning in pinyon-juniper woodlands. Thus, initial floristics of a site may be used to predict the general character of post-cutting understory response. We agree with Everett and Ward (1984) that making quantitative predictions of plant response are more difficult due to several unknowns, including status of seed bank reserves and post-treatment climate conditions.

Early secondary succession in the cut treatment was dominated by perennial bunchgrass and bluegrass groups in terms of biomass production and cover. In western juniper and other pinyon-juniper woodland studies, annuals, especially cheatgrass, have initially dominated after tree removal by cutting (Vaitkus and Eddleman 1987), chaining (Tausch and Tueller 1977), fire (Barney and Frischknecht 1974, Quinsey 1984), and herbicide application (Evans and Young 1985). For many years it was assumed that succession in treated woodlands went through a standard successional progression beginning with several years of annual dominance followed by successive periods of grass and shrub primacy until trees re-occupied the site. More recently others have demonstrated that plant succession in treated pinyon-juniper woodlands is governed by multiple entrance points dependent on site characteristics and understory composition (Everett and Ward 1984, Everett 1987). Barney and Frischknecht (1974) and Quinsey (1984) reported that the annual stage may be bypassed in areas with fair perennial herbaceous cover prior to disturbance. Results from our study support the multiple entrance point model. In our study, pretreatment densities of perennial bunchgrass species (about 2–3 plants m^{-2}) were sufficient for bunchgrasses to recover and largely dominate the understory component after cutting. Whether this density value is indicative of perennial grass response on other similar sites has not been adequately tested.

There was a compositional shift in biomass production toward later developing, deeper rooted perennial grasses and forbs after cutting. In cut plots, later developing (April–July), deeper rooted perennials (e.g. Thurber's needlegrass, squirreltail, bluebunch wheatgrass) became more dominant components of the understory while in woodland plots Sandberg's bluegrass made up the majority of understory biomass. For example, in 1993 perennial bunchgrasses and forbs represented 56% of total biomass in the cut treatment. In woodlands these same groups only accounted for 27% of total biomass. These results highlight the fact that resource availability on this site becomes limiting for later developing understory plants in established woodlands.

Biodiversity has become an important component in the management of rangelands. Diversity is important because species reductions or losses are perceived to negatively effect the quality and quantity of ecosystem services (West 1993). On this site, dominance by juniper reduced understory diversity. Plant diversity was nearly 2 times greater (P<0.05) in cut plots in 1992 and 1993 compared to the woodlands (Table 5). The higher diversity indices (Hill's N1 and N2) in the cut treatment resulted from a greater variety of perennial and annual forb species (Table 6). A year, treatment, and zonal interaction indicated that diversity indices (N1 and N2) were greatest in cut plot duff zones in 1993 (Table 5). It is not clear what produced this interaction but it may result from differences in microsite characteristics influencing seed germination or plant establishment (e.g. nutrient availability, seed bank reserves, soil moisture conditions). In both treatments species numbers were greater in a wet compared to a dry year. The number of species increased by 11 in cut plots and by 9 in the woodland in 1993. The increase in the number of species resulted from emergence of native and introduced annual forbs and native perennial forbs. The high densities of pale alyssum relative to other species reduced species evenness in both treatments (Table 5). Species evenness tended to be lowest in woodland duff locations in both years compared to other treatment zones.

Because plant diversity quickly increased after cutting it does not appear that juniper dominance inhibited the recovery potential of this sites floristic diversity. Thus, it may take many years of woodland dominance before understory species are effectively removed from a site. It has been demonstrated that soil seed bank reserves and viability decline with woodland establishment and age (Koniak and Everett 1982). While our diversity values provide important information on the structure of site understory composition we do not have the ability to assess their importance or linkage to ecosystem function, an important component to evaluating range health.

Management Considerations

The results indicate restoration of woodland sites requires patience. Understory

Table 6. Herbaceous species numbers in clearcut and woodland treatments in 1992 and 1993. Column means sharing the same lower case letter are not significantly different (P>0.05)

		Species Grouping					
Year	Treatment	Perennial Grass	Annual Grass	Perennial Forb	Native Ann. Forb	Non-native Ann. Forb	Total Herbaceous[2]
1992	Cut	7.8 ± 0.3 b	1.8 ± 0.2 b	8.9 ± 0.6 c	9.9 ± 0.7 c	3.5 ± 0.2 b	34.3 ± 1.5 c
	Woodland	6.4 ± 0.3 a	1.1 ± 0.1 a	3.9 ± 0.4 a	2.5 ± 0.3 a	2.0 ± 0.0 a	16.4 ± 0.7 a
1993	Cut	7.8 ± 0.3 b	2.0 ± 0.0 b	15.0 ± 0.6 d	10.8 ± 0.7 c	5.9 ± 0.4 c	45.6 ± 2.0 d
	Woodland	6.5 ± 0.4 a	1.5 ± 0.2 ab	6.6 ± 0.7 b	7.5 ± 0.7 b	2.9 ± 0.3 b	25.4 ± 0.7 b

response was subtle and limited in the dry year, 1992, before responding dramatically in the wet year, 1993. Thus, it may take several years for understory species to respond to the removal of juniper, particularly during dry periods. However, the lack of a significant understory response the first year after cutting may not be unusual even in wet years. Studies in pinyon-juniper woodlands have shown delays of 1 to several years before the understory fully responds to removal of tree interference under favorable growing conditions (Barney and Frischknecht 1974, Tausch and Tueller 1977, Everett and Ward 1984, Vaitkus and Eddleman 1987). This is because it takes time for existing plants to grow larger and new plants to become established.

Cutting of trees on sites similar to the one used in this study will increase forage production and quality, improve watershed characteristics through increased ground cover, and increase plant diversity. However, variability in site characteristics (soils, aspect, elevation, understory composition) across the western juniper ecosystem will also influence understory response to juniper control. Additional research is required to develop models which assist land managers in predicting understory response and successional pathways after cutting trees across a variety of woodland dominated sites because not all sites will respond similarly. Because cutting is an expensive management alternative this treatment should only be applied to areas where a good understory response would be expected. Successional models would assist resource managers in targeting those areas where desirable understory vegetation may be successfully restored by juniper cutting.

