JANUARY 1974
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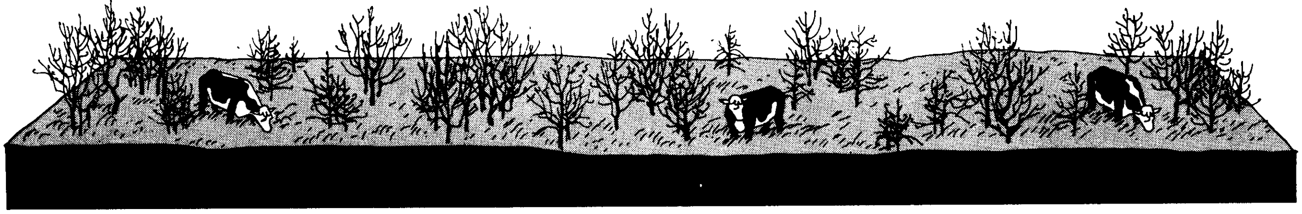
JOURNAL OF RANGE MANAGEMENT

SOCIETY FOR RANGE MANAGEMENT

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



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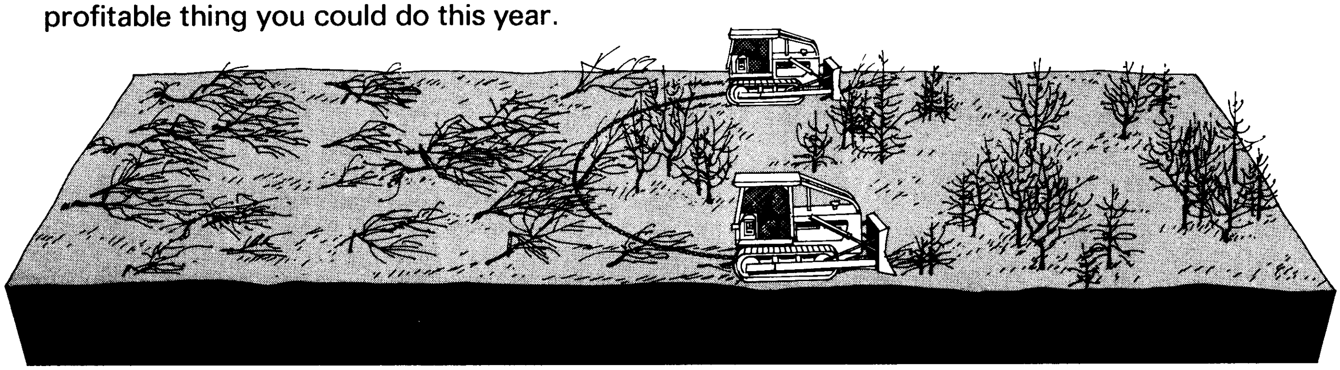

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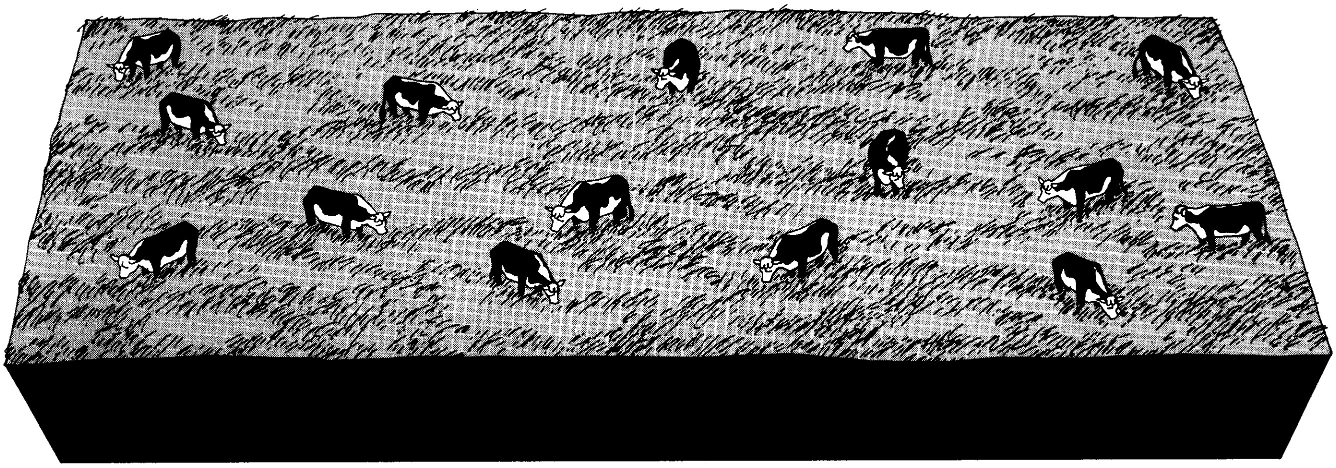

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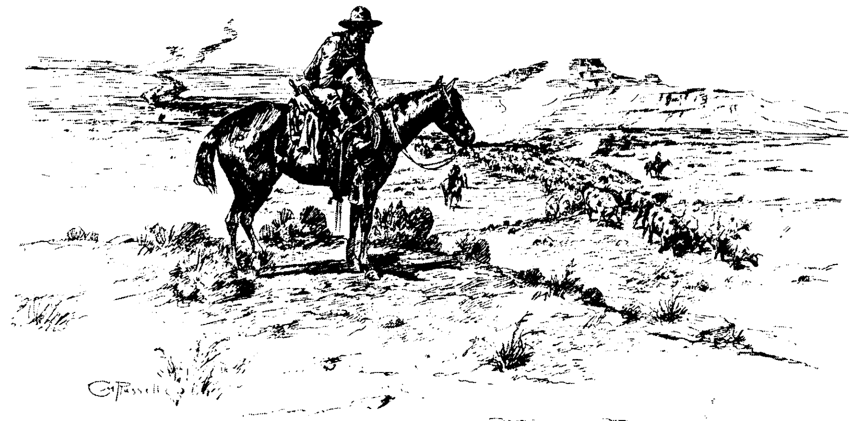

THE TRAIL BOSS

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The objectives for which the corporation is established are:

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

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

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

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

–to promote professional development of its members.

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COVER: Dozed juniper being burned near Baird, Texas. Fireline in the foreground (see article by Henry A. Wright, page 5).

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Range Burning

HENRY A. WRIGHT

Highlight: *There are many uses for prescribed burning in the management of forests, chaparral, grasslands, watersheds, and wildlife. Some of these uses have been pointed out in this paper. There are also many dangers in using fire, both in its application and in its results. To minimize harmful effects, fire should never be used during extended dry periods; burns should always take place when the soil is damp or wet. Moreover, the user should be an experienced professional with a thorough knowledge of ecosystems, weather, and fire behavior.*

We know a lot about the effect of fire on western rangelands and its value as a tool, but information necessary to conduct specific prescribed burns is generally inadequate or nonexistent. Thus, the use of fire is frightening, and many desirable prescribed burns just don't get started. Few land managers have the training or courage to conduct a burn. Most have been exposed only to catastrophic fires, which are untimely, have undesirable effects, and scare everyone in their path.

There are other fears which inhibit prescribed burning. One is a fear of the liability consequences if a fire gets away. This fear affects individual landowners and also influences government agencies. Another fear, which has been important in the past but may be less so now, is a concern about one's career if he lets a fire get away.

In this paper I intend to point out the usefulness of prescribed burns in many plant communities, the reasons why most wildfires are detrimental, and how prescribed burns can be conducted. Hopefully, it will stimulate some thinking and encourage others to use fire as it has been used in parts of the West.

The author is professor of range management, Department of Range and Wildlife Management, Texas Tech University, Lubbock.

The paper is a contribution of the College of Agricultural Sciences, Texas Tech University, No. T-9-128.

Manuscript received August 2, 1973

Use of Fire as a Tool

Where prescribed burning is an applicable tool, many objectives can be achieved simultaneously. Increased herbage yields, increased utilization, increased availability of forage, improved wildlife habitat (more food with unburned patches for cover), control of undesirable shrubs, a mineral seedbed for establishment of commercial trees, and control of various diseases (e.g. liver fluke and brownspot) can all be achieved with one burn. For example, in mesquite (*Prosopis glandulosa*)-tobosa (*Hilaria mutica*) communities in west Texas (Fig. 1), we use fire to (a) remove accumulated litter, (b) increase yields of tobosa (Fig. 2), (c) increase palatability of tobosa, (d) reduce mesquite canopy to acceptable levels, (e) top-kill mesquite and leave the stems in a state where wood borers will attack and aerate them to such an extent that they will be easily consumed by a reburn, (f) kill 40 to 80% of three species of cactus, and (g) kill undesirable annual broomweeds (*Xanthocephalum dracunculoides*) (Wright, 1972a). By contrast, spraying this same community with 2,4,5-T will not increase yields of tobosa (Dahl et al., 1971), will not increase palatability of tobosa, will not kill pricklypear (*Opuntia phaeacantha*) or cholla (*O. imbricata*), and will leave the wood of mesquite resistant to wood borers.

Fire also achieves multiple objectives in the aspen parkland of Alberta, Canada. Fall or spring burns in the aspen forest (a) top-kill all woody plants such as quaking aspen (*Populus tremuloides*), snowberry (*Symphoricarpos occidentalis*), rose (*Rosa woodsii*), raspberry (*Rubus strigosus*), gooseberry (*Ribes oxyacanthoides*), willow (*Salix* sp.), and silverberry (*Elaeagnus commutata*), (b) provide a seedbed for the establishment of forage seedlings, (c) increase the supply of palatable browse for cattle, (d) sharply increase the food supply and habitat for white-tail deer and ruffed grouse, and in the grasslands (a) eliminate litter buildup from rough fescue on north-facing slopes, and (b) during wet years maintain stable forage yields (Bailey, 1972, personal communication).

Management after a burn is essential for obtaining desirable results. Grazing animals will frequently concentrate on a burn because the feed is more palatable, nutritious, and readily available. For this reason burning must be done on a manageable unit basis. If small areas within large pastures are burned, animals will concentrate on the burn, regardless of how long the rancher waits to turn the animals in. This is why burns are often criticized for killing the grass when in reality they probably produce more grass than control areas. Moreover, burning small areas may be an effective way to get animals to overbrowse some species such as aspen and thus destroy some brush.

Prescribed Burns vs Wildfires

Because of the variety of seasons and weather conditions in which a burn can occur, one must be careful how he interprets the results of a fire study. If the data is from a wildfire, the fire probably occurred during a very dry year. If the data is from a prescribed burn, the fire probably occurred during a wet year.

Fig. 1. *A sprayed mesquite-tobosa community in west Texas. Dead plant material is in excess of 5,000 lb/acre, and annual grass yields are only 1,100 lb/acre. The dead standing mesquite stems are also an obstacle in handling livestock.*

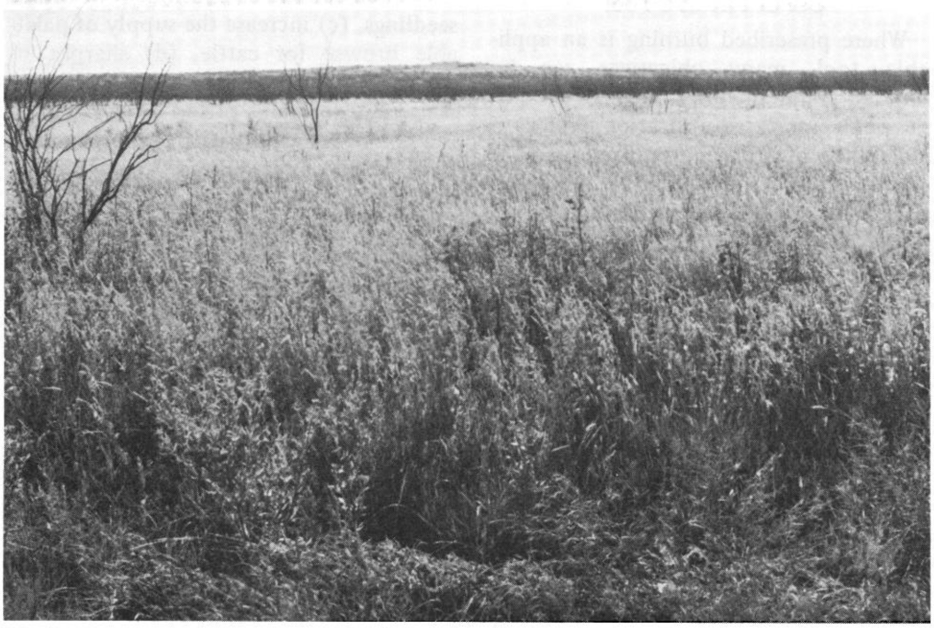

Fig. 2. *A mesquite-tobosa community 3 months after burning. Current grass production is about 3,000 lb/acre, and most mesquite stems have been burned down. Resprouts of the trees have been suppressed and 30% of the trees have been root-killed.*

Naturally, fires during dry years are harmful because they magnify drouth stress on plants, whereas fires during wet years are generally beneficial because moisture is generally not limiting and fires increase soil temperature and stimulate nitrification.

As an example, in west Texas tobosa produced 2813 lb/acre after burning during a wet year in 1969 and only 625 lb/acre after burning during a dry year in 1971 (Wright, 1972a). The controls produced 1128 and 954 lb/acre, respectively. Yields from the burned plots are typical for a comparison of results of a prescribed burn with those of a wildfire. Ideally, a prescribed burn should be conducted during the dormant season, when the soil is wet, relative humidity is 20 to 60%, average wind velocities are 5 to 15 mph, and air temperature is 65 to 75°F.

In addition to occurring during dry years, wildfires frequently occur during the active growing season, which is very untimely and severely damages many plants. For best results, burns should be conducted when preferred plants are dormant. In southern states, spring burning favors the desired warm season plants over cool season plants. By contrast, in the Northwest fall burning is preferred to minimize damage to the dominant cool season plants.

Effect of Fire on Vegetation

The usefulness of fire to stimulate forage production in stagnated grassland communities has been demonstrated by many researchers (Weaver and Tomanek, 1951; Weaver and Albertson, 1956; Ehrenreich, 1959; Hadley and Kieckhefer, 1963; Vogl, 1965; Wright, 1972a; and Anderson et al., 1970). Buildup of litter in excess of 2,000 lb/acre lowers soil temperatures, which reduces bacterial activity, ties up nutrients, and slows the general nitrogen cycling process, particularly during cool, wet years. In dry years, however, when wildfires are prevalent, litter is important for insulation and protection from flash floods.

Other benefits occur in the Great Plains. Cool season plants such as annual broomweed are easily controlled by spring burning (Wright, 1969). By contrast, the warm season perennial grasses are greatly favored. This is a good example of how fire can be used successfully as a management tool to depress one plant and enhance another. Moreover, the utilization of coarse, unpalatable species can be increased for 6 months to 1 year (Heirman and Wright, 1973; Klett, et al., 1971). Pricklypear, tasajillo (*O. leptocaulis*), and cholla can easily be killed with the use of fire (Heirman and Wright, 1973). Fire does not kill the pricklypear or cholla directly, but insects attack them after fire. We have recorded second-year mortalities of pricklypear after burning as high as 85%.

In the Northwest, burning should be done in the fall to favor the dominant, cool season perennial plants. If burning is done in early summer, perennial bunchgrasses will be killed and annuals such as cheatgrass (*Bromus tectorum*) increase in dominance in the community (Wright and Klemmedson, 1965). Fall burning is one of the best treatments to retain desirable forbs and kill sagebrush (*Artemisia triden-*

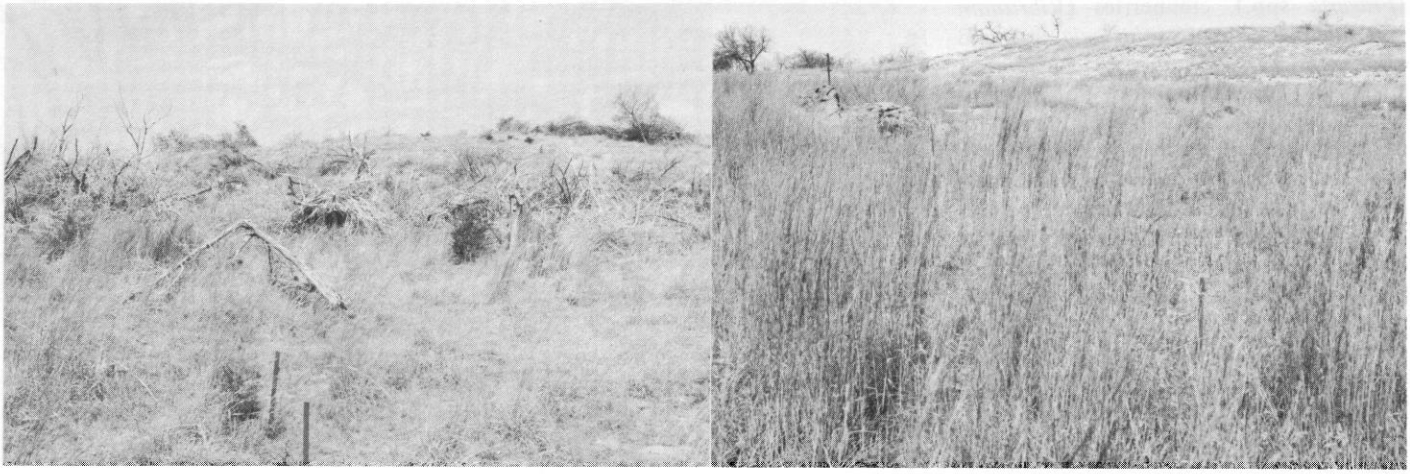

Fig. 3. *Following tree-dozing and the establishment of young ashe juniper from seed (left), fire can keep grasslands relatively free of ashe juniper (right) for 15 to 20 years.*

tata), although it temporarily harms bunchgrasses such as needleandthread (*Stipa comata*) and Idaho fescue (*Festuca idahoensis*) (Blaisdell, 1953; Wright and Klemmedson, 1965; Conrad and Poulton, 1966). Rhizomatous species such as thickspike wheatgrass (*Agropyron dasystachyum* and plains reedgrass (*Calamagrostis montanensis*) are favored by fall burning (Blaisdell, 1953). Undesirable shurbs such as horsebrush (*Tetradymia canescens*) and downy rabbitbrush (*Chrysothamnus puberulus*) are also favored by burning. Bitterbrush (*Purshia tridentata*) is severely harmed by burning (Nord, 1965).

Where fires are prevalent in grasslands, they have considerable value in controlling brush (Humphrey, 1958; Sauer, 1959; Wright, 1972b). Griffiths (1910) and Wooten (1916) believed that fires almost entirely prevented the establishment of undesirable shrubs in the southern desert. Griffiths stated that because of the slow growth of shrubs, he felt that they could be controlled by fires that occurred only once in 10 years. Drouth and competition from healthy grasses interact with fire to further restrict the growth of shrubs (Johnson, 1962; Wright, 1972b). However, when domestic livestock graze these grassland areas, competition from grasses is lessened, fires are less frequent, and shrubs increase.

Juniper is one of the best examples of a shrub being controlled by fire in grasslands (Fig. 3). Most species are nonsprouters and are readily killed by fire. Thus, juniper is generally found in the rougher and more dissected topography of grasslands (Wells, 1970).

By contrast, stagnant communities of chaparral are greatly rejuvenated by occasional fires (Hanes, 1971). Decadent stands of mixed-chaparral brush will produce 13 to 106 lb/acre of browse (Gibbens and Schultz, 1963), whereas after burning these same communities produce from 750 to 2,750 lb/acre (Biswell, 1969). However, fire is not necessary for true chaparral communities to maintain their identity (Hanes, 1971).

Shrub species which are dependent upon seed for survival, such as many juniper and chaparral species, can be eliminated from a community if fires are too frequent. This is why juniper is not a climax species on grasslands, but is climax on rocky breaks where it is protected from frequent fires (Burkhardt and Tisdale, 1969). Since nonsprouting species must reach a certain age to set seed (Hanes, 1971), a burning frequency of more than 15 years has been considered most desirable for the maintenance of these shrubs (Biswell, 1969). Otherwise, a change in the relative frequencies of various species of shrubs following fire will occur, as has been reported by Buell and Cantlon (1953) in New Jersey and Horton and Kraebel (1955) in California.

For years our forests were protected from fire by foresters whose training was dominated by European philosophy. Today we know that this was the wrong approach, because most of our forests evolved with fires. Without the natural sequence of fire, our forests have become plagued by inadequate reproduction, overstocking, stagnation, diseases and insects, as well as excessive fuel accumulation (Vogl, 1971). Protection of redwoods (*Sequoia gigantea*) in the Sequoia National Park has created a dog-hair thicket of young pines (*Pinus ponderosa* and *P. lambertiana*), white fir (*Abies concolor*), incense cedar (*Libocedrus decurrens*), and mature brush, with no regeneration of redwoods (Kilgore, 1970). Now expensive handwork, along with prescribed burning, is being used to protect these trees from the threat of disastrous wildfires and ultimate extinction.

Natural fires occur in ponderosa pine every 5 to 10 years (Weaver, 1951a; Kallander, 1969). They not only reduce hazards from wildfires, but they thin the stands, prepare a mineral seedbed for regeneration, and maintain a healthy understory (Weaver, 1951b). Shrubs are killed back, but most resprout vigourously and appear fully recovered 11 years after the fire. Prescribed burning techniques for this vegetation type have been developed by Biswell et al. (1955) and Buck (1971).

In the Douglas-fir zone of the Intermountain region, shrubs utilized by wildlife are favored by fires and have a dominant influence on plant communities for 20 to 50 years (Mueggler, 1965; Lyon, 1969). Species greatly enhanced by fire include Scouler willow (*Salix scouleriana*), serviceberry (*Amelanchier alnifolia*), Rocky Mountain maple (*Acer glabrum*), huckleberry (*Vaccinium* sp.), thimbleberry (*Rubus parviflorus*), and oceanspray (*Holodiscus discolor*). Scouler willow is especially abundant after burning (Mueggler, 1965; Leege, 1969). All of these species are sprouters and increase in density because root crowns of single plants produce multiple sprouts (Lyon, 1966).

Berry plants which are preferred by many species of wildlife,–blackberries, thimbleberries, raspberries (*Rubus* spp.), gooseberries (*Ribes* sp.), strawberries

(*Fragaria* spp.), cranberries (*Vibrunum* sp.), huckleberries (*Gaylussacia* sp.), and blueberries (*Vaccinium* spp.)—thrive after fires. In forests of the northeastern United States, blueberries (*Vaccinium angustifolium, V. myretelloides,* and *V. vacillans*) persist for years in the understory of unburned communities as decadent plants. For maximum production of berries, they must be rejuvenated periodically by removal of dead or decadent stems and clones (Sharp, 1970). Brown (1960) found blueberries consistently more prevalent on areas with a fire history than on adjacent unburned communities.

Effect of Fire on Wildlife

Planned uses for wildlife should follow more of our prescribed burns and wildfires. It should not always be necessary to restock a forest with trees for the sole objective of growing as many trees as soon as possible. Land has many uses, as the United States Forest Service emblem depicts, and we should strive for variety. Variety is especially important in wildlife habitat management.

Following the Tillamook burns in Oregon that devastated 355,397 acres, deer and other wild animals and birds increased dramatically (Isaac, 1963). Not only was forage more plentiful, but the deer were healthy and free of liver fluke and lungworms that had plagued the coast deer herds for years before the wildfire. Biologists discovered that the fire had wiped out the dry-land snail, which is the intermediate host for liver fluke and certain lungworms over vast areas.

Deer, elk, moose, bobwhite quail, wild turkey, doves, prairie chicken, sharptails, ruffed grouse, waterfowl and many song birds are favored by fires which create variety in habitat (Miller, 1963; E. Komarek, 1963). The Kenai National Moose Range in Alaska is in the Boreal Forest and would never have been set aside as a moose range had it not been for the widespread fires occurring on the peninsula from 1870 to 1900 (Spencer and Hakala, 1964). Moose thrive on willow, quaking aspen, and shoots of paper birch (*Betula papyrifera* var. *Kanaica*), which grow luxuriantly after burns. By contrast, caribou are not favored by these browse foods. During the winter caribou feed principally on slow-growing lichens, some of which require more than a century for reestablishment following destruction by fire (Scotter, 1964).

Fig. 4. *Dozed ashe juniper in the background is a volatile fuel and gives off dangerous firebrands while burning. Grass in the foreground is a nonvolatile fuel and does not give off firebrands.*

Other subclimax animals that have reportedly increased following fires are cougars, wolves, coyotes, deer mice, ground squirrels, and beavers. Climax species such as bobolinks, sparrows, caribou, martens, wolverines, tree squirrels, and grizzly bear usually decrease.

Many people have a misconception about animals being killed by fires. Occasionally, animals are killed by fires, particularly large wildfires, but most vertebrates manage to escape the heat of fires by flying or running away, going below the ground a few inches, hiding in rock outcrops, or seeking islands missed by the fire. Studies in California by Howard et al. (1959) showed that fire did not harm cottontails, rats, mourning doves, quail, and several species of birds. In fact, the number of all animals increased immediately after the fire. Phillips (1965) listed a large number of ungulates associated with forests and woodland-savanahs in east Africa; the only report of any mature animals being killed by fire was after a fire in 1869 in which a dead elephant and buffalo were found. Phillips noted that occasionally a few species of very young animals were killed by fires.

Fires adversely affect population densities of animals principally by altering the habitat – not by killing. Habitat, more than anything else, determines the species and their densities. A patchy burn (about 20% unburned area) is most desirable for wildlife. This leaves adequate cover for upland and big game and a winter food supply of various nuts and acorns. Prescribed fires, in general, greatly increase the diversity of wildlife species, as well as population densities on all vegetation types (R. Komarek, 1963; Marshall, 1963).

Techniques for Burning

There are two basic fuel types (Fig. 4)—nonvolatile and volatile (fuels containing ether extractives such as waxes, oils, terpenes, and fats). Grasses and hardwoods are nonvolatile fuels, whereas chaparral, sagebrush, juniper, and slash are volatile fuels. Nonvolatile fuels such as grass are relatively safe to burn. Procedures to burn such fuels have been outlined by Wright (1972a). Volatile fuels, however, are explosive and create serious firebrand problems. They can be burned safely, but wide firelines and a thorough knowledge of weather and fire behavior are necessary (Green, 1970; Wright et al., 1972).

Our procedure for burning 4,000 lb/acre or more of nonvolatile fuel is as follows:

(a) Cut a 10-ft fireline on the upwind sides of the area to be burned (Fig. 5). In this example we are assuming that the prevailing winds are from the southwest.

(b) Cut a 15-ft fireline on the downwind sides (in this example north and east) of the area to be burned.

(c) Cut a 10-ft fireline 100 ft inside the north and east sides (downwind).

(d) Backfire the 100-ft strip on the downwind sides when winds are less than 8 mph and when relative humidities are between 50 and 60%. The fire is very docile under these conditions and if a spot fire occurs, it can be easily extinguished.

(e) After the downwind firelines have been burned, the main portion of the pasture can be burned with a wind that averages from 8 to 15 mph. Winds in excess of 8 mph are necessary to burn down standing woody stems (Wright, 1972a). Relative humidities should average from 25 to 40%.

These conditions can be varied with experience, depending on the amount of fine fuel and the goal of the burning. For example, a goal of killing shrubs or burning logs with light fuel (less than 2,000 lb/acre), requires a wind in excess of 8 mph. If the only concern is to remove dead litter, a backfire for the main burn is sufficient. In practice, we usually burn around a prescription because the weather is seldom perfect.

The primary dangers in burning grasslands come from tumbleweeds and firewhirls. Tumbleweeds will ignite and then tumble, leaving flames in their path. Firewhirls develop where wind shears occur, such as when a headfire runs into a backfire, or a fire goes up slope into a wind. We have seen several firewhirls develop when headfires met backfires while winds were 10 to 15 mph. We have also seen two huge firewhirls develop when winds were light and variable. For these reasons, we prefer to burn with a steady wind and never burn into backfires, unless we have at least a 300 ft fireline. Burning should be done *with* canyons, not across them.

Our procedure for burning volatile fuels on the Edwards Plateau in Texas is quite different (Fig. 6). It is illustrated below, where juniper has been dozed and there is adequate grass to carry the fire.

(a) Graze the pasture heavily before spring green-up.

(b) Doze 10-ft firelines on each side of a 400-ft wide strip on the downwind sides (north and east in this example) of the pasture to be burned.

(c) While the grass is green (between May 1 and June 1), burn the large piles of dead fuel in the 400-ft strips (black splotches in Fig. 6). Wind should be less than 10 mph, and relative humidity should be above 45%. Care should be taken not to burn into areas with thick leaf mats of oak leaves. Oak leaves will ignite easily from cinders. Wait at least one day to burn piles of dozed juniper after receiving 0.25 inch of rain. Small piles must be dry to ignite easily and to burn completely. After pile burning is completed (June 1), defer the pasture so that adequate grass fuel will be available to burn the pasture the following spring.

(d) Eight months later in February, burn grass in the strips. If the grass fuel is more than 2,000 lb/acre (e.g. little bluestem), burn when wind is less than 8 mph and relative humidity is 50 to 60%. If the grass fuel is less than 2,000 lb/acre (e.g. buffalograss), burn when wind is less than 8 mph and relative humidity is 25 to 40%. This prepares the firelines for the major burn that follows.

(e) Burn into the prepared firelines when wind is 8 to 15 mph and relative humidity is 25 to 40%. If there are large

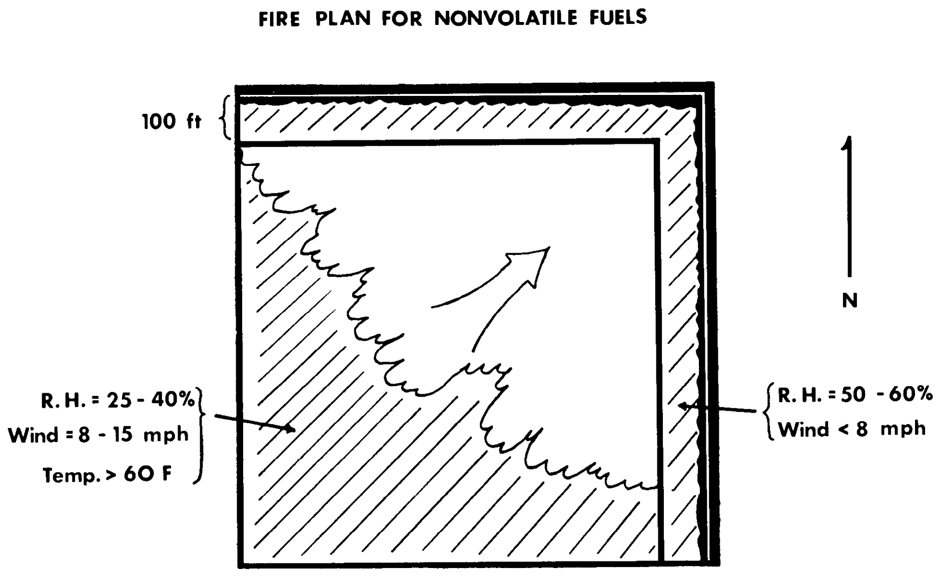

Fig. 5. *After firelines are cut, a 100-ft strip on the downwind sides (north and east) of a pasture is backfired with winds less than 8 mph and with relative humidities between 50 and 60%. Then the pasture is headfired with the prevailing wind (southwest) averaging from 8 to 15 mph and relative humidities from 25 to 40%.*

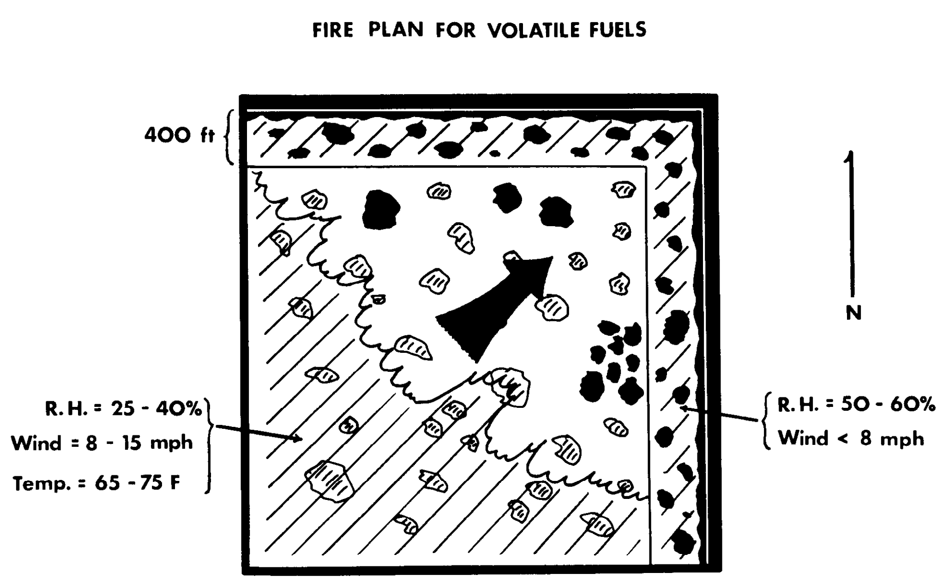

Fig. 6. *When the grass is green, juniper piles in the 400-ft strip (black splotches) on the downwind sides (north and east) are burned with wind velocities less than 10 mph and relative humidity above 45%. Eight months later (when grass is dormant), the grass in the 400-ft strip is burned when the wind is less than 8 mph and relative humidity is between 50 and 60%. Lower relative humidities may be used if the grass fuel is less than 2,000 lb/acre. All large concentrations of piles are backfired on the downwind sides of main area to be burned, and then the entire area is burned into the prepared firelines with a wind of 8 to 15 mph and a relative humidity of 25 to 40%.*

concentrations of piles within 50 to 60 ft of each other on the downwind sides, backfire them before headfiring the general area.

These volatile fuels put up live firebrands that can easily travel 1,000 ft and ignite other fuels at this distance during dry years. Thus, weather at the time of burning is extremely important. Large piles of volatile fuels can be safely burned during dry, freezing weather, but flare-ups will be common during the following warm weather.

Current research also indicates that firebrands are not a serious problem when maximum winds are less than 5 mph, when 10-hr time-lag fuel moisture is over 15%, when air temperature is below 60°F, and when burns are conducted within 24 hr of a rain (Bunting, 1974). Any other time they can ignite punky wood or cow chips. They can also ignite bark and wood if the cinder is large enough and falls in a tight spot. Grass is very difficult for firebrands to ignite, unless the brands are flaming or they fall in a tight bunchgrass.

Temperatures

Mineral soil surface temperatures of grassland fires vary from 182°F to 1260°F for fuels that vary from 1546 to 7025 lb/acre (Stinson and Wright, 1969). Temperatures above 150°F in these fires generally last only from 0.9 to 5.4 minutes (Stinson and Wright, 1969), which indicates that seeds of most plants can survive in grass fires (Daubenmire, 1968). Plant tissue, however, is easily killed with temperatures above 150°F that last from 1 to 12 minutes, depending on moisture content of the plant tissue (Wright, 1970). The relation between time and temperature to kill plant tissue is an exponential function (Hare, 1961).

Below the mineral soil surface, temperatures decrease sharply (Heyward, 1938; Bentley and Fenner, 1958). Under longleaf pines, where the principal fuel was grass, the majority of temperatures at depths of 1/8 to 1/4 inch in soil ranged from 150 to 175°F and generally persisted for 2 to 4 minutes, after which they declined rapidly (Heyward, 1938). Soil temperature increases were negligible below a depth of 1/4 inch, even when flames were 12 ft high.

Above the soil surface, temperatures rise very rapidly during fires (Bentley and Fenner, 1958; Ito and Iizumi, 1960; Whittaker, 1961). Whittaker found that some temperatures were 932°F greater at 8 inches above than at ground level. Davis and Martin (1960) measured temperatures as high as 1600° F at 1 ft above a fire in 8 year-old gallberry-palmetto roughs. Where trees are present in heavy grass fuels, temperatures on the windward side are commonly 700°F, while temperatures on the lee side are about 1400°F (Fahnestock and Hare, 1964). This is why trees are often scorched on one side only.

Bunchgrasses with large accumulations of dead plant material often generate high temperatures for a long period of time after the main fire has passed (Wright, 1971). The passing fire ignites the outer edge of the plant and then fuel within the plant generates temperature up to 1000°F within 1 hr. Temperatures above 200°F for over 2 hr are common in large bunchgrasses, but not in small bunchgrasses or rhizomatous species.

Where heavy logs and deep brush are piled, duff surface temperatures vary from 1150 to 1841°F (Isaac and Hopkins, 1937; Bentley and Fenner, 1958). Maximum temperatures 3 to 15 ft within and above brush piles are commonly 2000°F and can be as high as 2600°F (Countryman, 1964).

Safety

We have a major responsibility for conducting prescribed fires safely so that they do not go beyond the planned fire lines. Unfortunately, we only have minimal research data on how to conduct prescribed burns. We have a few excellent practioners around the world who know how to conduct prescribed burns, but their rules are general, sometimes regional in nature, and very little information is documented. For example, the people who burn in the Kruger National Park in South Africa do a lot of burning every year and are good at it, but they cannot tell us under what relative humidity, wind speed, fuel moisture, etc., they burn, except in relative terms.

To conduct burns safely, the fire boss needs precise research data on which to base a fire plan. We are getting this kind of data in Texas, and it is being collected in a few other states. We can give precise prescriptions to burn mesquite-tobosa and dozed ashe juniper communities.

Despite our efforts to get good field-tested research on prescribed burns, we must still acknowledge that conducting prescribed fires is dangerous. People must be informed about these dangers—what they are and how we make plans to combat them. The unexpected behavior of a fire is always a threat, and only the man with years of experience can attempt to forecast most of the dangers. Thus, during the burning of volatile fuels, a dozer should be on standby and the area should be patrolled with pumper trucks.

Backfires are much safer to conduct than headfires, but they are also less damaging to brush species. Fast-moving headfires consistently do more damage to brush and trees than slow-moving backfires (Fahnestock and Hare, 1964). Backfires are also more difficult to keep burning in many fuel types unless the wind and relative humidity are unsafe. We prefer to use headfires as outlined previously. They are more destructive to shrubs and require less fuel to carry them.

As preparations for a burn begin, the fire boss should maintain contact with a fire weather forecaster from the U. S. Weather Service. These people are trained to give "spot weather forecasts" for specific areas, and give much better forecasts than the local area forecaster. It is generally necessary to follow weather patterns for several days ahead of a planned burn, so that you can pick an appropriate day for burning.

Pollution

Recent information on pollution from wood smoke has been summarized by Komarek (1970) and Dieterich (1971). In general, air-borne particulates are the primary pollutant of fires. However, they are short-lived. Hydrocarbons are another combustion product, but few, if any, appear in the combustion of wood products that are important in photo-chemical reactions (Fritchen et al., 1970). Carbon monoxide is a pollutant from fires, but it seems to oxidize quite readily (Fritchen et al., 1970) and does not pose an immediate threat to people, plants, or animals (Dieterich, 1971). Forest fires, including wildfires and prescribed burns, produce only 8% of all pollutants in the United States (Dieterich, 1971). This percentage can be influenced by the dryness of fuels at the time of burning. Dry fuels burn much cleaner than green fuels (Darley et al., 1966).

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Asphalt-Fiberglass for Precipitation Catchments

LLOYD E. MYERS AND GARY W. FRASIER

Highlight: *Field experience gained in the construction of nine water harvesting catchments since 1962 has shown that field-fabricated asphalt-fiberglass coverings are a dependable means of providing water for livestock on many rangeland areas. Initial construction costs, including site preparation and labor, were less than $1.25 per square yard. The asphalt-fiberglass coverings are easy to install, require no sophisticated equipment or skills, and are highly resistant to mechanical damage to wind or animals.*

Efficient management of many large rangeland areas requires adequate and dependable livestock water supplies. Sufficient numbers of reliable streams and wells are frequently not available. Ponds built by damming intermittent streams often go dry just when they are needed the most. As a result, ranchers in some areas haul water for their livestock at costs estimated as high as $38 per 1,000 gallons (Pearson et al., 1969). Collection of precipitation by artificial catchments could provide water at less cost than hauling. Economic analyses have shown that installation of water harvesting catchments can be a sound investment for the stockman (Workman et al., 1968). Such catchments have been and are being built by governmental agencies to obtain water for livestock.

Many materials and methods have been investigated in attempts to lower the cost of artificial catchments (Myers, 1967). Some of these are promising but need further development. One relatively new material, field-fabricated asphalt-fiberglass, appears worthy of immediate consideration by rangeland managers. Field experience since 1962 has shown that this material is strong, durable, relatively easy to install, and costs less than sheet steel or butyl rubber.