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Influence of pasture management on soil biological quality

MANAS R. BANERJEE, DAVID L. BURTON, W. P. (PAUL) MCCAUGHEY, AND C.A. GRANT

Authors are post doctoral research associate and associate professor Department of Soil Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2; and scientists at Agriculture and Agri-Food Canada, Research Centre, Brandon, Manitoba, Canada R7A 5Y3

Abstract

The long-term sustainability of pasture management systems, whether related to structural stability or nutrient dynamics, is dependent upon maintaining soil biological properties. This study investigates the extent to which the microbiological and biochemical properties of soil can change with season and pasture management system, including their likely value as indicators of soil quality. The experiment was conducted on a 30-ha pasture near Brandon, Manitoba. Seasonal fluctuations were observed in the soil microbial and biochemical properties. In general, these fluctuations were mainly independent of the small variations in soil organic matter content but were more closely related to soil water content. The data also suggests an impact of stocking rate and grazing system on soil microbial biomass C and on N mineralization potential. However, because duration of the investigation, limited number of replications and the high soil variability encountered, it is not yet possible to recommend any particular grazing system and/or stocking rate favorable for the maintenance of soil biological quality. The trends suggest that light, continuous grazing systems had the largest microbial biomass and nutrient mineralizing activity.

Key Words: Microbial biomass carbon, soil enzyme activity, grazing system, stocking rate, rotational grazing

Resumen

La sustentabilidad a largo plazo de los sistemas de manejo de potreros, ya sea relacionados a la estabilidad estructural o la dinámica de nutrientes, depende de mantener las propiedades biológicas del suelo. Este estudio investigo la cantidad a la que las propiedades microbiológicas y bioquímicas del suelo pueden cambiar con la estación y el manejo del potrero, incluyendo su valor probable como indicadores de la calidad del suelo. El experimento se condujo en un potrero de 30 ha cerca de Brandon, Manitoba. Se observaron las fluctuaciones estacionales de las propiedades microbianas y bioquímicas del suelo. En general, estas fluctuaciones fueron principalmente independientes de las pequeñas variaciones del contenido de materia orgánica, pero estuvieron muy relacionadas al contenido de agua del suelo. Los datos también sugieren un impacto de la carga animal y del sistema de apacentamiento en la biomasa microbiana y el potencial de mineralización de carbón y nitrógeno. Sin embargo, debido a la duración de la investigación, el limitado número de repeticiones y la alta variabilidad encontrada, no es posible recomendar un sistema de apacentamiento y/o una carga animal favorable para mantener la calidad biológica del suelo. Las tendencias sugieren que una carga ligera con el sistemas de apacentamiento continuo tuvo la mayor biomasa microbiana y la mayor actividad mineralizante de nutrientes.

The grazing of pasture and range lands by livestock is common practice in Canada and elsewhere and grazing management systems have been shown to influence the soil-plant ecosystem (Warren et al. 1986). The duration and intensity of grazing may affect conservation of soil, water and biological organisms. It has been suggested that the inclusion of a livestock component might play a significant role in increasing the long-term sustainability of agricultural ecosystems (Magdoff 1995). According to Hart and Hoveland (1989) grazing livestock exert 4 primary effects on pasture: a) Defoliation of herbage reduces photosynthetic capacity and may reduce root development, carbohydrate storage, and N_2 fixation. b) Selectivity for plant parts and plant species in a mixed stand may affect relative productivity and persistence of the species present and invasion of undesirable species. c) Trampling damages plant tissue, increases soil bulk density, and slows water infiltration. d) Excretion concentrates urine and dung in small areas and affects plant palatability and nutrient cycling.

Grazing systems may contribute to maintaining high forage nutritional value on pastures (Howarth and Goplen 1983). The quality of forage sustained in rotationally stocked pastures has been reported to be greater than that in pastures stocked continuously (Walton et. al. 1981), but in both rotational and continuous systems, seasonal fluctuations in forage quality have been noted (Jung et al. 1985). Sharrow (1983) demonstrated that better nutrition is provided to animals in rotationally than continuously stocked paddocks, because amounts of plant biomass are greater. Grazing system and stocking intensity experiments in pasture research have focused on livestock weight gains, and forage quality and quantity (Langlands and Bennett 1973, Walton et al. 1981, Jung et al. 1985). However, the nutritional quality and quantity of forages in pasture also depend on the quality of the soil in which they grow. The maintenance and improvement of soil quality is fundamental to sustaining soil fertility and productivity. Soil microbial and biochemical properties are related to soil fertility and productivity. The extent to which these properties can change with season or pasture management system is of interest from several viewpoints, including their likely value as indicators of soil quality (Doran and Parkin 1994). Thus, livestock grazing and stocking rate might affect soil microbial activities and their role in nutrient transformation in pasture land. Our object was to determine the effects of grazing system (including stocking rate) and season on microbial and biochemical properties of soil.

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The soil biota is the main driving force behind nutrient and energy transformations in soil. Through the production of enzymes, soil organisms mediate the major catalytic processes in soil as well as being themselves substrates for decomposition. The microbial community inhabits the soil environment, responding to physical, chemical or biological perturbation. Soil biological properties were chosen to represent the soil environment in which organisms must exist (soil organic matter content, water content), the microbial community itself (microbial biomass C and N content) and biochemical activity of the microbial population (N mineralization, arylsulfatase and phosphatase). The biochemical activities were chosen to be representative of the major nutrients (N, P and S) which influence plant productivity. In this work we evaluate the magnitude and change in these properties, albeit over a limited time frame, and interpret these findings in the context of soil quality and productivity.