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Performance of Asphalt-Fiberglass Catchments

Nine asphalt-fiberglass catchments, fabricated on site by saturating glass matting with low viscosity asphalt emulsion and then sealing with roofing grade asphalt emulsion, have been constructed since 1967. Five of these were installed in areas of such rugged terrain that use of 4-wheel drive vehicles was necessary to gain access. Two installations were on sites where buried rocks up to 3 feet in diameter could not be removed and no other type of ground cover, including reinforced butyl sheeting, could have been used.

Performance of eight of these catchments has been excellent. Seal coat application was not made on the ninth catchment until 16 months after base coat application, and the seal coat asphalt did not bond satisfactorily to the oxidized base coat. No significant deterioration or mechanical damage by wind or animals has been observed on any of the other catchments. As further evidence of durability, asphalt-fiberglass linings installed in two small reservoirs during 1962 and 1964 are still in reasonably good condition despite an almost total lack of maintenance. Deer have climbed in and out of one of these reservoirs, on 45° side slopes, with no damage to the lining. Plant growth problems have been limited to two catchments in Hawaii. On one of these catchments, windblown seeds sprouted in three 2-ft^2 patches of soil on the surface. These were removed in less than 5 min by hand pulling. On the other catchment, some grass grew through the membrane near the edge because of inadequate soil sterilization before catchment installation.

Since 1967, runoff from a 2,500-ft^2 asphalt-fiberglass catchment at the Granite Reef Test Site near Mesa, Arizona, has averaged 95% of the rainfall measured by a standard weighing raingage. This is in an 8-inch average annual rainfall area where, on the average, 50% of the total rainfall occurs in storms of less than 0.4 inch. Eighty percent of the total rainfall occurs in storms with rainfall intensities of less than 0.2 inch/hour. Preliminary rainfall-runoff measurements for the catchment on Maui, Hawaii, in a 100-inch average annual rainfall area, indicated good rainfall collection efficiency.

Water running off an asphalt surface can be discolored by oxidized asphalt, particularly in arid regions. The discoloration is directly proportional to the time between rains and inversely proportional to the volume of runoff (Frasier et al., 1970). Discoloration is minimal in high rainfall areas. The discolored water is odorless and tasteless and is readily consumed by cattle.

Construction of Catchments

Catchments should be installed on a natural slope of 5 to 20%. All vegetation must be cleared to bare soil, and rocks larger than 1-inch diameter should be removed by hand raking. Larger rocks that are partially buried in the soil may be left in place if there are no sharp projections and the rock surface merges smoothly with the soil surface as shown in Figure 1. A low berm or dike is constructed around the perimeter of the catchment, as shown in cross section in Figures 2 and 3. When water is conveyed from the catchment to the storage structure through a pipe, the berms on the lower side can be made higher to provide short-term water storage on the catchment during high intensity rainfall, thereby reducing the required pipe size. The catchment surface and berms should be compacted with a roller or rubber-tired vehicle to obtain a reasonably smooth surface. To prevent regrowth of vegetation, a suitable soil sterilant should be applied. A trench, at least 5 inches wide and 4 inches deep, is dug on top of the berms around the plot for anchoring the edges of the asphalt-fiberglass cover.

The fiberglass used is fabricated from multiple-length, chopped glass strands bonded into a continuous mat 36 to 72 inches wide with a polyester resin sizing which softens when treated with asphalt. Starting on the lower berm of the catchment, the fiberglass is unrolled in a strip transverse to the slope with the lower edge extending into the bottom of the anchor trench. The ends of this fiberglass strip and subsequently laid strips must also extend into the side trenches. Care should be taken to avoid wrinkles. The fiberglass is then coated with 1/2 to 3/4 gal of asphalt emulsion per square yard to saturate the mat and bond it to the underlying soil as shown in Figure 4. Both cationic and anionic emulsions with 60% solids have proved satisfactory for this base coat. The asphalt can be applied with standard gear pump asphalt spray equipment, or it can be poured on the fiberglass from buckets and spread with soft-bristled industrial floor brooms. After the first fiberglass strip is coated, the next strip is unrolled, overlapping the first strip about 4 inches, and coated with asphalt. This procedure is continued up the slope until the entire catchment is covered. The asphalt emulsion softens the sizing in the matting, allowing it to conform to minor irregularities in the catchment surface within a few hours. Immediately after this base coat is applied, the trenches around the catchment are partially backfilled to prevent wind from damaging the covering before the asphalt sets and hardens.

The seal coat is applied after the base coat has cured and is no longer tacky. During warm, sunny weather, the base coat will cure in 1 or 2 weeks. Light rainfall during the curing will not ordinarily damage the base coat, but installations should be made during clear weather if possible. During this time, any "fishmouth" wrinkles in lap joints should be repaired to prevent wind or water entry. This is easily done by cutting the wrinkle lengthwise along the center of the wrinkle, pressing the cut edges flat, placing a fiberglass patch over the wrinkle, and saturating the patch with asphalt emulsion.

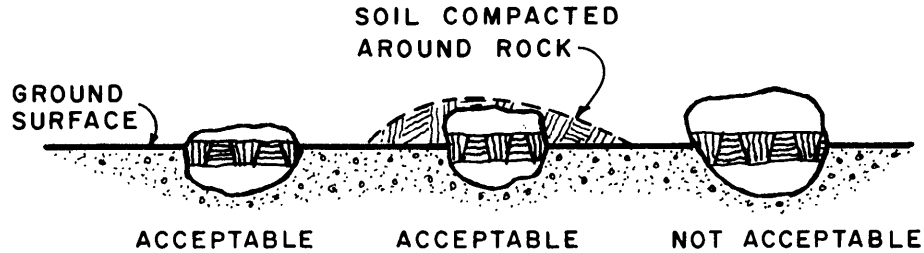

Fig. 1. *Illustration of acceptable and nonacceptable buried rocks.*

The seal coat used is a roofing type asphalt-clay emulsion, with a minimum solids content of 48%, guaranteed for 10 years when applied to a roof at a rate of 1/3 gal per yd^2. The seal coat is applied to the fiberglass by spraying or spreading with brooms at a rate of 1/3 to 1/2 gal per yd^2. Good coverage of lap joints is easier with brooms than with spraying, because the material can be brushed against the laps to fill any small voids. A single, carefully applied seal coat should be adequate for catchment surfaces. Seal coats usually require 2 days of clear, warm weather for curing. Rain can seriously damage uncured seal coats. After the seal coat application, the anchor trenches are completely backfilled.

Maintenance of Catchments

All water harvesting structures should be visited at least every 6 months to make sure float valves, drinking troughs, water storage systems, and catchment surfaces are maintained in good operating condition. A new seal coat will have to be applied to an asphalt-fiberglass catchment surface every 5 to 10 years, depending on the quality of the material used and the care with which it was applied. Exposure of the white fiberglass will indicate the need for a new seal coat. The catchment should be given a light tack coat of cutback asphalt to ensure bonding of the seal coat to the oxidized surface.

Although properly constructed asphalt-fiberglass catchments are highly resistant to mechanical damage, such damage can occur. Holes in the cover are easily repaired with a patch of fiberglass matting saturated with asphalt emulsion. Large patches should also be given a seal coat. Windblown seeds can germinate and grow in any soil accumulating on the lining surface. The plants and soil should be removed. Penetrating-type plants such as yucca (*Yucca* sp.) or nut sedge (*Carex* sp.) not removed or killed during plot preparation can grow up through the

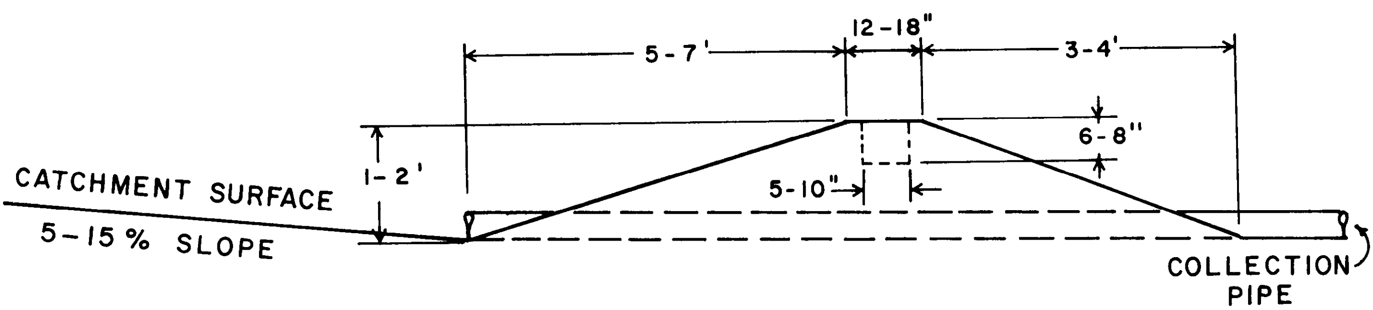

Fig. 2. *Desired shape of berm at lower edge of catchment area.*

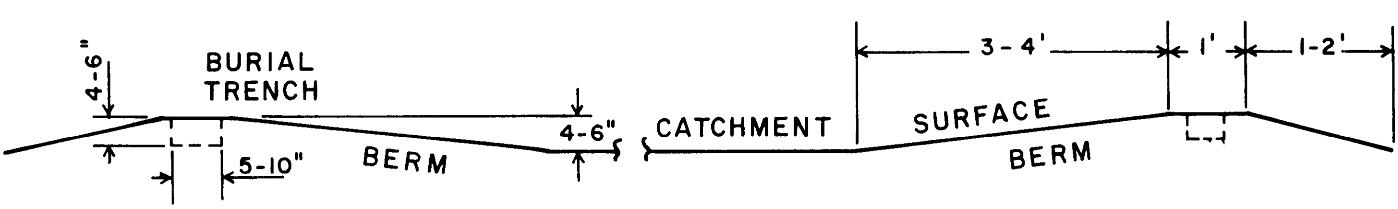

Fig. 3. *Berm shape for sides of catchment area.*

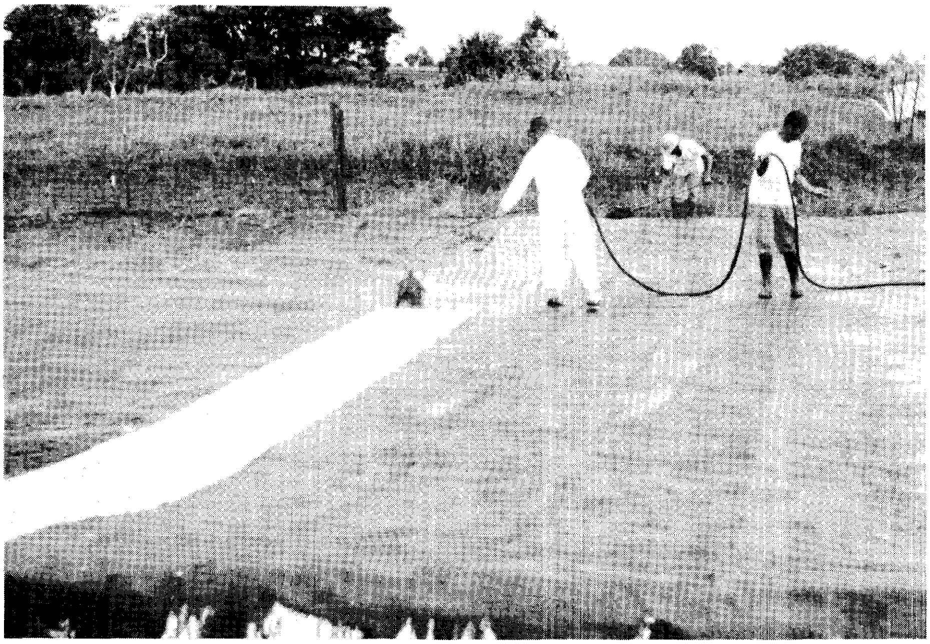

Fig. 4. *Laying the fiberglass mat and spraying with asphalt emulsion.*

Table 1. Construction costs for 1,100-y asphalt-fiberglass catchment.

Item	Cost	
Plot preparation		
Bulldozer, 6 hr at $20	$120	
Labor, 14 hr at $3.50	49	
Supervision, 10 hr at $6	60	$2:
Soil sterilant		
Monoborchlorate, 150 lb at 14 cents	$ 21	
Labor, 2 hr at $3.50	7	
Supervision, 1 hr at $6	6	$:
Asphalt-fiberglass		
Fiberglass 1½ oz, 1,200 yd² at 40 cents	$480	
SS-2 emulsion, 550 gal at 30 cents	165	
Brooms, 3 at $5	15	
Labor, 20 hr at $3.50	70	
Supervision, 10 hr at $6	60	$7̸
Seal coat		
Roofing emulsion, 370 gal at 60 cents	$222	
Brooms, 3 at $5	15	
Labor, 8 hr at $3.50	28	
Supervision, 4 hr at $6	24	$28
Total		$1,34

lining. Small plants can be killed by injecting soil sterilant under the lining. Large plants can be removed by cutting the lining, digging them out, and patching the cut area.

Catchment Construction Costs

Detailed on-site costs for constructing an asphalt-fiberglass catchment on a rough, rocky, brush-covered site near Safford, Arizona, are presented in Table 1. Three men spent 7 hours raking cobbles and debris from the 1,100-yd² site after brush clearing, rough smoothing, and berm construction by a bulldozer. Asphalt emulsion was purchased in 55-gallon drums, and the price includes the cost of the drums. Total on-site cost was $1,342. A second catchment, installed on a relatively rock-free, naturally smooth site near Tombstone, Arizona, cost less. The site was prepared by a road grader in 1 hour, with no hand raking, and the asphalt was purchased at a bulk lot price in the user's drums. On-site cost of this 1,100-yd² catchment was $1,050. Experience in constructing nine asphalt-fiberglass catchments indicates that, by making necessary adjustments in costs of materials, equipment, and wages, the information in Table 1 gives a reasonable estimate of probable construction costs. The total cost of the collected water is also dependent upon water storage costs, land costs, and the precipitation (Cooley et al., 1972; Dedrick et al., 1969).

The above costs do not include site selection, surveying, or travel to and from the job. These costs will be required for any type of catchment construction. Similarly, fencing costs are not included. The Tombstone catchment, installed in July 1971, was not fenced because the asphalt-fiberglass is resistant to damage by animal traffic. Observations a year later showed no damage from cattle walking on the catchment surface.

Advantages

Field experience gained in the construction of nine water harvesting catchments since 1962 has shown that field-fabricated asphalt-fiberglass coverings are a dependable means of providing wat for livestock on many rangeland area Catchments can be constructed with th material at an initial cost, including si preparation and labor, of less tha $1.25/yd².

The asphalt-fiberglass coverings a easy to install, requiring no sophisticate equipment or skills. The material h been successfully installed on surfaces tc rough for more conventional-type catcl ment materials. Maintenance on tl covering is simple and should require le than 3 man-hours per year between se

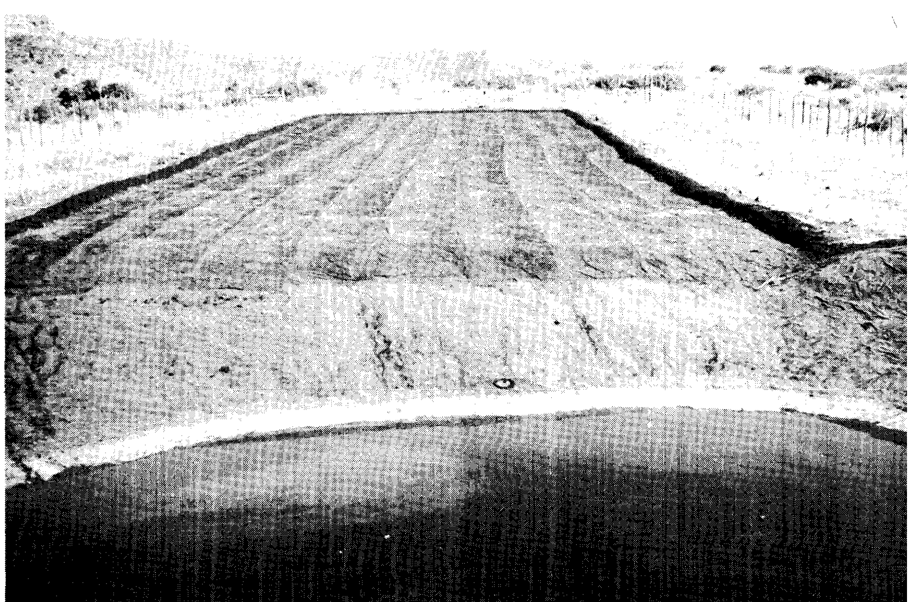

Fig. 5. *Completed asphalt-fiberglass lined catchment and reservoir on Fort Apache Indi Reservation.*

coat applications.

The asphalt-fiberglass is flexible during installation, permitting the lining to conform to surface irregularities. After complete curing, the lining becomes semirigid and is highly resistant to damage by wind or animals walking on the surface.

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Spring Food Habits of White-tailed Deer in the South Texas Plains

JAMES H. EVERITT AND D. LYNN DRAWE

Highlight: *During the spring seasons of 1970 and 1971, rumen analyses were used to determine food preferences of white-tailed deer on the H. B. Zachry Randado Ranch in South Texas. A total of 83 plant taxa were found to be eaten by this deer herd. Forbs comprised an average of 37.1% by volume of the diet, browse 33.1%, and cacti 17.5%, while grass comprised only 2.5% volume of the diet. Pricklypear cactus was heavily consumed and comprised an average of 15.4% of the total diet. Forbs were most heavily utilized in early spring. Perennial species were more prevalent than annuals in the diet. Important differences occurred in the diet between years, between early and late spring, and between the three major range sites on the study area.*

Increased emphasis on hunting for recreation has focused attention on improved management of wildlife in general, and of deer in particular. Ramsey (1965) emphasized that potential economic returns from deer were greater than from livestock under average prices and adequate deer harvest. Since the white-tailed deer provides a significant amount of recreation to the public and is a source of economic returns to the landowner, a knowledge of the food habits of the white-tailed deer is essential if deer herd management is to improve.

Deer food habits studies have been conducted in many parts of the United States. Atwood (1941) lists more than 600 plants utilized by white-tails in the United States. Because of the variability of plant species from area to area, no general list of deer food preferences can be made.

Numerous studies have been conducted on the food habits of white-tailed deer in Texas. Hahn (1945), McMahan (1964), and Kelley (1970) found deer in the Edwards Plateau of Central Texas to be primarily browsers, but grasses and forbs were important during spring. Davis (1951) and Davis and Winkler (1968) also found browse to be the major food of white-tailed deer in South Texas; however, forbs were important in spring. Grasses were utilized little and were important only in winter and early spring. Chamrad and Box (1968) conducted a winter and spring food habits study on the Welder Wildlife Refuge in South Texas and found deer to be grazers, with forbs and grasses comprising 90% of the diet. Drawe (1968) investigated midsummer food habits of deer on the Welder Refuge and found forbs to constitute over 60% of the diet. Browse accounted for 33% of the diet, while grass was not significant.

This paper reports the results of a study of the white-tailed deer's spring food habits on the H. B. Zachry Randado Ranch in the western portion of the South Texas Plains. Because of limited time, only spring food habits were studied; diet for the other seasons is being determined by another researcher. The objectives of this study were (1) to determine spring food preference of white-tailed deer on the ranch; (2) to compare food preferences in Spring, 1970, with those of Spring, 1971; (3) to compare early spring with late spring diet; and (4) to determine food preferences on various range sites of the ranch.

Study Area

The H. B. Zachry Randado Ranch is located approximately 28 miles southwest of Hebbronville and 26 miles northeast of Zapata on the Jim Hogg-Zapata County line. The ranch consists of 7,500 acres of native rangeland enclosed by an 8-foot high, deer-proof fence. This area is included in the South Texas Plains vegetational region (Gould, 1969).

The climate of this area is mild with short winters and relatively warm temperatures throughout the year. Average annual rainfall for Jim Hogg County is 20.78 inches. Heaviest rains occur in May and September, with monthly averages of 2.66 and 3.65 inches, respectively, (Texas Almanac, 1970).

Temperatures are high with a yearly average of 71.3°F.[1] January is the coldest month with an average minimum temperature of 47°F, while July is warmest with an average maximum of 99°F.[2]

The topography of the ranch can be described as flat, but broken by caliche and gravel ridges.

Four major range sites have been named on the ranch in a concurrent research study (Higginbotham, 1972) (Table 1). The first of these is the shallow ridge site associated with Zapata fine

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[1] Soil Conservation Service Records, Hebbronville, Texas; unpublished data.

[2] Don Meyer, Climatologist, Hebbronville, Texas; personal communication.

sandy loam soils. This site is dominated by brushy species with little herbaceous understory. Second is a sandy loam site, associated with McAllen, Garceno, and Brennan fine sandy loam soils. This site is dominated by mesquite, but other species also occur there. Third is the Ramadero site, which supports dense brush and consequently less herbaceous vegetation. It is associated with Ramadero sandy clay loam soils. Fourth is the deep sand site, which is relatively open with an intermixture of brush, grasses, and annual forbs. It is associated with Nueces-Sarita soils.

There are approximately 200 head of cows and calves on the ranch. A three-pasture, two-herd, prescription-rotation grazing system is practiced. Cattle are moved approximately every 4 months. Deer have continuous access to all areas occupied by cattle. There is a large population of white-tailed deer on the ranch, estimated by aerial census to be 400 head, or an average of one deer to 19 acres.

Methods

Food habits were determined by rumen analysis. A total of 62 deer, predominantly does, were randomly collected at 2- to 3-week intervals from early February through early June of 1970 and 1971. Due to relatively warm winters, spring begins in early February and is marked by the appearance of many species of annual forbs. February 1 through March 31 was designated early spring, while April 1 through June 8 was designated late spring. A total of 23 deer were collected during spring 1970, while 39 were collected during spring 1971.

Study animals were randomly collected during early morning and late evening feeding hours from various range sites; however, they were grouped into three range sites. Those obtained from the small deep sand site were grouped with those from the large, surrounding sandy loam site because of apparent use of both sites by the animals. Variable numbers of deer were taken at each collection date. A maximum of seven were taken on one date while only two were obtained on another. Plant species composition data for the various range sites were obtained from a concurrent study (Higginbotham, 1972). Species composition of woody plants was determined in that study by using line transects (Canfield, 1941), while the point frame was used to determine herbaceous composition (Tothill and Peterson, 1962).

After collection the entire rumen was removed from each deer and a 1-quart random sample was taken. Samples collected in 1970 were preserved in formalin, while those collected in 1971 were frozen in an attempt to maintain sample quality. Samples were analyzed by the point frame method (Chamrad and Box, 1964). Using this method, both percent volume and percent frequency of occurrence of a species were obtained.

After analysis and identification of rumen samples the species were grouped into five classes: (1) browse, (2) forbs, (3) grass, (4) cacti, and (5) unknown material. Data were summarized and averaged according to forage class, early and late spring, years, and range sites. All data reported are averages for the category indicated.

Since food availability largely determines diet, a means of comparing the two was needed. The preference rating formula described by Chamrad and Box (1968) was employed:

$$\text{Preference Rating} = \frac{\%\ \text{Frequency of Occurrence} \times \%\ \text{Volume}}{\text{Availability Factor}}$$

Percent volume for each species utilized was derived from the percentage of total points contacting that species in the sample. Percent frequency of occurrence was the percentage of deer in which a given plant species was found. The availability factor is a numerical value related to plant abundance on the range, and plant species composition data from the range were used in determining it. Numerous scales have been used to classify the abundance of species. Vestal (1943) presented unequal scales for rating species in communities. Due to species diversity on the study area, the following scales were used:

Availability Class	Availability Factor
Rare (0-.50% composition)	1
Occasional (0.51%-2.50% composition)	2
Frequent (2.51-7.50% composition)	3
Abundant (>7.50% composition)	4

Data were subjected to analysis of variance. All statistical comparisons presented are significant at the .05 level.

Table 1. Major plant species of the Zachry Ranch and range sites on which they dominate.

Species[1]	Site[2]
Woody	
Acacia berlandieri	1
A. greggii	2,4
A. rigidula	1
Aloysia lycioides	3
Celtis pallida	2,3,4
Colubrina texensis	3
Condalia obtusifolia	2,3
Larrea divaricata	1
Leucophyllum frutescens	1
Lycium berlandieri	4
Porlieria angustifolia	2,3
Prosopis glandulosa	2,3,4
Schaefferia cuneifolia	2
Zanthoxylum fagara	3
Cacti	
Opuntia leptocaulis	2,4
O. lindheimeri	2,4
Grasses	
Aristida purpurea	4
Bouteloua trifida	1,2
Brachiaria ciliatissima	4
Buchloe dactyloides	2
Cenchrus ciliaris	2
Cenchrus incertus	4
Chloris cucullata	2,3
Digitaria californica	3
Eragrostis oxylepis	4
Pappophorum bicolor	2
Paspalum setaceum	4
Setaria texana	1,3
S. firmula	1,3
S. leucopila	2,3
Trichloris pluriflora	3
Forbs	
Aphanostephus riddellii	1,2,3
Dyssodia tenuiloba	1
Parthenium confertum	1,2,3
Physalis viscosa	2,3,4
Ambrosia psilostachya	3
Aphanostephus kidderi	4
Callirhoe involucrata	4
Cynanchum barbigerum	4

[1] Plant names are according to Correll and Johnston (1970).
[2] Site 1 = shallow ridge; Site 2 = sandy loam; Site 3 = ramadero; Site 4 = deep sand.

Results and Discussion

Overall Food Preferences

Based on analyses of 62 rumens, average volume percentages for the various forage classes were 33.1% browse, 37.1% forbs, 2.5% grass, 17.5% cacti, and 9.4% unknown. Percentages of browse and forbs were significantly higher than those of other classes.

A total of 83 different plant taxa were identified (Table 2). Of this total there were 51 forbs, 25 browse species, 5 grasses, and 2 cacti. Perennials were more prevalent than annuals in the diet. A large number of annual forbs were recorded, but few of these contributed high volumes to the diet. Grass was utilized only to a minor extent. These data indicate that, where given a choice, the white-tail will select a herbaceous diet. The Zachry Ranch offers this choice, i.e. there is a good intermixture of brushland and grassland, and the ranges have been placed in fair condition.

From this variety of species, however, there were 10 major taxa that made up 53% of the diet. Among these were three forbs, six browse species, and one cactus. This narrows the number of so called "major" species, but it should be emphasized that the remaining 73 "minor" species made up almost 50% of the volume of the diet.

The three major forbs included perennial lazy daisy (*Aphanostephus riddellii*), groundcherry (*Physalis viscosa* var. *cinerascens*), and winecup (*Callirhoe involucrata*). The most heavily utilized of these was perennial lazy daisy.

Among the six browse species were mesquite (*Prosopis glandulosa*), granjeno (*Celtis pallida*), lotebush (*Condalia obtusifolia*), guayacan (*Porlieria angustifolia*), catclaw acacia (*Acacia greggii*), and coma (*Bumelia celastrina*). Mesquite beans (mast) were a heavily utilized item when available.

Pricklypear cactus (*Opuntia lindheimeri*) was heavily utilized by this herd of deer during the study. It had the highest percent volume of any species in the diet. Both fruits and pads of pricklypear were utilized. Several individual rumens contained as much as 50-75% volume of pricklypear.

Comparison of 1970 and 1971 Food Habits

Deer diets did not differ significantly between spring 1970 and spring 1971. There was, however, a significant difference between percentages of unknown material for the 2 years.

Based on rumen contents of 23 deer collected in spring, 1970, average consumption was 30.3% browse, 33.0% forbs, 2.8% grass, 20.4% cacti, and 12.5% unknown. Averages for 39 deer collected in 1971 were 34.8% browse, 39.4% forbs, 2.2% grass, 15.8% cacti, and 7.5% unknown.

Forbs were the most preferred food items during both years, but they oc-

Table 2. Overall frequency (%) of occurrence and volume (%) of plant species in the diet of white-tailed deer for the spring seasons of 1970 and 1971 on the Randado Ranch in South Texas.

Species or variety	Frequency	Volume
Forbs		
Acalphya radians Torr.	T[1]	T
Acanthaceae	1.6	0.02
Acleisanthes obtusa (Choisy) Standl.	6.5	0.44
Ambrosia psilostachya DC.	6.5	0.76
Aphanostephus kidderi Blake	21.0	2.26
A. riddellii T. & G.	79.0	9.55
Callirhoe involucrata (Torr.) Gray	24.2	2.50
Cassia texana Buckl.	8.1	0.24
Cirsium texanum Buckl.	6.5	0.18
Clematis drummondii T. & G.	1.6	0.03
Compositae	9.7	0.13
Convolvulus arvensis L.	6.5	0.24
Cynanchum barbigerum (Scheele.) Shinners	12.9	0.48
Dalea aurea Nutt.	33.9	1.11
Dyssodia tenuiloba (DC.) Robins	14.5	0.53
Evax verna Raf.	1.6	0.02
Euphorbia prostrata Ait.	4.8	0.08
Gaillardia pulchella Foug.	1.6	0.03
Gaura brachycarpa Small	19.4	1.00
Helianthus annus L.	6.5	0.10
Lesquerella gracilis (Hook.) Wats	12.7	0.87
Lepidium sp.	4.8	0.13
Linum imbricatum (Raf.) Shinners	T	T
Menodora heterophylla Moric.	6.5	0.45
Nothoscordum bivalve (L.) Britt.	T	T
Oenothera sp.	1.6	0.66
Palafoxia rosea (Bush) Cory.	4.8	0.18
Parthenium confertum Gray	35.5	2.00
Petalostemum decumbens Nutt.	21.0	0.84
Phacelia sp.	T	T
Phyla incisa Small	1.6	0.03
Physalis visoca L. var. *cinerascens* (Dun.) Waterfall	30.6	2.97
Plantago hookeriana Fisch. & Mey	9.7	0.45
Polygonaceae	1.6	0.03
Portulaca mundula I. M. Johnst.	T	T
Psilostrophe gnaphalodes DC.	30.6	1.10
Pyrrhopappus multicaulis DC.	1.6	0.02
Ratibida columnaris (Sims) D. Don	3.2	0.08
Rhynchosia americana (Mill.) C. Metz.	8.1	0.18
Rumex crispus L.	1.6	0.02
Schrankia latidens (Small) K. Schum.	14.5	0.27
Sida filicaulis T. & G.	8.1	0.31
Solanaceae	1.5	0.08
Sphaeralcea pedatifida Gray	9.7	0.65
Thelesperma sp.	16.1	1.06
Verbena sp.	1.6	0.03
Verbena plicata Greene	8.1	0.58
Vicia leavenworthii T. & G.	1.6	0.02
Zexmenia hispida (H.B.K.) Gray	3.2	0.11
Zornia bracteata J. F. Gmel.	8.1	0.29
Unknown forbs	77.4	4.31
Grasses		
Aristida sp.	T	T
Cenchrus ciliaris L.	4.8	0.50
C. incertus M. A. Curtis	1.6	0.02
Paspalum setaceum Michx.	1.6	0.08
Setaria firmula (Hitch. & Chase) Pilger.	1.6	0.10
Unknown grass	41.9	1.71
Browse		
Acacia berlandieri Benth.	16.1	1.14
A. greggii Gray	43.5	2.35
A. rigidula Benth.	9.7	0.63
A. tortuosa (L.) Willd.	12.9	1.00
Bumelia celastrina H.B.K.	29.0	2.32
Castella texana (T. & G.) Rose	27.4	1.24
Celtis pallida Torr.	50.0	3.85
Cercidium texanum Gray	3.2	0.10
Colubrina texensis (Torr. & Gray) Gray	12.9	0.26
Condalia hookeri M. C. Johnst.	6.5	0.34
C. obtusifolia (Hook) Weberb	32.3	2.84
Diospyros texana Scheele[2]	9.7	1.34
Diospyros texana Scheele[3]	4.8	0.08
Ephedra antisyphlitica Berl.	11.3	0.26
Eysenhardtia texana Scheele	8.1	0.55
Krameria ramosissima (Gray) Wats	8.1	0.18
Leucophyllum frutescens (Berl.) I. M. Johnst.	14.5	0.35
Lycium berlandieri Dun. var. *berlandieri*	21.0	1.10
L. carolinianum Walt. var. *quadrifidum* (Dun.) C. L. Hitchc.	3.2	0.05
Porlieria angustifolia (Engelm.) Gray	29.0	2.50
Prosopis glandulosa Torr.	17.7	8.77
P. glandulosa Torr.	12.9[2]	0.16
P. reptans Benth. var. *cinearascens* (Gray) Burk	T	T
Schaefferia cuneifolia Gray	29.0	0.63
Xanthocephalum sarothrae (Pursh.) Shinners	T	T
Yucca treculeana Carr.	3.2	0.08
Zanthoxylum fagara Sarg.	17.7	0.58
Unknown browse	24.2	0.42
Cacti		
Opuntia leptocaulis DC.	22.6	2.08
O. lindheimeri Engelm. var. *tricolor* (Griffiths) L. Benson[3]	56.5	8.68
O. lindheimeri Engelm[2]	29.0	6.74
Unknown material	100.0	9.40

[1] Trace, observed in rumen sample but not recorded as a direct hit.
[2] Mast.
[3] Vegetative.

curred at a slightly higher percentage in 1971. Perennial lazy daisy was the most prevalent forb in the diet both years, but winecup occurred in considerably higher volume in 1971.

Browse was found in slightly larger amounts in the 1971 diet than in 1970. A number of differences were found in the browse species consumed between the 2 years. Differences were also found in the percent volume which these species contributed to the diet. Mexican persimmon (*Diospyros texana*) mast was a major constituent in the 1970 diet, when it comprised 3.6% volume, but it did not occur in the 1971 diet. Mesquite mast contributed a large volume in both years, but was consumed in larger amounts in 1971 when it occurred at 10.7% volume as compared to 5.5% in 1970. Catclaw acacia accounted for 3.5% volume of the 1971 diet, but was utilized considerably less in 1970 when it comprised only 0.8% volume. Other woody species such as granjeno, guayacan, coma, and lotebush comprised large percent volumes both years.

Cacti occurred in higher volume in the 1970 diet than in 1971. This difference was attributed to the higher rate of occurrence of pricklypear mast in the 1970 diet. Tasajillo (*Opuntia leptocaulis*) was of equal importance during both years.

Grass was not utilized in large amounts in either year, as its percent volume was 2.8% in 1970 and 2.2% in 1971.

Early Spring vs Late Spring

In comparing deer food habits between early and late spring over both years, some major differences were found. The early spring diet was based on analyses of 25 rumens. Average percent volume for early spring was 23.2% browse, 51.5% forbs, 2.3% grass, 12.9% cacti, and 9.6% unknown. Late spring diet was determined from analyses of 37 rumens. Percentage volume for the major forage classes was 39.6% browse, 27.5% forbs, 2.6% grass, 20.6% cacti, and 9.2% unknown.

There was a significant difference in the percentage of forbs consumed between early and late spring. Forbs were the most important item in early spring. In late spring, however, with the development of mesquite beans and pricklypear mast, there was a shift away from forbs. Perennial lazy daisy comprised over 12% of the early spring diet. Annual lazy daisy (*Aphanostephus kidderi*) was also widely utilized, comprising 4.8% volume of the diet. Other important forbs in early spring were golden dalea (*Dalea aurea*), western ragweed, (*Ambrosia psilostachya*), bladderpod (*Lesquerella gracilis*), wild honeysuckle (*Gaura brachycarpa*), thelesperma (*Thelesperma* sp.), groundcherry, and winecup. With lower total consumption of forbs in late spring there was a decrease in number of species selected. Perennial lazy daisy was still the dominant forb, comprising 7.8% of the diet. Groundcherry was also heavily consumed, accounting for 3.5% volume. Other species found in considerable volume were false ragweed (*Parthenium con-*

Table 3. Frequency (%) of occurrence, volume (%), availability, and preference of major forage plants utilized by white-tailed deer on the sandy loam range site of the Randado Ranch in South Texas during the spring seasons 1970 and 1971.

Species	Frequency[1]	Volume[2]	Availability factor[3]	Preference rating[4]
Forbs				
Aphanostephus riddellii	73	10.2	3	248
A. kidderi	24	2.4	1	58
Callirhoe involucrata	36	3.9	3	47
Dalea aurea	49	1.6	1	78
Gaura brachycarpa	27	1.4	1	38
Parthenium confertum	33	2.0	3	22
Petalostemum decumbens	27	1.2	1	32
Physalis viscosa	30	4.2	3	42
Psilostrophe gnaphalodes	33	1.5	1	50
Thelesperma sp.	24	2.0	1	48
Browse				
Acacia greggii	49	3.2	2	79
Bumelia celastrina	27	2.0	1	54
Castela texana	24	1.3	2	16
Celtis pallida	42	3.6	2	76
Condalia obtusifolia	30	3.1	2	47
Lycium berlandieri	24	1.5	1	36
Prosopis glandulosa[5]	16	8.3	3	44
Zanthoxylum fagara	30	1.0	1	30
Cacti				
Opuntia leptocaulis	18	1.6	1	29
O. lindheimeri[6]	52	7.6	1	395
O. lindheimeri[5]	33	5.5	1	182

[1] Frequency of occurrence in 33 rumens.
[2] Percent volume = Number point hits per species ÷ Total number sampling points in 33 rumens.
[3] Availability factor: rare = 1, occasional = 2, frequent = 3, abundant = 4.
[4] Preverence rating = (% frequency of occurrence × % volume) ÷ availability factor.
[5] Mast.
[6] Vegetative.

Table 4. Frequency (%) of occurrence, volume (%), availability, and preference of major forage plants utilized by white-tailed deer on the Ramadero range site of the Randado Ranch in South Texas during the spring seasons of 1970 and 1971.

Species	Frequency[1]	Volume[2]	Availability factor[3]	Preference rating[4]
Forbs				
Ambrosia psilostachya	27	3.1	3	28
Aphanostephus riddellii	87	10.4	3	302
A. kidderi	27	4.0	1	108
Callirhoe involucrata	20	1.7	1	34
Parthenium confertum	33	0.9	3	10
Physalis viscosa	33	3.5	2	58
Browse				
Acacia greggii	53	2.1	1	111
Celtis pallida	60	5.3	3	106
Condalia obtusifolia	40	1.6	1	64
Diospyros texana[5]	20	3.5	2	35
Porlieria angustifolia	53	2.7	2	72
Prosopis glandulosa[5]	27	12.4	4	84
Cacti				
Opuntia leptocaulis	33	2.7	1	89
O. lindheimeri[6]	67	8.1	1	543
O. lindheimeri[5]	27	6.6	1	178

[1] Frequency of occurrence in 15 rumens.
[2] Percent volume = Number point hits per species ÷ Total number sampling points in 15 rumens.
[3] Availability factor: rare = 1, occasional = 2, frequent = 3, abundant = 4.
[4] Preference rating = (% frequency of occurrence × % volume) ÷ availability factor.
[5] Mast.
[6] Vegetative.

fertum) and winecup.

There was a significant difference in the percentage of browse consumed between early and late spring. The most preferred browse species in early spring was granjeno, which comprised 4.4% volume. Catclaw, coma, and guayacan were other browse species heavily consumed in early spring. The increase in use of browse in late spring was attributed to the abundance of mesquite mast. This one species provided 14.7% of the late spring diet and occurred in high volume in a number of individual rumens. Mesquite leaves and stem tips were utilized very little. Mexican persimmon mast also contributed to this increase, as it comprised 2.2% of the late spring diet. Lotebush was significant in late spring, comprising 4.0% volume. Other browse species which comprised significant portions of the late spring diet were allthorn goatbush (*Castela texana*), granjeno, catclaw, guayacan, and coma.

Cacti were important in the early spring diet when this class comprised 12.9% volume. They became increasingly important in late spring with the development of pricklypear mast when it contributed 20.6% to the total diet. There was a significant increase in the percentage of cacti from early to late spring diet.

Grass was of little importance in either early or late spring, comprising only 2.3% and 2.6% volume, respectively. There was no significant difference between these percentages.

The percentages of unknown material for the two periods were not significantly different.

Sandy Loam Site

Thirty-three deer were collected from the sandy loam range site. Their diet consisted of 71 different plant taxa, including 42 forbs, 23 browse species, 4 grasses, and 2 cacti. Forbs contributed an average of 43.3% volume to the diet, browse 30.8%, cacti 14.6%, grass 2.1%, and unknown 9.1%. Percentages of browse and forbs were significantly higher than the other classes.

Twenty species comprised 68.7% of the diet on this site (Table 3). These included 10 forbs, 8 browse species, and 2 cacti.

Ramadero Site

Browse and forbs were the most preferred deer foods from the Ramadero site. Of 15 deer collected from this site, 35.2% volume of their diet consisted of forbs, while 34.1% was browse. These two classes were significantly higher than the other classes. Cacti were of secondary importance, contributing 17.5% to the diet, while grass comprised 2.9%. The portion unidentifiable to forage class was 10.3%.

Fifty-two different plant taxa were identified in the diet from the Ramadero site. Forbs contributed nearly two-thirds of these with a total of 29 taxa. There were 20 browse, 2 cacti, and 1 grass taxa.

A total of 14 species comprised 68.5% of the diet on this site (Table 4). Twelve of these were perennials, while two were annuals.

Shallow Ridge Site

The diet of 14 deer from the shallow ridge site contained 47 plant taxa, including 24 forbs, 20 browse, 2 cacti, and 1 grass. Browse was the most important item in the diet, comprising 38.8% of the total volume, cacti 24.6%, forbs 24.3%, and grass 2.9%. Approximately 9.4% was unidentifiable to forage class.

Browse was significantly higher than the other classes. Thirteen different plant taxa contributed 69.4% volume to the diet (Table 5). Of these, 10 were perennials and 3 were annuals.

Table 5. Frequency (%) of occurrence, volume (%), availability, and preference of major forage plants utilized by white-tailed deer on the shallow ridge range site of the Randado Ranch in South Texas during the spring seasons of 1970 and 1971.

Species	Frequency[1]	Volume[2]	Availability factor[3]	Preference rating[4]
Forbs				
Acleisanthes obtusa	14	1.6	1	22
Aphanostephus riddellii	86	7.4	4	159
Dyssodia tenuiloba	21	1.0	2	11
Lesquerella sp.	21	1.8	1	38
Parthenium confertum	43	3.1	4	33
Browse				
Acacia berlandieri	50	4.8	4	60
Bumelia celastrina	71	5.5	1	391
Celtis pallida	57	3.0	1	171
Condalia obtusifolia	36	4.1	1	148
Porlieria angustifolia	57	6.9	2	197
Prosopis glandulosa[5]	14	6.0	1	84
Cacti				
Opuntia leptocaulis	21	2.7	1	57
O. lindheimeri[6]	50	10.9	1	545
O. lindheimeri[5]	29	10.7	1	310

[1] Frequency of occurrence in 14 rumens.
[2] Percent volume = Number point hits per species ÷ Total number sampling points in 14 rumens.
[3] Availability factor: rare = 1, occasional = 2, frequent = 3, abundant = 4.
[4] Preference rating = (% frequency of occurrence × % volume) ÷ availability factor.
[5] Mast.
[6] Vegetative.

Summary and Conclusion

Due to the mosaic pattern of the soil types on the ranch, many of the same plant taxa occurred in deer diets from all three range sites. Ten species contributed a major percent volume to the diet. These were perennial lazy daisy, groundcherry, winecup, granjeno, lotebush, mesquite, guayacan, catclaw acacia, coma, and pricklypear cactus.

A total of 83 plant taxa were found to be eaten by white-tailed deer on the Zachry ranch. Perennials were more sought after than annuals. Spring food habits of the white-tailed deer were dependent on availability of vegetation, but were also influenced by individual deer preferences.

It should be apparent from the data presented in this study that managers should strive for a good intermixture of vegetative types if they want to provide good deer habitat. Forbs are a very important part of the diet of white-tails, but browse species must be provided for both food and cover.

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Estimating Intake and Digestibility of Native Flint Hills Hay

M. RAMA RAO, LENIEL H. HARBERS, AND ED F. SMITH

Highlight: *In vivo and in vitro studies were conducted on native hay from the Flint Hills harvested at three stages of maturity from an area annually burned in late spring. Intake and digestibility declined with stage of maturity. In vivo organic matter intake and digestibility was satisfactorily estimated using fecal nitrogen and fecal organic matter output data as independent variables. A somewhat less reliable estimate of digestibility was provided by in vitro fermentation.*

The Flint Hills of Kansas form a unique rangeland area of approximately 1.8 million hectares. It is used for continuous grazing by beef cows and for summer grazing by steers. Further improvement in production would be likely with estimations of intake and nutrient digestibilities of native pastures. A series of studies was therefore conducted to establish prediction equations for organic matter digestibility and intake from esophageally collected samples and fecal residue. The results obtained using hay harvested at different stages of maturity are presented in this report.

Methods

Native hay was harvested during June, July, and September, 1971, from an area burned annually in late spring. Harvested hay was allowed to sun dry for 2 days, then was baled and stored indoors until used.

Two groups of six yearling Angus steers (average weight, 272 kg) were used in four metabolism trials in a randomized incomplete block design. For 10 days prior to a 7-day collection period, the steers were maintained on hay (amount offered daily being equivalent to 2.50% of body weight). Mineralized salt blocks and water were readily accessible.

Four esophageal samples from each hay were collected at four different times, two replications on each of four occasions. Simultaneously, a sample from each cutting of hay was hand picked for the control. Samples were frozen immediately and stored until analyzed.

Feed and fecal samples were dried in a forced-air oven at 50°C for 72 hr for proximate analyses (A.O.A.C., 1970); those used for cell-wall constituents were dried in acetone according to Goering and Van Soest (1970).

For in vitro studies, we used the two-stage, 24-hour fermentation method of Tilley and Terry (1963). Inoculum was obtained from two ruminally fistulated Hereford steers maintained on a mixture of prairie and alfalfa hays plus 2.0 lb of a 16% protein concentrate with minerals. In vitro dry matter digestibilities of esophageally and hand sampled hays were compared to in vivo digestibilities determined from total collection. In vitro digestibility values of esophageal samples were used to establish a regression for estimating in vivo dry matter digestibility of the three individual hays.

Data were subjected to least squares analyses of Harvey (1960). Duncan's new multiple range test was used to separate significant differences among means (Steel and Torrie, 1960). Regression analyses were obtained by a stepwise deletion procedure described by Draper and Smith (1966). Data differing at the 5% level of probability have been considered significant.

Results and Discussion

Crude protein, ash, crude fiber, and nitrogen-free extract values for esophageally collected hay samples were different from those for the hand-picked samples: crude protein and ash were higher; crude fiber and nitrogen-free extract lower (Table 1). There was no difference resulting from frequency of collection; nor was there any sample × time interaction.

A threefold increase in phosphorus and decreased calcium were observed in esophageal collections. Phosphorus in fistulae samples is increased significantly by salivary contamination (Lesperance et al., 1960); excessive saliva removal may decrease calcium content (Ansotegin et al., 1971).

Digestibility and Intake

Dry and organic matter intakes for the three hays declined

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Table 1. Means and standard errors of chemical composition (%) of native hays cut at three growth stages.

Time and collection method	Ash	Crude protein	Crude fiber	N-free extract	Calcium	Phos-phorus
Hay harvest time						
June	7.7[a,2]	5.8[a]	33.0[a]	45.9[a]	0.4[c]	0.2[a]
July	7.4[a]	4.8[b]	34.8[b]	45.7[a]	0.3[a]	0.2[a]
September	8.9[b]	3.8[b]	33.0[a]	46.6[a]	0.3[a]	0.2[a]
S. E.[1]	0.22	0.19	0.38	0.48	0.03	0.02
Sample collection method						
Esophageal	9.3[c]	5.1[c]	32.8[a]	44.8[a]	0.2[b]	0.3[b]
Handpicked	6.7[a]	4.4[b]	34.4[b]	47.3[b]	0.4[c]	0.1[c]
S. E.[1]	.18	.16	.31	.40	.02	.02

[1] Standard error.
[2] Means in the same column followed by the same letter are not significantly different at the 5% probability level as determined by Duncan's new multiple range test.

gradually (Table 2). Consumption of June hay was significantly greater than that of September hay, indicating, as Heaney (1969) has suggested, that as a plant matures it has a depressing effect on voluntary intake.

Digestibility of nutrients usually decreased more between hays cut in June and July than they did between hays cut in July and September (Table 2). Crude protein and acid detergent fiber digestibilities in September hay were each about 20 units lower than for June hay (Fig. 1). Their relative digestibilities seemed a good indicator of the quality of those native hays.

In Vivo vs In Vitro Digestibility

In vitro digestibility of hand-picked samples was lower than that of esophageal samples (Fig. 2). In hand-picked samples, the in vitro digestibility of July hay was 2 or 3 units higher than that of June or September hay. In esophageally collected samples, in vitro digestibility of July and September hay was the same: the June sample was 4 units higher.

The correlation coefficient between in vivo and esophageal in vitro dry matter digestibility was 0.77. The simple regression equation gave this value:

$\hat{Y} = -47.86 + 2.05$ (IVDMD), where

$\hat{Y}$ = Estimated dry matter digestibility (%)

IVDMD = In vitro dry matter digestibility (%)

A collaborative study using good quality hay indicated that in vitro dry matter digestibility values ranged from 57.1 to 64.2% with correlation coefficients from 0.79 to 0.97 (Barnes, 1969). In our studies dry matter intake was low, resulting in high in vivo digestibility. Nutritive value indexes for these hays harvested in June, July, and September were 43.48, 35.05, and 28.35, respectively (standard forage value—70.00).

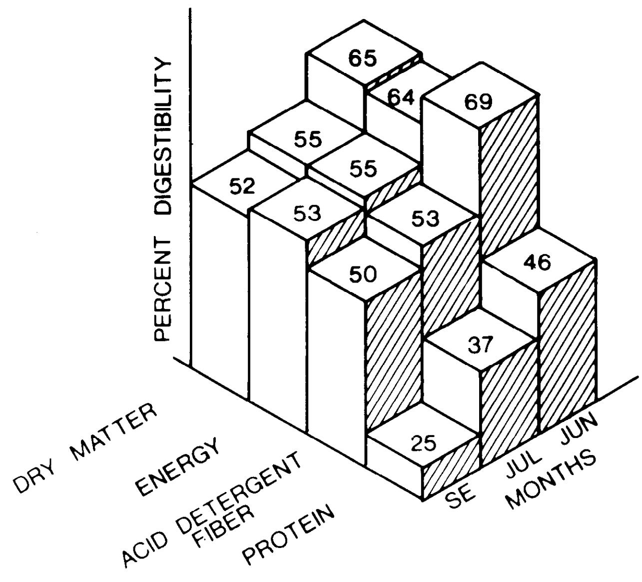

Fig. 1. *Comparison of in vivo digestibility of dry matter, energy, acid detergent fiber, and crude protein of native hay harvested at three stages of maturity.*

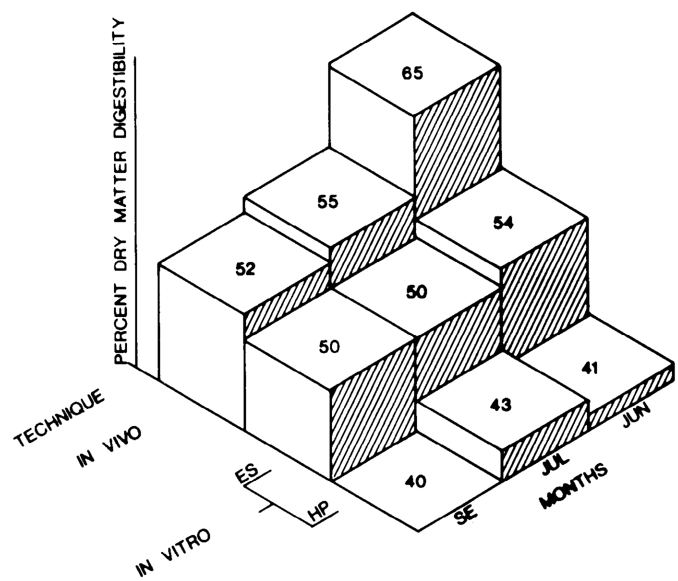

Fig. 2. *Comparison of in vivo and in vitro (ES = esophageal samples; HP = handpicked samples) digestion of native hay dry matter at three stages of maturity.*

Table 2. Means of herbage intake (kg) and digestibility coefficients (%) of hays cut at three growth stages.[1]

Date	Intake: Dry matter	Intake: Organic matter	Digestibility coefficients: Crude fiber	Nitrogen free extract	Neutral detergent fiber	Hemi-cellulose	Cellulose
Hay harvest time							
June	5.7[a,2]	5.3[a]	70.9[a]	69.4[a]	70.9[a]	76.8[a]	70.1[a]
July	5.3[a]	4.9[a]	65.1[b]	56.4[b]	59.0[b]	70.4[b]	60.6[b]
September	4.2[b]	3.8[b]	59.2[c]	59.3[b]	53.8[c]	68.3[b]	62.0[b]

[1] Each value for date of cut represents an average of six replications.
[2] Means in the same column followed by the same letter are not significantly different at the 5% probability as determined by Duncan's new multiple range test.

The indigestible residue from in vitro incubation differs from that of animal feces, thus in vivo digestibility is not a constant characteristic of a herbage (Tilley and Terry, 1963). That limits the accuracy with which in vivo digestibility can be predicted from in vitro data. In vivo digestibility possibly varies much more than does in vitro digestibility under controlled conditions (Irvin, 1960). Poor quality hays may require longer fermentation times to duplicate in vivo digestibility values, especially when in vivo intake is low so that retention time is high and in vivo digestibility is increased. Our experimental animals were confined to metabolism stalls, thus introducing an additional bias.

Estimating Intake and Digestibility

All of the previously mentioned organic variables, their squares, and cross-products were subjected to stepwise deletion regression analyses to determine those most closely related to organic matter intake and digestibility. Intake was best described by a simple regression of the crossproducts of fecal nitrogen and organic matter. Digestibility was described by fecal nitrogen minus both fecal organic matter and the square of fecal nitrogen. Both regressions were highly significant.

$$\hat{Y}\ (OMI) = 1.128 + 1.7524\ (F \times N) \pm 0.44$$

$$\hat{Y}\ (OMD) = -40.69 + 171.98\ N - 6.48\ F - 61.79\ (N)^2 \pm 3.0$$

OMI = Estimated organic matter intake (kg/day)
OMD = Estimated organic matter digestibility (kg/day)
F = Fecal organic matter (kg/day)
N = Fecal nitrogen (g/100g)

Average estimated organic matter intake was 5.12, 4.96, and 3.89 kg; observed intakes for hays cut during June, July, and September was 5.29, 4.91, and 3.82 kg, respectively (Table 2). The correlation coefficient was 0.78 with a *t* value of 6.02, both highly significant statistically. Estimates of forage intake are improved by multiple regressions such as these which include terms for fecal output (Arnold and Dudzinski, 1963). Arnold et al. (1964) found no evidence that the relation of organic matter intake, fecal organic matter, and fecal nitrogen is altered under grazing conditions, suggesting that our data with confined animals have merit.

These experiments indicate that both level and digestibility of protein in native Flint Hills hays decrease dramatically with stage of maturity. Gross energy digestibility is depressed only slightly. Estimates of organic matter intake and digestibility require only fecal nitrogen and organic matter in regression equations. Other analytical components from proximate and Van Soest analyses did not improve the equations, probably because no attempt was made to interfere with the animal's selectivity of the hay.

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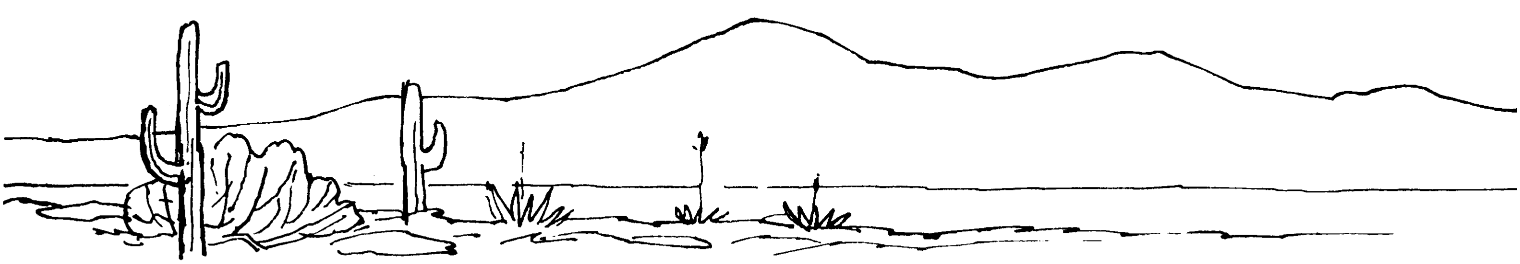

Range Vegetation and Sheep Production at Three Stocking Rates on *Stipa-Bouteloua* Prairie

S. SMOLIAK

Highlight: Stipa-Bouteloua *prairie was grazed by sheep at three stocking rates over a 19-year period. Under continuous heavy grazing the vegetative cover and forage yield deteriorated mainly through the large increase in blue grama and the decrease in the more productive grasses. The mature ewes grazed at the heavy rate were lighter in body weight and gave birth to smaller lambs, which were weaned at lower body weights, than those grazed at the moderate or light intensities of use. The* Stipa-Bouteloua *prairie should be stocked at not less than 1.0 acre per ewe per month to maintain the vegetative cover in a productive condition.*

Controlled grazing trials with sheep in the northern Great Plains area have been limited in number. In Montana, Woolfolk (1949) studied three rates of grazing and found that a minimum of 0.67 surface acre of range per month was required for normal development and maintenance of a dry yearling ewe. At this rate of stocking there was some improvement in the range vegetation and a desirable carry-over of unused forage at the end of each grazing season. On heavily stocked range, yearling ewes gained significantly less weight than those on conservatively or lightly stocked range. After 6 years of heavy stocking, the composition of the range vegetation shifted from a predominance of perennials to a cover of low-value annual species. In Wyoming, Lang et al. (1956) used ewes and lambs to evaluate three rates of grazing on shortgrass prairie over a 10-year period. Both ewes and lambs gained more per animal on the lightly grazed pastures than on those heavily utilized. Blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) and buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm.) increased in percentage of total basal cover with increasingly close grazing. Needleandthread (*Stipa comata* Trin. and Rupr.) and western wheatgrass (*Agropyron smithii* Rydb.) decreased with increased grazing pressure. After 9 years, forage production on the heavily grazed pastures was considerably less than on those lightly or moderately used. In a second 10-year trial (Rauzi and Lang, 1967), significantly more midgrasses were produced on lightly grazed pastures than on moderately grazed pastures, but no differences in lamb or ewe body weight gains were found.

Results of stocking rate studies on *Stipa-Bouteloua* prairie grazed by cattle have been reported (Clarke et al., 1943; Peters, 1955). However, changes in composition of vegetation resulting from grazing by cattle and reaction of species to cattle grazing are different from those brought about by sheep grazing (Thetford et al., 1971).

The present study was initiated in 1951 to determine the effect of sheep grazing at three stocking rates on the floristic composition and forage production of *Stipa-Bouteloua* prairie and on lamb and ewe production.

Study Area and Methods

The vegetation of the area has been described by Clarke et al. (1942, 1943) and Smoliak (1965). The grazing trial was conducted at the Agriculture Canada Research Substation, Manyberries, Alberta, from 1951 to 1969.

Native range was grazed at rates of 0.83, 1.0, and 1.25 acres per ewe per month during a 9-month grazing period. The experimental area consisted of three summer fields, 100, 120, and 150 acres, respectively, grazed by white-faced, mature ewes and their lambs for 6 months, May 1 to October 31, and three fall-spring pastures, each half the size of the original three, grazed by ewes at the same rates for 3 months, November 1 to December 31 and from April 1 to 30. (Fig. 1) During the three remaining winter months, January 1 to March 31, the ewes were pen fed 3.3, 4.0, and 5.0 lb alfalfa hay per head per day in groups corresponding to the grazing rates.

During the period 1951 to 1963, 20 ewes with lambs, and from 1964 to 1969, 18 ewes with their lambs, and 3 yearling ewes were grazed in each of the fields. Each year, an equal number of ewes from each age group, ranging from 2 to 7 years old, were maintained on each treatment. The ewes remained on the experiment until they were 7 years old or were barren for 1 year. Temporary replacements for ewes that died during the trial were made with ewes of similar age from the main flock. Permanent replacements were made in each treatment each April 1, with an equal number of 2-year-old ewes retained as lambs from within each treatment.

The ewes bred and lambed while in the winter fields. Two rams were used each year, and half the ewes in each treatment were pen bred at night to each ram. The breeding season lasted from November 15 to December 31 each year from 1952 to 1963, and from November 1 to December 15 each year from 1964 to 1969. Lambs were weaned on October 1, except during the period 1952-1963, when ram lambs were weaned the third week of August.

Initial, 28-day, and final weights were recorded for the ewes and lambs on the summer and winter treatments. The sheep were penned overnight without feed and water (15 hours) and then weighed. Birth weights of lambs and weights and condition scores of ewes were obtained within 24 hours of lambing. Weaning weights of lambs were adjusted for sex and type of birth and rearing by employing the constants developed by MacNaughton (1956).

Effects of grazing on the plant cover were determined by the point quadrat method (Clarke et al., 1942). A total of 4,200 points were taken on each pasture in the summer in each year of the study. Forage production and utilization was estimated by the difference method from yields obtained from 10 caged and uncaged square-yard plots in each pasture at the end of the grazing season.

Results

Vegetation

Vegetational analysis of the three summer fields showed that differences in percentage basal area occurred after 19 years of grazing by sheep (Table 1). Blue grama increased in basal area on the heavily grazed field, whereas needleandthread increased on the moderately and lightly grazed fields. Junegrass (*Koeleria cristata* (L.) Pers.) and Sandberg blue-

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Fig. 1. *Ewes on fall pastures usually encountered difficult grazing conditions. However, during January 1 to March 31 they were fed hay in pens.*

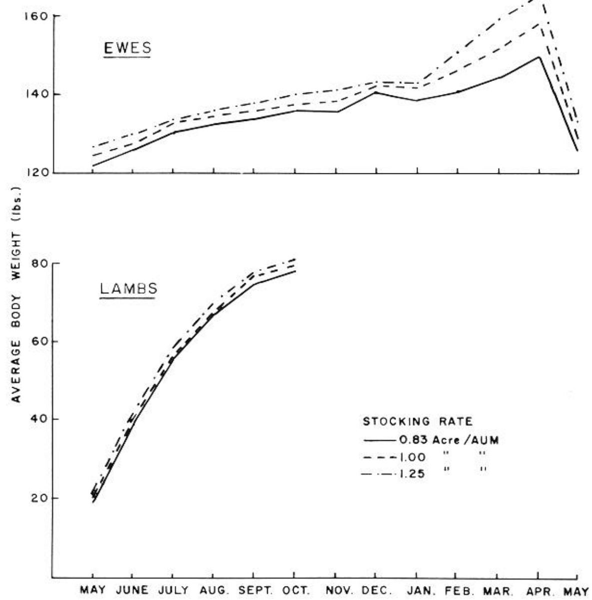

Fig. 2. *Average 28-day weights of ewes and lambs grazed at three stocking rates, 1951–1969.*

grass (*Poa secunda* Presl.) increased in basal area on all fields. Western wheatgrass decreased in basal area on the heavily and moderately grazed fields, but the greatest decrease was on the heavily grazed field. Sedges decreased in area on the lightly grazed field. The total grass and sedge cover increased on all fields but the changes were not significant.

Taller growing grasses, needleandthread, western wheatgrass, and "other grasses" decreased in percentage composition (Table 1) under 19 years of heavy grazing. In 1951 taller grasses contributed 37.6% toward total composition, excluding little clubmoss (*Selaginella densa* Rydb.), but in 1969 the contribution was only 16.4%. Short growing grasses, blue grama, Junegrass, and Sandberg's bluegrass contributed 38.1% of the total composition in 1951 and 63.6% in 1969. Composition values for fields grazed moderately and lightly show that grass cover improved slightly during the study period. The percentage composition of blue grama decreased and that of needleandthread increased during this period.

Percentage basal area of fringed sage (*Artemisia frigida* Willd.) decreased on all fields, and that of moss phlox (*Phlox hoodii* Richards) and pricklypear (*Opuntia polyacantha* Haw.) decreased on the heavily and moderately grazed fields. Woolly plantain (*Plantago purshii* R. and S.) increased in basal area on fields grazed heavily and moderately. There was a general decrease in basal area and composition of total forbs on all fields. Little clubmoss increased in basal area on all fields.

Forage production over the 19-year period reflected the effects of seasonal (April to July, inclusive) precipitation and grazing (Table 2). During the first 6

Table 1. Basal area (%) and composition (%) of vegetation on fields grazed at three intensities, Manyberries, Alberta, 1951–1969.

	Heavy				Moderate				Light			
	Basal area		Composition		Basal area		Composition		Basal area		Composition	
Species	1951	1969	1951	1969	1951	1969	1951	1969	1951	1969	1951	1969
Blue grama	2.2	3.6**	32.7	48.3	2.9	2.8	36.3	33.6	2.8	2.4	37.4	29.2
Needleandthread	0.5	0.5	7.5	6.5	0.7	1.2	8.8	14.3	0.4	1.3**	5.0	16.1
Junegrass	0.1	0.4**	1.8	6.0	0.3	0.6**	3.2	6.9	0.2	0.6**	2.8	7.9
Western wheatgrass	1.9	0.7**	28.0	9.9	1.6	1.2	20.5	14.3	1.7	1.7	22.6	20.5
Sandberg bluegrass	0.2	0.7**	3.6	9.3	0.5	0.9**	5.9	10.7	0.4	0.9**	6.0	11.4
Other grasses	0.1	0.0	2.1	0.0	0.2	0.0	2.0	0.0	0.0	0.0	0.0	0.0
Sedges	1.1	1.1	15.8	14.4	0.9	0.8	10.5	9.5	1.1	0.5**	14.6	6.1
Total grasses and sedges	6.1	7.0	91.5	94.4	7.1	7.5	87.2	89.3	6.6	7.4	88.4	91.2
Fringed sage	0.1	trace	0.8	0.3	0.2	0.1	2.1	1.2	0.2	trace	2.5	0.3
Moss phlox	0.2	0.1*	2.9	1.6	0.4	0.3	5.0	4.0	0.1	0.1	1.3	1.7
Woolly plantain	0.1	0.2**	2.1	3.2	0.3	0.4*	3.5	4.6	0.4	0.3	5.0	4.0
Prickly pear	0.1	trace	1.8	0.5	0.1	trace	1.7	0.6	0.1	0.1	1.9	1.2
Other forbs	0.1	0.0	0.9	0.0	trace	trace	0.5	0.3	0.1	0.1	0.9	1.6
Total forbs	0.6	0.3	8.5	5.6	1.0	0.8	12.8	10.7	0.9	0.6	11.6	8.8
Totals	6.7	7.3	100.0	100.0	8.1	8.3	100.0	100.0	7.5	8.0	100.0	100.0
Little clubmoss	10.7	26.0**			9.7	22.6**			9.8	18.7**		

* Significantly different from 1951 values at $P<0.05$.
**Significantly different from 1951 values at $P<0.01$.

Table 2. Precipitation (inches), forage production (lb/acre oven-dry) and forage utilization (%) during grazing experiment, 1951–1969, Manyberries, Alberta.

Year	Precipitation April to July incl.	Heavy: Forage produced	Heavy: % utilization	Moderate: Forage produced	Moderate: % utilization	Light: Forage produced	Light: % utilization
1951	6.10	395	43	440	37	455	21
1952	5.21	415	57	435	52	480	39
1953	8.40	510	43	530	39	620	32
1954	7.94	415	60	450	53	530	44
1955	13.28	410	48	445	46	620	37
1956	8.19	650	50	690	44	700	39
1957	4.40	360	56	435	47	475	44
1958	5.05	315	72	365	50	395	34
1959	5.82	255	68	335	46	345	40
1960	5.38	330	84	420	68	455	63
1961	3.07	145	96	250	75	330	68
1962	6.58	140	86	265	55	300	52
1963	5.76	130	79	260	54	310	47
1964	6.26	110	85	185	54	230	50
1965	16.48	315	65	340	54	360	45
1966	6.10	335	64	385	45	430	36
1967	6.90	265	60	340	50	390	45
1968	4.95	290	78	385	69	420	66
1969	3.80	95	95	125	71	195	62
Average 1951–1969	6.82	309 a	68 a	373 ab	53 b	423 b	45 b
Average 1928–1969	6.29						

[a-b]Means followed by the same letters are not significantly different at the 5% level. (Duncan's multiple range test.)

years of the trial (1951 to 1956, inclusive), when the average seasonal precipitation exceeded the long-term average, forage production in the three fields was similar. From 1957 to 1969 differences in forage production became more evident on fields grazed at the three intensities. Average production of forage on the heavily grazed field was significantly less than on the lightly grazed field. Average production of forage on the moderately grazed field did not differ from that on the heavily or lightly grazed fields.

Consumption of forage generally was greater at the heavy rate of use than at the moderate or light rates (Table 2). The percentage consumption of forage was low during the years of favorable growth, 1951 to 1959. However, during the last 10-year period, 1960 to 1969, forage consumption averaged 78% at the heavy rate, 60% at the moderate rate, and 54% at the light rate of use.

Table 3. Sheep production at three rates of grazing, Manyberries, Alberta, 1951–1969.

Characteristic	Heavy	Moderate	Light
Ewes			
Summer gains (lb)	12.3 a	12.3 a	12.6 a
Winter gains (lb)	−10.1 a	−9.4 ab	−7.7 b
Average annual gain (lb)	2.2 a	2.9 ab	4.9 b
Number ewes died	8	13	15
Lambs			
Number born	542 a	542 a	534 a
Number weaned	446 a	442 a	450 a
Birth weight (lb)	9.5 a	9.7 ab	10.0 b
Corrected weaning weight (lb)	78.6 a	81.6 b	81.6 b
Summer gain (lb)	57.2 a	58.1 a	58.0 a
Lamb weaned (lb/year)	1793 a	1830 a	1855 a
Ewe lambing record			
% rated Good condition	52.5 a	67.7 b	72.5 b
% rated Fair condition	24.7 a	21.1 ab	15.5 b
% rated Poor condition	17.0 a	8.5 b	6.5 b
% died, dry, or aborted	5.8 a	4.7 a	6.5 a

[a-c]Means followed by the same letters are not significantly different at the 5% level. (Duncan's multiple range test.)

Animal Production

There were significant differences in body weight gains during the winter period and in average annual weight gains of ewes grazing at the different intensities (Table 3). Summer body weight gains of ewes were similar under the three rates of grazing over the 19-year period. Mortality of ewes increased as grazing intensity decreased, but these differences were not significant.

There were no differences in total number of lambs born or weaned at the three rates of grazing. However, birth weights and corrected weaning weights differed significantly. Lambs born and weaned on the heavy rate of grazing regime were lighter than those on the light rate of grazing. Lambs on the moderately grazed field had a greater corrected weaning weight than lambs on the heavily grazed field. There were no differences in summer gains of lamb or in total pounds of lamb weaned per year at the various rates of grazing.

During lambing, a greater proportion of ewes that graded "good" in condition had been grazed at the moderate or light rate of use. A greater proportion of ewes graded "fair" or "poor" had been grazed at the heavy rate. There were no differences in percentage of ewes that were dry or that died or aborted at the various rates of grazing.

Average 28-day weights of ewes and lambs are shown in Figure 2. Ewes that grazed at the light intensity of use consistently weighed more than those that grazed at the heavy rate throughout the year. Ewes that grazed at the moderate rate were intermediate in body weight. The ewes were heaviest and body weight differences among stocking rates were greatest during April, before lambing. During the summer period lambs on the lightly grazed fields were consistently heavier than those on the heavily grazed fields, but the differences were not significant.

Total gains per acre of ewe and lamb in summer were 16.2, 13.6, and 11.0 lb on the heavy, moderate, and light rates of grazing over the 19-year period. These differences were similar in each of the study years and were significant. The gains per acre on the heavily grazed field ranged from 9.1 lb (1955) to 22.8 lb (1962) and the gains on the lightly grazed field ranged from 6.4 lb (1955) to 14.9 (1962 and 1965).

Table 4. Lambing weights (lb) of ewes at three rates of grazing, Manyberries, Alberta, 1951–1969.

Year	Heavy No. of ewes	Heavy Weight	Moderate No. of ewes	Moderate Weight	Light No. of ewes	Light Weight
1951	15	124.3 a[1]	16	123.8 a	17	120.8 a
1952	20	111.6 a	20	110.5 a	20	111.6 a
1953	20	128.4 a	18	125.2 a	20	132.0 a
1954	19	127.8 a	19	127.6 a	19	135.0 a
1955	19	129.3 a	20	135.4 a	20	138.0 a
1956	20	111.8 a	18	108.9 a	19	115.2 a
1957	20	112.0 a	19	111.9 a	20	120.6 a
1958	18	112.0 a	19	123.8 b	20	123.6 b
1959	20	122.7 a	18	127.3 b	20	135.8 c
1960	20	131.8 a	20	139.7 b	19	148.8 c
1961	19	139.1 a	20	143.6 a	20	147.7 a
1962	18	128.3 a	19	135.9 b	19	141.8 c
1963	16	139.7 a	19	144.5 a	18	148.2 a
1964	20	130.1 a	20	136.6 b	19	142.9 c
1965	17	129.6 a	17	143.6 b	17	144.3 b
1966	20	120.4 a	21	126.4 b	20	131.8 c
1967	19	125.9 a	20	137.9 b	18	141.3 b
1968	21	143.7 a	21	148.4 a	19	151.9 a
1969	20	137.7 a	21	145.7 b	20	155.8 c
Total or mean	361	126.6 a	365	131.4 b	364	136.2 c

[1] Within each year, means followed by the same letter do not differ significantly at the 5% level.

During the first 7 years there were no differences in lambing weight of ewes on the various grazing intensities (Table 4). In 9 of the remaining 12 years ewes grazed at the heavy rate were lighter than those grazed at the moderate or light rates at lambing time.

Discussion and Conclusions

Continuous heavy grazing by sheep changed the vegetative cover of *Stipa-Bouteloua* prairie. The large increase in basal area of blue grama, the decrease of western wheatgrass, and the scarcity of needleandthread on the heavily grazed field are characteristic changes in range deterioration. Similar changes in vegetation subjected to heavy grazing by sheep have been shown by Woolfolk (1949), Lang et al. (1956), and Rauzi et al. (1967). Under light grazing, the decrease in cover of blue grama and the increase in needleandthread is an indication of range improvement.

The changes in the vegetative cover were reflected in forage production. Under the heavy rate of grazing, the decrease in productivity of forage was due to the increase in amount of blue grama, the decrease in amount of western wheatgrass, and the reduced vigor of the plant cover. Increases in basal area of blue grama have been shown to affect the production of underground plant material and some of the soil properties in the Ah horizon (Smoliak et al., 1972). The blue grama plants on the heavily grazed field were observed to be more numerous and smaller than those on the lightly grazed field. Woolfolk (1949) indicated that close grazing and severe trampling associated with heavy stocking prevented small blue grama mats from merging into compact clumps.

The reduction in basal area of forbs resulted from heavy utilization of these species. Fringed sage, utilized during early summer on all fields, was restricted in growth in most years. Pricklypear was observed to have been eaten by the sheep in certain years. In general, all perennial forbs species decreased when grazed by sheep. Annual forbs of low forage value, such as woolly plantain, increased under these conditions. An increase in annual forb species, reported by Woolfolk (1949), occurred when recovery of palatable perennial forbs was retarded by heavy stocking with sheep. The findings of the present study contrast with those of Clarke et al. (1943), who reported that increases in perennial forbs occurred on ranges heavily stocked with cattle. Lodge (1954) noted an increase in abundance of broad-leaved species on grazed mixed prairie in southwestern Saskatchewan.

Production of forage on the three fields was closely related to body weight of ewes. Continuous heavy grazing reduced forage production and ewe body weights, especially during the last 12 years of the study. The lower feed supplies present on the heavily grazed fields were shown to affect wool production and body weight of ewes at shearing (Smoliak and Slen, 1972). The reduced forage supplies also affected birth and weaning weights of lambs. However, body weights of lambs (Fig. 1) during April 1 to August 31 and total pounds of lamb weaned were not influenced by grazing intensity.

The present study indicates that *Stipa-Bouteloua* mixed prairie should be stocked at not less than 1.0 acre per mature ewe per month. Heavier stocking rates depressed forage production and resulted in a deteriorated vegetative cover and in lower body weights of ewes and weaning weights of lambs. Stocking at 1.0 acre per mature ewe per month maintained the vegetative cover in a productive condition.

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Presettlement Vegetation of Cache Valley, Utah and Idaho

A. C. HULL, JR., AND MARY KAY HULL

Highlight: *Explorers and early settlers found abundant grass and little sagebrush in Cache Valley in northeastern Utah and southeastern Idaho. Excessive grazing by livestock after settlement caused the grass to decrease and the sagebrush to increase. Most grassland areas were eventually plowed for dry-land or irrigated farming. However, in the dry-farm belt are many steep or rocky slopes, inaccessible corners, and similar areas that have not been plowed, irrigated, heavily grazed, or burned in recent years. Many of these areas support vegetation that, except for increased sagebrush, is undoubtedly similar to that described by explorers, early settlers, and historians.*

About 60% of Cache Valley, so named for the huge fur caches made here by the trappers, is in northeastern Utah and 40% in southeastern Idaho. The valley floor extends north and south slightly over 50 miles and varies from 5 to 12 miles in width. The valley, 4,400 to 5,200 feet in elevation, is completely surrounded by mountains with peaks up to 9,980 feet. Precipitation on or near the valley floor ranges from 15 to 20 inches annually. In the surrounding mountains it reaches 50 inches. Spring and winter are the seasons of highest precipitation.

As Mary Ann Maughan (1898) viewed Cache Valley with the first company of permanent settlers in 1856, she exclaimed, "Oh, what a beautiful valley!" In 1832 Ferris (1940) wrote: "One of the most extensive and beautiful vales of the Rocky Mountain range . . ., producing everywhere most excellent grass . . .." Hayden (1879) called Cache Valley the garden spot of Utah.

Stansbury's official report (1852) indicated that Cache Valley had the finest range imaginable for any number of cattle and that any amount of hay might be cut without interfering with range for the cattle. An 1870 report to the U. S. Commissioner of Agriculture stated that Cache Valley was probably the finest grazing section in the entire Salt Lake basin and must become a favorite pasture ground for stock raisers (U. S. Dep. Agr., 1871).

In 1825, as Peter Skeene Ogden's Hudson Bay trapping party traversed the length of the valley, they repeatedly mentioned plains covered with huge herds of buffalo (Miller, 1952, 1954). The 1841 Bartleson wagon train (Kelly, 1930), and Fremont (1845) and his party traveled in 1843 through the north and west parts of the valley. Both Fremont and Bidwell of the wagon train mention a fine cover of grass.

Notes from the public land survey of Cache Valley (Utah section in 1855-78, and Idaho section in 1872-73) indicate good grass for grazing and sometimes for mowing on most areas; sagebrush is rarely mentioned (U. S. Govt., 1855-78 and 1872-73). The Trenton and Cornish area on the west side of the valley was called the Big Range because of its abundant grass and excellent grazing. Sagebrush in this area was rare when the 1876 land

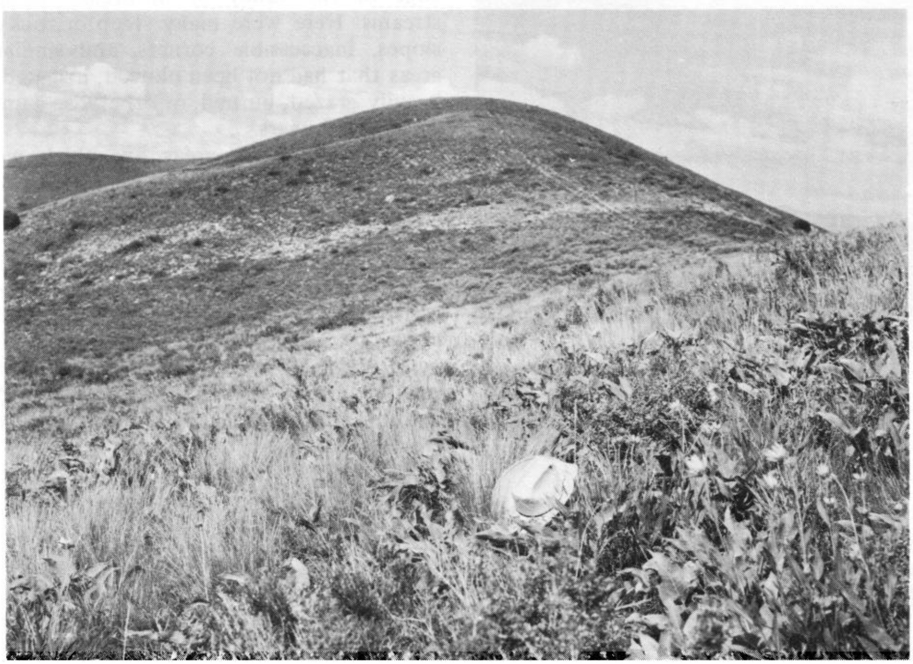

Fig. 1. *This excellent stand of bluebunch wheatgrass and forbs, with scattered bitterbrush and sagebrush, south of Weston, Idaho, has had little grazing for the past 50 years. Except for more sagebrush at present, the vegetation is probably similar to that found on the Big Range of the Trenton-Cornish area at the time of settlement.*

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Fig. 2. *A good stand of bluebunch wheatgrass with forbs and scattered sagebrush at Mapleton, Idaho, has had only light grazing for many years. This represents a grassland with some sagebrush that grew on many of the foodhills and benches before settlement.*

Fig. 3. *This heavy stand of 7-foot reed canary grass near Logan, Utah, is representative of the heavy grass that grew in the moist valley-bottom soil and provided winter feed for livestock and cover for bears.*

survey was made. However, grazing was very heavy, and by 1888 sagebrush covered the foothills and much of the flats (Simmonds, 1970).