Materials and Methods

The experiment was conducted on a 30-ha pasture near Brandon, Manitoba (49° 52' N; 99° 59' W; Elevation 363 m above sea level). Initially, the pasture consisted of approximately 70% alfalfa (*Medicago sativa* L.), 25% meadow bromegrass (*Bromus biebersteinii* Roem and Schult.) and 5% Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski). The area was seeded in 1990 and pastures were fertilized with N, P, K, and S to meet Manitoba provincial soil test recommended levels. The site was located on an Orthic Black Chernozem soil rated as class 5 Souris fine sandy loam soil (Ehrlich et al. 1957) Analysis for plant macronutrients was conducted by NorWest labs and indicated the following results: N, 14.0 kg ha^{-1} (CaCl2 extract); P, 40.1 kg ha^{-1} ($NH_4C_2H_3O_2/CH_3COF$ extract); K, 256.4 kg ha^{-1} ($NH_4C_2H_3O_2/CH_3COF$ extract); and S, 21.1 kg ha^{-1} ($CaCl_2$ extract). The area was subdivided into eight, 3.7-ha pastures, which were allocated to a factorial combination of treatments, consisting of 2 stocking rates (H, heavy; 8 steers per pasture, or 2.2 steers ha^{-1} ; and L, light; 4 steers per pasture, or 1.1 steers ha^{-1}) and 2 grazing intensities (C, continuous and R, 10-paddock rotational). Each treatment combination was replicated twice in a completely randomized design. Animals were moved through rotationally stocked pastures based on the anticipated length of the forage regrowth period.

Grazing began when available herbage was judged to be sufficient for grazing in the spring of each season, at an approximate plant height of 15–20 cm (18 May 1993; 20 May 1994; 17 June 1995). Soil samples were collected 24 October 1994, 24 May 1995 and 31 July 1995. To minimize the impact of spatial variability on the estimates of soil properties, 10 soil cores (0–10 cm) were collected and composited into 1 sample in a plastic bag with 2 field replications. Samples were stored in a cooler and brought to the laboratory for analysis. The total number of soil samples analyzed was 24.

Soil organic C was estimated using wet oxidation in dichromate and potentiometric titration (Yeomans and Bremner 1988). Total N was measured via dry combustion using a Leco FP-428 N analyser. Organic nitrogen was calculated as the difference between total N and extractable NH_4^+ and NO_3^-. Water content was determined gravimetrically.

Microbial biomass C and N contents in soils were measured by chloroform fumigation and direct extraction (Voroney et al. 1993), using 25 g of soil, 24-hour chloroform fumigation, and a 50 ml 0.5 M K_2SO_4 extracting solution. A k_C-factor of 0.45 was used to estimate biomass C (Wu et. al. 1990) and a k_N-factor of 0.45 was used to estimate biomass N (Jenkinson 1988). Determination of dissolved organic C and total soluble N were performed on 0.5 M K_2SO_4 soil extracts (25 g soil: 50 ml extractant, 1 hour shaking) using a Technicon Autoanalyzer II (Technicon Industrial method 455-76W/A and 759-84I respectively).

Nitrogen mineralization potential of soils from the 24 October 1994 samples was determined using periodic leaching of constituted soil columns (Campbell et al. 1993). Fifty grams each air dried soil and sand (soil:sand 1:1) were mixed together, placed in a leaching tube and 100 ml of 10 mM $CaCl_2$ used as the leaching solution. The experiment was run for 20 weeks and leachates were collected at 2-week intervals. The leachates were analyzed using a flow injection system analyzer for NH_4-N and NO_3-N.

Stanford and Smith (1972) developed a model for estimation of the potentially mineralizable N (N_0) of a soil and the rate of N mineralization (k) by incubating the soil at optimum conditions and measuring the N mineralized (N_{min}) and time of incubation (t), assuming that organic N mineralization at optimum conditions followed first-order kinetics. The following model of Stanford and Smith (1972) was used in the present study to calculate potentially mineralizable N and rate constant using a nonlinear regression program (SAS, Inc. 1985):

$$N_{min} = N_0 \, (1 - e^{-kt}) \qquad \textbf{(1)}$$

The content of arylsulfatase, acid phosphatase and alkaline phosphatase enzymes were assessed by measuring maximum potential activity (V_{max}) using the technique of Tabatabai (1982). One gram of soil was incubated with different substrates; p-nitrophenyl sulfate (pH 5.8) for arylsulfatase activity, *p*-nitrophenyl phosphate (pH 6.5) for acid phosphatase activity and *p*-nitrophenyl phosphate (pH 11.0) for alkaline phosphatase activity. The production of *p*-nitrophenol, indicative of enzyme activity, was quantified by measuring absorbance at 400 nm using a spectrophotometer.

Statistical analysis of the data were performed by analysis of variance and post-hoc analysis using the statistical package SuperANOVA (Abacus Concepts 1991).

Results and Discussion

Soil properties

Samples collected in fall of 1994 (20 October 1994) indicated that neither grazing system nor stocking rate had a significant effect on soil bulk density (Table 1). Soil bulk density, measured on 14 July 1995, was not significantly influenced by grazing system (continuous vs. rotational) but was significantly increased at higher stocking rates (Table 1). Water content was significantly ($P<0.05$) lower in the summer sample than in the fall and spring samples, but there were no significant stocking rate or grazing system effects (Table 2). The carbon and nitrogen content of the soil organic matter were measured in the spring and summer of 1995 (Table 3). The only significant effect was the effect of stocking rate on organic N content in the continuously grazed system. Changes in the quality and quantity of soil organic matter generally occur slowly. Changes in organic matter content are difficult to quantify in short-term studies because of the changes are small relative to the large background levels of organic matter and because soil variability (Bosatta and Argen 1994). These small changes, when they can be detected, may be indicators of longer-term impacts of management system on soil quality. Quantifying relatively small changes is even more difficult in pasture systems

Table 1. Influence of grazing system on soil bulk density measured at 3 depths in samples collected on 20 October 1994 and 14 July 1995.