Settlers, historians, and students of early history tell of the excellent grass in Cache Valley (Maughan[1]; Tullidge, 1889; Hovey, 1925; Olson and Olson, 1927; Stewart, 1941; and Ricks, 1953 and 1956). Mary Ann Hull came to Franklin, Idaho, with the first settlers in 1860. She stated that there was good grass on the benches and foothills east of Franklin and Preston, with only widely spaced sagebrush plants on the higher slopes and no sagebrush in swales and areas of deep soil. After settlement, the local livestock and, later, migratory sheep used this area so heavily that the grass decreased and the sagebrush increased. Within 40 years after settlement, sagebrush was abundant and the settlers could count the migrating bands of sheep by the clouds of dust[2].

Hanson (1939), Hanson and Stoddart (1940), Stoddart (1941), and Tisdale et al. (1969) concluded that northern Utah and southern Idaho were essentially a grassland with small amounts of sagebrush but that uncontrolled livestock grazing had reduced the perennial grass and allowed sagebrush to increase.

Study Areas

To determine the vegetation in Cache Valley before it was changed by the white man, we reviewed literature on early vegetation and also searched the valley floor up to 5,200-foot elevation for good stands of native vegetation. We tried to locate areas where explorers and settlers had described the vegetation. The best stands of native vegetation and those that seemed to resemble the original vegetation were in the dry-farm belt around the edge of the valley or in breaks along streams. Here were many steep or rocky slopes, inaccessible corners, and similar areas that had not been plowed, irrigated, heavily grazed, burned, or otherwise damaged for 50 years.

We selected 73 areas on which we recorded the presence and estimated the abundance of 47 of the more important herbaceous and woody species. The abundance of a species was the average stand found on the various sites of an area. This varied from rare, through poor, fair, and good, to very good as compared with what might be expected for this species on the sites of that area. Areas averaged about 2 miles apart, and 6 miles was the greatest distance between areas.

We counted annual growth rings on sagebrush plants on most areas and on trees on some areas.

Present Vegetation

Much of the unplowed land in the valley has been heavily grazed and supports dense stands of big sagebrush (*Artemisia tridentata*) and cheatgrass (*Bromus tectorum*) and minor stands of perennial grass and forbs. From the literature we concluded that originally there had been much grass, with limited sagebrush in the valley. We found that the areas traveled by the Hudson Bay trappers (Miller, 1953, 1954), Fremont (1954), and the Bartleson wagon train (Kelly, 1930) and the area called the Big Range (Simmonds, 1970) still have good grassland remnants (Fig. 1).

Many of the protected or moderately used areas had good stands of grass and forbs, with little sagebrush (Fig. 2). On such areas, beardless bluebunch wheatgrass (*Agropyron spicatum* var. *inerme*)[3] was the most abundant species and was the only native grass that grew in major amounts on all 73 areas. Other native grasses with rare to good stands on many areas and in order of abundance were: streambank wheatgrass (*Agropyron riparium*), basin wildrye (*Elymus cinereus*), Junegrass (*Koeleria cristata*), Sandberg bluegrass (*Poa secunda*), western wheatgrass (*A. smithii*), and various bluegrasses (*Poa* spp.). Ridge tops and areas of sandy soil supported Indian ricegrass (*Oryzopsis hymenoides*), needle-andthread (*Stipa comata*), and sand dropseed (*Sporobolus crytandrus*).

Five exotic grasses are spreading and are undoubtedly adapted to Cache Valley: cheatgrass, crested and intermediate wheatgrasses (*A. desertorum* and *intermedium*), and bulbous and Kentucky bluegrasses (*Poa bulbosa* and *pratensis*).

The tall grass in the moist valley bottom was used by the American Fur Company and later by the early settlers for wintering cattle (Stansbury, 1852; Ricks, 1953). This grass has been altered by grazing, cultivation, and water development. Patches of basin wildrye, called big bunchgrass by the settlers, and reed canary grass (*Phalaris arundinacea*) probably resemble the original tall grass (Fig. 3).

Early records rarely mention forbs. However, palatable forbs were probably abundant, especially on the north exposures and favorable sites. At present, arrowleaf balsam-root (*Balsamorhiza sagittata*) is the most abundant forb species and was found on all 73 areas. Other major forbs in order of abundance were little sunflower (*Helianthella uniflora*), stone seed (*Lithospermum*

[1] Peter Maughan's letter quoted in Deseret News, June 22, 1859.

[2] Personal communication in 1934.

[3] At Red Rock Pass and some other locations, especially in the northwest part of the valley, there is considerable bluebunch wheatgrass (*A. spicatum*). In this paper both forms are called bluebunch wheatgrass.

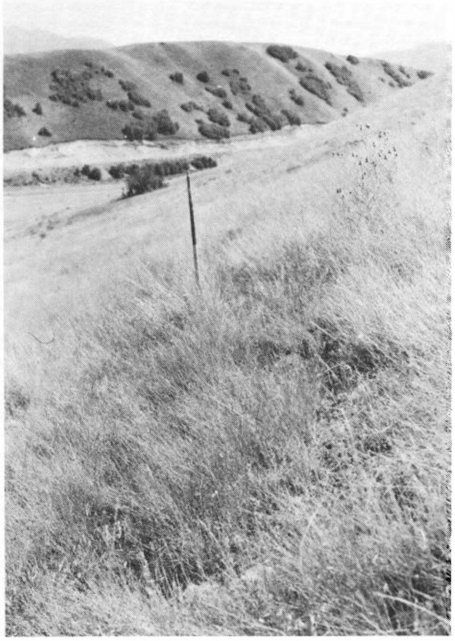

Fig. 4. *This bluebunch wheatgrass near Avon, Utah, has been moderately grazed by sheep for at least 60 years. Grazing has been just heavy enough to eliminate many forbs and to maintain a good stand of grass but little sagebrush.*

ruderale), flax (*Linum lewisii*), lupine (*Lupinus* spp.), cleft-leaf balsam (*B. macrophylla*), hawksbeard (*Crepis* spp.), yarrow (*Archillea lanulosa*), and penstemon (*Penstemon* spp.). The forbs seemed to be damaged more than the grasses by heavy grazing, especially sheep grazing (Fig. 4).

From early records, sagebrush was found in small amounts. It has increased and in 1972 was found on all 73 areas. Other shrubs in order of abundance were: bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus* spp.), chokecherry (*Prunus* spp.), serviceberry (*Amelanchier alnifolia*), wild rose (*Rosa* spp.), bigtooth maple (*Acer grandidentatum*), and Utah juniper (*Juniperus osteosperma*). Probably rabbitbrush, maple, and juniper have increased, but the other woody plants have changed little since settlement.

Maximum growth rings on the sagebrush plants ranged from 21 at Red Rock pass to 81 at Cornish. Almost half of the areas had sagebrush with over 50 rings. However, in this area it is difficult to accurately determine the age of sagebrush plants much beyond about 50 years. At about this age most stems split and the exposed central rings break up. Adjacent juniper or maple trees usually had more growth rings than the older sagebrush plants.

Conclusions

Early records show that Cache Valley was predominantly a grassland area. Comparing the early records with present conditions, there has been a decrease in grasses and palatable forbs and an increase in sagebrush. Today we find undisturbed areas that, except for increased sagebrush, probably closely resemble the original vegetation.

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The Zootic Disclimax Concept

ALAN A. BEETLE

Highlight: *Some ecologists are using the term "zootic climax" in the same sense that range managers use the term "zootic disclimax." If our national parks are to be managed in order that they be natural, it will be important for administrators to understand these two terms and how they differ from the Climatic Climax.*

No matter how vigorously protested or ignored, it can hardly be considered a secret that throughout this century many reports of poor range conditions in Wyoming have involved the ungulate populations in two national parks, Yellowstone and Grand Teton (Preble, 1911; Roosevelt 1912; Graves and Nelson, 1919; Sheldon, 1927; Beetle, 1952, 1961, 1962, and 1968).

Citing only one or two of these—in 1947, Victor H. Cahalane of the Biology Division of the National Park Service reported in the *Journal of Mammalogy* that "winter range within Yellowstone Park has been severely damaged by decades of over-use" and that "overpopulations of mammals threatened destruction of vital forage."

On adjoining Forest Service lands, A. K. Wogensen of the Forest Service in 1951 estimated 27,000 acres in the Gros Ventre, 12,000 acres near Jackson, and 8,000 acres in the Hobach were "range in poor or depleted condition on which accelerated soil loss is evident. Normally should be taken out of use." That is if the use involved cattle permits, then the use could be cancelled; but because the use is wild game, numbers actually increased.

Lest you think that the reports of damage are confined to the winter range, see what A. R. Croft of the Forest Service administration and Lincoln Ellison of the Intermountain Forest and Range Experiment Station in 1960 said about "Damage—and in some cases destruction—of the soil and vegetation on the high mountain range-watersheds which supply more of the elk's spring, summer, and fall feed.

"Damage to these vital resources that has resulted in low productivity of forage—and in some cases no productivity at all—cannot long continue without serious consequences. The problem is real and vital. It has many aspects that reach far beyond the welfare of the animals themselves because erosion of watershed soil also affects water quality, streamflow characteristics, fish habitat, aesthetic values, and the economy of local communities. The problem calls for statesmanlike action by all those interested in the welfare of the elk and the range and watersheds on which they depend. A program of management that will assure perpetuity of the elk and the related soil and forage resources is urgently needed."

There are many exclosures on western range lands. Traditionally when a contrast has appeared, the plants inside have been labelled decreasers and increasers and their relative composition has been accepted as an indication of range quality. Increasers associated with invaders inside have been signals of range deterioration. Exclosures have been used to create a climatic climax. On livestock ranges that have departed from climatic climax, animal numbers have been reduced as a matter of course. The assumption has been implicit that overgrazed ranges offered less nutrition and less ground cover. Lower nutritive content of forage has been assumed to be a contributive cause of lower calf crops, and ground cover has been related to erosion and water quality. As will be shown, to advocates of the zootic disclimax these things may be quite natural, if not unavoidable.

In 1971, several papers were published by the naturalists in Grand Teton and Yellowstone National Parks evaluating range practices for those areas. As a footnote to the history of range and wildlife management, it should be recorded that in the latter half of the twentieth century there is a school of ecologists whose ideas center around their term "zootic climax."

These concepts have some rather unusual aspects which deserve to be discussed fully, since many of them are contradictory to current textbook teachings in curricula of range or wildlife management in which climatic climax is considered to be natural. As Houston (1971a) says, "A national park ecosystem requires a unique approach to research and management." Again in 1972, Houston says, "Criteria used in forestry and range and wildlife management, where vegetation and wildlife are harvested as a crop, do not necessarily apply to national

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parks." At times, Forest Service personnel, the Sierra Club, and wildlifers do not think of wilderness (or game) areas as different from a park.

This school has developed as a direct result of percussive numbers of grazing ungulates in and around two national parks, Yellowstone and Grand Teton.

The term "zootic climax" is ascribed to Daubenmire (1968) and is defined as a "stabilized biotic disclimax." The assumption of the new school is that in national parks, in national forests, and on big game ranges such disclimax stability is more natural than a climatic climax. It is created and maintained by native ungulates regardless of whether they are occupying their traditional range (as the elk are), or are occupying greatly enlarged ranges (as the moose are); and whether or not the balance has already been upset by the elimination of a native ungulate such as the bison.

Since, by definition, climate dictates climax and since, also by definition, a "zootic climax" is dictated by a biotic influence which is asymptotic (i.e. if the grazing ungulate is removed, the trend created away from climatic climax is reversible) the term has to be "zootic disclimax."

Because exclosures tend to recreate climatic climaxes which contrast sharply with zootic disclimax, exclosures are being removed from Grand Teton and Yellowstone National Parks. According to Cole (1971), "Interpretations that such exclosures illustrate how things should be in a park would more often than not be confusing artificial with natural conditions." Quoting again from Cole (1971), interpretations based on exclosures "require an awareness that protected vegetation represents an artificial 'standard' which increases in artificiality over time." Exclosures are only good as a "measure of succession rate or site potential without the biotic effects of large herbivores."

On August 16, 1972, Gary E. Everhardt, superintendent of Grand Teton National Park, wrote to Senator Clifford Hansen as follows (see Archives, Society for Range Management, University of Wyoming library):

> Prior to the summer of 1972, four range exclosures were present in Grand Teton National Park. Two of these were removed by the Youth Conservation Corps this summer. The two remaining exclosures are scheduled for removal in the future as funds and manpower become available.
>
> These exclosures are rectangular plots of 5 to 15 acres surrounded by a fence substantial enough to exclude large grazing animals. They were established during the 1950's to determine the influence of grazing animals on vegetation. They demonstrate that a somewhat different vegetation pattern results when the influence of large mammals is removed. When the exclosures were established, less information was available on past levels of game use in the Jackson Hole area than is now available. More recent studies have established beyond question that large populations of elk have been present in the Jackson Hole area for many years—certainly since the arrival of white man.
>
> Primary management goal of the National Park Service is to maintain ecosystems in as natural a state as possible. Large game populations are part of these natural ecosystems. Conditions within exclosures clearly represent a departure from natural conditions.
>
> Misinterpretations of the situation within exclosures are often made. It is commonly assumed incorrectly that the condition inside the exclosure is the natural condition. The National Park Service has received no information which indicates a valid need for the continued maintenance of the four exclosures within Grand Teton National Park. Since they constitute a departure from natural conditions, are a significant aesthetic intrusion and are sources of public confusion and misinformation, it is not deemed wise to continue spending public funds for their maintenance. When a voluntary work force was made available for removal of two of the exclosures, advantage was taken of this circumstance.

Mr. Everhardt, a relatively new administrator in Grand Teton National Park, has not been informed about the history, use, maintenance, study or need for range exclosures.

With range exclosures eliminated as evidence of what is pristine, the void is filled by the use of old photos. When one uses old photos, one soon finds that what one has been led to believe is "aesthetic" is not really compatible with "scientific values." Such unaesthetic habitat features as bare ridges, browse line, and fire scars become quite acceptable.

However, according to Loop (1972), "No attempt is made to 'turn back the clock' so that the landscape appears exactly as it did in 1809, when John Colter arrived. The important consideration is that natural ecological forces must be allowed to operate, subjecting animal and plant communities to the same processes of selection which have influenced them for thousands of years."

Overwinter mortality acts as a natural check on population, and even if this mortality is high, it is still natural. Predators are useful to justify "the maintenance of representative populations of native ungulates" but are not essential to their population control. If the forage deteriorates and leads to poor nutrition in the ungulates, and if this in turn leads to low rates of ungulate increase because of infant mortality, either prenatally or post-natally, this is also natural.

The dominant grazing ungulate is the apex of the food chain and the only element in the habitat worthy of consideration if one wishes to "preserve representative natural environments and native biota as integrated wholes (i.e. ecosystems)." This means that if associated animals (even associated grazing ungulates like the deer) are forced into marginal situations and decrease in numbers, this is natural. If the plant populations become disclimax permanently, this is natural.

Dominant grazing ungulates will not reduce the food sources that limit their own densities according to Houston (1971a), who states: "Ungulates participate in plant successional processes and may be capable of reducing or eliminating remnant vegetation types that are no longer a number-limiting food source." On this basis, there should be concern for aspen as a community in this area. Those concerned with the survival of rare and endangered species will find little comfort in this "rationale" which can account for the elimination of a whole community.

The only force equally natural with ungulate grazing is fire. This has been proven by photographs. According to Loop (1972), "In view of the undisputable past role of fire as a key process shaping patterns of vegetation, continued attempts at total fire suppression in National Parks will clearly result in a loss of any semblance of natural ecosystems."

According to Cole (1971), "Primary succession is slower without the biotic effects of large herbivores," but "fire" may cause "unnatural secondary or retrogressive succession" just as do "artificially maintained densities of domestic or wild herbivores"; but on the other hand, "even natural densities of wild herbivores maintain some vegetation within their habitats as stabilized seral stages, or what may be called zootic climaxes." At this point one is faced with the question as to whether "wild" fires can undo the ecological changes caused by ungulate grazing.

There is a disputable theory that coniferous forests always replace aspen and fire is necessary to restore the aspen disclimax. Old photos show that woody vegetation, both brush (sagebrush) and forest (conifers) have increased with the years of protection from fire, while other brush (willows) and other forests (aspen) have decreased.

According to Houston (1971b), neither willow nor aspen are important feed sources for the northern Yellowstone herd and therefore are also ecologically unimportant.

Since this group advocating the acceptance of the zootic disclimax is new, traditionalists should be tolerant while some of the inconsistencies are worked out. It appears that (1) Cole (1971) has offered two ecologically different definitions of zootic climax: (a) "stabilized seral stage"; and (b) "stabilized biotic disclimax," and which is meant should be clarified; (2) with fire and ungulate grazing assuming roles as the only natural forces in ecosystems, it will be necessary to show how climates and the fragile soil mantles fit into the scheme of things; (3) aspen regenerate without fire in all exclosures in the Teton County area. The latter is not an important fact since quaking aspen is no longer an important food source. But if not an important food source and not an intrinsic climax type, why try to regenerate quaking aspen with fire? (4) granting that management decisions and objectives may differ in a national park, research in a national park is not "unique." Aren't the laws of natural science universal? (5) a more definite statement on how an "ecologically complete habitat" is identified needs to be developed, especially since the new school chooses to apply the principles equally to Yellowstone and to Grand Teton National Parks and it is not clear how the unlimited winter feeding of elk in the national elk refuge contributes to an "ecologically complete habitat."

As long ago as 1937, W. B. Grange of the Section of Food Habits, Division of Wildlife Research, Branch of Bioligical Survey, had a proper perspective in his "Feeding Wildlife in Winter." What he said then is as applicable to good range management as ever:

> Under strictly natural conditions, game-mammal populations are usually well adjusted to the available browse and range; if not, the undesirable animal surplus is removed by various natural agencies, so that increase is held in sufficient check to prevent outrunning the food supply.
>
> It is to be realized that two separate problems are present for solution in each instance of food failure:
>
> (1) the problem of emergency feeding, by which the animals may be tided over winter; and
>
> (2) the more difficult matter of so restoring the range that emergency feeding will no longer be necessary.

The advocates of the new school that gives greater reality to zootic disclimax than to climatic climax point to the surplus of animals as their success—the failure to feed them naturally belongs to range managers.

But let us return to 1937 and Mr. Grange: "Most situations of this kind, fortunately, do not appear in a single winter but result from causes that have been operating for several years. Consequently, there are numerous danger signals that the game manager can read well in advance of the actual emergency. One of these is the establishment of a 'deer line' in woodland tracts, that is, the disappearance of the lower vegetation up to a level that the deer can reach by standing on their hind legs, a common method of obtaining browse feed. By the time the deer line has been formed, the range is already far deteriorated. It is important, therefore, to note the beginning of this overgrazed condition, and keen observers will be able to detect an incipient deer line. Another indication of range deterioration is the eating of certain relatively unpalatable species of browse in quantity."

Reports continue to be circulated indicating that there is no need for concern about elk management in Wyoming. As recently as last December (Jorgason, 1972), the *Wyoming Wildlife* magazine reported that "summer range for the northern Jackson Hole elk herd is ample for the herd's present needs. Vegetative checks have been made to determine the effects of elk foraging on these summer ranges and elk use on key plants has only been 50 percent or less."

Is the whole zootic disclimax concept a whitewash of elk management policies, or does it deserve a place in our textbooks?

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Root Dynamics of a Shortgrass Ecosystem

DALE L. BARTOS AND PHILLIP L. SIMS

Highlight: *Seasonal dynamics of roots of a shortgrass ecosystem were determined at 2-week intervals for the two growing seasons of 1969 and 1970 and at monthly intervals during the intervening fall and winter. Soil cores were taken to a depth of 80 cm during the first growing season to determine the amount and distribution of roots in the soil profile. Root samples in the second year were only taken to a depth of 10 cm, with periodic sampling to 80 cm. Some 55% of the root weight was found in the 0- to 10-cm segment, and 69% was found in the upper 20 cm of the soil profile. There were significant differences among sampling dates in root weights in the upper 10-cm increment. The mass of roots in the lower portion of the profile remained somewhat constant throughout the sampling period. No significant differences were found in the root mass among four grazing intensity treatments (ungrazed, light, moderate, and heavy).*

Vital contributions of plant roots include absorption of water, initiation of nutrient cycling, supporting structures for photosynthetic material essential for energy capture and transfer, and soil development and stability. An insight into the effect of herbivores and environmental factors on seasonal and annual dynamics of belowground plant organs is useful for increased understanding of the functioning of grassland ecosystems.

Several studies have included measurements of the effect of herbage removal upon root weights (Biswell and Weaver, 1933; Schuster, 1964; Lorenz and Rogler, 1967; and Hanson and Stoddart, 1940) and quantitative measurements of roots in various grassland types (Weaver, 1958; Weaver and Zink, 1946; Bray, 1963; and Dahlman and Kucera, 1965). Generally, herbage removal has been shown to be somewhat detrimental to root growth. However, in North Dakota no significant differences were found in amount and vertical distribution of roots in heavily and moderately grazed pastures after 45 years of treatment (Lorenz and Rogler, 1967).

The purpose of this research was to study seasonal and annual dynamics of the root system of a shortgrass prairie and to determine the influence of grazing by large herbivores on the underground portion of plants.

Study Area and Methods

The study plots were located on the Pawnee Site, U. S. IBP Grassland Biome[1], 40 miles northeast of Fort Collins, Colorado. Four areas used in the study had been grazed by cattle for 32 years at the following intensities: ungrazed, light, moderate, and heavy (Jameson, 1969).

[1] The Pawnee Site, U.S. IBP Grassland Biome, is located on the Central Plains Experimental Range (U.S. Dep. Agr., Agricultural Research Service) and adjacent to the Pawnee National Grassland (U.S. Dep. Agr., Forest Service).

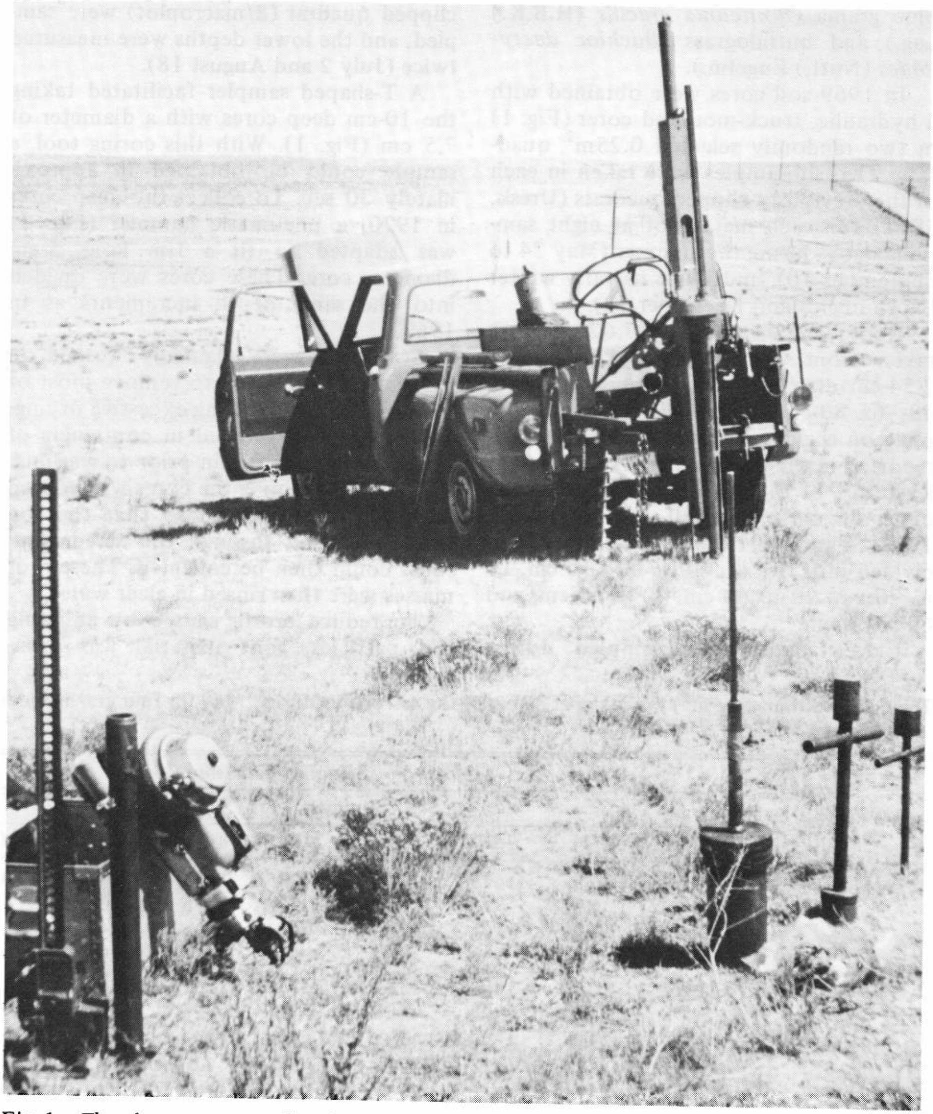

Fig. 1. *The three root sampling instruments used were the pneumatic hammer (left front), a T-shaped sampler (right front), and the hydraulic coring truck (background).*

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Table 1. Root mass (g/m²) in the upper 10 cm of the soil profile during 1969 and 1970 for four grazing intensity treatments at the Pawnee Site, U.S. IBP Grassland Biome.[1]

Grazing intensity	Sampling date (month/day) 1969										1970											Avg
	5/24	6/21	7/02	7/16	7/31	8/13	8/27	9/10	11/08	12/18	4/24	5/08	5/22	6/04	6/19	7/02	7/17	7/29	8/12	8/26	9/12	
Ungrazed	768	1047	978	784	732	768	717	806	829	623	949	1190	1034	944	1202	724	1278	1163	1147	883	945	925
	43[2]	66	56	66	28	35	68	33	24	29	15	15	16	15	17	19	19	22	14	3	14	
Light	709	798	997	642	483	570	818	1014	694	602	968	967	854	957	968	792	1171	1022	1079	885	976	850
	86	68	71	45	28	48	43	70	16	19	10	18	16	16	21	18	14	17	17	16	11	
Moderate	783	696	835	680	738	677	895	845	721	614	1044	1013	917	920	1180	1306	1304	1150	946	1026	1103	933
	43	92	30	101	74	80	105	69	26	33	15	21	20	15	21	49	24	23	15	29	21	
Heavy	849	868	748	666	492	806	968	812	858	578	938	1098	884	928	1191	940	1067	1138	1065	916	1133	896
	17	10	46	26	47	70	70	50	40	24	17	18	21	16	29	29	15	20	16	20	23	
Average	777	852	889	693	611	705	777	869	776	612	975	1067	922	937	1135	940	1205	1118	1059	928	1039	901

[1] Weights include plant crowns.
[2] Standard error of the mean.

Light, moderate, and heavy grazing averaged 21, 37, and 54% removal of the current year's growth, according to Klipple and Costello (1960). Replicate macroplots (.5-ha each) were established within the four grazing treatments on a loamy plains range site. Ascalon soils predominate and support, as dominants, blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) and buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.).

In 1969 soil cores were obtained with a hydraulic, truck-mounted corer (Fig. 1) in two randomly selected 0.25m² quadrats. Two subsamples were taken in each of the previously clipped quadrats (Uresk, 1971) for each macroplot at eight sampling dates during the summer (May 24 to September 10), and twice in early winter (November 8 and December 18).

Root core diameters of 7.62 cm were taken from 0- to 40-cm depths, and 2.54-cm diameter cores were taken from 40- to 80-cm depths. Preliminary sampling on the Pawnee Site and earlier work reported in the literature indicated that at least 95% of the roots would occur in the upper 80 cm of the soil profile (Weaver, 1958; Shantz, 1911). The 80-cm core was divided into five sections: 0 to 10 cm, 10 to 20 cm, 20 to 40 cm, 40 to 60 cm, and 60 to 80 cm.

Eleven dates were sampled during 1970 at approximately 2-week intervals during the growing season. Modification of the 1969 sampling technique was implemented in 1970 to facilitate more rapid and efficient collection of roots. The 0- to 10-cm increment was sampled more intensively during the 1970 growing season. Three 0- to 10-cm cores per clipped quadrat (8/macroplot) were sampled, and the lower depths were measured twice (July 2 and August 18).

A T-shaped sampler facilitated taking the 10-cm deep cores with a diameter of 7.5 cm (Fig. 1). With this coring tool, a sample could be obtained in approximately 30 sec. To collect the deep cores in 1970, a pneumatic hammer (Fig. 1) was adapted to fit a 1-m long, 5-cm diameter core. These cores were divided into the same depth increments as in 1969.

Soil cores were manually washed on the day of collection to remove most of the soil, thus preventing excessive drying. Soil cores were soaked in containers of water for 15 to 30 min prior to washing. All water containing the cores was poured over a 32-mesh screen so that the soil material passed through the screen and roots could then be collected. These root masses were then rinsed in clear water.

To reduce errors caused by adhering soil particles, root material was oven-dried for 48 hr at 105°C, weighed, ashed at 610°C for 4 to 8 hr, and reweighed. Data on belowground material were then expressed on an ash-free basis and the values converted to grams per square meter.

The deep samples taken in 1970 were used to develop a regression equation which was used to predict total root mass from 0- to 10-cm increments. These values were calculated so a comparison could be made between 1969 and 1970 samples.

Results and Discussion

Individual samples for root measurements were taken on 21 sampling dates between May 24, 1969, and September 14, 1970. All data for the 0- to 10-cm increments (Table 1) includes both the plant crowns and roots. These data show that the amount of roots in the upper 10 cm of the soil profile for the different grazing intensity treatments varied significantly (P.<05) between sampling dates with no apparent trend. This variability may be attributed to the fluctuation in amounts of root crowns which were not separated from the root component, and, therefore, may have masked a seasonal trend in root dynamics.

Table 2. Root mass (g/m²) in the upper 80 cm of the soil profile during 1969 for four grazing intensity treatments at the Pawnee Site, U.S. IBP Grassland Biome.[1]

Grazing intensity	Sampling date (month/day) Summer								Fall		Average
	5/24	6/21	7/02	7/21	7/31	8/13	8/27	9/10	11/08	12/18	
Ungrazed	1350	1606	1473	1342	1129	1204	1189	1406	1381	1006	1309
	32[2]	116	98	65	22	45	106	43	19	35	
Light	1279	1230	1623	1082	981	994	1355	1640	1162	1006	1235
	98	54	126	62	43	72	94	100	26	28	
Moderate	1424	1080	1405	1163	1184	1137	1398	1511	1169	1074	1254
	78	128	28	130	71	94	103	104	33	36	
Heavy	1417	1589	1258	1095	852	1447	1724	1311	1302	990	1301
	41	81	75	10	57	126	92	70	45	35	
Average	1368	1376	1440	1171	1037	1190	1417	1472	1254	1019	1275

[1] Weights include plant crowns.
[2] Standard error of the mean.

Table 3. Root mass (g/m²) in the upper 80 cm of the soil profile during 1970 for four grazing intensity treatments at the Pawnee Site, U.S. IBP Grassland Biome.[1, 2]

Grazing intensity	Sampling date (month/day)											Average
	4/24	5/08	5/22	6/04	6/19	7/02	7/17	7/29	8/12	8/26	9/14	
Ungrazed	1639	1827	1706	1635	1837	1464	1896	1806	1794	1588	1636	1711
	42[3]	77	49	42	79	67	71	71	68	43	42	
Light	1654	1653	1565	1646	1654	1517	1816	1696	1741	1589	1660	1654
	42	42	46	42	42	55	73	47	55	43	43	
Moderate	1714	1690	1614	1616	1821	1918	1917	1796	1637	1700	1760	1744
	50	17	42	42	75	103	102	69	42	48	60	
Heavy	1630	1756	1588	1622	1828	1632	1731	1786	1730	1613	1783	1700
	42	58	43	42	77	42	54	66	53	42	66	
Average	1659	1731	1618	1630	1785	1633	1839	1771	1726	1623	1710	1702

[1] Weights include plant crowns.
[2] These data were estimated using a predictive equation which was formulated using actual data collected on two sampling dates (July 2 and August 26). The equation used was Y + 1122 + .9768X, where X is the root mass in the upper 10 cm and Y is the root mass in the upper cubic meters of soil.
[3] Standard error of the mean.

On the average there were about 900 g/m² of root material in the upper 10 cm of the soil profile on the shortgrass prairie. In general there was more root material in the moderately grazed and the ungrazed grasslands than in the lightly grazed and heavily grazed treatments. On the average, the lightly grazed treatment had the least amount of root material in the upper 10 cm of the soil profile. These treatment differences were significantly different at the $P<.10$ level of probability.

In 1969 the amount of roots in the upper 80 cm of the soil profile in the heavily grazed treatment ranged from 852 g/m² at the end of July to 1724 g/m² in late August (Table 2). All treatments had a peak root mass during early summer followed by a decline. This was followed by a general increase in the mass of roots by fall. No similar trend was apparent in 1970 (Table 3). Generally, a decrease in the amount of root material occurred between the November and December sampling period in 1969. This decrease was approximately 400 g/m²/80 cm.

The maximum, as well as the minimum, amounts of roots and crowns were recorded in the heavily grazed treatment. During the summer of 1969 all treatments were found to reach the minimum amount of roots on July 31, except for the moderately grazed treatment (Table 2). Although this treatment had slightly more roots on July 31 than on June 21, the difference was not statistically significant. The data from the November sampling indicate that total roots and crowns in all treatments decreased during the fall. The December sampling period shows a uniform root mass which is lower than the November period for all treatments.

During the summer of 1970 (Table 3) the amount of root material for the upper 80 cm of the soil profile varied as follows for each grazing treatment: Heavy grazing, 1828 g/m² (June 19) to 1613 g/m² (August 26); moderate grazing, 1614 g/m² (May 22) to 1918 g/m² (July 2); light grazing, 1517 g/m² (July 2) to 1816 g/m² (July 17); and ungrazed, 1464 g/m² (July 2) to 1896 g/m² (July 17).

Analysis of variance of the data using a factorial design showed no differences in the root mass among the grazing treatments. Significant differences were found only among dates, depth increments, and the dates by depth increment interaction.

The lack of grazing treatment effect is in contrast to many results reported in the literature. Most grazing studies have shown that root mass decreased with increased grazing intensity (Schuster, 1964; Lorenz and Rogler, 1967; Biswell and Weaver, 1933; Cook, Stoddart, and Kinsinger, 1958; and Jameson and Huss, 1959). Pearson (1965) and Smoliak et al. (1972) reported an increase in root mass with increased grazing pressure. The root extraction procedures used in this study did not recover all root material, i.e. fine roots passed through the 32-mesh screen. This factor may mask some treatment differences, if some treatments had significant amounts of small roots.

Research has shown that grass roots stopped growing when the aerial portions were clipped. Crider (1955) found that for various species no root growth occurred for 6 to 18 days after clipping. He also found that roots of clipped plants weighed one-eighth as much as the roots of the unclipped plants. Clipped blue grama, for example, produced approximately 85% less root biomass than unclipped blue grama.

On the Pawnee Site, 55% of the root and crown weight occurred in the upper 10 cm and 69% in the upper 20 cm of the soil profile. These data are comparable to values for blue grama-buffalograss communities reported by Weaver (1958) who found 79% in the upper 15 cm and Weaver and Zink (1946) who found 80% in the upper 35 cm of soil. In addition to the above, 16% of the total roots collected occurred between 20 and 40 cm, 9% between 40 and 60 cm, and 6% between 60 and 80 cm of the soil profile.

These data indicate that shortgrass prairies have a shallow root system maintained by low and erratic precipitation (Stoddart and Smith, 1955). Weaver (1958) substantiated this finding by stating that blue grama and buffalograss have a shallow root system which probably derives maximum benefit from soil water furnished by light showers. Weaver and Albertson (1943) indicated root depth corresponded to the most frequent depth of penetration of soil water under the ambient rainfall regime. Shantz (1911) indicated that the shortgrass root system was limited to the upper 18 inches of soil. Markle (1917) suggested that a superficial root system was due to soil water content, and Weaver and Crist (1922) said the main factor was available water. Most roots occur in the upper levels of the soil profile (Weaver, 1958; Nilsson, 1970) and decrease rapidly with depth (Dahlman and Kucera, 1965). Nilsson (1970) stated that grass roots were concentrated in the upper soil layers because grasses are shallow rooted and, further, that grass roots have thicker proximal parts.

Distribution of the root mass in this study follows that hypothesized by other investigators (Nilsson, 1970; Hanson and Stoddart, 1940; Ovington, Heitcamp, and Lawrence, 1963). Varying degrees of grazing had no significant influence on the amount of roots and crowns present. Concentration of shortgrass roots in the upper layers of the soil might be attributed to frequent small and shallow penetrating rain showers.

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Condition and Trend of the Big Sagebrush/Needleandthread Habitat Type in Nevada

PAUL T. TUELLER AND WILBERT H. BLACKBURN

Highlight: *Condition and trend of the big sagebrush/needleandthread habitat-type was studied at 23 sites in northern and eastern Nevada. An inference approach was used to quantify range trend in one field season. The habitat-type was located and described in excellent, good, fair, and poor condition. Trend relationships show that needleandthread is a decreaser, while big sagebrush, squirreltail and green rabbitbrush are increasers. Quantitative guidelines are developed for each condition class.*

Condition and trend of range vegetation are of primary concern to range managers. Sound range management plans depend on an understanding of secondary succession. *Range condition* is defined as "range health" and *range trend* as "change away from or toward a desirable condition" (Bailey, 1945). In addition to direction, Bailey states that "range trend has aspects of velocity and selectivity." The concept of range condition can be traced back to the turn of the century when workers such as Smith (1895), Griffith (1903), and Wooton (1908) recognized deteriorated range condition and recommended that stocking be such as to "improve the condition" of the range. Sampson (1919) made the first major contribution to our knowledge of condition classification. The four broad stages in plant succession he described correspond closely to present day condition classes of excellent, good, fair, and poor. Humphrey (1945) developed a condition classification which was based on current production and expressed in terms of the amount the same site should produce.

Dyksterhuis (1949) and Parker (1954) first proposed quantitative ecology as a means of evaluating condition and trend. Dyksterhuis (1949) grouped species, based upon response to grazing, into a quantitative system of range classification. Species were grouped and identified as "decreasers," "increasers," and "invaders." These groupings were graphed to show their relative cover in relation to percentages of climax vegetation and in response to years of overgrazing. The course of degeneration was divided into

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four condition classes. Parker (1951 and 1954) developed a similar procedure based on forage density, composition, and vigor, wherein a plant species is listed in one of three groups: (1) desirable, (2) intermediate, and (3) undesirable. Johnson and Reid (1964) evaluated the range condition on a pine/bunchgrass range in Colorado. They classified range condition by the relative production of desirable plants and stated that the "desirable plants increase or decrease with improvement or deterioration of the range."

Our objectives were to measure vegetation changes as found on the big sagebrush/needleandthread habitat-type in Nevada and to develop guidelines to evaluate the health of this habitat-type with quantitative condition classes.

The habitat-type is defined by Daubenmire (1952) as "the collective area which is capable of supporting the same homogeneous climax plant association."

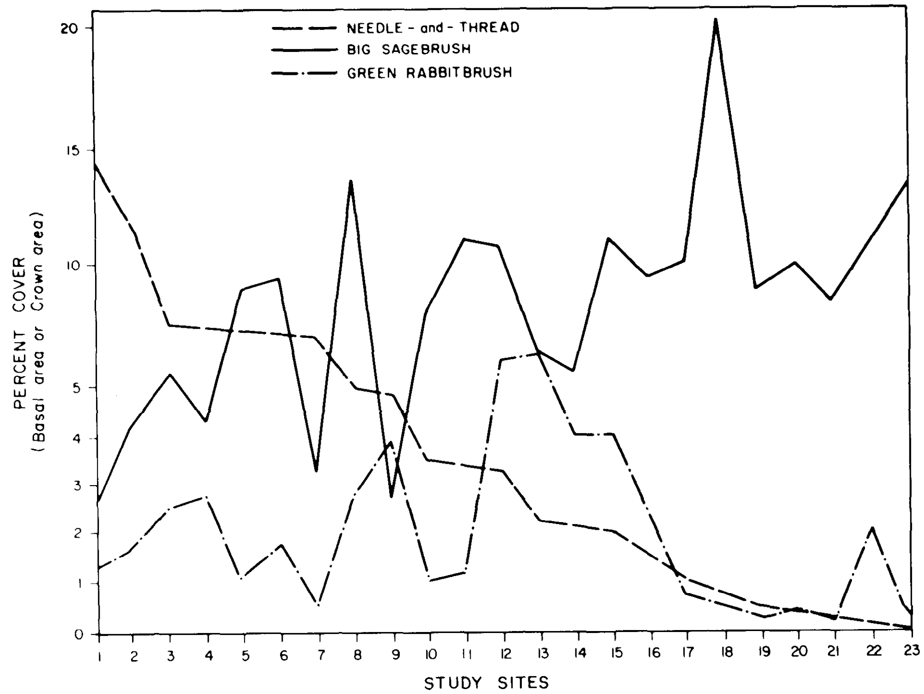

Fig. 1. *Cover increase-decrease curves for needleandthread, big sagebrush, and green rabbitbrush by study site.*

Study Areas

Study areas were two rangeland watersheds: 1) Rock Springs Watershed (T45N, R18E) located 46 miles southeast of Wells, Nevada, and 2) Duckwater Watershed (T14N, R55E) located 33 miles southeast of Eureka.

The big sagebrush/needleandthread habitat-type was found at elevations of 5,340 to 6,580 feet on west, northwest, north, northeast, or south-facing modern drainageway floodplains and smooth and dissected alluvial fans of 1 to 12%. Soils are members of a sandy, mixed, nonacid, frigid family of Typic Torripsamments and are usually found on modern drainageway floodplains of canyons dissecting many of the north-south trending mountain ranges found in the Great Basin.

Big sagebrush dominates the vegetation, with needleandthread most abundant on sites which appear in good condition; otherwise, bluestem wheatgrass, squirreltail, and Sandberg bluegrass are the most abundant grasses.

Methodology

Vegetation trend can be measured by various techniques. For example, vegetation can be inventoried at the time a plot is established and reinventoried every few years. A second approach is to measure vegetation inside and outside an exclosure at the time of construction, and reinventory at appropriate intervals. In this method a control is provided. However, both procedures require a period of several years to detect vegetation trend.

The inference technique, used in this study, requires a much shorter time period. It is assumed that study areas have approximately the same site potential, i.e., if any one of the sites is given the proper use or degree of rest, it could attain a condition equal to or approaching the best condition. The best condition site can be defined as that site nearest climax or nearest a preconceived quantitative expression of excellent condition. Habitat-types can be recognized from vegetative, climatic, soil, and topographic features, and can be located and studied in several different successional states. An inference technique has the advantage that results can be obtained at the end of any given field season. The principal disadvantage is inherent in the difficulty of interpretation brought about by seeming differences or similarities in site potential.

A total of 23 macroplots were placed within predetermined boundaries of the big sagebrush/needleandthread habitat-type. Relict areas, water developments, and fence line contrasts were used to study the habitat-type in various successional stages. The study sites were determined to have a similar effective environment. Elevation, soil, aspect, and latitude were homogeneous. Where slight differences occurred in elevation and aspect, it was judged that these differences were compensating in effect and each study site had potential to produce the same climax vegetation.

Soils belonging to the same family offer the best evidence that site potentials are equivalent. Soil families are classified on the basis of their characteristics that influence plant growth. The soil classification unit serves as an index to site potential and reflects the result of a great variety of ecological parameters that have not been fully described and perhaps cannot be.

Basal area and crown cover measurements were obtained in a 100-ft square macroplot by a modification of the tech-

Table 1. Mean and range values computed for 12 characteristics of 23 locations of the big sagebrush/needleandthread habitat-type.

Characteristic	Mean	Range
Big sagebrush (% crown cover)	8.45	2.0 to 20.8
Rubber rabbitbrush (% crown cover)	1.59	0.0 to 5.8
Needleandthread (% basal area)	4.04	0.1 to 14.1
Total perennial shrubs (% crown cover)	10.04	4.0 to 21.0
Bare ground (%)	38.56	26.0 to 55.0
Litter (% cover)	54.93	37.5 to 74.0
Pavement (% cover)	5.87	0.0 to 12.5
Rock (% cover)	0.61	0.0 to 5.0
pH A1	6.87	6.2 to 7.9
Conductivity A1 (m hos/cm)	0.18	0.1 to 0.4
Organic matter A1 (%)	1.41	0.6 to 2.6
Cation exchange capacity A1 (meq/100 g)	6.30	3.4 to 9.5

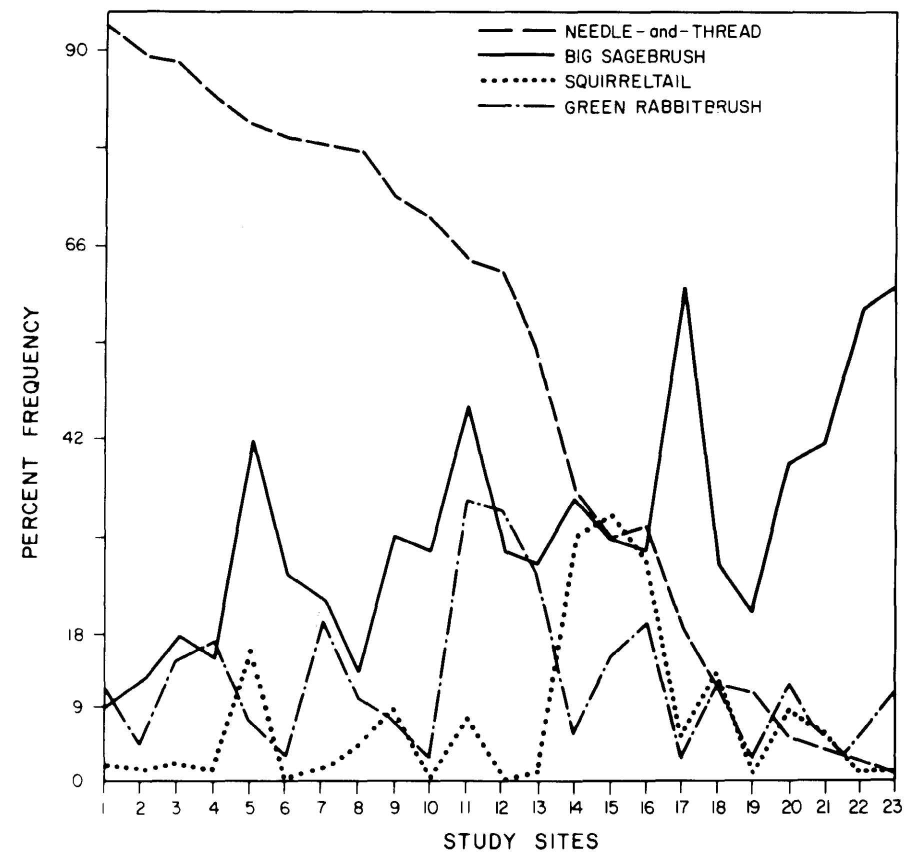

Fig. 2. *Frequency increase-decrease curves for needleandthread, big sagebrush, squirreltail, and green rabbitbrush by study site.*

nique described by Poulton and Tisdale (1961). Frequency sampling procedures (Hyder, et al., 1963) were used to provide an estimate of relative abundance and homogeneity. A 20- by 20-inch frame was used. Bare ground, litter and pavement (1/4 to 1 inch in diameter) and rock (> 1 inch in diameter) were determined by an adaption of the point frame method (Goddall, 1952).

An all-possible simple linear correlation analysis was used to detect relationships among certain species and other variables encountered in the habitat-type.

A soil profile description was made at each macroplot with the procedures outlined in the Soil Survey Manual (U.S. Dep. Agr., 1951) and the Seventh Approximation (U. S. Dep. Agr., 1960). The following parameters were selected because they have been suggested as indicative of vegetation and soil relationship (Eckert, 1957). Samples from the A1 and B2 horizons were analyzed for conductivity (mhos/cm), pH (from a saturated paste), and organic matter (%). Cation exchange capacity (meq/100g) was determined only on those samples from the A1 horizon (U. S. Dep. Agr., 1954). Family level identifications were made in accordance with the Seventh Approximation (U. S. Dep. Agr., 1960) and revisions (U. S. Dep. Agr., 1970).

Table 2. Mean and range in frequency values (%) of plant species computed for 23 locations on the big sagebrush/needleandthread habitat-type, all study sites combined.

Species	Mean	Range
Big sagebrush (*Artemisia tridentata* Nutt.)	30.93	9.0 to 56.0
Green rabbitbrush (*Chrysothamnus visicidiflorus* (Hook.) Nutt.)	12.54	0.0 to 35.0
Needleandthread (*Stipa comata* Trin. and Rupr.)	52.15	1.0 to 95.0
Indian ricegrass (*Oryzopsis hymenoides* Roem. and Schult.)	10.46	0.0 to 52.5
Sandberg bluegrass (*Poa secunda* Presl.)	20.04	0.0 to 86.5
Bluestem wheatgrass (*Agropyron smithii* Rydb.)	33.56	0.0 to 61.5
Squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith)	12.44	0.0 to 78.5
Prickly phlox (*Leptodactylon pungens* (Torr.) Rydb.)	3.48	0.0 to 16.5
Cheatgrass (*Bromus tectorum* L.)	6.22	0.0 to 62.5
Longleaf phlox (*Phlox longifolia* Nutt.)	5.41	0.0 to 26.5
Cryptantha (*Cryptantha micrantha* (Torr.) Jtn.)	5.00	0.0 to 37.0
Total perennial shrubs	46.08	18.0 to 81.5
Total perennial grasses	133.87	94.0 to 208.5

Results and Discussion

Basal Area and Crown Cover

Table 1 shows the mean and range fo: 12 characteristics (basal area, crowr cover, soil features) from 23 locations Significant correlations are discussed be low. Needleandthread, the dominant per ennial grass, an increaser, was arrayec from high to low as an indication oi condition by site (Fig. 1).

Needleandthread is negatively cor related (*r* = –.567) with big sagebrusl (Fig. 2). This relationship suggests that a: needleandthread decreases in basal area big sagebrush crown cover increases Quantitatively, needleandthread de creased from 7.5 to 1.4% basal area as bi; sagebrush increased from 1.3 to 13.5% crown cover.

Big sagebrush is positively correlated (*i* = .931), with total perennial shrubs denoting the dominance of this shrub ir the habitat-type. Big sagebrush is alsc positively correlated (*r* = .477) witl conductivity of the A1 horizon, indicating that total salts tend to increase with ar increase in crown cover.

The cover of perennial shrubs is cor related (*r* = .431 and *r* = .466) suggesting that perennial shrubs occur with greatei cover on sites of higher conductivity and organic matter. Organic matter is posi tively correlated (*r* = .462) with cation exchange capacity.

The correlation coefficients for fre quency data are similar to those com puted for basal area and crown cover but in some instances are higher (Table 2). The dominant perennial grass, needleand thread, expresses a highly significant neg ative relationship with big sagebrush (*r* = –.633) and squirreltail (*r* = –.606) (Fig. 4). This strongly suggests that big sagebrush and squirreltail increase as needleand thread decreases. For example, as needle andthread frequency approaches 81%, big sagebrush nears 8% (Fig. 2). Likewise, needleandthread nears 83% as squirreltail frequency approaches 0%. The data also indicate that needleandthread and blue stem wheatgrass are negatively related (*i* = –.344). However, this relationship is not significant.

Big sagebrush shows a positive rela tionship (*r* =.571) with squirreltail, which helps to verify that these two species are increasers in this habitat-type. Big sage brush is highly correlated (*r* = –.542) with perennial grass frequency. This offers evidence to substantiate the statement that perennial grasses decrease as big sagebrush increases. Big sagebrush and organic matter are positively correlated (r = .587), suggesting that this species occurs with a high frequency on sites with high organic matter or causes high organic matter, depending on site location. These results are similar to those obtained with cover data.

Green rabbitbrush was positively correlated with prickly phlox (r = .506) and longleaf phlox (r = .603), but was negatively related to cheatgrass (r = −.422). This suggests that green rabbitbrush, prickly phlox, and longleaf phlox respond similarly in the habitat-type, and that green rabbitbrush is more abundant on sites with less cheatgrass.

Sandberg bluegrass and bluestem wheatgrass are correlated with total perennial grasses (r = .460 and r = .518, respectively), indicating that these two grasses are important in the perennial grass component. Cheatgrass has high frequency values on sites where pH (r = .695), conductivity (r = .644), and cation exchange capacity (r = .473) were also high relative to other sites in the series studied.

Conductivity and pH were correlated (r = .688), and cation exchange capacity has a positive relationship with organic matter (r = .462). These relationships were natural expectations.

Increase-Decrease Curves

Increase-decrease curves are based on significant correlations. These curves are not actually increase-decrease curves over time but are curves based on greater or lesser amounts of important species. This variation is a result of the habitat-type occurring in different conditions, each on sites with similar site potential. It is assumed that deterioration took place over time and that the dominant perennial grass will decrease first under grazing pressure, thus allowing less desirable species to increase.

Macroplot locations are arrayed on the basis of decreasing needleandthread. Big sagebrush and green rabbitbrush crown cover is plotted against needleandthread to show their response to inferred differences in condition (Fig. 1). As needleandthread decreases, big sagebrush definitely increases. Green rabbitbrush, however, increases to a certain point then decreases.

Frequency data from the big sagebrush/needleandthread habitat-type shows curves similar to those obtained from cover data (Fig. 2). As needleandthread decreases in frequency from 95 to 1%, big sagebrush increases from 9 to 59%; squirreltail also increases from 1 to 30%. Green rabbitbrush shows a similar pattern, increasing from 11 to 32%, then decreasing to 13%.

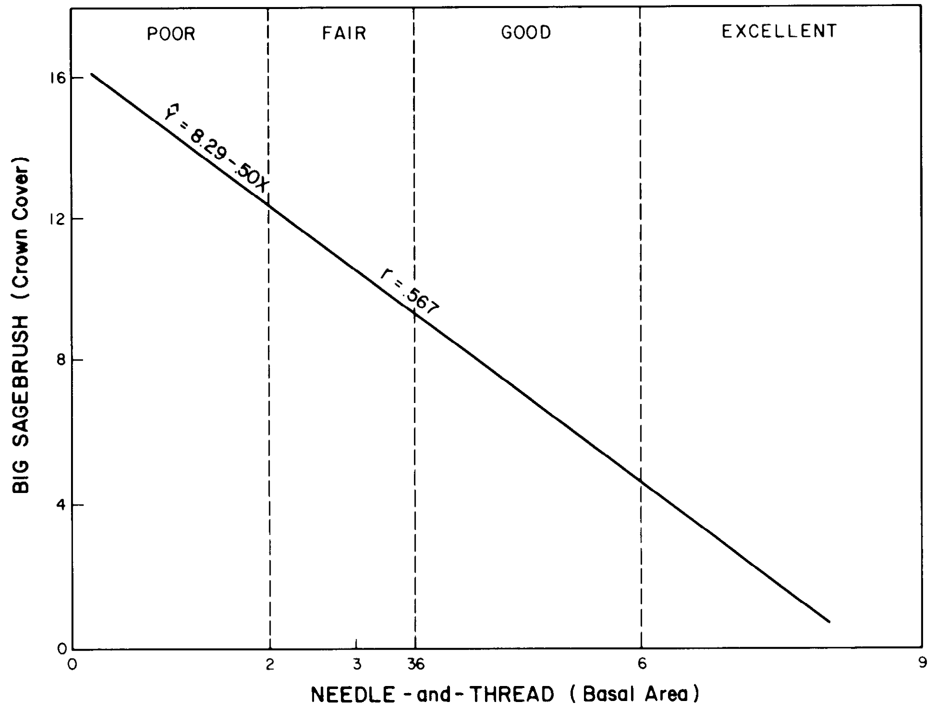

Fig. 3. *Condition classes as developed from cover data, showing the relationship between big sagebrush and needleandthread.*

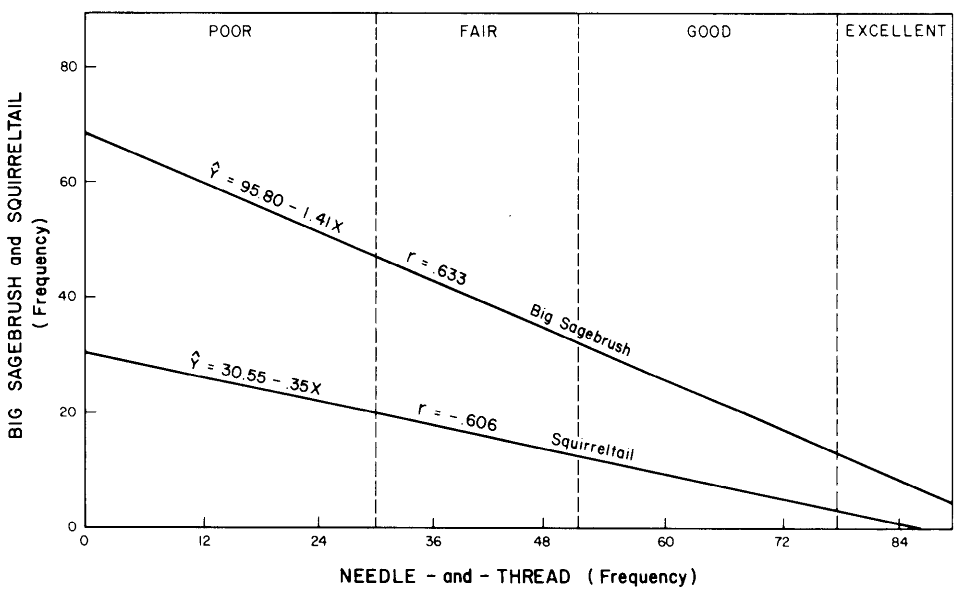

Fig. 4. *Condition classes as developed from frequency data, showing the realtionship of big sagebrush and squirreltail with needleandthread.*

Condition Classes

Condition classes are developed using several significant species. Cover and frequency data arrayed for the dominant perennial grass are divided into excellent, good, fair, and poor condition using natural breaks in the data. The regression lines for those species significantly correlated with the dominant perennial grass are plotted in Figs. 3 and 4. These lines eliminate irregularity in the relationships, thus allowing more than one species to be used in developing criterion for the condition classes.

Condition classes as developed suggest that when the habitat-type is in excellent condition, the cover of needleandthread would be about 6% and that big sagebrush would fall between 1 and 4.5% (Table 3). When frequency of occurrence

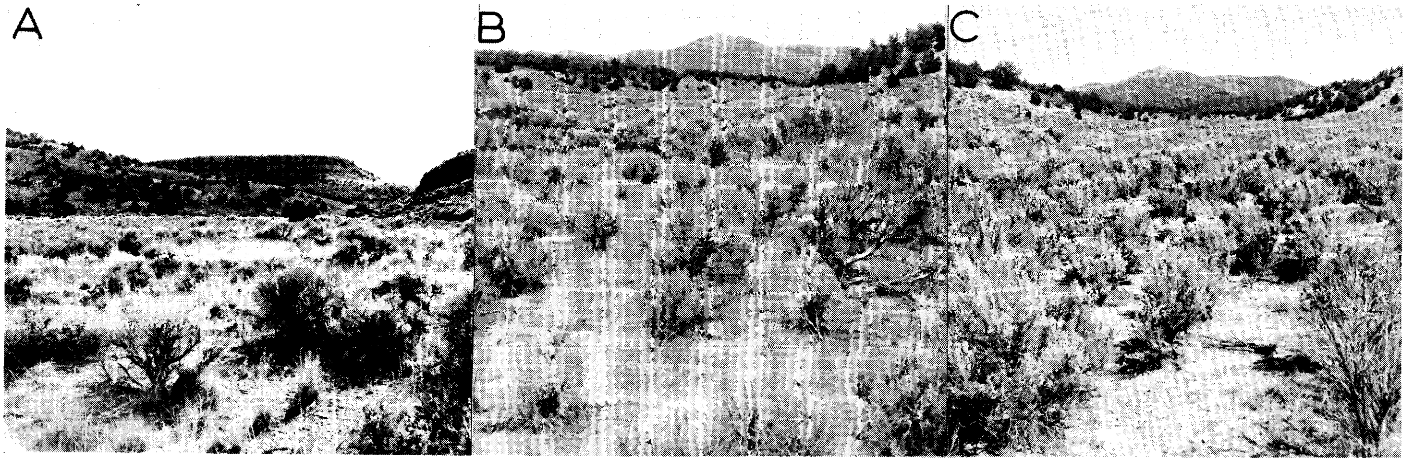

Fig. 5. *The big sagebrush/needleandthread habitat-type in (A) excellent, (B) good, and (C) poor condition. Sites B and C were in the same drainage bottom with site C being closer to a source of livestock water.*

is used to portray excellent condition, needleandthread would have a 78% frequency, big sagebrush between 4 and 13%, and squirreltail less than 3% (Figs. 1 and 3).

Conversely, when the habitat-type is in poor condition, the cover of needleandthread would be less than 2% and big sagebrush between 12 and 16%. The frequency of needleandthread would drop to less than 30%, big sagebrush increase to between 46 and 67%, and squirreltail frequencies would be above 20% (Figs. 1 and 3).

This habitat-type in excellent condition would have relatively little big sagebrush, but needleandthread would be very abundant (Fig. 5). When the habitat-type starts to deteriorate by grazing or other means, the dominant grass, needleandthread, would decrease and big sagebrush, squirreltail, and yellowbrush increase (Fig. 5).

Needleandthread is not eliminated from the habitat-type all at once, but as deterioration continues the plants are gradually reduced in basal area, height, and overall vigor. This reduction continues until needleandthread is eliminated from shrub interspaces (Fig. 5c), leaving surviving plants protected under the shrubby species. This reduction in the dominant perennial grass releases less desirable species, allowing them to increase.

Table 3. Frequency (%) and cover (%) of needleandthread, big sagebrush, and squirreltail by condition classes for the big sagebrush/needleandthread habitat-type.

Condition class and measurement	Needleandthread	Big sagebrush	Squirreltail
Excellent			
Frequency*	78.0 +	5.0 to 13.0	0.0 to 3.0
Cover	6.0 +	1.0 to 4.5	**
Good			
Frequency*	51.0 to 78.0	13.0 to 32.0	3.0 to 12.0
Cover	3.6 to 6.0	4.5 to 9.2	**
Fair			
Frequency*	30.0 to 51.0	32.0 to 46.0	12.0 to 20.0
Cover	2.0 to 3.6	9.2 to 12.3	**
Poor			
Frequency*	0.0 to 30.0	46.0 to 67.0	20.0 to 30.0
Cover	0.0 to 2.0	12.3 to 16.4	**

* Frequency samples refer to presence and absence determinations in a 20- by 20-inch frame.
**Cover not estimated.

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Effects of Light and Temperature on Germination of Sideoats Grama

D. F. COLE, R. L. MAJOR, AND L. NEAL WRIGHT

Highlight: *Seed from three sources of sideoats grama (*Bouteloua curtipendula *(Michx.) Torr.) were planted on one- and two-way thermogradient plates to determine the effects of light, constant and alternating temperatures, and temperature duration on germination over a range of 10 to 40°C. The direction of the temperature gradients was switched on various 24-hour cycles consisting of the following combinations: 4–20, 8–16, and 12–12 hours. Dormancy was not broken by any set of alternating temperature combinations. Light did not promote the rate or completeness of germination. The seed from various sources differed in the totality of germination over the entire thermogradient plate. The best germination over the entire plate was obtained with the 12–12 hour cycle, followed in turn by the 8–16 hour cycle and finally the 4–20 hour cycle for seed source 63, 1969 seed. As the imbalance of time cycles increased, the exposure of seed to continuous extreme temperatures increased also, thereby lowering total germination. Optimum temperatures for maximum germination of each source differed depending upon year of seed production and duration of the specific temperature.*

Seed germination of sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) is influenced by dormancy (Coukos, 1944), temperature (Toole, 1938), germination inhibitors (Sumner and Cobb, 1962; Major, 1972), and interactions between storage conditions and time (Coukos, 1944). The procedures recommended for germination by the Association of Official Seed Analysts (1970) are: (a) alternating temperature of 15 to 30° C, (b) 8 hours of light at the higher temperature, (c) the use of blotters moistened with 0.2% KNO_3 as the germination medium.

Previous research on germination of sideoats grama has been limited to a relatively few discrete constant or alternating temperatures. Development and description of the thermogradient plate (TGP) by Larsen (1971) provided a method to determine the optimum temperature for rapid and maximum germination of various seed. Larsen and Skaggs (1969) found that a constant 25° C was optimum for germination of crambe (*Crambe abyssinica* Hochst. ex R. E. Fries) seed using the TGP. Larsen et al. (1973) reported that dormancy affected the germination speed and pattern of rescuegrass (*Bromus carthartícus* Vahl.) on the TGP. They further reported that clipping the distal end of the pericarp increased germination of dormant seed.

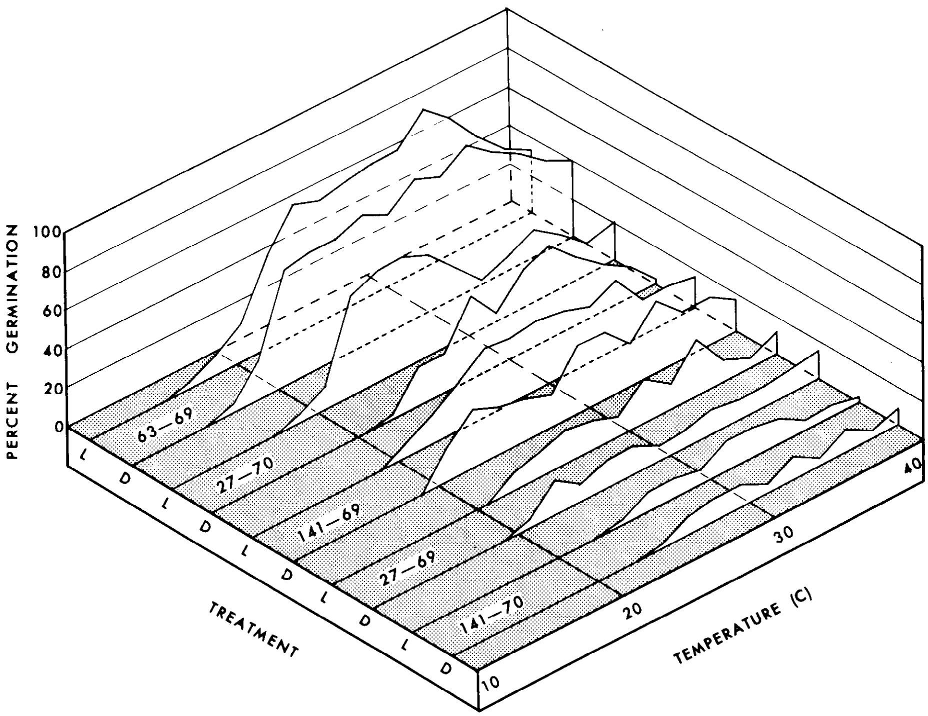

Fig. 1. *Effects of light and a range of constant temperatures (10 to 40°C) on germination of seed from different sources of sideoats grama. L = light. D = dark. 63-69 = source 63, seed produced in 1969. 27-70 = source 27, seed produced in 1970, etc.*

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The study is a contribution from the Seed Quality Research Laboratory, Agr. Res. Serv., U.S. Dep. Agr., Beltsville, Maryland, and the Department of Agronomy and Plant Genetics, Univ. of Ariz., Tucson. (Arizona Agricultural Experiment Station Journal Paper No. 2055.)

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Objectives of the present study were to determine the effect of light, constant and alternating temperatures, and the length of the alternating temperature cycle on the germination of sideoats grama and to determine if any combination of alternating temperatures and temperature durations would break seed dormancy.

Materials and Methods

Seed units of three seed sources of sideoats grama were produced as described by Major (1972) at the Plant Materials Center, Tucson, Arizona, in 1969 and 1970. The origins of each seed source were: (a) source 27, Texas–Texas P.M.C., PM-T-56, Orange Grove, (b) source 63, New Mexico–"Vaughn," Tucson P.M.C., lot 3196, and (c) source 141, Plant Introduction number 279525, from Argentina (Major, 1972). Spikes containing one or more caryopses were considered a seed unit or "seed."

Effects of light (100 ft-c at seed level, cool-white fluorescent and incandescent) and a range of constant temperatures from 10 to 40° C on germination were determined. The TGP was used in a one-way mode to establish the temperature gradient. Four replicates of 25 seed from each seed lot were planted at 15 different temperature positions on the TGP. Two TGP's were used, one covered with a black cloth and the other exposed to light for 8 hours daily. The experiment was repeated and data from similar treatments were combined.

The effects of light and a range of alternating temperatures of 10 to 40° C also were determined using the TGP in a two-way mode. The temperature gradient (10 to 40° C) was alternated on a 12-hour cycle. Light described above was alternated with dark on a 12-hour cycle. Two seed units of source 63, seed produced in 1969, were planted at each of 900 locations on the TGP and were spaced 2.54 cm apart in all directions.

The effects of time between temperature alternation and year of production were determined on each seed source in complete darkness. The TGP was used in the two-way mode. Temperature gradients (10 to 40° C) were established on two cycles; (1) 8 hours in one direction and 16 hours in one direction at a right angle to the 8-hour direction (8-16), (2) 4 hours in one direction and 20 hours in one direction at a right angle to the 4-hour direction (4-20). Seed were planted as previously described on the two-way TGP.

Two blotters were used in all experiments (in duplicate) as the medium for germination. Seed were considered germinated when one radicle per seed unit was at least 1 cm in length and the shoot visible. Germination counts were made 7

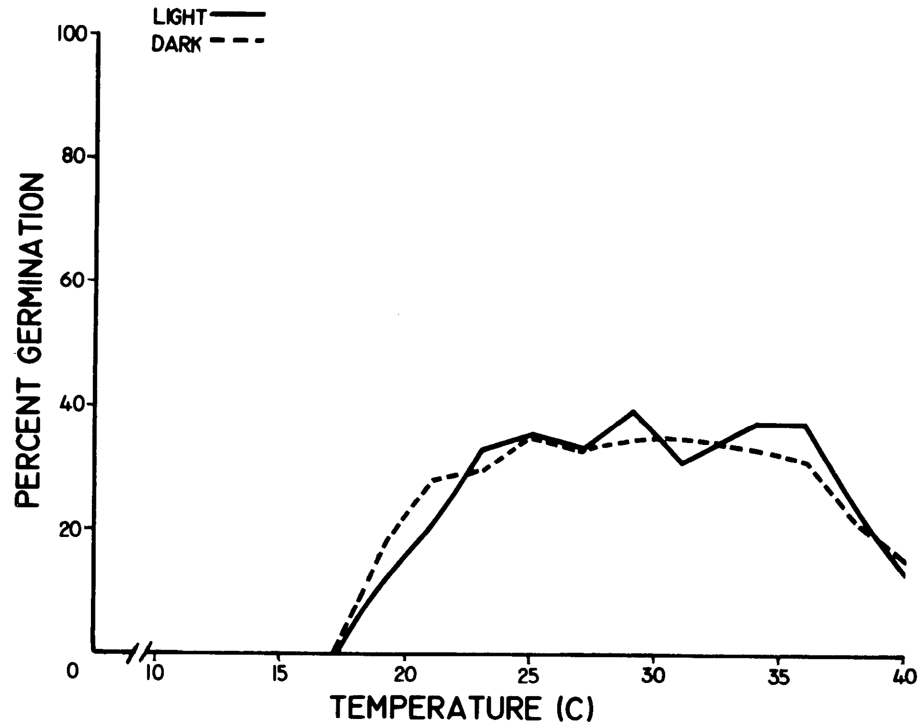

Fig. 2. *Effects of light and a range of constant temperatures (10 to 40° C) on germination of sideoats grama averaged over all seed sources.*

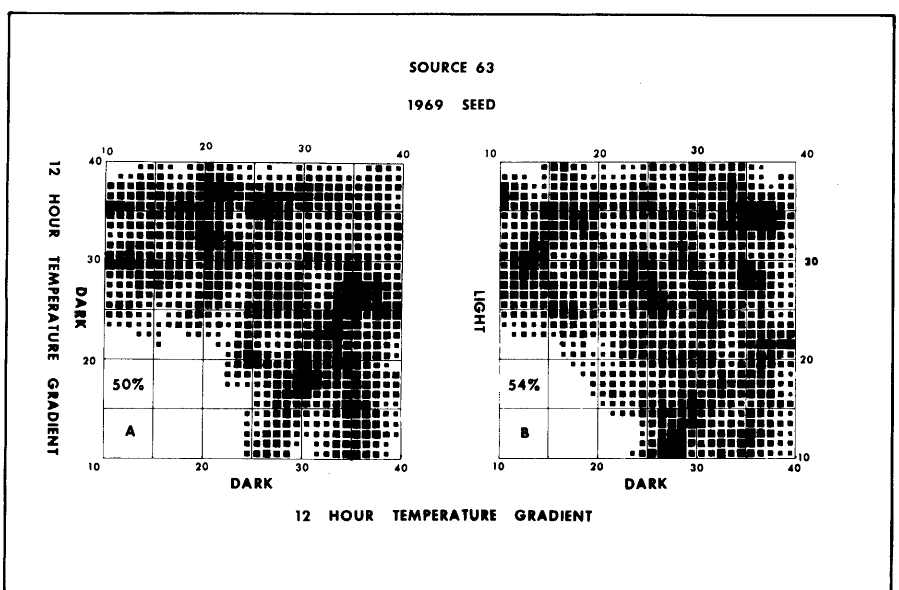

Fig. 3. *Effects of light and a range of alternating temperatures (10 to 40° C) on germination of seed from source 63, 1969 seed, of sideoats grama. The temperature gradients were alternated on a 12-12 hour cycle. The larger "squares" represent higher germination percentages (9 different sizes).*

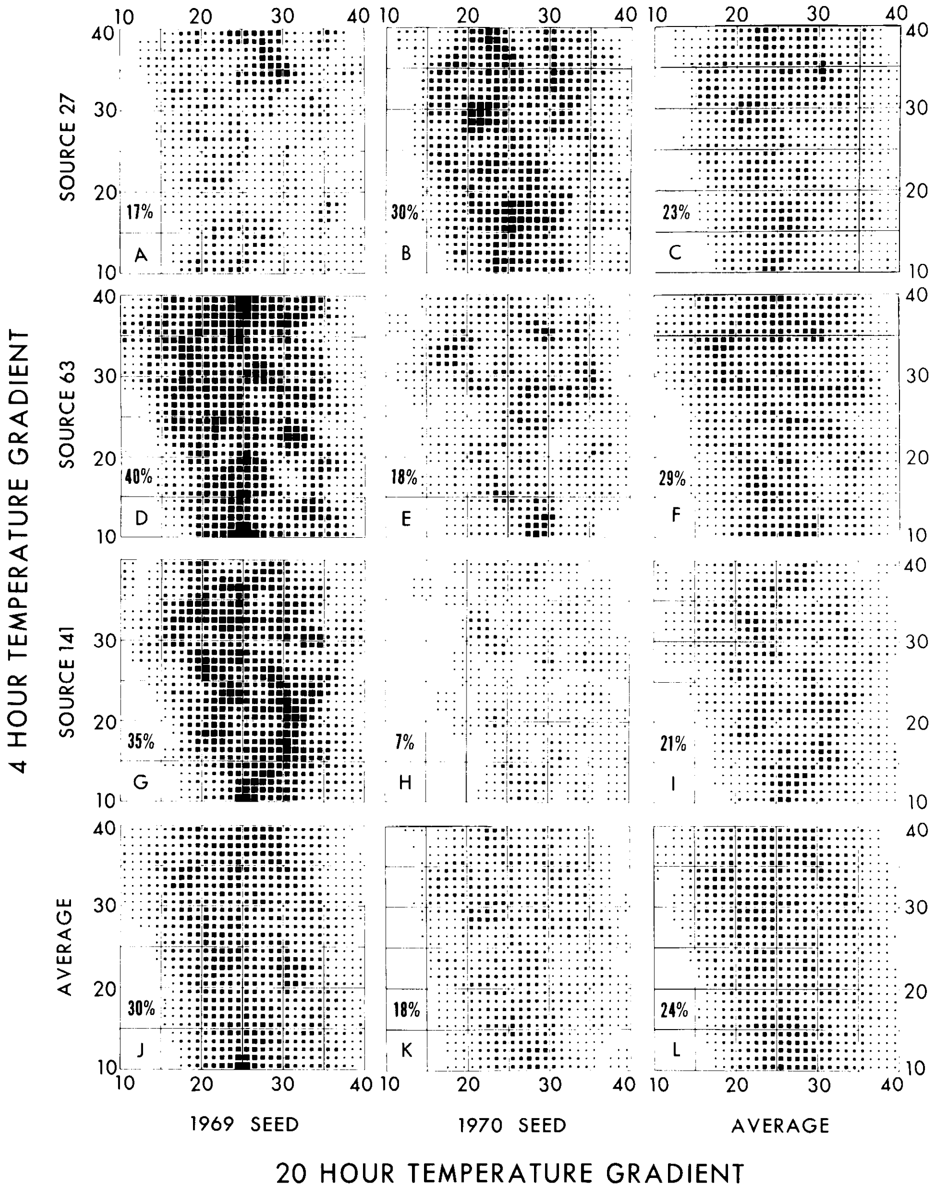

Fig. 4. *Germination pattern of sideoats grama seed on a two-way thermogradient plate in constant dark with a range of alternating temperatures of 10 to 40°C. The temperature gradients were alternated on a 4-20 hour cycle. The larger "squares" represent higher germination percentages (9 different sizes).*

days after planting. Moisture content of the blotters was maintained by watering when needed. A green safelight was used during watering to prevent a light reaction.

Intensity of germination diagrams (Larsen and Skaggs, 1969) were plotted for the two-way TGP data by using a moving average of each position with its adjacent 8 positions. Outside rows and columns were "weighted" by appropriate values. Larger "squares" on the intensity diagram represent a higher percentage germination.

Results and Discussion

Major (1972) classified source 27 as dormant and sources 63 and 141 as nondormant when germinated at the temperatures recommended by the Association of Official Seed Analysts (1970). However, seed produced in the same region in different years within sources exhibited different levels of dormancy. Major (1972) further showed that dehulling broke the dormancy and the seed germinated at the recommended temperature.

Seed from source 63, produced in 1969, showed less dormancy than seed from the other sources (Fig. 1). Differences between years of production were found for sources 27 and 141. At constant temperatures germination was not influenced by light (Figs. 1 and 2).

Light did not influence the completeness of germination of seed from source 63 when the temperature gradients were alternated on a 12-hour cycle (Fig. 3). Percentages in the lower left corner of each intensity diagram (Figs. 3, 4, and 5) represent the percent of seed that germinated for each seed source over the entire thermogradient plate. Results reported here on the influence of light on germination support previous research (Cole, 1971; Sumner et al., 1960; Toole, 1938) in that light is not a specific requirement for germination of sideoats grama.

Seeds were stored from time of harvest to the spring of 1972 at 5° C and a relative humidity of 15%. Coukos (1944) reported that dormancy in sideoats grama was prolonged at cool storage conditions. Effects of a range of alternating temperatures on two different alternating cycles are shown in Figs. 4 and 5. No specific alternating temperature combination or temperature duration appeared to break dormancy of this species. Germination occurred over a wide range of temperature combinations.

Maximum germination for sources 63 and 141 occurred with seed produced in 1969 (Fig. 4 d,g and Fig. 5 d,g), whereas, maximum germination of source 27 occurred with seed produced in 1970 (Fig. 4b, and Fig. 5b). Averages over all seed sources revealed that the seed produced in 1969 was less dormant than that produced in 1970 (Fig. 4 j,k and Fig. 5 j,k).

More seed germinated with the 8-16-hour alternating cycle (Fig. 5); and the 4-20-hour (Fig. 4) cycle reduced germination of all accessions at alternating temperatures above 35 and below 15°C of 20-hour duration.

Comparison of data for source 63, from Figs. 3, 4d and 5d, indicates that a 12-hour alternating cycle at the recommended temperature of 15-30 provides a more favorable environment for germination than an 8-16 hour cycle. Research with Kentucky bluegrass (*Poa pratensis* L.) showed that temperature alternation promoted germination in darkness when the daily period at 25° C is between 4 and 14 hours (Toole and Borthwick, 1971).