			Bulk Densities	
System	Density	Depth	October 1994	July 1995
		(cm)	- - - - - - - ($Mg\ m^{-3}$) - - - - - - -	
Continuous	High	15	1.54	1.60
		30	1.43	1.55
		45	1.32	1.55
Continuous	Low	15	1.41	1.51
		30	1.32	1.51
		45	1.36	1.51
Rotational	High	15	1.48	1.61
		30	1.39	1.63
		45	1.34	1.54
Rotational	Low	15	1.46	1.48
		30	1.42	1.51
		45	1.43	1.50
ANOVA				
Grazing System			ns	ns
Stocking Density			ns	0.001
GS*SD			ns	ns
Depth			0.005	ns
GS*Depth			ns	ns
SD*Depth			ns	ns
GS*SD*Depth			ns	ns

Table 2. Soil gravimentric water content as measured at the Brandon pasture study site on 3 dates.

	Grazing	Stocking rate		
Sampling time	System	Light	Heavy	**Mean**
		- - - - - - - - - - - - - - - - (%) - - - - - - - - - - - - - - - -		
24 Oct. 1994	Continuous	12.4	9.9	11.2
	Rotational	11.1	11.7	11.4
	Mean	11.8	10.8	11.3a
24 May 1995	Continuous	14.1	12.5	13.3
	Rotational	13.1	12.3	12.7
	Mean	13.6	12.4	13.0a
31 July 1995	Continuous	9.0	5.7	7.4
	Rotational	8.0	9.1	8.6
	Mean	8.5	7.4	8.0b

a, b Means within column differ ($P < 0.05$) if followed by different letter

Table 3. Influence of grazing system on soil organic carbon and nitrogen as measured on samples collected on 3 dates.

Sample Date	Grazing System	Stocking Rate	Organic C	Organic N	C:N
			- - - - - - - - ($g\ kg^{-1}$)- - - - - - - -		
24 May 1995	Continuous	High	16	1.3 b	12.1
		Low	17	1.7 a	10.3
	Rotational	High	18	1.5 ab	11.6
		Low	20	1.4 ab	14.3
31 July 1995	Continuous	High	16	1.5	10.7
		Low	32	3.2	9.7
	Rotational	High	19	1.9	10.2
		Low	19	1.7	11.0

a, b Means within column differ ($P < 0.05$) if followed by different letter

where there is high inherent variability in organic C contents (Herrick and Whitford 1995). The use of composite samples was intended to reduce this variation but the results presented in Table 3 reflect high variability, with differences in the mean as great as 100% not reflecting statistically significant differences. The relatively large change in soil organic N (Table 3) in the low stocking rate of the continuously grazed system may reflect variation resulting from the patchy distribution of nitrogen inputs associated with animal feces.

Sampling time had a significant ($P < 0.001$) effect on extractable C concentration (Table 4). Extractable C was least in summer and positively correlated with soil water content (Table 5). Ross et al. (1995) found maximum extractable C concentrations in early spring but reported it as a function of sieving and smearing of the soil. These differences reflect both the effects of water and animal grazing on plant growth and root exudation which is a major source of extractable carbon in soil. Differences in manure production could have also contributed to these differences. In general, significant changes were detected in the soil microbial and biochemical properties at the different sampling times. Some of these differences were related to seasons or soil water content; other environmental factors may also be involved. Spatial variability was reduced by composite sampling (Speir et al. 1984). However, spatial variability greater than that seen in cropped soils is characteristic of rangeland soils (Herrick and Whitford 1995). Temperature would have had some influence on the temporal variability of these properties. However, no attempt has been made to model or remove the influence of temperature fluctuations on biochemical activity in this study.

Extractable N concentration in soil did not vary among sampling periods with an overall mean value of 7.5 $\mu g\ N\ g^{-1}$ soil and individual treatment means ranging from 2.9–10.6 $\mu g\ N\ g^{-1}$ soil. The correlation of extractable N with soil water content was not as strong as that of extractable C (Table 5).

Microbial biomass

Chloroform fumigation and direct extraction of freshly sampled soil was used for biomass determination in this study. Tate et al. (1991) advocated the use of fresh rather than pre-incubated soil, favoring the more versatile extraction procedure for measuring soil microbial biomass, especially for pasture soils. Banerjee and Chapman (1996) reported the range of microbial biomass C as 902–1485 $\mu g\ g^{-1}$ soil in sandy clay loam to clay loam grassland soils. Our values for biomass C (Table 6) in this study on a fine sandy loam soil were much less (209–629 $\mu g\ g^{-1}$ soil) and similar to their values for arable soil biomass C range (62–795 $\mu g\ g^{-1}$ soil). Microbial biomass C content varied signif-

Table 4. Extractable C content in soil at the Brandon pasture study site

		Stocking rate		
Sampling time	Grazing system	Light	Heavy	Mean
		($\mu g\ g^{-1}$ soil)		
24 Oct. 1994	Continuous	49.8	48.4	49.1
	Rotational	46.9	46.1	46.5
	Mean	48.4	47.4	47.9a
24 May 1995	Continuous	51.4	50.5	51.0
	Rotational	48.6	46.4	47.5
	Mean	50.0	48.5	49.3a
31 July 1995	Continuous	11.3	19.3	15.3
	Rotational	7.1	16.7	11.9
	Mean	9.2	18.0	13.6b

a, b Means within column differ (P < 0.05) if followed by different letter

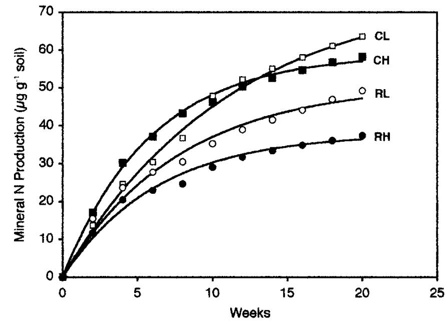

Fig. 1. Nitrogen mineralization kinetics of soils at the Brandon pasture study site. (CL = Continuous grazing and Light stocking rate; CH = Continuous grazing and Heavy stocking rate; RL = Rotational grazing and Light stocking rate; RH = Roational grazing and Heavy stocking rate.

icantly (P<0.001) during the year, lowest in samples taken in summer, the driest time of the year, and higher in spring (Table 6). Although biomass C content in fall and spring did not significantly differ, biomass C was correlated significantly with field water content (Table 5). Appreciable seasonal fluctuations have also been observed by DeLuca and Keeney (1994) in prairie soils. Biomass C also had a significant positive relationship with the extractable C in soil (Table 5).

Like other soil parameters, microbial biomass C was not affected by grazing system (Table 6). In contrast, stocking rate had a significant (P<0.07) impact on the soil biomass C content, which decreased at the high stocking rate. This impact is likely the result of increased stocking intensity decreasing the photosynthetic capacity of herbage and subsequent root development (Hart and Hoveland 1989). Langlands and Bennett (1973) observed that as stocking rate increases, nutrients located in the animal pool increase and those in the plant pool decrease. They found that as stocking rate increased, herbage availability, root weight, basal cover and soil pore space declined, but soil nutrient composition appeared to be unaffected by changes in stocking rate, especially in the surface soil. Decreased photoassimilated C input to the root might reduce microbial growth and lower soil microbial biomass C (Smith and Paul 1990). Microbial biomass is the most labile pool in soil and can be a rapid indicator of any changes in the soil management system (Carter 1986, Bosatta and Argen 1994).

Biomass N content was significantly (P<0.001) affected by the time of sampling but neither grazing system nor stocking rate had any significant impact (Table 7); although soil biomass N tended to decrease with increasing stocking rate. Like biomass C, biomass N was positively correlated with soil water content and extractable C, but not with extractable N (Table 5). This suggests that extracted N is derived from a different pool or additional pools than that of the soil microbial biomass N (Stockdale and Rees 1994).

Nitrogen mineralization

Mineralization patterns reflect changes in substrate availability, microbial activity, and the balance between gross mineralization and immobilization. Kinetic models furnish a mathematical description of net mineralization rates (Ellert and Bettany 1988). Cumulative net mineralization rates were fit to a first-order kinetic model (Stanford and Smith 1972). Models of mineralization kinetics are the attempt to demonstrate soil biological processes, rather than pure mathematical exercises in finding the best fitting curve (Ellert and Bettany 1988). The model may oversimplify natural processes, but it should fit better than alternative models based on competing theories about the processes which produced the data set (Jowett et al. 1974). Although we did not investigate the seasonal effect on N mineralization potential, Ross et al. (1984) reported no evident seasonal pattern in N mineralization potential under grazed pasture soils of New Zealand. Our attempt was to observe whether grazing system and/or stocking rate had any effect on net mineral N production and rate of N mineralization. Net soil mineral N production (Fig. 1, Table 8) was higher under continuous grazing (mean 60.5 $\mu g\ g^{-1}$ soil) than under rotational grazing (mean 43.0 $\mu g\ g^{-1}$ soil) but, the difference was not significant (P= 0.34). Stocking rate also did not significantly affect mineral N production in soil. These results are consistent with Langlands and Bennet (1973) who found stocking rate did not significantly alter soil nutrient levels. Similar observations were also made in relation to effects of grazing and stocking treatments on N mineralization potential in soil (Fig. 1). Rates of N mineralization were highest during the

Table 5. Pearson's correlation coefficients between the soil parameters

Parameters	Biomass N	Extract C	Extract N	Ary-lsulfatase	Acid Phosphatase	Al Phosp	Water
Biomass C	0.74***	0.71***	-0.27	0.53**	0.55**	-0.13	0.88***
Biomass N		0.56**	-0.25	0.12	0.25	-0.25	0.56**
Extract C			-0.31	0.36	0.17	0.45*	0.67***
Extract N				-0.42	-0.16	0.15	0.43*
Arylsulfatase					0.44*	0.26	0.68***
Ac Phosp						-0.21	0.68***
Al Phosp							-0.23

*,**,*** represent statistically significant at p< 0.05, p< 0.01, p< 0.001, respectively
Extract C = Extractable C; Extract N = Extractable N
Ac Phosp = Acid phosphatase; Al Phosp = Alkaline phosphatase

Table 6. Soil microbial biomass C content at the Brandon pasture study site

Sampling time	Grazing System	Stocking rate Light	Heavy	**Mean**
		- - - - - - - - - - - - - ($\mu g\ C\ g^{-1}$ soil) - - - - - - - - - - - - -		
24 Oct. 1994	Continuous	612	456	534
	Rotational	557	525	541
	Mean	585	491	538a
24 May 1995	Continuous	629	475	552
	Rotational	576530	553	
	Mean	603	503	553a
31 July 1995	Continuous	350	209	280
	Rotational	288	318	303
	Mean	319	264	292b

a,bMeans within column differ ($P < 0.05$) if followed by different letter

Table 7. Soil microbial biomass N content at the Brandon study site

Sampling time	Grazing System	Stocking rate Light	Heavy	**Mean**
		- - - - - - - - - - - - - ($\mu g\ C\ g^{-1}$ soil) - - - - - - - - - - - - -		
24 Oct. 1994	Continuous	63.8	66.2	65.0
	Rotational	99.6	67.8	83.7
	Mean	81.6	67.0	74.3a
24 May 1995	Continuous	70.7	52.1	61.4
	Rotational	51.1	38.3	44.7
	Mean	60.9	45.2	53.1a
31 July 1995	Continuous	28.2	19.3	23.8
	Rotational	15.7	27.2	21.5
	Mean	22.0	23.3	22.7b

a,bMeans within column differ ($P < 0.05$) if followed by different letter

Table 8. Kinetic description of N mineralization rate of soils collected from the Brandon Pasture study.