Maximum germination of seed from all sources when temperatures were alternated on a 4-20 cycle, occurred in the temperature range of 20 to 30° C for 20 hours independent of the temperature for the remaining 4 hours of the cycle (Fig. 4 j,k,l). This is contrasted with the much broader range of temperatures of maxi-

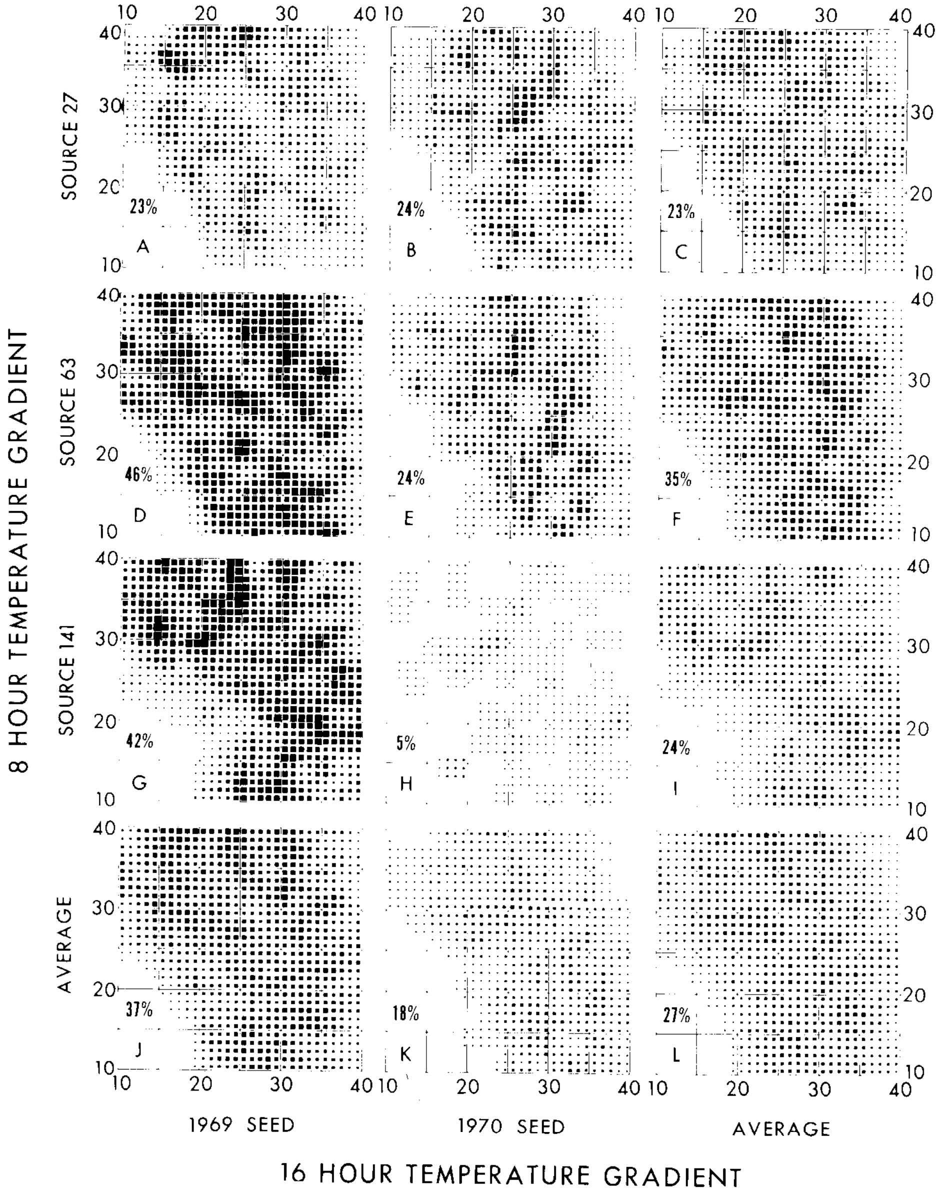

Fig. 5. *Germination pattern of sideoats grama seed on a two-way thermogradient plant in constant dark with a range of alternating temperatures of 10 to 40° C. The temperature gradients were alternated on a 8-16 hour cycle. The larger "squares" represent higher germination percentages (9 different sizes).*

mum germination with an 8-16-hour alternation (Fig. 5 j,k,l).

Regions of maximum germination for seed from each source differed in different years and duration of the specific temperature. An example is source 27, in which 1969 seed germination was maximized on a 4-20-hour cycle at temperatures of 35-30° C (Fig. 4a), respectively, and at an 8-16 hr cycle at temperatures of 35-15° C (Fig. 5a), respectively. Several other examples are apparent upon examination of the other seed sources and temperature cycles. Thompson (1970a) showed that maximum germination of different species of Caryophyllaceae occurred at different temperatures. He further reported that different seed sources of (*Silene secundiflora* Otth.) germinated over a broader range of temperatures as dormancy was reduced (Thompson, 1970b). The data reported here indicate that sources 63 and 141 germinated at a lower temperature than source 27 on both temperature alternation cycles (Fig. 4 and 5). This suggests that sources 63 and 141 may be better adapted to cooler climates or that they may have originated in different environmental conditions than source 27.

The recommended temperature (Assoc. Off. Seed Anal., 1970) resulted in less germination by seed from all seed sources than other temperatures which were more favorable. These data suggest that low temperatures for 16 hours may be either too low, or too long, or both. Increasing the low temperature to 20° C or changing to a 12 hour alternating cycle should provide a better environment for maximum germination.

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Longleaf Uniola and Spike Uniola Require Shade

GALE L. WOLTERS

Highlight: *Three years after establishment, longleaf uniola and spike uniola plants under 92% shade were larger, more numerous, and more vigorous than those receiving more sunlight. Herbage production was 10 times greater in 92% shade than in full sunlight. Protein, phosphorus, calcium, and ash content of the herbage increased as shade deepened, while crude fiber and N.F.E. content decreased.*

Because of their ability to grow under tree canopies and to provide green herbage in winter, longleaf uniola (*Uniola sessiliflora*) and spike uniola (*U. laxa*) are important forage plants in the extensive loblolly-shortleaf pine-hardwood forest type of the South. As a matter of observation, the two grass species grow even under the densest tree cover and are rare or absent on well-lighted sites.

In an effort to provide more specific information, a study was made to determine how artificial shade of several intensities affected establishment, growth, and chemical composition of the two grasses. Since measurements were made throughout the year, the research also provided data on seasonal aspects of the plants' growth.

Procedure

The study took place on the Palustris Experimental Forest in central Louisiana. The nearly level area had deep, medium-textured soils with imperfect internal drainage. It was thus typical of soils where longleaf and spike uniola occur most abundantly. All woody vegetation was removed, and the old rough was burned during December, 1966, to facilitate seedbed preparation.

Sixteen 8-by 10-ft plots separated by 10-ft aisles of native cover were systematically established in an exclosure. Plots were spaded and leveled initially during February, 1967, and were rotary-tilled twice in April.

A composite mixture of longleaf uniola and spike uniola seed, collected in the nearby forest the previous fall, was hand-seeded on the freshly raked plots in late April. About ¼ pound (air-dry weight) of pretreated (Wolters, 1970) uncleaned seed was applied per plot. Seeds were placed in parallel rows 12 inches apart and covered with a very thin layer of tamped soil.

Shade intensities of 0, 30, 63, and 92% were randomly assigned and replicated 4 times. Cloth woven to produce the prescribed shade intensity was placed 3 ft above the soil surface.

Measurements of longleaf uniola were made periodically during 1967, 1968, and 1969 to determine number of leaves and tillers per plant, length and width of basal leaves, and height of seed stalks. Counts of longleaf and spike uniola plants/ft^2 coincided with phenological measurements. Herbage production was determined in September, 1969, by clipping four randomly located 1-by 1-ft quadrats on each plot. Samples were oven-dried at 75°C, weighed, and composited for chemical analysis. Seed production was determined by hand-stripping two 1.55-by 1.55-ft quadrats on each plot. Germination was tested during the winter of 1969-1970. Environmental measurements included temperature and relative humidity at 4 inches above the soil surface. All measurements were made within a 6-by 8-ft sampling area centered on each plot.

A profuse growth of weedy forbs and grasses annually invaded the study plots. The competing vegetation was plucked by hand during September 1967, June and September 1968, and June 1969.

Morphological Development

Air temperature directly above the control plots (0% shade) averaged less than 2°F warmer than above the coolest treatment (92% shade). Likewise, relative humidity above the controls was less than 2 percentage points lower than above the

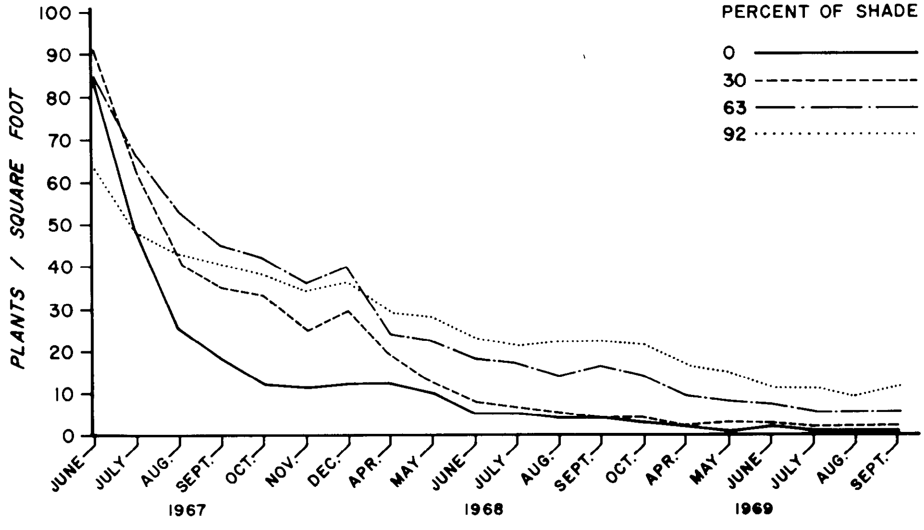

Fig. 1. *Uniola plants per square foot under four levels of shade. The peaks in late 1967 were probably caused by delayed germination.*

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densest shade. Except for the degree of shade, treatments apparently influenced plant microenvironment negligibly.

By the end of June, 1967, seedling density averaged 81 plants/ft^2. Most plants were in the third-leaf stage of development, and the lowermost leaf averaged about 1.8 mm wide. Lengths of basal leaves under 0, 30, and 63% shade were similar (13.5 mm average), while leaves under 92% shade were significantly longer (20.3 mm).

During the first year, seedling mortality ranged from about 50% under 92% shade to 85% under full sunlight (Fig. 1). By mid-September, 1969, survival averaged 18% under heavy shade and about 1% in full sunlight. Though mortality was high on all plots, plant density from mid-August, 1967, to the close of the study was significantly greater under 63 and 92% shade than in full sunlight (Fig. 2).

Plants in heavy shade were dark green and appeared more vigorous than the yellowish-green plants receiving more sunlight. Daubenmire (1955) states that when shade plants are exposed to full sunlight they may not be able to synthesize chlorophyll at a rate fast enough to replace what is lost by decomposition.

Shading also appeared to influence species establishment. Longleaf uniola made up approximately 65% of the stand in 92% shade; spike uniola comprised 60 to 68% of the stand under less shade.

Shading significantly increased the number of leaves per plant. Annually in September the average for longleaf uniola was 3.4 leaves under 92% shade and 2.0 in full sunlight (Table 1). Numbers of leaves under 30 and 63% shade were intermediate.

The period when new leaves developed at a maximum rate appeared to occur prior to June. Many were initiated during the fall and winter, grew slowly but continuously throughout the winter, and matured the following summer; such a pattern is characteristic of a cool-season plant (Huss, 1964). Yarlett (1965) also considered both longleaf and spike uniola to be cool-season growers.

During 1967 plants under 0 and 30% shade bore the greatest number of leaves in June. Thereafter leaf density decreased with each successive inventory. Under 63 and 92% shade, number of leaves per plant increased up to mid-August to September, and then declined. Leaf density closely paralleled leaf browning and drying, which was observed first in full sunlight and then at successive later dates under increased shade. Apparently intense sunlight hastened leaf maturity.

During the first year, basal leaves continued to increase in length until late October, but during successive years maximum length was generally obtained in July or August. In September leaf length

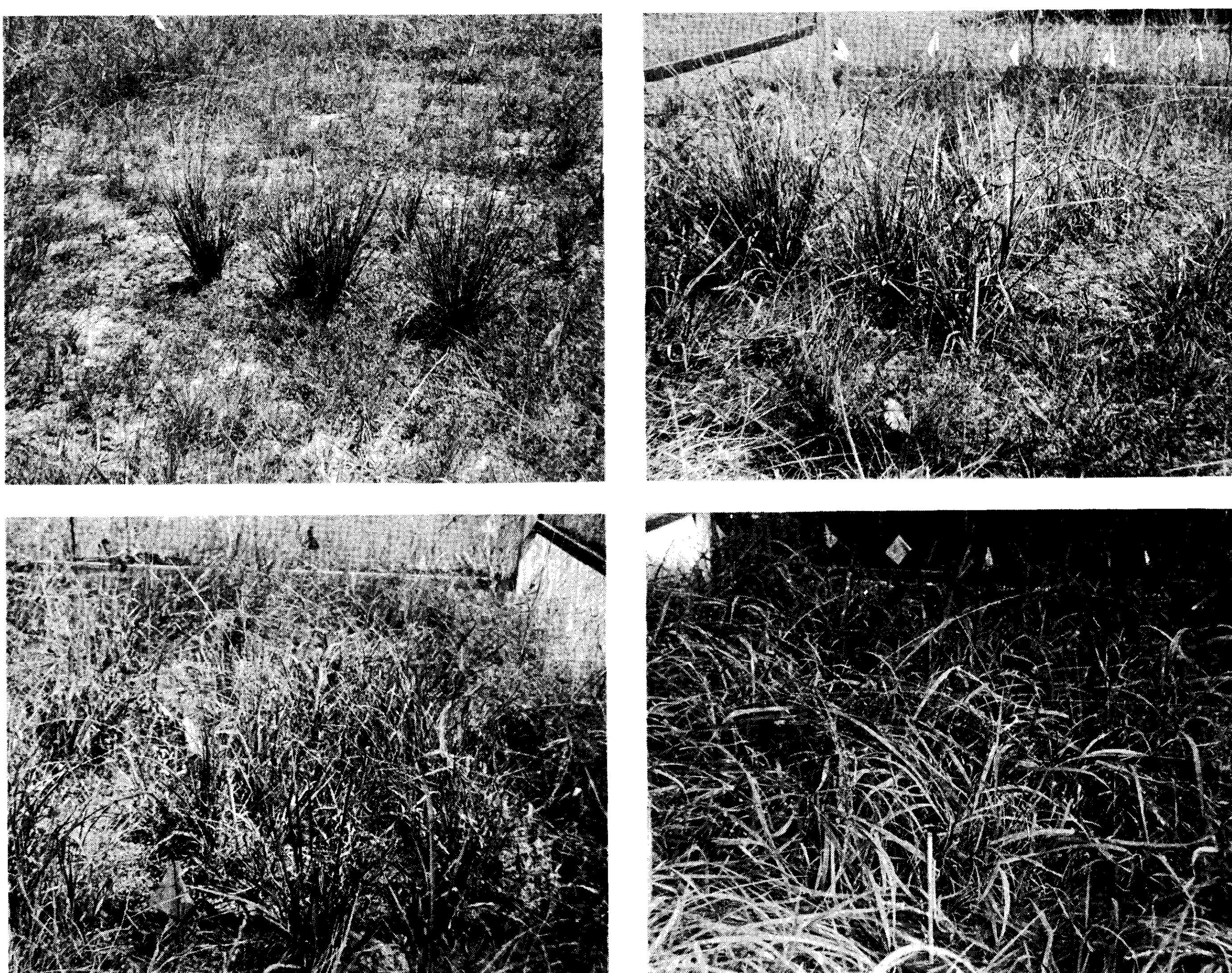

Fig. 2. *Comparison of the size and abundance of uniola in full sunlight (upper left), 30% shade (upper right), 63% shade (lower left), and 92% shade (lower right). Photos were made in September, 1969, by which time other grasses had invaded the plots.*

Table 1. Morphological development of longleaf uniola during September 1967, 1968, and 1969 under four levels of shade.

Date	Percent of shade			
	0	30	63	92
September 28, 1967				
Plants/ft²	13.0 b[1]	34.0 a	44.0 a	38.0 a
Leaves/plant	1.7 c	2.1 bc	2.5 b	3.2 a
Length of basal leaf (mm)	39.2 ab	36.3 b	39.3 ab	54.4 a
Width of basal leaf (mm)	1.7 a	1.7 a	1.9 a	2.2 a
Number of tillers/plant	0.1 a	0.1 a	0.3 a	0.7 a
September 23, 1968				
Plants/ft²	3.0 c	4.0 c	14.0 b	22.0 a
Leaves/plant	2.5 b	3.0 b	3.2 ab	3.8 a
Length of basal leaf (mm)	42.5 b	56.7 b	67.9 b	121.9 a
Width of basal leaf (mm)	2.2 b	2.5 b	2.6 b	3.6 a
Number of tillers/plant	1.1 b	1.8 b	3.2 a	3.4 a
Seedstalks/ft²	0.0 a	0.1 a	0.8 a	1.2 a
Length of seedstalks (mm)	0.0 a	211.0 a	260.0 a	620.0 a
September 18, 1969				
Plants/ft²	1.0 c	2.0 c	5.0 b	11.0 a
Leaves/plant	1.8 a	2.9 a	2.8 a	3.2 a
Length of basal leaf (mm)	55.5 c	97.0 b	102.2 b	137.4 a
Width of basal leaf (mm)	2.0 c	3.5 bc	4.7 ab	5.6 a
Number of tillers/plant	4.3 b	8.3 b	13.2 a	6.9 b
Seedstalks/ft²	1.1 c	4.0 bc	8.0 ab	9.8 a
Length of seedstalks (mm)	153.0 a	372.0 a	483.0 a	569.0 a
Seed yield (lb/acre)	0.0 a	0.0 a	123.0 a	230.0 a
Herbage yield (lb/acre)	173.0 c	759.0 bc	1,319.0 ab	1,839.0 a

[1] If followed by a common letter, treatment means in the same row are not significantly different at the 0.05 level.

averaged 46, 63, 70, and 105 mm for plants grown in 0, 30, 63, and 92% shade. Basal leaves of new tillers generally initiated growth in August. Since they were averaged in with the mature ones, the effect was to decrease length in fall.

The period of leaf width growth coincided with that of length growth. Except in 1967, basal leaves were 50 to 90% wider under 92% shade than in full sunlight, with the average annual leaf width ranging from 3.4 to 2.0 mm, respectively. Basal leaf growth in 63% shade was intermediate.

In 1967 tillering was initially observed in mid-August. By November tillers were present on about ¼ of the plants in 0 and 30% shade and on nearly all plants in 92% shade. Tillering occurred during every month of the year but was most apparent during the fall. Treatments did not appear to influence the number of tillers per plant, but the sampling procedure may have masked differences. During the first growing season, tillers were easily distinguished from seedlings; during successive years adjacent plants intermingled and counting was very difficult.

Initiation of seedstalks was observed as early as June 1 and as late as October during a mild fall. Usually, growth had begun by the first of July. Flowering likewise varied but was generally at its peak during late August and September. Some flowers were observed as late as mid-November, but most seeds were mature by mid-October.

No seedstalks appeared in 1967 and only a few in 1968. In 1969, however, seedstalk numbers increased significantly with degree of shading. Neither seedstalk length (which was highly variable), seed production, nor germination rate (average 52%) was significantly affected by the level of shade.

Herbage Production and Analyses

Herbage production was 173 lb/acre in full light, 759 lb in 30% shade, 1,319 lb in 63% shade, and 1,839 lb in 92% shade. The differences were significant. McDonough (1969) and Harshbarger and Perkins (1971), working with eastern grasses and partridgepea, reported increased growth with up to 55% shade. Leithead et al. (1971) stated that longleaf uniola is best adapted to areas that are shaded more than 50% at midday.

Protein, phosphorus, calcium, and ash in longleaf and spike uniola herbage increased with shade intensity (Table 2). Under 92% shade, protein was more than 50% higher and phosphorus content was more than double that in full sunlight. Content of crude fiber and nitrogen-free extract declined with increased shade intensity. Fat (ether extract) content was unaffected. Burton et al. (1959) reported similar responses of protein and phosphorus to shading in coastal bermudagrass; they also found that cellulose and lignin increased, but total available carbohydrates decreased with shading.

Table 2. Chemical analysis (%) of longleaf and spike uniola herbage collected during September 1969.

Chemical component	Percent shade			
	0	30	63	92
Protein	5.7	6.6	7.4	9.3
Fat	2.4	2.4	2.5	2.3
Fiber	33.0	34.2	34.8	30.9
Ash	9.9	9.3	10.2	15.6
Calcium	.19	.21	.20	.27
Phosphorus	.03	04	.05	.07
N.F.E.	49.0	47.5	45.1	41.9

Conclusions

On the basis of present data and supporting literature, longleaf and spike uniola should be classed not merely as shade-tolerant but as shade-dependent. Maximum growth and production were obtained with 92% shade, while in full sunlight survival and growth were poor.

Growth patterns typify uniolas as cool-season plants that produce beneficial winter herbage for cattle and wildlife.

It appears that both amount of forage and nutritive values can be varied by manipulation of overstory density. Where trees provide the shade, however, they also compete for moisture and nutrients. Such effects probably must be allowed for if attempts are made to apply the present findings to forest grazing land conditions.

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Mechanical and Chemical Range Renovation in Southeastern Wyoming

FRANK RAUZI

Highlight: *Range renovation by strip spraying atrazine, pitting, and a combination of the two treatments was evaluated at the Archer Substation near Cheyenne, Wyoming. Perennial grasses plus sedges produced significantly more on the renovation treatments than on the check. Blue grama was more vigorous, remained green later into the season, and was more available for livestock use on the plots strip sprayed with atrazine than on the pitted or check treatments. Forage yields and composition were influenced by years and by amount and distribution of the April, May, and June precipitation.*

Range renovation has been defined as "the improving of rangeland by discing or other mechanical means" (Huss, 1964). Rangelands have been improved by managing grazing; controlling undesirable species such as sagebrush, cacti, and poisonous plants; and by using chemicals. Fertilization of some range sites has proved beneficial by increasing forage production and changing the species composition.

Pitting, furrowing, and ripping are the mechanical renovation methods most widely accepted in the Great Plains. At the Archer Substation in southeastern Wyoming, over a 24-year period (1942-1965), pitted pastures were stocked 25% heavier than moderately grazed non-pitted pastures (Rauzi, 1968). Branson et al, (1966) stated that factors related to soil moisture capacity are the most important determinants of success of mechanical treatment. They also pointed out that medium to medium fine textured soils are the most suitable for mechanical treatments. According to Wight and Siddoway (1972), surface modification increased plant growth and precipitation use efficiency by increasing the plant-available water, changing the species composition, and increasing the nutrient supply. They also stated that the effectiveness of a surface modification treatment depends on site and vegetation characteristics.

Rangelands that have been mechanically treated must be properly managed to obtain maximum benefits. Renovation may be of little or no benefit with certain site and climatic conditions.

The purpose of this study was to compare forage production and composition as affected by range pitting with and without a herbicide applied in strips, and a herbicide applied in strips with no other treatment.

Methods

The study area was in southeastern Wyoming at the Archer Substation, approximately 10 miles east of Cheyenne, at an altitude of about 6,100 ft. The soil on the experimental area is a Ascalon fine sandy loam, a member of the fine loamy, mixed mesic family of Aridic Argiustolls formed by fluvial outwash.

The native vegetation is characteristic of the shortgrass plains. Blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) are the principal species. Midgrasses include western wheatgrass (*Agropyron smithii*), needle-andthread (*Stipa comata*), and Junegrass (*Koeleria cristata*). Sandberg bluegrass (*Poa secunda*) is scattered throughout the area. Grasslike plants include both needleleaf sedge (*Carex eleochris*) and threadleaf sedge (*Carex filifolia*). The abundance of annual grasses and forbs common to the area is largely determined by the prevailing weather.

In early April, 1967, replicated plots 25 x 100 ft were established in a randomized block design. Approximately one-half of the experimental area is nearly level; the slope of the other half ranges from 1% to 3%. Twenty pounds per acre of active atrazine was applied in strips on six plots with a tractor-mounted spray boom. The sprayed strips were 7 inches wide with 15 inches of nonsprayed area between strips. Three of the atrazine-treated plots were pitted parallel with the sprayed strips. Pitting was done with a four-disc eccentric range pitter 10 days after the six plots were sprayed with atrazine. Three other plots were also pitted at this time, and three plots were left as check.

In the spring of each year (1967 through 1971) three subplots 4 ft^2 (14 5/16 x 40 1/4 inches) were located at random within each main plot, and the previous year's vegetation was removed before plant growth started. Forage within the subplots was harvested each September. The harvested forage was separated by major species. Annual grasses, forbs, and Sandberg bluegrass generally matured earlier than the other species, and a large part of their production was lost before harvest. After the subplots were harvested, the experimental area was grazed by sheep.

Yield of air-dry forage was determined for the major speices, total grass, dryland sedges, and total forage. Forage yields were analyzed by analysis of variance. Duncan's multiple range test for significance was applied at the 5% probability level. Vegetation composition was determined by weight.

Results and Discussion

Yields of the individual major species and total forage yields varied with years and treatments. Seasonal precipitation for the 51-year record averages 78% of the annual total, and 58% of the seasonal precipitation normally occurs during April, May, and June. The annual, seasonal, and April, May, and June precipitation for the study period and the 51-year average are shown in Table 1. Significant

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Table 1. Annual and growing season precipitation (inches) for the 1967–71 period, and the 51-year average at the Archer Substation, Wyo.

Year	Annual	April to September	April, May, and June
1967	16.54	13.74	9.93
1968	15.85	13.10	9.49
1969	13.98	9.74	5.74
1970	15.30	11.30	7.35
1971	13.15	9.86	6.69
5-year average	14.96	11.55	7.84
51-year average	14.65	11.45	6.67

differences in yields of individual species and total forage found between years may be due to variation in amount and distribution of the precipitation. The results obtained for each treatment will be discussed separately

Check

The stand of western wheatgrass was good on the check plots, but growth was generally stunted except during 1967 when precipitation was above-average. Table 2 shows the yields of individual major species during the study. The lower yields of the individual species and total forage in 1969 was due to below average precipitation. Average yields of buffalograss, total perennial grass, and sedges were significantly less on the check than the average yields for the other three treatments.

Forbs and annual grasses were important the first, fourth, and fifth year, when they accounted for 13% to 16% of the total forage produced. Dryland sedges remained nearly constant in the composition and contributed less than 10% of the total forage produced.

The average total forage on the check was significantly less than on the pitted or pitted plus atrazine treatments, and was the same as on the atrazine treatment.

Total forage was highest the first year (1967) because of above-average precipitation. Below-average precipitation occurred during 1966, which may have influenced the high forage yields obtained in 1967. During 1968 the amount and distribution of the precipitation were nearly the same as during 1967, but forage yields were half those obtained in 1967. Apparently, soil nutrients were insufficient in 1968 to sustain forage yields comparable to those of 1967.

Vegetative composition was determined by weighing the separated and air-dried herbage harvested in the fall each year. The vegetative composition was influenced mainly by precipitation and treatment. Blue grama and sedges increased on the check during 1969, a year of below-average precipitation, then declined as other species increased (Figs. 1 and 2). The amount of buffalograss tended to decrease slightly after the first year.

Pitted

The eccentric range pitter reduced vegetative cover by approximately one-third; additional vegetation was covered by the sod thrown out of the pit (Fig. 1). Lambsquarters (*Chenopodium album*) was abundant on these plots the first year and accounted for 24% of the total forage produced. It has been observed that a disturbance to the native sod or a year of

Table 2. Yields (lb/acre) of western wheatgrass, blue grama, buffalograss, dryland sedges, forbs, total perennial grass and sedges, and total forage from mechanically and chemically treated plots at the Archer Substation. 1967–1971.

Species and years	Treatments: Check	Pitted	Atrazine	Pitted & atrazine	Mean
Western wheatgrass					
1967	484	460	136	108	297[a] [1]
1968	251	307	214	156	231[b]
1969	55	183	89	267	148[b]
1970	201	338	242	365	286[a]
1971	253	651	334	507	436[a]
Mean	248[a]	387[a]	203[a]	280[a]	
Blue grama					
1967	624	439	912	604	645[a]
1968	324	344	679	831	544[bc]
1969	291	281	268	595	358[d]
1970	396	482	562	881	580[ab]
1971	435	267	613	468	446[cd]
Mean	414[a]	363[a]	607[a]	676[a]	
Buffalograss					
1967	125	121	214	269	182[a]
1968	93	87	136	282	150[ab]
1969	25	85	57	139	76[c]
1970	76	207	101	210	148[ab]
1971	30	73	131	176	102[bc]
Mean	70[c]	115[bc]	128[b]	215[a]	
Dryland sedges					
1967	66	89	20	11	47[b]
1968	56	81	38	4	45[b]
1969	59	91	22	7	45[b]
1970	77	149	39	10	69[a]
1971	67	137	21	27	63[ab]
Mean	65[a]	109[a]	28[a]	12[a]	
Forbs					
1967	189	665	4	12	217[a]
1968	16	96	0	13	31[c]
1969	3	21	1	210	59[bc]
1970	120	105	271	319	204[a]
1971	186	83	107	103	120[b]
Mean	103[a]	194[a]	123[a]	131[a]	
Total perennial grass and sedges					
1967	1300	1123	1280	993	1174[a]
1968	723	819	1068	1273	971[b]
1969	430	640	435	1007	628[c]
1970	750	1198	944	1466	1090[ab]
1971	785	1128	1100	1178	1048[ab]
Mean	798[c]	982[b]	965[b]	1183[a]	
Total forage					
1967	1488	1788	1286	1004	1392[a]
1968	741	953	1068	1286	1012[b]
1969	435	672	435	1217	690[c]
1970	927	1394	1121	1785	1307[ab]
1971	1144	1485	1337	1454	1355[a]
Mean	947[b]	1258[a]	1049[b]	1349[a]	

[1] Means among treatments and years with the same letters are not significantly different at the 5% level.

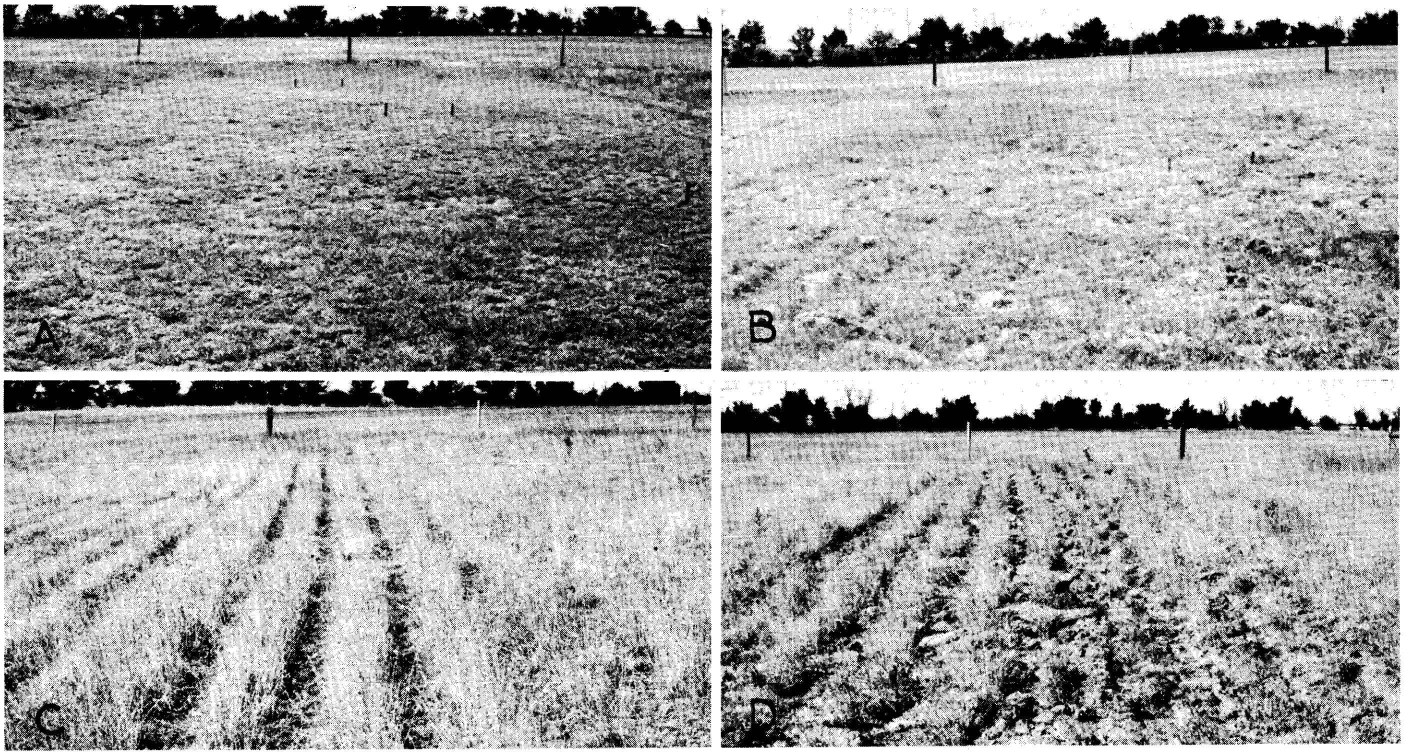

Fig. 1. *Check, mechanically, and chemically treated plots at the Archer Substation in August 1969. (A) check plot; (B) pitted with the eccentric range pitter in the spring of 1967 (Note the sod thrown out of the pits has not completely broken down); (C) strip-sprayed with atrazine (Note the growth and seed heads on the blue grama); (D) pitted and strip-sprayed atrazine treatment. (Pitting effect is noticeable as well as the vigorous growth of the blue grama.)*

above-average precipitation at this location generally results in an abundance of lambsquarters. Western wheatgrass and buffalograss tended to increase and blue grama to decrease (Fig. 2).

There was a small increase in the amount of dryland sedges, and the amount of forbs varied with years after the first year. Annual grasses, mainly sixweeks fescue (*Vulpia octoflora*) and cheatgrass brome (*Bromus tectorum*), increased. The abundance of sixweeks fescue varied with years and was never considered a problem. Hylton and Bement (1961) stated that the density of sixweeks fescue may be related directly to prevailing temperature and moisture availability during August, September, and October preceding the summer growing season.

Significantly more total perennial grass and sedges and total forage were produced on the pitted plots than on the check. As the pits weathered and partially revegetated, their effectiveness decreased. Western wheatgrass, buffalograss, scarlet globemallow (*Sphaeralcea coccinea*) and some annual grasses occupied the pits at the end of the study.

Atrazine

Six days after the atrazine was strip sprayed on the plots a snow storm deposited 1.15 inches of water. The wet snow caused the atrazine to migrate laterally as well as vertically. As a result, annual and perennial forbs and annual grasses were not present on these plots for the first 3 years. The atrazine was sprayed in 7-inch strips with 15 inches of untreated native sod between strips. After the migration of the atrazine, the sprayed strips averaged 10 inches in width. Thus about 45% of the vegetation was removed on these plots.

In the spring for the first 3 years following treatment, numerous chlorotic western wheatgrass plants were noted in the sprayed strips. These plants died back when available water became limiting. During the fourth year, other species as well as numerous western wheatgrass plants became established in the sprayed strips. Annual forbs, mainly Russian-thistle (*Salsola kali*) and lambsquarters, occupied the sprayed strips the fourth year, indicating that the atrazine was no longer active. Soil samples were taken from the 0- to 2-inch, 2- to 4-inch, and 4- to 6-inch depths in September, 1970, for a bioassay to determine activity of the atrazine. Oats were grown in the soil samples and survived, indicating that the atrazine was no longer effective.

Blue grama was the dominant species in the nonsprayed area and gave the appearance of having been seeded in rows (Fig. 1). The first 3 years, blue grama produced a profusion of seed heads on stalks averaging 16 inches in height. The basal leaves made excellent growth and remained green late in the season. Buffalograss, western wheatgrass, and dryland sedges were scattered throughout the nonsprayed area. Sedges were a minor constituent of the composition and added little to the total forage production. Total perennial grasses and sedges accounted for 88% of the total forage over the 5-year period; blue grama accounted for 83% of that total. Kay (1971) reported dry matter yields from a sward of red brome (*Bromus rubens*), Arabiangrass (*Schimus arabicus*), and red stem filaree (*Erodium circutarium*) were increased six-fold by atrazine at 1 lb/acre in California. Forage crude protein was also increased significantly, as was nitrate-nitrogen.
was nitrate-nitrogen.

By 1971 the atrazine-sprayed strips were between 7- and 8-inches wide, as the grasses were reoccupying the sprayed strip. Further encroachment by native vegetation into the sprayed strips was noted in 1972. Thus, the longevity of this treatment appears to be between 5 and 7

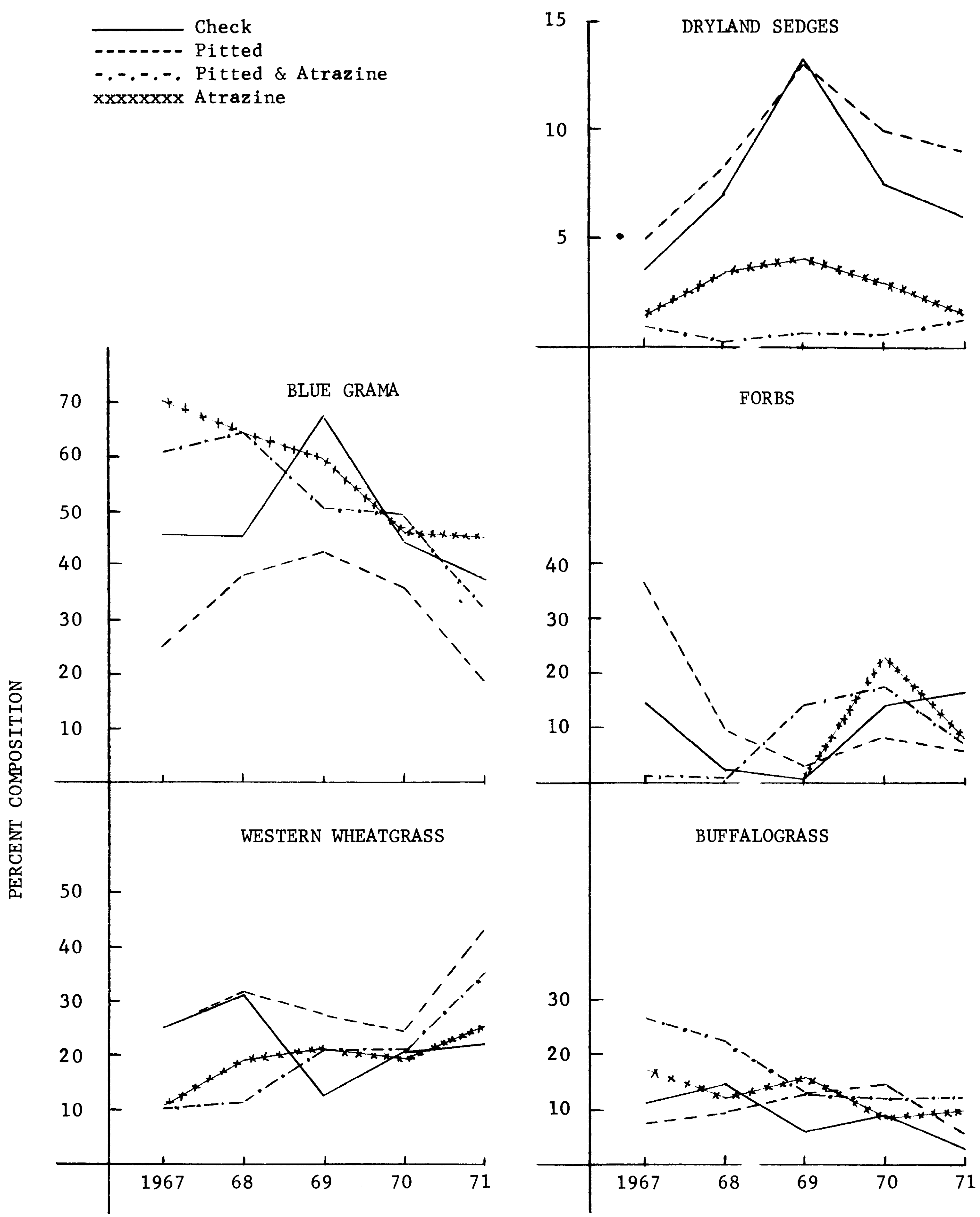

Fig. 2. *Percentage composition by weight over a 5-year period from shortgrass rangeland mechanically and chemically treated in 1967 (Archer Substation).*

years under these soil and moisture conditions.

The atrazine strips were east-west oriented, and the prevailing winds at this location were northwesterly. Wind, water, and splash erosion removed approximately 1 1/2 inches of soil from the center of the sprayed strips and smaller amounts at both sides, giving the strip a somewhat dish-shaped appearance. Thus, continuous strips would not be recommended because of the erosion hazard on some soils. Atrazine-sprayed strips should be broken in a pattern similar to that obtained with an eccentric range pitter.

Blue grama and buffalograss declined in the percentage composition, as western wheatgrass and forbs increased. Western wheatgrass increased because numbers of plants in the sprayed strip increased. Forbs were nonexistent until the fourth year when they accounted for 23% of the total. By the fifth year, however, they accounted for less than 10% of the total.

Pitted and Atrazine

This treatment reduced the vegetation an estimated 75% to 80% the first year. The migration of the atrazine in April may have been partially responsible for this large reduction (Fig. 1). Annual and perennial forbs were not found on this treatment for the first 2 years, but grasses rapidly occupied the bare areas. During the third year, Russianthistle, lambsquarters, and a species of mustard were numerous on this treatment. These plants became established where the atrazine either was not active or had lost its effectiveness during the third year following treatment. Because of soil disturbance from pitting, and possibly the atrazine, there was significantly more buffalograss on this treatment than on any other treatment.

Blue grama and buffalograss declined rapidly after the first year of treatment, whereas western wheatgrass steadily increased. After 2 years of practically no forbs, their population increased for 2 years and then declined to about the same amount on all treatments except the check. Sedges were of little importance but showed a slight increase the fifth year.

Despite severe reduction of vegetation the first year following treatment, production of perennial grass and sedges and total production over the 5-year period was greater than for the other treatments. However, there was no difference between any of the renovation treatments the fifth year after treatment.

Conclusions

Herbage yields and the botanical composition were largely influenced by the amount and distribution of the April, May, June precipitation regardless of treatment. A significantly larger total production of perennial grasses and sedges was obtained from the renovation treatments than from the check.

Blue grama increased in vigor and volume particularly on the plots strip sprayed with atrazine. Thus more blue grama was available for livestock use, and blue grama on sprayed plots remained green later in the season than it did on the check.

The effectiveness and longevity of a renovation treatment depends upon the range site, climate, and management. At this location longevity of pitting alone appears to be about 15 years (Rauzi, 1968). The longevity of range pitting and strip spraying of atrazine should be the same as pitting alone. It is estimated that the longevity of the strip spraying alone would be 5 to 7 years.

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SRM ANNUAL ELECTION RESULTS

The ballots returned in this year's election of officers were counted on December 12. A total of 1,994 ballots were received by the November 30 deadline, and the following candidates were selected by the membership to serve the Society over the next 3 years.

President Elect .... **Dillard H. Gates**
Directors .... **Richard E. Eckert, Jr.**
Carlton H. Herbel

These new officers will be installed at the 1974 Annual Meeting in Tucson, at which time **Peter V. Jackson**, the current president elect, will succeed Martín H. González as president of the Society. Gates will serve as SRM president in 1975 and the two newly-elected directors will serve for the 3-year term 1974-76.

Retiring next month from the Board of Directors are Floyd E. Kinsinger, the immediate past president, and S. Wesley Hyatt and Bob J. Ragsdale, directors. These three men have made substantial contributions to the Society's programs; their past service is acknowledged with sincere gratitude.

Dr. Gates is a native of Nebraska. He received his training at the University of Nebraska and Utah State University, and currently is director of the Rangeland Resources Program, Oregon State University. He has served as an FAO consultant in Iraq and in 1971 was coordinator of the BLM's California Desert Program.

Both Dr. Eckert and Dr. Herbel are associated with the Agricultural Research Service, USDA, the former as Western Region range scientist, stationed at Reno, Nev., and the latter as range scientist at the Jornada Experimental Range, Las Cruces, N. Mex.

Ballots and tally sheets are kept on file in the Executive Secretary's office for a period of 1 year.

Herbicide Plus Various Additives for Follow-up Control of Shredded Mesquite

RONALD E. SOSEBEE

Highlight: *One group of 300 honey mesquite trees that had been shredded in the summer of 1969 were sprayed in June, 1970, and another group of 300 trees were sprayed in June, 1971 with 2,4,5-T (amine and ester formulation) plus an additive. Niacin (1.6 ppm) with 2,4,5-T amine applied in 1970 produced a high percentage root mortality on 1-year-old regrowth, whereas either biotin (2.4 ppm), pyridoxin (2.1 ppm), or thiamine (3.4 ppm) plus 2,4,5-T amine applied in 1971 produced a high percentage root mortality on 2-year-old regrowth. The use of these B-vitamins plus 2,4,5-T appears to be an effective and inexpensive method of follow-up control for regrowth of shredded honey mesquite. The cost of the B-vitamins was less than 5 cents/acre.*

Mechanical shredding of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) induces basal sprouting, which often produces a problem greater than the one caused by the original stand of trees. Therefore, mesquite must be shredded every 1 to 2 years to be effectively controlled (Rechenthin et al., 1964). Pilot research conducted on mature honey mesquite growing on 6 sites revealed that percentage root kills could be increased significantly when a riboside, B-vitamin, or cytokinin was applied simultaneously with 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T) Sosebee, 1972). Muzik (1967) found a similar response in control of *Amsinckia intermedia* with 2,4-Dichlorophenoxyacetic acid (2,4-D). The following study was designed to determine the effectiveness of various additives applied in combination with phenoxy herbicides on control of honey mesquite regrowth following shredding.

Procedures

The study was conducted on the Post-Montgomery Estate Ranch near Post, Texas, using trees that were growing on a deep hardland site. They had been shredded during the summer of 1969. On June 18, 1970, and June 22, 1971, 300 trees (each date) were sprayed with either 2,4,5-T butyl ether esters (Esteron 245[1]) or the triethylamine salts of 2,4,5-T (Veon 245[1]) alone or in combination with one or all of the following additives: adenine (0.1 ppm), ascorbic acid (176.0 ppm), biotin (2.4 ppm), kinetin (2.1 ppm), mono ("coco" dimethylamine) succinate (37.4 ppm), niacin (1.6 ppm), pyridoxin (2.1 ppm), and thiamine (3.4 ppm). The concentrations of the various additives used were adapted from Muzik (1967). No tree was treated more than once.

Fifteen trees per treatment were permanently marked and individually sprayed. A 3.25-gal compressed air garden sprayer was used to apply the herbicide. Manufacturer's recommendations were followed for the herbicide mixture. Basically, it was 1 oz of Esteron 245 (4 lb a.e./gal) dissolved in an ounce of diesel oil and water added to make 1 gal (or 3 lb 2,4,5-T ester/100 gal emulsion), or 1 oz of Veon 245 (4 lb a.e./gal) dissolved in 1 gal of water (or 3 lb 2,4,5-T amine/100 gal solution).

At the time of herbicide application, the following environmental parameters were measured: soil temperature, soil water content, air temperature, and relative humidity. Phenological development was also evaluated for each tree treated.

Root mortalities were determined after the second growing season following spraying. Trees were considered dead if no evidence of sprouts or live tissue could be found.

Orthognol comparisons were used to determine differences between the treatments involving the amine and ester formulation of 2,4,5-T and between results obtained from the hormone-type vitamins and the other additives applied in solution with the herbicides.

Results

Herbicide application was delayed until the soil temperature (12 to 24-inch depth) reached at least 75°F (Table 1). Plants were all in similar stages of phenological development at the time of spraying. In 1970, the first year after shredding, none of the plants produced any flowers or pods. In 1971, only a few plants had begun to flower and produce pods. However, at the time of herbicide application, all trees had mature leaves that had turned from light to dark green in color. These trees were sprayed approximately 80 days after bud burst.

Root mortality was increased by spraying honey mesquite regrowth with an herbicide solution applied alone or with an additive the first or second year following shredding (Table 2). Root kills obtained from application of the herbicide solution containing 2,4,5-T amine were significantly greater than root kills obtained from herbicide solutions containing 2,4,5-T ester (Table 3). Likewise, 2,4,5-T amine plus the hormone-type vitamins produced significantly greater root kills than the other herbicide solutions using the amine formulation of 2,4,5-T.

Discussions and Conclusions

Shredding honey mesquite is an important mechanical method of control, especially in parts of the Rolling Plains of

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Sincere appreciation is extended to Mr. Robert Wadley, computer programmer, Dr. Jim Grumbles, The Dow Chemical Company, and Mr. Harry Culver, Pennwalt Chemical Corporation for their excellent cooperation during this study. I wish to thank my colleague Dr. B. E. Dahl for his assistance in this study. I wish especially to thank the Post-Montgomery Estate for letting us conduct this research on their ranch.

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[1] Use of trade names does not constitute endorsement by the authors or Texas Tech University but they are used for the convenience of the readers.

Texas. However, it can become quite expensive if it has to be repeated every 1 to 2 years. Rechenthin et al., (1964) reported that maintenance mowing, if done annually, costs about $1.50 to $3.00/acre. The use of 2,4,5-T plus a member of the vitamin B complex appears to be a relatively inexpensive and an effective alternative method for controlling regrowth of formerly shredded honey mesquite.

The addition of water soluble vitamins (B-vitamins) to the amine formulation of 2,4,5-T (which also is water soluble) may partially account for the results obtained in this study. However, Hull (personal communication) found similar results in the control of honey mesquite with the amine formulation of 2,4,5-T. The plant mechanism influenced by the addition of niacin, thiamine, biotin, or pyridoxin to the 2,4,5-T solution is not fully understoood. However, Ketalleper (1963) found that certain plants sprayed with B-vitamins or ribosides markedly improved their growth at low soil temperatures. Technically, B-vitamins such as thiamine, and niacin, and possibly pyridoxin (Bonner and Bonner, 1948; Ziegler and Ziegler, 1962) respond as plant hormones. They are synthesized in the leaves primarily and utilized in the growth and development of the roots. Lack of sufficient quantities of hormone-type B-vitamins apparently reduces root growth. Consequently, the effectiveness of herbicides is reduced.

Although all treated plants were not killed, the growth of the resprouts was suppressed to the extent that it would be more economical to spray than to periodically shred (Fig. 1). Resprouts of unsprayed trees on the study site grew to a height of 4 to 5 ft by the end of the second growing season after shredding; whereas, those resprouts sprayed either the first or second year after shredding only attained a height of approximately 2 ft. Also, the basal sprouts of sprayed trees previously shredded but not killed appeared to be less vigorous than the resprouts of those trees shredded but not sprayed.

The cost of spraying regrowth from shredded mesquite varies with applicator and type of application (i.e., ground spray rig vs. aerial application). However, if one employed

Fig. 1. *Contrast between unsprayed resprouts (right foreground) and 1971 sprayed resprouts (left foreground). Herbage production is essentially the same around both plants but it is obscured by the mesquite foliage on the unsprayed plant.*

Table 1. Environmental conditions on dates of herbicide application to honey mesquite regrowth.

	Spray dates	
Environmental factor	June 18, 1970	June 22, 1971
Soil temperature, 6 inches[1] (°F)	80	83
Soil temperature, 12 inches (°F)	79	82
Soil temperature, 18 inches (°F)	77	83
Soil temperature, 24 inches (°F)	75	81
Soil Water Content, 0–6 inches[2] (%)	4	7
Soil Water Content, 6–12 inches (%)	7	9
Soil Water Content, 12–18 inches (%)	8	9
Soil Water Content, 18–24 inches (%)	9	8
Air temperature (°F)	88	82
Relative humidity (%)	48	52

[1] Soil temperature was determined by using a glass laboratory thermometer inserted into a hold at the various depths. Each value represents an average of 3 replications.
[2] Percent soil water was determined from gravimetric samples. Each value represents an average of 3 replications.

Table 2. Root mortality (%)[1] of honey mesquite regrowth resulting from 2,4,5-T applied either alone or with an additive.

	Spray dates		
Treatment	June 18 1970	June 22 1971	Totals
2,4,5-T amine	14	7	21
plus adenine	0	21	21
plus ascorbic acid	14	21	35
plus biotin	7	40	47
plus kinetin	7	27	34
plus mono ("coco" dimethylamine) succinate	14	21	35
plus mixture of metabolites	0	21	21
plus niacin	40	27	67
plus pyridoxin	7	50	57
plus thiamine	21	60	81
2,4,5-T ester	0	0	0
plus adenine	0	21	21
plus ascorbic acid	14	21	35
plus biotin	14	7	21
plus kinetin	0	21	21
plus mono ("coco" dimethylamine) succinate	7	21	28
plus mixture of metabolites	14	27	41
plus niacin	21	7	28
plus pyridoxin	0	0	0
plus thiamine	7	0	7

[1] Mortality was determined in the fall after the second growing season, following spraying.

Table 3. Orthogonal comparisons of various treatment groups involving the influence of two herbicides plus different additives on root mortality in honey mesquite.

2,4,5-T amine solutions vs. 2,4,5-T ester solutions	*
Herbicide solutions containing niacin, thiamine, and pyridoxin vs. others (within 2,4,5-T amine solutions)	*
Herbicide solutions containing niacin vs. thiamine and pyridoxin (within 2,4,5-T amine solutions)	N.S.
Herbicide solutions containing thiamine vs. pyridoxin (within 2,4,5-T amine solutions)	N.S.
Herbicide solutions containing niacin, thiamine, and pyridoxin vs. others (within 2,4,5-T ester solutions)	N.S.
Herbicide solutions containing niacin vs. thiamine and pyridoxin (within 2,4,5-T ester solutions)	N.S.
Herbicide solutions containing thiamine vs. pyridoxin (within 2,4,5-T esther solutions)	N.S.

* Significant at the 0.05 level.
N.S. Nonsignificant at the 0.05 level.

aerial application of 2,4,5-T at a cost of $2.50 to $3.00/acre plus 5 cents/acre or less for the B-vitamins once every few years, spraying is more economical than annual maintenance mowing.

Additional study is needed to determine the optimum concentration of hormone-type B-vitamins that should be used in combination with an herbicide to obtain maximum root kills. Also, the mechanisms of synergistic response caused by the B-vitamins is an area that needs to be explored. There appears to be a great future for the use of B-vitamins in brush control programs.

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Atrazine Residue and Seedling Establishment in Furrows

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Highlight: *Deep furrows made with shovel openers and simulated disk-type furrows were evaluated for removal of atrazine residue from the seeded row and for seedling establishment in the atrazine-fallow technique of range seeding. Atrazine residue in all furrow treatments was below the toxic level for crested and intermediate wheatgrasses. Established stands of both species were similar in all furrow treatments. Therefore, the deep-furrow rangeland drill with disk openers appears suited for large-scale application of the atrazine-fallow technique.*

Good stands of perennial grasses were established experimentally by the atrazine-fallow technique of weed control and seeding in deep furrows (Eckert and Evans, 1967; Eckert et al., 1972). Deep furrows removed soil contaminated with herbicide residue from the seeded row and improved microclimate for the seedling. Furrows were made with shovel-type openers not suited to large-scale rangeland seeding. The disk-type opener is the only practical implement for this use. Furrows made with disk openers are smaller and of different shape than those made with shovel openers. Therefore, before widespread use of the atrazine-fallow technique is attempted, the type of deep furrow made with disk openers needs to be evaluated for: 1) atrazine residue in the seeded row, and 2) favorable microclimate, as indicated by success of seedling establishment.

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Methods

This study was conducted during the fallow and seedling years of 1970-71 and 1971-72 at one site in northeastern California. Precipitation in these two years was 12.6 and 8.1 inches respectively. Soil was described as a member of a fine loamy, mixed, mesic family of typic Argiustolls. Cheatgrass (*Bromus tectorum*) and tumble mustard (*Sisymbrium altissimum*) were controlled with 1 lb/acre atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] applied to 24- by 48-ft areas in the fall of 1969 and 1970 in two separate studies. One year after herbicide application, four seedbed treatments were imposed on 6- by 6- ft plots: 1) seed drilled into the surface soil; 2) seed drilled in bottom of furrows made with shovel-type openers (these furrows were about 6 inches deep and 8 inches wide and had loose soil in the bottom); 3) seed drilled in the bottom of furrows made with shovel-type openers after all loose soil was removed (these furrows were about the same size as those in method two); and 4) seed drilled in furrows made with a hoe to simulate those made by the disk openers of a deep-furrow rangeland drill (these furrows were about 3 inches deep and 4 inches wide and contained no loose soil). These four seedbed treatments were fall-seeded with a Planet Jr. drill[1] to Amur

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

Table 1. Range in atrazine residue (ppm) in the surface 4 inches of soil at time of seeding in fall of the fallow year and in spring of the seedling year and seedling density in May (plants/ft of row), and stand frequency in October (% occupancy/ft of row) in four types of seedbeds for 1970–71 and 1971–72 studies.

Seedbed treatment and species[1]	1970–71				1971–72			
	Atrazine		Plant		Atrazine		Plant	
	Fall residue	Spring residue	Density	Frequency	Fall residue	Spring residue	Density	Frequency
Drilled in soil surface	0.07–0.14	<0.04–0.09			<0.04–0.18	<0.04–0.07		
Agde			3.4a[2]	25a			2.5a	37a
Agin			3.3x	82x			0.3x	18x
Simulated disk furrow	<0.04–0.06	<0.04			<0.04–0.08	<0.04		
Agde			2.4a	64b			9.2c	87b
Agin			3.7x	90x			1.4x	52y
Shovel furrow	<0.04–0.06	<0.04–0.05			<0.04–0.12	<0.04		
Agde			2.5a	55b			4.8ab	85b
Agin			3.7x	90x			1.4x	50y
Shovel furrow-cleaned	<0.04–0.06	<0.04			<0.04	<0.04		
Agde			1.6a	48b			7.0bc	78b
Agin			4.1x	92x			1.3x	47y

[1] Agde—Nordan crested wheatgrass. Agin—Amur intermediate wheatgrass.
[2] Means for each species were compared each year. Means for the density and frequency of crested wheatgrass (a-c) or intermediate wheatgrass (x-y) followed by the same letter are not significantly different (0.05) as determined by Duncan's Multiple Range Test.

intermediate wheatgrass (*Agropyron intermedium*) and Nordan crested wheatgrass (*A. desertorum*) at the rate of two pure, live seeds/inch of row in 18-inch rows. Plots of each species were three rows wide and 6 ft long. The experimental design was a randomized block with four replications.

Seedling density (plants/ft of row) was determined monthly from emergence in March until individual seedlings could not be distinguished, usually May. Stand frequency (% occupancy/ft of row) of established plants was measured in October.

Atrazine residue in the seed row was determined at time of seeding in fall of the fallow year and in spring of the seedling year. Soil samples were collected by 1-inch increments to a 4-inch depth below the bottom of furrows and to an 8-inch depth below the surface of the drill treatment in each species plot. Atrazine content was determined by ultraviolet spectrophotometry (Mattson et al., 1970).

Results and Discussion

Atrazine residue in the surface 8 inches of soil in the drill treatment at time of seeding ranged from <0.04 to 0.18 ppm (Table 1), with little residue below 4 inches. However, residue in the surface 2 inches was 0.13 to 0.18 ppm. This amount of herbicide is toxic to wheatgrass seedlings. All three furrow treatments reduced the amount of atrazine residue in the seed row. Soil displaced in the furrowing treatments was deposited as a berm. Therefore, most of the residue to depth of furrowing was also removed, and seed was planted in soil with a low atrazine content. The shovel-furrow treatment was not as effective as the other two treatments in 1971. Shovel openers stirred the soil during furrowing, and some of the upper 2 inches of soil remained in the furrow. In 1971, residue in this loose soil (0.12 ppm) was near the toxic level of 0.13 ppm suggested for wheat (Talbert and Fletchall, 1964) and for wheatgrass (Eckert et al., 1972). The other two furrowing treatments removed most of the loose soil from the furrows, and residue level in the seed row was reduced.

Atrazine residue in all furrow treatments in the spring of both seedling years did not exceed 0.05 ppm (Table 1). These levels did not damage wheatgrass seedlings. Residue in the drill treatment was 0.07 and 0.09 ppm at the 1-2 and 2-3 inch depths, respectively. This residue was sufficient to damage some seedlings of both species at the one- and two-leaf stages.

In areas where fall germination of seeded species occurs regularly, furrow seeding in an atrazine fallow would be essential, because residue levels in the surface 2 inches of soil are toxic. Use of furrows should also reduce the possibility of damage to spring-germinated seedlings from toxic residue levels that could result from improper application of atrazine or insufficient degradation and leaching in a dry fallow year.

The density and frequency of intermediate wheatgrass and the density of crested wheatgrass plants were similar among seedbed treatments in 1971 (Table 1). However, frequency of established crested wheatgrass plants was significantly greater in furrows in 1971. In 1972, seedling density of intermediate wheatgrass was similar on all treatments, while crested wheatgrass density and the frequency of established plants of both species were increased by all furrow treatments. In both years, frequency of each species was similar among furrow treatments.

This study shows: 1) all furrow treatments removed atrazine residue from the seeded row, and the simulated disk-furrows were as effective as those made with shovel openers, and 2) similar seedling stands and plant establishment in all kinds of furrows indicate a similarity of microclimate. Therefore, on the basis of atrazine residue and microclimate characteristics resulting from its use, the deep-furrow rangeland drill is suited for large-scale application of the atrazine-fallow technique for establishment of perennial grasses.

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Effect of a Wetting Agent and Nitrogen Fertilizer on Establishment of Ryegrass and Mustard on a Burned Watershed

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Highlight: *A wetting agent was applied by sprinkler irrigation to nitrogen-fertilized plots on a burned watershed in southern California. The wetting agent decreased the total production of mustard (*Brassica nigra *and* B. Campestris*) and increased the number of ryegrass seedlings (*Lolium rigidum *and* L. multiflorum*). Where a wetting agent was applied, the moisture conditions at the soil surface were more favorable for seedling establishment and the grass was favored over mustard. In a subsequent laboratory experiment, the wetting agent suppressed mustard seedlings but had a lesser suppressive effect on ryegrass. The differential phytotoxicity was presumably responsible for much of the difference between grass and mustard seedling establishment in the field test. Nitrogen fertilizer increased total plant production and in combination with the wetting agent further enhanced the establishment of ryegrass, but not mustard.*

Rates of runoff and erosion during the first winter after fire are high on burned watersheds in southern California. Fire destroys the plant canopy, exposing the surface soil particles to dislocation by raindrop impact. A water-repellent layer that impedes infiltration, causing overland flow and erosion, can also be formed during fire. Under such conditions, attempts to revegetate may be unsuccessful.

Burned watersheds are often seeded with ryegrass (*Lolium multiflorum, L. subulatum,* or *L. rigidum*) as a means of reducing the severity of erosion. Generally the grass is seeded from September to mid-November. Several months may pass before enough rain falls to germinate the seed. If rainfall is delayed until December or January, low temperatures retard growth of the grass. The rainy season often begins with intense rainstorms. Therefore, considerable erosion is likely even though ryegrass has been seeded.

Wetting agents have been suggested as a remedial treatment to reduce erosion and promote plant growth. These chemicals, when applied properly, increase infiltration into water-repellent soils. Krammes and Osborn (1969) reported that wetting agents can reduce erosion and runoff by 40%. They must be applied carefully if they are to remain effective. A recent treatment of an entire watershed failed when a wetting agent became ineffective after aging on the soil for over a month (Rice and Osborn, 1970).

Plant cover can be increased on burned watersheds by wetting agents. For example, a plot study showed a fourfold increase in annual grass cover when a wetting agent was applied (Osborn et al., 1964). A subsequent laboratory study showed that seeds may not germinate on a water-repellent sand unless a wetting agent is added (Osborn et al., 1967) However, wetting agents can also have a toxic effect on plant growth (Endo et al., 1969).

In 1970, a forest fire burned a watershed in the West End Soil Conservation District of Cucamonga near Los Angeles. To protect high-value property, district officials decided to try inducing early plant growth by means of sprinkler irrigation and seeding of annual ryegrass (*L. rigidum*). This treatment afforded us an opportunity to try a wetting agent to remedy water repellency evident in the soil. The wetting agent was applied with the irrigation water through a sprinkler. Several levels of nitrogen were also applied, because nitrogen is considered the nutrient most likely to be deficient on chaparral areas (Hellmers et al., 1955). The field study suggested the possibility of an interaction between ryegrass and mustard (*Brassica nigra* and *B. campestris*) treated with the wetting agent. Therefore, we also did a follow-up laboratory study using seedlings of ryegrass (*L. multiflorum*) and mustard (*B. nigra*).

This paper reports field trials where a wetting agent was applied by sprinkler to plots fertilized with nitrogen and a subsequent laboratory study undertaken to clarify possible phytotoxic effects observed in the field.

Experimental Design and Methods

Field Studies

The study area was at 790 m elevation on a south-to-southwest facing slope near the mouth of San Antonio Canyon in the San Gabriel Mountains of southern California. Vegetation prior to burning was a chamise chaparral type composed mainly of chamise (*Adenostema fasciculatum*) and sage (primarily *Salvia millifera*). Slopes of the study plots ranged from 65 to 75%. The 8-ha study area and surrounding 16,000 ha had been burned by a wildfire during the summer of 1970 and seeded aerially with ryegrass in the fall. A water-repellent layer was present over most of the area.

On the study area, we laid out 32 plots, each 6 by 10 m. They were established in four blocks of eight plots each, with an upper and a lower tier of four plots in each block. Three levels of ammonium nitrate fertilizer were applied to randomly

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selected plots in the upper and lower tiers. One plot in each tier was not fertilized. Fertilizer levels of 45, 90, and 135 kg/ha of nitrogen were broadcast as granulated ammonium nitrate before irrigation was started.

A nonionic wetting agent[1] was applied to the four lower-tier plots in each block. It was injected into the sprinkler system with a chemical injection pump at a concentration not exceeding 1,650 ppm. The application rate was 243 1/ha of active ingredient. Our control of the sprinkler irrigation system was limited to insuring that the water was sprayed as uniformly as possible among the experimental plots.

Humidity during the period of irrigation was low. Irrigation was carried on for only 5 days, after which more than 12.7 cm of rain fell. Although we made no further efforts to evaluate the sprinkler trial, it is unlikely that any ryegrass seed germinated as a result of irrigation.

Gravimetric determinations of soil water and counts of plant density were made during winter. At the end of the growing season in June, vegetation was clipped from a square meter of each plot, and the oven-dry weights of forbs, grass, and shrubs were determined.

Laboratory Study

The laboratory study was conducted under controlled environmental conditions, where it was set up as a completely randomized factorial experiment with five replicates. The treatments consisted of applying ammonium nitrate fertilizer and wetting agent at the same rates as in the field studies, using ryegrass and mustard planted separately and together.

We used about 180 g of air-dry water repellent soil in each of 120 aluminum soil cans. Ammonium nitrate was dissolved in distilled water and made up in solutions with concentrations of nitrogen, allowing us to add 10-ml aliquots to each soil can to get the appropriate amount of fertilizer. Similarly, wetting agent was mixed with distilled water and added in 10-ml aliquots to the appropriate soil cans. When the treatment called for omission of fertilizer or wetting agent or both, a 10- or 20-ml aliquot of distilled water was added to the soil can. The ryegrass or mustard seeds or both were placed in six spots in each soil can after the first 20 ml of solution was added to the soil surface. In 40 cans (five cans for each of the eight fertilizer-and-wetting-agent combinations), 12 ryegrass seeds were sown. We followed the same procedure when using 12 mustard seeds. Finally, 12 ryegrass and 12 mustard seeds were placed together in the remaining 40 cans. After the seeds were planted, the final 10 ml of distilled water was spread uniformly over the soil surface in each soil can.

Relative humidity in the chamber was maintained at about 65% during the germination period. The can lids were left loosely in place for 3 days. On the 3rd day, the lids were removed and seedling condition was evaluated. We observed seedling growth and condition daily for the next 12 days. During the first 7 days, the soil surface was kept moist by adding distilled water. During this period, about 30 ml of water was added to the cans and about 20 ml was lost, mainly by evaporation from the soil surface. We lowered the relative humidity in the chamber to about 40% from 65% after the 7th day to assess the ability of the seedlings to withstand increased moisture stress. The soil was allowed to dry to approximately 3% on an air-dry basis before additional water was provided.

Results and Discussion

Water Penetration and Erosion

Soil water was sampled on December 4, 1970, after 17.3 cm of rain had fallen. This rain started germination. On December 15, 1970, soil was again sampled, and the total rainfall by then was 19.3 cm. We combined data for both dates, because the gravimetric water content of any particular layer on December 4, 1970, was not statistically different from that of the same layer 11 days later (Table 1). Furthermore, differences between the fertilizer treatments on either date were not significant, so the data were summarized only by wetting agent and soil depth. The water content of the 0- to 1-cm layers in the plots treated with wetting agent differed significantly from that in the untreated plots at the 1% probability level. Apparently, wetting agent allowed water to wet the formerly water-repellent 0- to 1-cm layer. Water content of the 1- to 3- and 3- to 8-cm soil depths did not differ statistically between the treated and untreated plots even though infiltration was better on the treated plots (Table 1).

Table 1. Average soil water content (%) at three soil depths on plots treated with a wetting agent and on untreated control plots

Item	Soil depth (cm) 0-1	1-3	3-8
Treated plots	21.7	18.0	17.8
Untreated plots	10.4	13.4	15.5
Difference	11.3[1]	4.6	2.3

[1] Statistically significant at the 1% probability level.

The soil surface was drier on the untreated plots for at least two reasons. First, less water was probably absorbed during the rain because of the water-repellent layer. Second, water repellency also restricted capillary movement of water to the surface and allowed it to dry out (DeBano et al, 1967).

We did not measure erosion, but we observed moderate rilling in the untreated areas and virtually none in the treated areas. Improved infiltration was the most likely reason for reduced erosion on the treated plots.

Germination and Establishment of Plants

The wetting agent treatment favored the establishment of ryegrass and discouraged the establishment of mustard. Most seedlings of ryegrass and mustard in the treated plots were established quickly after the first rainstorm, whereas in the untreated plots establishment of grass and forb seedlings was distributed over a longer period of time (Table 2). This difference suggests that the treatment resulted in a more moist soil surface (Table 1) and enhanced germination. The surface 1-cm layer on the treated plots had an average water content of 21.7% compared to 10.4% on the untreated plots. The amount of additional water retained in the upper 8 cm on the treated soil was about 40,000 1/ha.

At first, we concluded that the different response of ryegrass and mustard was an allelopathic effect produced by

Table 2. Plant density (plants/m²) on plots treated with a wetting agent and on untreated plots, on two sampling dates.

Species and treatment	Dec. 15, 1970	Jan. 19, 1971	% Change
Ryegrass			
Untreated plot	46	60	30
Treated plot	77	75	−2
Mustard			
Untreated plot	30	82	173
Treated plot	20	25	25

[1] The wetting agent used is sold under the commercial name of "Water-In." The active ingredient is ALKYL polyethylene glycol ether. Trade names and commercial products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

the ryegrass. In a subsequent laboratory test, however, the wetting agent suppressed germination of both species, but to a greater degree in the mustard than in the ryegrass.

We found no indication that the level of nitrogen fertilizer applied affected the density of ryegrass and mustard.

Plant Production

The effect of wetting agent on germination and establishment of herbaceous plants was reflected in plant production at the end of the growing season. The increases in total plant and grass production on plots treated with wetting agent were statistically significant (Fig. 1). The wetting agent almost doubled the growth of ryegrass while retarding production by mustard.

Total plant production on the untreated plots increased with higher rates of nitrogen fertilization, but the increase was not statistically significant because replicates varied greatly. Nitrogen applied to the plots treated with wetting agent increased total plant production only slightly, although the proportion of ryegrass and mustard at different levels of fertilizer showed marked changes. The wetting agent apparently increases productivity on the site, and the differing levels of fertilizer merely redistribute the productivity between ryegrass and mustard. The differential response of ryegrass and mustard was not observed on the untreated plots, where both mustard and ryegrass increased slightly with increasing nitrogen.

Laboratory Germination

Most ryegrass and mustard seeds in the laboratory study germinated, but there was an early and conspicuous difference between the seedlings developing from seeds in treated and untreated cans. Three days after seeding, only primary roots were visible on the mustard and ryegrass seeds treated with wetting agent. In contrast, untreated mustard and ryegrass not only had primary roots, but also had developed cotyledons up to 1 cm long. By then, the primary roots of the treated mustard had shown a peculiar geotropic response as well as excessive fine hair development on the roots. Instead of penetrating the soil, the primary roots grew along the surface of the soil in a more or less flat spiral fashion, and some roots tended to turn upward away from the soil surface. These phenomena were not observed in the roots developing from ryegrass or untreated mustard seeds.

Germination and seedling establishment were completed within 5 days after planting the seeds (Table 3). No change in number of plants was noted between then and the 7th day. When the two species were seeded in separate cans, there were significantly more plants in the untreated soil cans seeded to mustard than in the other treatment combinations. However, when the two species were mixed, there were significantly more seedlings of both ryegrass and mustard in the treatment, excluding the wetting agent.

The wetting agent also had a significant effect on the number of plants which grew at least 1 cm tall (Table 3). Seventy-nine percent of all germinated seedlings in the untreated soil cans were at least 1 cm tall after 5 days. After 7 days, 98% of the ryegrass and 85% of the mustard seedlings were 1 cm or more tall. In contrast, in the treated soil only

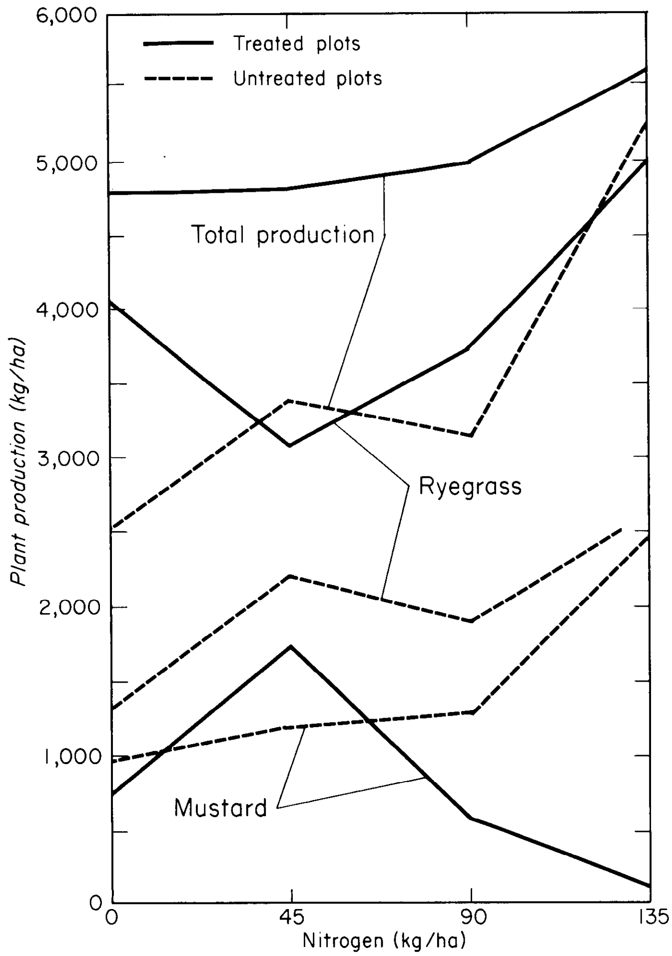

Fig. 1. *Plant production in response to fertilizer applications on plots treated with a wetting agent compared with untreated plots. Vegetation was measured at the end of the growing season, and totals include shrubs on some plots.*

Table 3. Germination and growth of ryegrass and mustard seedlings in cans of soil treated with wetting agent.

	Average plants per can after 5 days[1]		Average plants per can more than 1 cm tall			
			After 5 days		After 7 days	
Planting method	Treated	Untreated	Treated	Untreated	Treated	Untreated
Separate planting[3]						
Ryegrass	10.3 a[2]	10.6 a	4.6 b	8.0 c	9.2 b	10.2 b
Mustard	10.2 a	11.6 b	1.3 a	9.1 c	2.4 a	10.1 b
Mixed planting[3]						
Ryegrass	8.4 a	10.2 b	3.8 b	8.4 c	7.6 b	10.2 d
Mustard	9.0 a	10.8 b	2.0 a	8.5 c	3.6 a	9.0 c

[1] Includes all plants regardless of height.
[2] Within each block of 4 means, any values not followed by the same letter differ significantly at the 5% level of probability.
[3] Planted 12 seeds per soil can per species; 24 seeds total per can in mixed planting.

45% of the ryegrass and 17% of the mustard seedlings were 1 cm tall after 5 days. Ninety percent of the ryegrass and 31% of the mustard seedlings were at least 1 cm tall after 7 days in the treated soil cans. Growth of both ryegrass and mustard was slow in the treated soil, but ryegrass recovered from the effect of wetting agent more rapidly than did mustard.

The seedlings were watered on the 7th day and then subjected to water stress by lowering the relative humidity from 65 to 40%. After 6 days evaporation and transpiration lowered the soil water from 25 to 3%. The reaction of the plants to water stress did not differ between the soil receiving a wetting agent treatment and the untreated controls. The plants in both treated and untreated soil recovered equally well when they were watered again and the humidity was raised back to 65%.

Nitrogen fertilization adversely affected germination and seedling growth in the laboratory experiment. In the separate plantings, the total numbers of ryegrass and mustard plants were significantly less in the fertilized soil cans than in the unfertilized. Wetting agent and fertilizer levels did not interact significantly when the ryegrass and mustard plants were planted separately. When the two species were planted in mixed plantings, there were significantly fewer plants taller than 1 cm in the fertilized pots. The interaction between wetting agent and fertilizer was also significant in contrast with the separate plantings.

There were no significant interactions between species and fertilizer or between species and wetting agent. In both the mixed and separate plantings, the species differed significantly, but this difference was attributed primarily to the presence of the wetting agent rather than to differences in phytotoxicity between the plant species or soil treatment and plant species.

Conclusions

The results of these experiments have useful implications concerning germination and early establishment of seedlings under field conditions. For example, we observed that when fertilizers and wetting agents are applied in field trials, ryegrass often becomes the predominant plant in the treated areas. The differential response of ryegrass and mustard may partly explain the dominance of a site by ryegrass. Probably, other plant species are also strongly affected by a wetting agent. Consequently, species sensitivity could easily produce changes in the composition of the plant community. Under certain circumstances these changes may be desirable, whereas in other situations they may not be.

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Influence of Insects on Mesquite Seed Production

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Highlight: *In field sleeve cage studies we found that conchuela [*Chlorochroa ligata *(Say)] reduced mesquite seed production at least 70% at all population densities studied by sucking juices from immature seeds. The seed beetle* Algarobius prosopis *LeConte reduced production of viable mesquite seeds at least 22% at the population densities studied by consuming, during its larval stage, the seed cotyledons. A seasonal insect control program on mesquite revealed that the native insect populations generally reduced 1) the numbers of mesquite pods produced per tree, 2) the total numbers of seeds per pod, and 3) the percentage of good seeds.*

Honey mesquite [*Prosopis glandulosa* Torr. var. *glandulosa*] occurs on 56.2 million acres in Texas (Smith and Rechenthin, 1964) restricting livestock movement in the dense stands and reducing productivity where preferred plants must compete for moisture, light, and space. Control of mesquite by chemical or mechanical methods is often unsatisfactory because of inadequate kill, high cost, or need for treatment repetition. Because of the successful biological control of other noxious perennial plants, such as *Opuntia* spp. and *Hypericum perforatum* (Holloway, 1964), the use of insects to inhibit mesquite reproduction has been suggested. Typically when biological control of a weed is attempted, alien insects are imported into a country to combat an introduced plant, which being essentially free from its natural enemies has increased in abundance to such an extent that it is declared a noxious weed. However, many noxious plants such as mesquite are native and may not always lend themselves to typical biological control techniques. Andres (1971) has suggested the conservation of existing weed-feeding insects as a method of controlling native weeds, by allowing native insects to increase in numbers and by utilizing these insects in controlling native weeds. The literature related to natural control of native weeds in this country has been reviewed by Ueckert (1973).

Since mesquite produces large quantities of seeds, it has been suggested that natural enemies which reduce viable seed production may be significant factors in reducing the biotic potential and rate of ecesis of this noxious plant (Ueckert, 1973). Swenson (1969) considered the leaf-footed bug *Mozena obtusa* Uhler and the seed beetle *Algarobius prosopis* LeConte as the insects most detrimental to seed production of mesquite. Ueckert (1973) reported that leaf-footed bugs reduced viable seed production from 65% in a control to 4.3% at a population density of four per pod. Werner and Butler (unpublished report) found western flower thrips [*Franklinella occidentalis* (Pergande)] to be abundant on mesquite flowers in Arizona. Glendening and Paulsen (1955) considered the huisache girdler [*Oncideres putator* Thomson] to be detrimental to seed production because it girdled small pod-producing branches.