Grazing System	Stocking Rate	N_{min}	N_o	k	Regression Equation	Coefficient of Determination
		($\mu g\ g^{-1}$)	($\mu g\ g^{-1}$)	(wk^{-1})		
Continuous	Light	63	76	0.09	$N_{min} = 76(1-e^{-0.09t})$	0.99
Continuous	Heavy	58	59	0.17	$N_{min} = 59(1-e^{-0.17t})$	0.99
Rotational	Light	49	51	0.13	$N_{min} = 51(1-e^{-0.13t})$	0.98
Rotational	Heavy	37	38	0.16	$N_{min} = 38(1-e^{-0.16t})$	0.99

Table 9. Arylsulfatase activity in soil at the Brandon pasture study site

Sampling time	Grazing System	Stocking rate Light	Heavy	**Mean**
		- - - - - - - - - - (μg p-nitrophenol g^{-1} soil h^{-1}) - - - - - - - -- - -		
24 Oct. 1994	Continuous	42.8	31.9	37.4
	Rotational	47.7	51.9	49.8
	Mean	45.4	41.9	43.7a
24 May 1995	Continuous	90.5	72.5	81.5
	Rotational	89.1	69.4	79.3
	Mean	89.8	71.0	80.4b
31 July 1995	Continuous	44.4	43.4	43.9
	Rotational	44.1	58.7	51.4
	Mean	44.3	51.1	47.7a

a, b Means within column differ ($P < 0.05$) if followed by different letter

first 2 weeks of incubation and decreased with time as the labile organic N was depleted. The cumulative mineral N produced was usually lower than the estimated potential mineralizable N after 20 weeks of incubation, indicating some of the organic N fraction was still available for further mineralization (Table 8). The values of the rate constant (k) range from 0.09 to 0.17 wk^{-1} under continuous grazing (mean 0.13 wk^{-1}) and 0.13 to 0.16 wk-1 under rotational grazing system (mean 0.145 wk^{-1}).

Enzyme activities

Both arylsulfatase and alkaline phosphatase activities showed significant ($P< 0.05$) differences between sampling times, but did not show similar times of minimum and maximum activity (Tables 9 and 10). Arylsulfatase activity was highest during spring and alkaline phosphatase activity was highest during summer, but acid phosphatase activity was not significantly affected by sampling time (Table 11). In contrast, Ross et al. (1995) reported non-significant seasonal fluctuations of arylsulfatase activity but very marked seasonal fluctuations of phosphatase activity in their soils. Seasonal variation in soil enzyme activities have been shown by Ladd (1978) as well. As found here, fluctuations in enzyme activity have not always coincided with season, and are often difficult to interpret. In our study, grazing systems and stocking rates did not significantly impact arylsulfatase (Table 9) and alkaline phosphatase activities (Table 10) but acid phosphatase activity was significantly ($P<0.03$) decreased under heavy stocking compared to light stocking (Table 11). Grazing system had no significant effect on the acid phosphatase activity. Arylsulfatase and acid phosphatase activities were correlated significantly and positively with soil water and biomass C (Table 5), whereas alkaline phosphatase activity had no significant relationship with soil water and biomass C. Soil enzymes are probably derived to a considerable extent from soil microorganisms (Ladd 1978). In this study arylsulfatase and acid phosphatase were correlated with microbial biomass C but alkaline phosphatase was not (Table 5).

Overall, at this site seasonal fluctuations occurred in the microbial and biochemical properties reported here. In general, these fluctuations were mainly independent of the variations in soil organic matter content (Ross et al. 1984) but were more closely related to soil water content. Of the parameters examined here, N mineralization is perhaps the most useful in assessing the productivity of the site as it is primarily an assessment availability and quality (C:N ratio) of mineralizable substrates. Mineralizable N was lower under rotational than under continuous grazing. Measures of biomass C and N represent both the catalytic potential of the soil and a measure of substrate availability. The initial data does suggest increased stock-

Table 10. Alkaline phosphatase activity in soil at the Brandon pasture study site

Sampling time	Grazing System	Stocking rate Light	Heavy	**Mean**
		- - - - - - - - - - (µg p-nitrophenol g^{-1} soil h^{-1}) - - - - - - - - -		
24 Oct. 1994	Continuous	152.9	128.4	140.7
	Rotational	145.7	155.7	150.7
	Mean	149.3	142.1	145.7a
24 May 1995	Continuous	179.5	142.2	160.9
	Rotational	156.5	166.4	161.5
	Mean	168.0	154.3	161.2a
31 July 1995	Continuous	175.5	196.3	185.9
	Rotational	172.0	198.2	185.1
	Mean	173.7	197.2	185.5b

a, b Means within column differ (P < 0.05) if followed by different letter

Table 11. Acid phosphatase activity in soil at the Brandon pasture study site

Sampling time	Grazing System	Stocking rate Light	Heavy	**Mean**
		- - - - - - - - - - (µg p-nitrophenol g^{-1} soil h^{-1}) - - - - - - - - -		
24 Oct. 1994	Continuous	190.1	171.1	180.6
	Rotational	181.2	183.6	182.4
	Mean	185.6a	177.4b	181.5
24 May 1995	Continuous	225.8	173.0	199.4
	Rotational	212.4	170.8	191.6
	Mean	219.2a	171.8b	195.5
31 July 1995	Continuous	200.0	92.4	146.2
	Rotational	169.6	195.6	182.6
	Mean	184.8a	144.0b	164.4

a, b Means within row differ (P < 0.05) if followed by different letter

ing rate decreases soil microbial biomass C, mineralizable N, and acid phosphatase activity. The measures of enzyme content are more difficult to interpret as they indicate potential enzyme activity under conditions of excess substrate. Enzyme activity in soil systems is often primarily limited by substrate availability (Burton and McGill 1991). Due to the limited duration of the investigation, limited number of replications, and high soil variability encountered in this study, it may not be advisable to recommend any particular grazing system and/or stocking rate favorable for the maintenance of soil biological quality. The high degree of variation observed might be anticipated in view of the distribution of nitrogen rich feces and urine in pasture systems. Longer-term investigation involving more frequent sampling with increased replication is needed to assess more completely the impact of grazing system or stocking rate on soil biological characteristics. However, these preliminary results indicate possible adverse effects of excessively high stocking on soil health or quality.

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Book Reviews

The Western Range Revisited: Removing Livestock from Public Lands to Conserve Native Biodiversity. By Debra L. Donahue. 1999. University of Oklahoma Press, Norman, Oklahoma. [www.ou.edu/oupress]. 388 p. US$47.95 cloth. ISBN 0-8061-3176-4.

The principal point of this book is that removing livestock from many western rangelands is both ecologically desirable and legally justifiable. Debra L. Donahue uses the nearly 400 pages of this book to develop this central point in considerable detail. Including the introductory and the terminal chapters, this book consists of 10 chapters. Rather than provide a tedious chapter by chapter review, in what follows, I shall evaluate the contents of Chapters 4 through 8. This is where the bulk of Donahue's argument is developed. Consequently, a focus on these chapters should provide the reader with a good idea of the intellectual contributions of this book.

In Chapter 4, Donahue discusses the influence that cattlemen have had and continue to have on regional and national politics and on western society in general. After noting that ranchers and livestock producers possess political power disproportionate to their actual numbers, Donahue points out that on the basis of this power, cattlemen "have succeeded for 60 years in keeping grazing fees low and in avoiding widespread cuts in permitted numbers or seasons of use to improve range conditions" (p. 70). This chapter effectively debunks the notion that ranching is essential for the economic survival of the West. This is because across "the West, tourism vastly surpasses ranching in generating jobs and revenues" (p. 96).

Generally speaking, this chapter is well written; however, there are some disquieting aspects. In particular, Donahue's occasional unidisciplinary focus is baffling. For instance, she says that the "public and policymakers must look to ecologists, not myth marketers, for guidance in charting a course for the West's future" (p. 113). It is now well understood (see the paper by Charles Perrings and Brian Walker in the 1995 book *Biodiversity Loss: Economic and Ecological Issues*) that rangelands are *jointly determined* ecological-economic systems. Consequently, Donahue should have been unequivocal in noting that if policymakers are to chart an effective course for the West's future, then they will have to pay attention to *both* the ecology and the economics of western rangelands.

Chapter 5 contains a stimulating account of the ecology of western rangelands. This chapter effectively critiques the "niche theory" of Walter Webb and then it provides a nice discussion of the "state-and-transition" model of Mark Westoby and his colleagues. There are 2 salient points to note here. First, "plants on North American rangelands, particularly the drier of those lands, are not adapted to withstand the artificial pressures of grazing by domestic livestock" (p. 142). Second, rangeland managers should avoid altering plant communities beyond thresholds.

An already good Chapter 5 would have been even better had Donahue filled a few gaps in her discussion. For instance, she discusses the notion of "coevolution" without pointing out that this term was coined by Paul Ehrlich and Peter Raven in their classic analysis of butterflies and their foods. Similarly, her discussion of the inapplicability of the Clementsian model of succession to most western rangelands could have been expanded upon to note that recent research in ecology (see the paper by C.S. Holling in the 1995 book *Barriers and Bridges to the Renewal of Institutions*) has questioned the *general* applicability of the Clementsian model.

The preservation of biodiversity on arid western rangelands is the subject of Chapter 6. Following a perceptive account of edge effects, Donahue presents her landscape level proposal for the conservation of biodiversity on western rangelands. This proposal asks land managers to create *large* preserves in which livestock grazing is *banned*. This is a bold proposal and Donahue acknowledges that her suggested ban on livestock grazing is likely to be controversial. The rationale for a ban, and not a curtailment of grazing is that simply "curtailing livestock use will not achieve the goal of preserving and restoring arid land biodiversity" (p. 192). As Donahue puts it, "[c]victing livestock will be essential" (p. 192).

Although the proposal itself is presented with considerable clarity, the same cannot be said about all of the discussion that leads to this proposal. For example, given the interdisciplinary approach of this book, it is unclear why the author is concerned exclusively with the *ecologica*l value of biodiversity. Second, cost considerations are conspicuously absent from her discussion of the desirability of creating large preserves. On one occasion, without offering any evidence, Donahue simply asserts that the "costs or disadvantages of managing extensive tracts of BLM rangelands as biodiversity reserves would be *minor* and *vastly outweighed* by the benefits" (p. 188, emphases added).

Chapter 7 focuses on the legal ramifications of the proposal to ban livestock grazing from western rangelands. Two of this chapter's points deserve some comment. First, Donahue helpfully points out that the purpose of most range "improvements" is to expand a range's livestock production capacity. Consequently, it is not at all clear that such improvements will be able to restore or improve the condition of degraded grazing lands. Second, she notes that "the statutory requirement to weigh long-term benefits to the public (benefits attributable to conserving native biodiversity) against short-term benefits...counsels in favor of the proposed conservation program" (p. 218). This *equation* of the long-term benefits to the public with the benefits from the conservation of biodiversity is a key part of Donahue's proposal. Consequently, readers would have profited from a more *elaborate* discussion of this point.

The purpose of Chapter 8 is to evaluate the merits of 2 claims. The first is that public grazing is significant to the economic base of the West. The second is that the ranching way of life is worthy of preservation both for its own sake and for the sake of preserving the West's open spaces. Donahue does a fairly good job of demonstrating that both these claims are erroneous but there are weaknesses in her arguments. Here are 3 examples. On p. 249, Donahue contends that public goods are *best* provided by public ownership and that private ownership of a resource *will* result in the ecological deterioration of this resource. It is true that the private provision of public goods is generally plagued by the "free rider" problem. However, to make this discussion complete, Donahue should have noted that sometimes it is possible to create personalized markets for a public good. When this can be done, the private provision of a public good is efficient. Further, it is hardly axiomatic that private ownership of a resource will result in its deterioration. Indeed, private ownership has frequently been suggested as a solution to the problem of the commons.

On p. 260 Donahue argues that reduced production of beef will lead to *greater* revenue for beef producers because the demand for beef is *inelastic*. Unless the demand for beef is perfectly inelastic, this argument is not necessarily correct. In general, one would have to consider the elasticity of *both* the demand and the supply functions for beef to reach any conclusion about increased or decreased revenues. Finally, on pp. 275–6, Donahue misleadingly claims that if an activity is ecologically unsustainable, then it *must* also be economically unsustainable. The work of Mick Common and Charles Perrings (in *Ecological Economics*, 1992, Vol. 6, pp. 7–34) has shown that the criteria governing economic and ecological sustainability are largely *disjoint*. This means that ecological unsustainability does *not* automatically imply economic unsustainability.

Despite some errors of commission and omission, in general, this is an interesting and thought provoking book. It nicely shows how the occasionally opaque subject of range management can be made translucent, and even transparent, by analyzing the relevant issues from an interdisciplinary perspective. As such, I recommend this book to readers who are interested in learning more about biodiversity conservation and the use of public lands in the American West.—*Amitrajeet A. Batabyal*, Utah State University, Logan, Utah.

Biology and Management of Noxious Rangeland Weeds. Edited by R. L. Sheley and J. K. Petroff. 1999. Oregon State University Press, Corvallis, Oregon. 438 p. US$35.95 paper. ISBN 0-87071-461-9.

This book is really 2 complementary books in one volume. The first book (11 chapters and 144 pages) is a primer on weed management. The second book (25 chapters and 271 pages) covers 34 of the most problematic weeds in the western United States.

The first book focuses on 5 maxims for noxious weed management, which are to: (1) prevent new infestations from occurring; (2) inventory your land and direct resources first toward eradicating small satellite infestations; (3) control larger infestations with a variety of carefully selected tools using an integrated approach; (4) manage livestock grazing such that it provides desirable plants with adequate opportunities for recovery following grazing; (5) reseed disturbed areas with competitive grass species that are adapted to the local conditions and that will preempt resources that weeds would otherwise exploit.

Land managers and landowners will want to read the first book rather than jumping directly into the second book to find the chapter on one's favorite noxious weed. The first book is essential for readers to develop a solid foundation of knowledge that will enable them to understand what they need to consider when preparing a weed management plan. With that knowledge, readers can peruse the chapters on individual weed species that provide most if not all of the biological and management information on weeds they need to prepare a noxious weed management plan.

The first 11 chapters cover ecological and economic implications of weeds; surveying, mapping, and monitoring; coordinated weed management planning; economic evaluation of weed management on rangelands; integrated weed management; preventing noxious weed invasion; early detection and eradication; grazing; biological control; herbicides; and revegetating weed-infested rangeland.

The chapter on the ecological and economic implications of weeds is important because some readers will not appreciate how pervasive impacts of noxious weeds can be. Veteran weed managers can use the information on weed impacts to promote weed management programs within their organizations. The chapter on surveying, mapping, and monitoring provides a basic overview of these subjects as applied to weeds. The chapter on coordinated weed management planning encourages readers to view their weed management needs in a wider context than their own property and explains how different groups can work together to manage weeds across political and property boundaries. Economic evaluation of weed management can help managers decide how to allocate scarce resources rationally to weed control, as cost and benefits of weed control can vary widely among species and for different tracts of land. Integrated weed management is a dominant theme of the volume, with the authors emphasizing that using only one tool, e.g., herbicides, to manage weeds will likely lead to failure. The authors view manipulating three components of plant succession, namely disturbance, colonization and species performance, as the basis for integrated weed management. Prevention of weed species invasion is another principal theme of the volume because it generally has the highest leverage of any weed management activity. A chapter discusses early detection and eradication of weed infestations, which are probably the next most important activities for weed managers after prevention. This chapter ought to motivate landowners and managers to inspect their properties regularly to find new infestations when they are small and can often be eradicated fairly easily rather than simply controlled. Grazing is the most extensive land use in the western U.S., and poorly managed livestock grazing can contribute greatly to the invasion and spread of noxious weeds. On the other hand, proper management of livestock is an essential component of integrated weed management for managing weeds on lands that are grazed. The chapter on grazing explains how sheep and goat grazing can be used in a complementary manner with cattle to increase meat production and profitability while controlling many noxious weed species. Biological control of weeds using insects and pathogens has worked spectacularly in a few instances and holds promise for controlling weed species that are so entrenched that eradication is not feasible. A chapter explains the circumstances where biological control is most likely to be effective. Herbicides are widely used to control weeds; but many people know little about these chemicals. A chapter provides basic information about herbicides such as herbicide application, herbicide classification, mode of action, and how herbicides move about. Re-establishing competitive plant species in disturbed areas is a recurring theme of the book, and a chapter discusses seeding methods, species to seed, seeding rates and controlling weeds in re-seeded areas.

The chapters on individual weed species include the vast majority of worst noxious weeds that land managers will encounter in the western U.S. However, Californians may be disappointed that many of the weed species that are more or less unique to that state, e.g., fennel and giant reed, are not covered in this book. All chapters have the same basic format that helps readers find information quickly. In addition, all of the species chapters relentlessly promote the messages of prevention, integrated control, and re-establishing competitive vegetation in depleted areas.

I have one major complaint about the book, mainly that it is short on practical, step-by-step suggestions for people preparing weed management plans. For example, the chapter on surveying and mapping does not cite an example of an exemplary weed inventory. Perhaps the book was not designed to provide this level of practical advice, but I think the book would have been even more useful if it did. Another complaint is the uneven quality of the color photographs, some of which are excellent, while others are poor.

I found the chapter on snakeweeds to be misplaced. Broom snakeweed and threadleaf snakeweed are the only species native to the western U.S. included in the volume. I think one of the strengths of the book is the focus on aggressive, alien species that virtually everyone acknowledges are problems. While native plant species such as milkvetches, locoweeds, and snakeweeds cause significant economic loss to ranchers in some areas, native species have their constituencies who are not always anxious to promote control efforts on native species, especially using herbicides. I think it is wise for land managers to focus on aggressive alien invaders that have few friends in the public arena.

This is an excellent volume that should be read by people who are involved in weed management on western rangelands, which means just about every landowner and land manager, as well as range management students. The references are up to date and plentiful. The authors of the chapters include acknowledged experts on the subjects. I encourage the editors to revise this book periodically to include new information on weed management as it becomes available.—*Alan T. Carpenter,* Boulder, Colorado.

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