The most extensive studies of mesquite seed insects have been concerned with seed beetles. Many species of seed beetles are reported from the genus *Prosopis* (Bridwell, 1918; 1920a; 1920b; Hills et al., 1968; Kingsolver, 1972; Swezey, 1928). Female seed beetles deposit their eggs on mesquite seeds or pods, and the young larvae enter the pod and feed on the mesocarp tissue until the seed is fully grown and the cotyledons are hard; then they enter the seed and consume the cotyledons (Bridwell, 1919; 1920b). According to Kingsolver (1972), the seed beetle genus *Algarobius* is assumed to be host specific to mesquite. The range of *A. prosopis* is generally west of the Edwards Plateau in Texas, coinciding with the range of *P. glandulosa* var. *torreyana.* The range of *A. bottimeri* Kingsolver coincides closely with that of *P. glandulosa* var. *glandulosa*, which extends to the western edge of the Edwards Plateau. The ranges of these two species overlap in a narrow band extending from the middle of the Texas panhandle to the Big Bend, roughly along the Edwards Plateau limits (Kingsolver, 1972).

Swenson (1969) indicated that infestation of mesquite pods by seed beetles varies greatly with location. Glendening and Paulsen (1955) observed that 70 to 80% of the mesquite seeds in an Arizona study were destroyed by the beetles.

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Janzen (1969) reported that Central American species of legumes had evolved with certain mechanisms to resist seed beetle infestations, including the production of (1) large numbers and a large biomass of seeds per unit of photosynthetic tissue, (2) small seeds, and (3) chemical defensive compounds. Parasites of seed beetles have been described by Bridwell (1918) and Swezey (1928).

The objectives of this study were to investigate the impact of insects on mesquite seed production as an initial step in evaluating the possibilities of manipulating native insect populations to control mesquite biologically. The study was limited to an investigation of (1) the effect of native insect populations on mesquite seed production, and (2) the effects of various population levels of selected species of insects on pod and seed production of mesquite.

Fig. 1. *Conchuela [*Chlorochroa ligata *(Say)] (adult shown) sucks juices from mesquite seeds, leaving only a dry seed coat in the encocarp.*

Methods and Materials

Three study areas in West Texas included (1) the Texas Tech Research Farm, Lubbock County, (2) the 7-Bar Ranch, Dickens County, and (3) the Post-Montgomery Estate, Lynn County. The study area in Dickens Co. was located in the Rolling Plains; The Lubbock Co. and the Lynn Co. areas were in the southern High Plains.

Collections of insects were made in each study area from March to August, 1972, to determine the species associated with mesquite flowers and pods[1]. Population densities of thrips on mesquite flowers were determined from mid-April through early June. Twenty flowers of approximately equal phenological stage were collected weekly at each study area and the numbers of thrips per flower were recorded.

Two species of insects which were known to feed on mesquite pods and seeds were selected for field sleeve-cage studies. High population densities of conchuela [*Chlorochroa ligata* (Say)] (Fig. 1) occurred on immature pods of mesquite in June and July. Population densities of 0, 0.5, 1, 2, and 3 bugs per pod were used in field sleeve cage studies to determine the effects of conchuela on mesquite seed production. In Dickens County on June 15, 1972, the conchuela were placed in sleeve cages, each containing four immature mesquite pods. Each population density was replicated three times. After abscission, the ripe pods were collected, and the total numbers of seed produced per pod were recorded. The number of viable seeds were determined by hand-shelling the seeds, scarifying the seeds in concentrated sulfuric acid for 30 minutes (Sundararaj, 1966), and maintaining the seeds in a germination chamber between moist paper towels at 35°C. The number of seeds which had sprouted after 72 hours in the germinator were recorded. Seeds were considered sprouted when the radicle was 2 mm long.

Seed beetles [*A. prosopis*] (Fig. 2) reared from mesquite pods collected near Pyote, Texas, in 1971 were used in a sleeve cage study at the Lubbock Co. study area to determine their impact on mesquite seed production. Three replications of five population densities, 0, 0.5, 1, 2, and 3 beetles per pod, were introduced into sleeve cages, each containing four immature mesquite pods, on June 21, 1972. After abscission, the ripe pods were collected, and the total number of seeds produced per pod was recorded. The numbers of viable seeds were determined by the same methods described above.

An insect control program was conducted at each of the three study areas to determine the effect of native populations of insects on mesquite seed production. In early March, 1972, nine groups of 20 randomly selected mesquite trees in each area were flagged and numbered. Beginning April 1, one group of trees in each area was randomly selected and sprayed to dripping weekly with 7.7% A. I. solution of Cythion (0, 0-dimethyl phosphorodithioate of diethyl mercaptosuccinate) to control insects. Spraying was begun on seven additional groups at bi-weekly intervals until July 6; all spraying was terminated by July 20. One group was left unsprayed as a control.

Mesquite pods were collected from each tree in July, immediately before abscission. Pods were oven dried, weighed, and counted, and the mean weight of pods produced per tree was calculated. A random sample of 50 pods from each tree was used for seed analysis. The number of endocarps determined the total number of seeds for each sample. The pods were threshed in a machine similar to the one described by

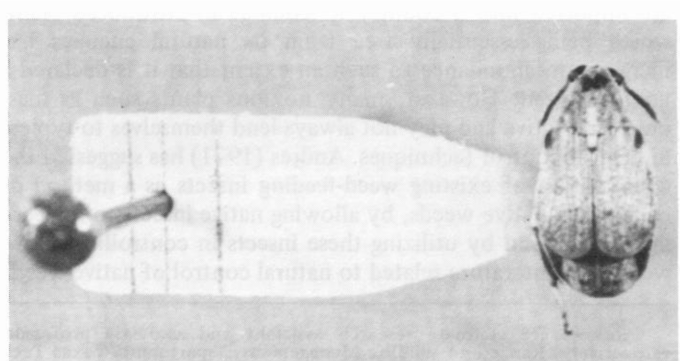

Fig. 2. *Adult seed beetle [*Algarobius prosopis *LeConte]. The larvae of this beetle enters mature mesquite seeds and consumes the cotyledons.*

[1]The following insect taxonomists of the U.S. Department of Agriculture, Agr. Research Service, Systematic Entomology and Beneficial Insect Introduction Laboratory are acknowledged for determinations of specimens: R. D. Gordon, J. L. Herring, J. M. Kingsolver, T. J. Spilman, R. E. Warner, R. E. White, R. J. Gagne, L. V. Knutson, C. W. Sabrosky, J. P. Kramer, P. M. Marsh, A. S. Menke, and F. D. Parker.

Flynt and Morton (1969). Seeds passing through the thresher were designated "good seeds," as insect-damaged seeds were destroyed by the machine. The number of good seeds produced by each tree was estimated by dividing the mean weight per seed into the total weight of all seeds recovered. There was little variation of seed weights within the individual trees; therefore 20 seeds per tree was an adequate sample to determine the mean seed weight. Mean number and percentage of good seeds per pod after shelling were calculated for statistical analyses.

Germination percentages were determined from 400 randomly selected seeds from each of the nine treatment groups in each study area. Seeds which were scarified during threshing were maintained at 35°C between moist paper towels in a germination chamber for 72 hours and recorded; then the sprouts were oven dried and weighed.

Chi-square analysis (Cochran and Cox, 1957) was used to determine differences in viable seed production from pods infested with various population densities of conchuela and seed beetles. Data from the insecticide-check study were analyzed as a completely randomized design with co-variance to determine differences between treatment dates for (1) total number of pods produced per tree, (2) mean weight per pod for each tree, (3) mean number of seeds produced per pod for each tree, and (4) percentage of good seeds per pod for each tree. Basal diameter and estimated canopy volume (Janzen, 1969) were used as covariants in the analysis to eliminate variation due to tree size. Duncan's multiple range test (LeClerg, 1957) was used where appropriate to separate treatment means. Data from the germination trials of seeds from the insecticide-check study were analyzed with Chi-square analysis (Cochran and Cox, 1957).

Results and Discussion

Identification of Insects Associated with Mesquite Flowers and Pods

Thrips and soldier beetles [*Chauliognathus basilis* LeConte] were the insects most frequently encountered on mesquite flowers. Mean population densities of thrips on mesquite flowers during late April, May, and early June at the Dickens Co., Lubbock Co., and Lynn Co. study areas were 43.0, 14.6, and 30.7 per flower, respectively. A preliminary sleeve-cage study indicated that the soldier beetles might favor seed production. Insects collected that were considered most important in reducing mesquite seed production included a leaf-footed bug [*M. obtusa*], conchuela [*C. ligata*], and a seed beetle [*A. bottimeri*]. More than 50 different species of insects were collected from mesquite flowers and pods from the three study areas (Table 1).

Fig. 3. *Mesquite seeds damaged by seed beetle larvae.*

Effects of Conchuela and Seed Beetles on Germination of Mesquite Seeds

In the sleeve cage studies we learned that conchuela destroys mesquite seeds by sucking juices from the seed, leaving only a dry seed coat in the endocarp. Pods in the control cages produced seeds with a much higher germination percentage (76%) than those produced in cages containing conchuela. Seeds produced from cages infested with conchuela

Table 1. Insects collected from mesquite flowers and pods in Dickens Co., Lubbock, Co., and Lynn Co., Texas.

Order	Family	Species
Coleoptera	Bruchidae	*Algarobius bottimeri* Kingsolver
		Mimosestes amicus (Horn)
	Buprestidae	*Acmaeodera gibbula* LeConte
		Agrilus palmicollis Horn
	Cantharidae	*Chauliognathus basilis* LeConte
	Cerambycidae	*Batyle ignicollis* (Say)
		Crossidius pulchellus LeConte
		Stenaspis solitaria (Say)
	Chrysomelidae	*Altica* sp.
		Babia sp.
		Chrysolina sp.
		Colaspoides or near
		Coscinoptera sp.
		Diabrotica undecimpunctata howardi Barber
		Phyllotreta sp.
		Saxinis knausi Schaeffer
	Coccinellidae	*Hippodamia convergens* Guerin
		Olla obdominalis (Say)
		Scymnus loewi Mulsant
	Curculionidae	*Compsus auricephalus* (Say)
		Colecerus marmoratus Horn
	Melyridae	*Dasytinae*, genus not determinable
	Meloidae	*Epicauta nigritarsis* (LeConte)
Diptera	Asilidae	*Efferia* sp.
	Calliphoridae	*Phaenicia sericata* (Meigen)
	Muscidae	*Orthellia caesarion* (Meigen)
	Tachinidae	*Euclytia flava* (Townsend)
		Nemorilla pyste (Walker)
Hemiptera	Anthocoridae	genus not determined
	Coreidae	*Mozena obtusa* Uhler
	Lygaeidae	*Neacoryphus bicrucis* (Say)
		Oncopeltus fasciatus (Dallas)
	Miridae	*Lygus* sp.
		Neurocolpus arizonae Knight
		Rhinacloa forticornis Reuter
	Pentatomidae	*Chlorochroa ligata* (Say)
		Podisus acutissimus (Stallings)
		Thyanta accerra McAtee
Homoptera	Cicadellidae	*Gypona* (Obtusana) *paupercula* Spangberg
		Norvellina texana (Ball)
	Cicadidae	*Pacarina puella* Davis
	Flatidae	*Ormenis saucia* (Van Duzee)
	Membracidae	*Stictopelta marmorta* Goding
		Tylocentrus recticulatus (Van Duzee)
		Vanduza sp.
	Psyllidae	*Heteropsylla texana* Crawford
	Rhopalidae	*Niesthrea sidae* (Fabricius)
Hymenoptera	Apidae	*Apis mellifera* L.
		Melissodes sp. near *ochraea* La Berge
	Braconidae	*Iphiaulax* sp.
	Colletidae	*Colletes hyalinus* Provancher
	Eumenidae	*Euodymerus annulatus* (Say)
	Halictidae	*Agapostemon texanus* Cresson
	Vespidae	*Polistes apachus* Saussure
Thysanoptera	Thripidae	Genus not determined

Table 2. Percent germination of seeds from mesquite pods infested at five population densities by *Chlorochroa ligata* (Say) and *Algarobius prosopis* LeConte.

Number of insects per pod	Percent germination	
	C. ligata	*A. prosopis*
0	76 a[a]	52 a
0.5	4 b	23 b
1.0	0 c	31 b
2.0	1 bc	30 b
3.0	0 c	29 b

[a]Values followed by the same letter within a column are not significantly different at the 95% probability level as determined by Chi-square analysis.

at 0.5 per pod were 4% germinable, while those from cages with one or three per pod were 0% germinable (Table 2).

Significantly more viable seeds were produced in the control cages than in the cages infested with seed beetles (Fig. 3). Differences in percent viable seeds among various population densities of seed beetles were not significant (Table 2). The low germination percentage, 52%, from pods in the control cages was attributed primarily to the natural population of seed beetles that had oviposited before the sleeve cages were attached. The seed beetle used in the cage study–*A. prosopis*–was not collected from either of the study areas, but we presume that the seed beetle endemic to the three areas [*A. bottimeri*] would have a similar influence on mesquite seeds.

Conchuela and seed beetles appeared to be effective in reducing the reproductive potential of mesquite. However, the history of conchuela as an economic pest of cotton (Frohlich and Rodewald, 1970) would probably preclude attempts to manipulate its population in many areas of the southwest where cotton is cultivated. Seed beetles of the genus *Algarobius* are believed to be host specific to mesquite (Kingsolver, 1972), and additional study should be conducted to determine the possibility of manipulating seed beetle populations in a biological control program for mesquite.

Effect of Insect Control on Mesquite Seed Production

The insecticide-check study was designed to determine the seasonal impact of insects on mesquite pod and seed production. Only general observations were made of relative insect population densities, and specific insects responsible for differences in viable seed production between treatments are not known.

Table 3. Adjusted means of four variables measured on mesquite trees initially sprayed on eight different dates, and a control, Dickens Co., Texas.[a]

Initial spray date	Total no pods/tree	Mean wt pod (g)	Mean no seeds/pod	Mean % good seeds
April 1	150.5 a	2.16 a	15.1 ab	50.6 b
14	151.5 a	2.06 a	16.4 a	50.9 b
28	157.0 a	2.17 a	15.8 ab	62.1 a
May 11	133.5 a	1.83 a	16.1 ab	48.2 bc
25	48.8 b	1.94 a	14.0 ab	44.1 bc
June 8	62.4 b	2.31 a	13.5 bc	38.8 c
22	81.6 b	2.13 a	13.6 bc	44.0 bc
July 6	40.1 b	1.73 a	11.3 cd	24.6 d
Control	40.5 b	1.80 a	10.3 d	21.4 d
Residual variance	9358.1	.544	15.08	246.7

[a]Values followed by the same letter vertically are not significantly different at the 95% probability level as determined by Duncan's multiple range test.

Total pod production varied significantly between dates of initiation of insect control (treatments) at the Dickens Co. (Table 3) and Lubbock Co. (Table 4) study areas. Most flower production at the Dickens Co. study area had ceased prior to May 25, and insect control initiated during the flower stage resulted in significantly higher pod production than insect control initiated during pod development (Table 3). The trend at the Lubbock Co. study area was also toward higher pod production from trees with insects controlled early in the season than from trees sprayed later in the season (Table 4). Differences in pod production between dates at the Lynn Co. study area were not significant (Table 5). Pod production was greater in Lynn Co. than in the other areas, probably because of lower population densities of insects.

Mean pod weights did not vary significantly between treatments at the Dickens Co. study area (Table 3). However, significant differences in mean pod weights between treatments were observed at the Lubbock Co. location (Table 4). Pod weights were generally lower for those trees sprayed later in the growing season at the Lubbock Co. study area. However, the trend at the Lynn Co. study area was toward higher pod weights from trees which were sprayed later in the season (Table 5).

The numbers of seeds per pod for the Dickens Co. and Lubbock Co. study areas varied significantly between treatments, with a trend toward production of fewer seeds per pod at the later dates of initiation of insect control (Tables 3 and

Table 4. Adjusted means of four variables measured on mesquite trees initially sprayed on eight different dates, and a control, Lubbock Co., Texas.[a]

Initial spray date	Total no pods/tree	Mean wt pod (g)	Mean no seeds/pod	Mean % good seeds
April 1	103.9 a	1.80 ab	12.8 ab	46.0 a
14	102.8 a	1.65 abc	12.4 ab	51.8 a
28	98.8 a	2.02 a	14.2 a	52.8 a
May 11	68.3 ab	1.69 abc	12.7 ab	53.3 a
25	72.5 ab	1.51 bcd	11.5 bc	51.7 a
June 8	95.0 a	1.69 abc	9.9 cd	51.2 a
22	35.7 b	1.38 cd	8.3 de	42.9 ab
July 6	68.4 ab	1.24 d	7.1 e	34.0 bc
Control	64.5 ab	1.57 bcd	9.8 cd	24.5 c
Residual variance	2814.5	.316	7.94	251.19

[a]Values followed by the same letter vertically are not significantly different at the 95% probability level as determined by Duncan's multiple range test.

Table 5. Adjusted means of four variables measured on mesquite trees initially sprayed on eight different dates and a control, Lynn Co., Texas.[a]

Initial spray date	Total no pods/tree	Mean wt pod (g)	Mean no seeds/pod	Mean % good seeds
April 1	230.0 a	2.00 acd	17.5 a	58.9 abc
14	273.3 a	2.15 abcd	17.2 a	64.7 c
28	169.3 a	1.83 a	17.3 a	65.0 bc
May 11	239.4 a	1.91 ad	17.6 a	59.7 c
25	216.5 a	2.12 abcd	16.6 a	55.6 ab
June 8	157.5 a	2.28 bcd	17.1 a	57.7 ab
22	182.7 a	2.34 bc	17.7 a	56.0 ab
July 6	209.3 a	2.22 abcd	15.5 a	52.5 a
Control	187.2 a	2.43 b	16.6 a	44.5 d
Residual variance	16883.4	.317	5.59	129.39

[a]Values followed by the same letter vertically are not significantly different at the 95% probability level as determined by Duncan's multiple range test.

4). Leaf-footed bugs were probably responsible for the reduced numbers of seeds per pod. The total number of seeds per pod did not differ significantly between treatments at the Lynn Co. study area (Table 5) where lower population densities of leaf-footed bugs were observed.

The percentage of good seeds varied significantly between treatments at all locations. A general decrease in percentages of good seed occurred with later spraying dates at all locations, and a significantly lower percentage of good seeds was produced by the unsprayed trees at the Lynn Co. study area (Tables 3, 4, and 5). Damage to seed by seed beetles, as well as damage to pods and seeds by sucking insects, contributed to a decreasing percentage of good seed throughout the season.

Germination trials on good seeds from the insecticide-check study revealed significant differences between treatments at all locations. However, no particular trends related to the dates of initiation of insect control were obvious or expected, as insect-injured seeds were almost always destroyed during the threshing process. Dry weights of sprouts did not vary significantly between treatments for any of the study areas.

Results of the seasonal insect control study indicate that insects have a definite detrimental effect on mesquite seed production. Native insect populations reduced the total production of mesquite pods from a mean of 131 pods per tree on sprayed trees to a mean of 97 pods per tree on unsprayed trees. The decrease in pod production was attributed to insects which attack mesquite flowers, such as thrips, and to leaf-footed bugs, which often caused premature pod abscission.

Trees subjected to native insect populations produced a mean of 30% good seeds at all locations while sprayed trees produced a mean of 51% good seeds. The pod-sucking insects, conchuela and leaf-footed bugs, and the seed beetles probably were primarily responsible for the 21% decrease in percentage of good seeds.

Trees protected from insects from flower set until pod development produced a mean of 148 pods per tree and a mean of 54% good seeds, whereas trees protected from insects subsequent to flowering (initially sprayed on or after June 8) produced a mean of 104 pods per tree and a mean of 45% good seeds.

Conclusions

Native insect populations have been shown to have a significant detrimental effect on the production of mesquite pods and viable seeds. Insects which attack mesquite flowers and young pods are more destructive than those that attack during the later stages of development of the pods. Both conchuela and seed beetles are effective in reducing percent germination of mesquite seeds; however, conchuela's status as a pest of cotton precludes the feasibility of attempting to manipulate its populations in many areas. Seed beetles of the genus *Algarobius* are believed to be host-specific to mesquite; thus, further study to determine methods of augmenting this insect for reducing production of viable mesquite seeds may be justified. Such studies should be based upon a thorough knowledge of the ecological factors affecting the insect population. Seed beetles overwinter in litter, thus good range management might prove to be effective in augmenting seed beetle populations. Kulman (1971) indicated that some defoliating insects require "physiologically weakened stands" to develop large populations. If this applies to flower- and seed-feeding insects of mesquite, then methods of weakening mesquite, such as perhaps the application of herbicides, might augment these insects. Fire has been shown to favor certain species of insects, while being detrimental to others (Carpenter, 1939; Hurst, 1971; Komarek, 1971); thus fire might provide a means of augmenting mesquite insect populations in some plant communities. Man has made many advances in the science of managing and controlling insect pests of economic crops. Perhaps in time he will adapt the same principles to the management of beneficial insects, such as those native insects which attack noxious plants.

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Microdensitometry to Identify Plant Communities and Components on Color Infrared Aerial Photos

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Highlight: *Image density differences in color infrared aerial photos can be used to discriminate individual shrub and tree species of a pinyon pine-juniper plant community. In addition, image density was used successfully to identify six general plant communities: ponderosa pine, spruce-fir, aspen, big sagebrush, native grasslands, and seeded grasslands. However, different sites and cultural treatments within native grasslands and ponderosa pine forest could not be so easily discriminated, even though visual differences were apparent in the photos.*

As we become increasingly aware of critical changes in our environment, we need better ways to inventory present environmental conditions and effectively monitor future departures from today's conditions. This need applies to nearly one-half of the contiguous United States classified as wildlands as much as it does agricultural areas and urban-industrial centers.

For decades wildland ecologists, range scientists, and others have obtained information about plant communities and other landscape features primarily by ground research and inference. Their purpose has been to identify plants and soils, classify and map plant communities and their components, and, over time, monitor changing conditions. These ground efforts have often fallen short of desired goals. Thus new, stimulating ideas and advances in technology, including wildland surveillance from aircraft and earth-orbiting spacecraft, are drawing increased attention. We now have a chance to develop successful methods to comprehensively identify, classify, inventory, and monitor changes in our wildland areas.

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Microdensitometry—An Approach to the Problem

Microdensitometry is potentially a useful tool for separating wildland plant communities on color infrared aerial photos. Microdensitometry, as used here, is the relative measurement of light transmission through images on positive film transparencies. The measurement is termed optical density or simply density. Doverspike et al. (1965), who conducted tests to identify tree species and land use classes, described the function of the microdensitometer.

The microdensitometer:

1) looks at a very small portion—as little as 1 micrometer diameter—of a photographic image at spectral levels selected to be compatible with the sensitivity levels and dye component spectral characteristics of the photographic materials
2) reads the optical density of the image by means of a scanning optical system and photo multiplier—log amplifier measuring system
3) scans the sample at a uniform rate, as slowly as 10 micrometers per minute or as rapidly as 250 millimeters per minute
4) presents the data graphically on a strip chart or, when used with analog converter, presents data digitally to a computer for reduction and analysis.

Variation in optical density of microdensitometer scan lines is caused by several factors. Doverspike et al. (1965) determined that aperture size did not improve land use discrimination using 1:1,188 scale photos, although it affected density. Aperture shape (round or rectangular) has less effect than other variables. They also determined that image density differences were greater in the blue region of the spectrum than in the red or green.

Rib and Miles (1969) tested the effects of aperture size and photo scale on imaged density differences among terrain features. They discovered that, as aperture size decreased or photo scale increased, more detail was recorded because of finer tonal patterns of imaged features. Finally, a point was reached where desired information was obscured due to granularity of the film.

Driscoll and Reppert (1968) used image density to discriminate between two forest communities and mountain grasslands in western Colorado on 1:4,600 scale color infrared transparencies. To a lesser degree, spruce-fir and aspen forests could be separated by this automated interpretation procedure.

Methods

Study Location and Required Aerial Photographs

Five study locations were selected in the Colorado mountains to represent various terrain features. These locations have been described in detail (Driscoll and Reppert, 1968) and are summarized in Table 1. All aerial photographs were taken in 1968.

The Blue Mesa Reservoir location was an extensive area including several plant communities. Each photo was taken at a scale (1:139,000) to include as much area as possible. At the time of the photography, September 30, aspen foliage was yellow, and offered a good opportunity to separate aspen forest from the dark green spruce-fir forest.

The Black Mesa location included several sites within a mountain grassland community. Site variation within this plant community was the subject of study. To image and identify small site features, large-scale (1:800) aerial photographs were taken in early August to represent a phenological date when these different sites might best be photographically differentiated.

The test location near McCoy was in an open pinyon-juniper woodland. A photo scale (1:1,100) and date (early August) were selected when individual species are most easily identified by visual photointerpretation (Driscoll and Francis, 1970; Driscoll, 1970).

Two test locations were established at the Manitou Experimental Forest in a ponderosa pine-bunchgrass area. One test location included an extensive area with four major plant communities. Photos were taken at a scale of 1:135,000 when the grassland communities were at maximum phenological difference (October 1) from each other and from the forest communities.

The second location at Manitou was within a native bunchgrass community, parts of which had been altered by fertilizers and herbicidal treatments. The objective of our experiment here was to determine the degree of density separation among the treatments. The scale (1:2,700) was selected to provide single photo coverage of relatively small areas at a time (early August) when there was maximum visual differences on the ground.

Ground Data

Ground data were collected at all areas for all plant communities and components (Francis, 1970). This insured a high probability of correctly assigning density values to the proper terrain features.

Table 1. Terrain features and plant communities in photographed areas.

Location	Features
Blue Mesa Reservoir (communities)	1) water body 2) big sagebrush community (*Artemisia tridentata* Nutt.) 3) aspen forest (*Populus tremuloides* Michx.) 4) Engelmann spruce (*Picea engelmannii* Parry)–subalpine fir forest (*Abies lasiocarpa* (Hook) Nutt.) 5) rock outcrops and bare soil
Black Mesa (range sites)	Two sites within a mountain grassland community (mixed grass and forb species) 1) low productivity 2) high productivity
McCoy (species)	1) pinyon pine (*Pinus edulis* Engelm.) 2) Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) 3) low sagebrush (*Artemisia tridentata arbuscula* (Nutt.) H.C.) 4) big sagebrush 5) bitterbrush (*Purshia tridentata* (Pursh) D.C.) 6) mountainmahogany (*Cercocarpus montanus* Raf.) 7) bare soil
Manitou (communities)	1) native pine-bunchgrass (mixed grass and forb species) 2) seeded pasture (*Poa ampla* Merr.) 3) uncut ponderosa pine forest (*Pinus ponderosa* Laws.) 4) selectively cut ponderosa pine forest
Manitou (cultural treatments)	All within native pine-bunchgrass community (mixed grass and forb species) 1) herbicide 2) fertilizer 3) herbicide plus fertilizer 4) untreated

Camera, Film and Microdensitometer

A Maurer KB-8[1] camera was used to obtain photos with Ektachrome Infrared Aero, type 8443[2], color infrared film with a Wratten 12 filter. This camera has a 70-mm format, cycles rapidly, and has shutter speeds up to 1/4,000 of a second. The lens used for large-scale photos was a 150-mm focal length Schneider Xenotar. For very small-scale photos, a Zeiss Biogon 38-mm lens was used. The camera was mounted in an Aero Commander 500B aircraft.

A General Aniline and Film Corporation Model 650 microdensitometer was used with a Honeywell "Electronik" Strip Chart Recorder attached to generate the scan lines (Fig. 1). Trial scans were made to determine effective aperture, color filter, and film scan speed combinations that would best discriminate between the various terrain features. Measured and visual comparisons indicated that a round aperture used with a green filter (Wratten No. 93) provided the best plant community and community component discrimination based on image density differences.

[1] Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture.

[2] Since the research represented herein was completed, the Kodak Ektachrome Infrared Film, Type 8443, has been discontinued. Instead, Kodak Aerochrome Infrared Film, Types 2443 and 3443, are now being produced. The infrared (cyan) sensitive layer of the new film types is slower than the same layer in the old film type. This results in a net effect of reduced red saturation in the photographs. The sensitometric characteristics of the two new film types are essentially the same, the main difference being that the 2443 film is on a 4-mil estar base and the 3443 film is on a 2.5-mil estar base. Both film types are "false color" or color infrared film.

Results

Very small-scale photos were used to make comparisons among the general plant communities. Figure 2 shows the mean and standard deviation in optical density of terrain features in the Blue Mesa Reservoir area. The resulting coefficient of variation provides for a comparison of density among different plant communities and the water and soil-rock features. The mean density of the water body separates it from all plant communities and the rock and soil areas. The communities show some overlap of image density at one standard deviation, although that of aspen forest does separate completely from the spruce-fir forest. There were larger coefficients of variation in the three plant communities compared to the water body, as would be expected since the water had a more homogeneous surface.

Mean densities for the two grassland communities at Manitou were discretely less than for the two forest communities (Fig. 3). The coefficient of variation was much less for the grasslands, especially the seeded area, than for the pine forest communities. The homogeneous big bluegrass area separated from native grassland. The coefficients of variation for the two ponderosa pine forests (Fig. 3) were greater than for the two forest types at Blue Mesa Reservoir (Fig. 2). The pine forest was more open than the spruce-fir or aspen forest. Consequently, there was more shadow and ground surface imaged through the forest canopy, which resulted in a greater range in density.

A test was made with large-scale color infrared photos of Black Mesa to determine if optical densities of two range sites were different (Fig. 4). The mean density of the more productive site was about 8% greater than the less productive site. However, large coefficients of variation produced severe overlap, and, thus, these sites were not easily separated.

Image densities of juniper, bitterbrush, and both sagebrush species at the McCoy area were sufficiently different to allow for absolute discrimination of these three kinds of plants (Fig. 5). In fact, the density ranges at one standard deviation did not overlap for these different plant genera. However, the two species of sagebrush did not separate from one another. Also, the mean densities of pinyon pine and mountainmahogany were so similar that minimum confidence

Fig. 1. *Microdensitometer (*left*) with a strip chart recorder attached (*right*).*

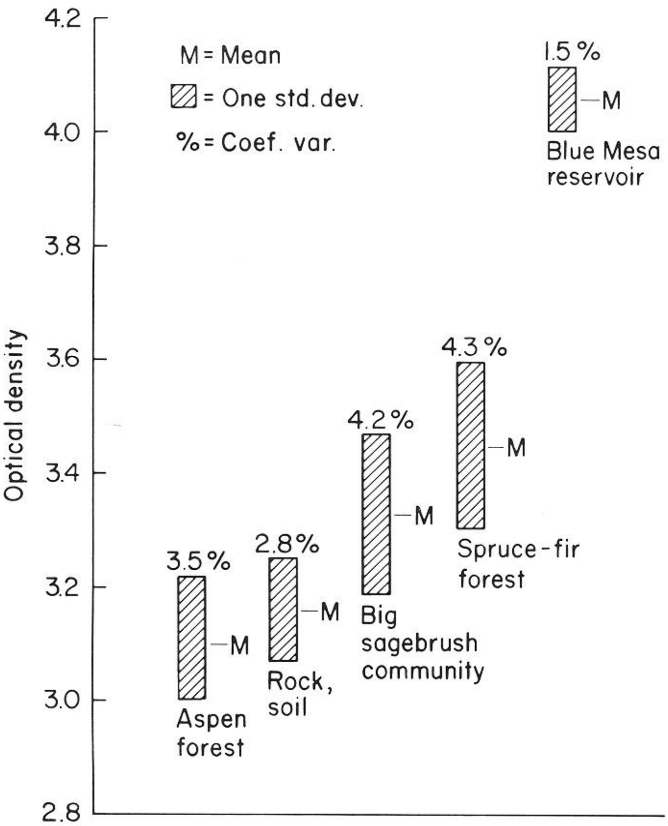

Fig. 2. *Optical film density of three plant communities, rock, soil, and a large water body. Blue Mesa Reservoir, photo scale 1:139,000, color infrared-8443, exposed September 30, 1968.*

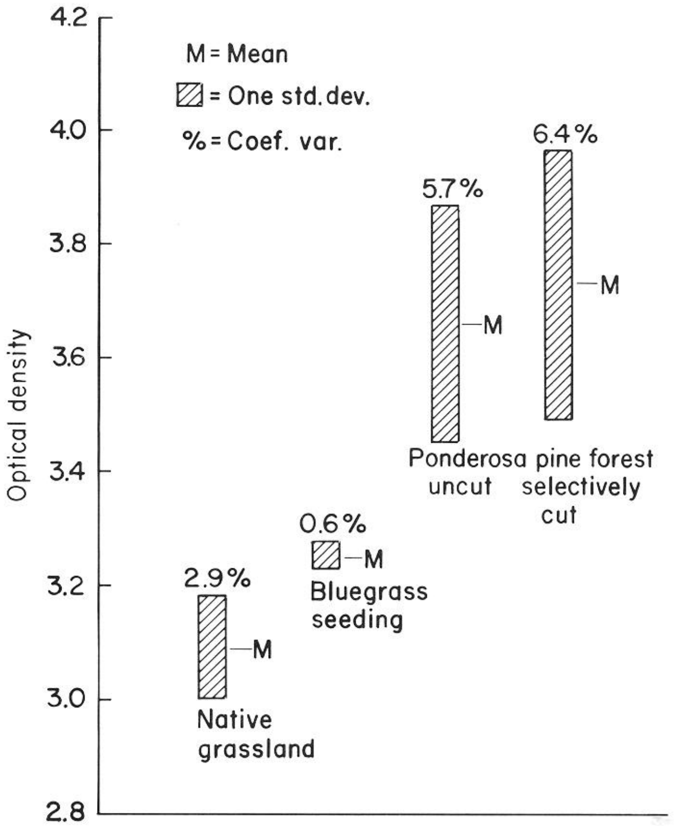

Fig. 3. *Optical film density of two grassland communities and two forest communities. Manitou, photo scale 1:135,000, color infrared-8443, exposed October 1, 1968.*

could be established for discrimination between these species. The reason for this is not known, since visual image characteristics provided for 100% correct identification of these species (Driscoll and Francis, 1970; Driscoll, 1970). The bare soil component of this area could be separated from all the shrub and tree species by image density differences.

The four cultural treatments at Manitou were minimally discrete on the basis of optical image density (Fig. 6). The range in mean density and coefficients of variation were comparatively high. Therefore, treatment effects could not be discriminated even though visual color differences were apparent in the photographs.

Discussion

Differences in optical density of film images examined in this study were such that the microdensitometer could separate some, but not all, plant communities and their components. There were seven absolute separations at three locations (Figs. 2, 3, and 5), and 10 partial separations from some of the other plant communities or components. Partial separation means that an absolute separation might be possible with additional research.

The relative homogeneity of a terrain feature is an obvious characteristic that affects image density. Features identified by densities with low coefficients of variation were the water body (Fig. 2), bluegrass seeding (Fig. 3), and soil (Fig. 5), as compared to the more heterogeneous plant communities.

Separation was minimal in three cases, each within a single plant community, even though differences were visible to a photointerpreter. Two cases involved cultural alterations of relatively homogeneous plant communities—a ponderosa pine forest (Fig. 3) and a native grassland (Fig. 6). The third case concerned inherent variation between different sites within a native grassland (Fig. 4).

This study indicates that microdensitometry has potential value in automated interpretation of plant communities and components on both very small- and large-scale photos. Very small-scale photos seem best suited for discriminating among general plant communities such as different forest and grassland systems. These results are similar to those of Aldrich (1971). He used microdensitometry with Apollo 9 color infrared photos obtained in March 1969 at a scale of 1:2,430,000 to identify 11 land units. As photo scale decreases, apparent resolution decreases and the heterogeneity of the terrain feature is integrated into less heterogeneous units.

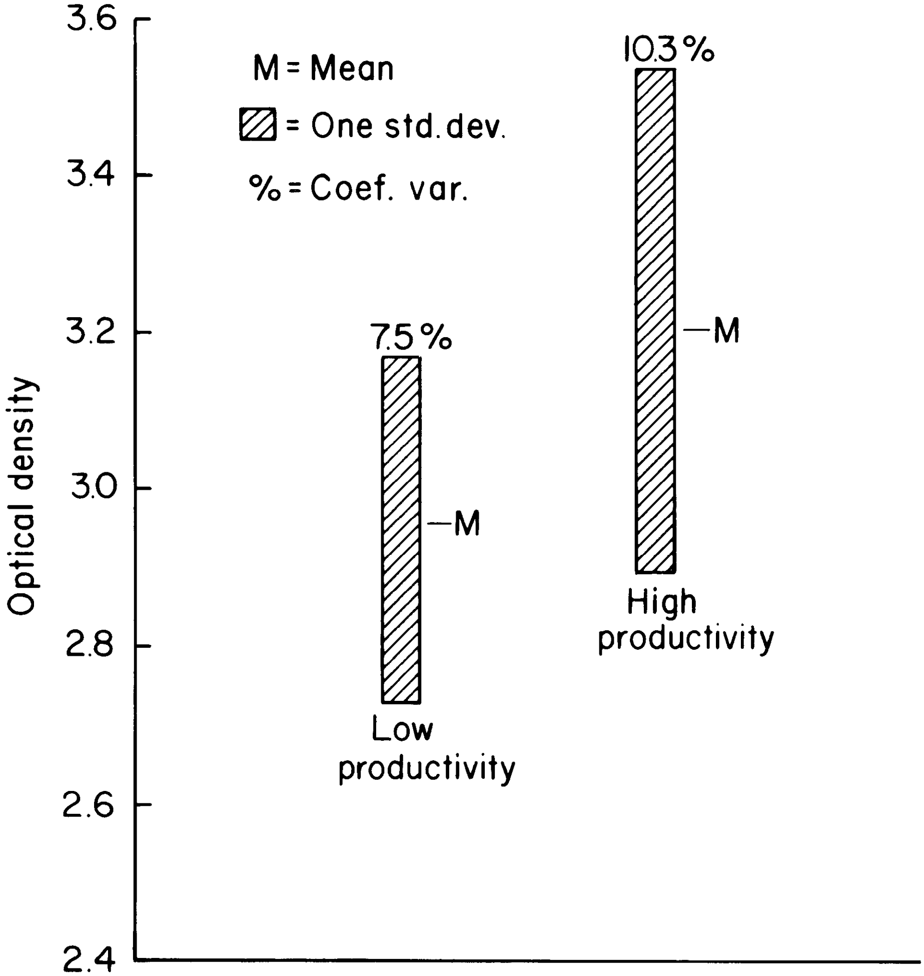

Fig. 4. *Optical film density of two grassland sites. Black Mesa, photo scale 1:800, color infrared-8443, exposed August 7, 1968.*

Large-scale photos are well suited to discriminate some specific components of plant communities. The results show that imaged density of some plant genera are sufficiently discrete to provide for potential automated photo interpretation of those plants. Image density of bare soil was always less than that for the other community components.

Additional research is needed to more positively identify seasonal and photo-scale effects on image density to increase the usefulness of this automated interpretation system. Also, since frequency and amplitude of the scan lines were different for the terrain features, each feature should show a distinctive pattern based on these values as well as mean density difference. Akça (1971) used image density, frequency, and amplitude of scan lines in a discriminant analysis process and reported a high degree of successful

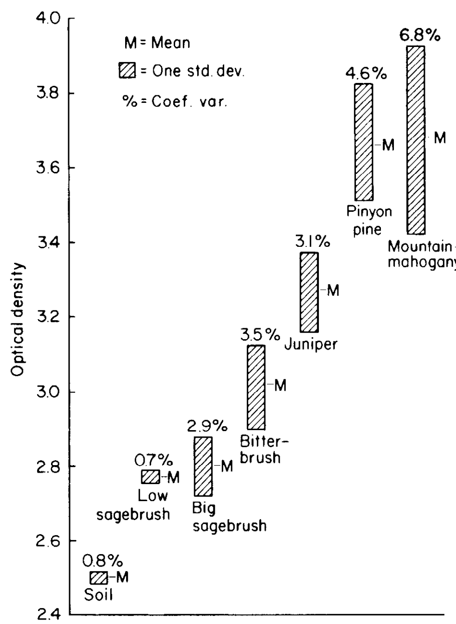

Fig. 5. *Optical density of two trees, four shrub species, and bare soil. McCoy, photo scale 1:1,100, color infrared-8443, exposed August 6, 1968.*

identification of 11 land use classes and forest stand types.

Steiner (1970), working with 11 crop classifications in Switzerland, suggested a 2-dimensional system utilizing time as well as the spectral dimension. He measured density of the 11 crops at 10-day intervals from early April into August and used linear discriminate analysis to analyze the data. The result was 100% correct crop classification.

The time dimension to assist in plant community classification is inferred in Figure 2. At the late September date the aspen leaves were yellow. Although this forest community separated from the spruce-fir forest, it was undifferentiated from the rock and bare soil, and to some extent, the big sagebrush community. Procurement of photographs, when the leaves are developing and when the trees are in full green foliage, would change the apparent optical density of the aspen forest. By combining density from several different phenological times, the aspen forest would likely separate from all other community types and other terrain features.

Steiner (1970) pointed out that sequential photographic coverage would be especially suitable from an orbiting survey satellite. The concept of using temporal change to assist in discrimination should have application for wildland plant communities.

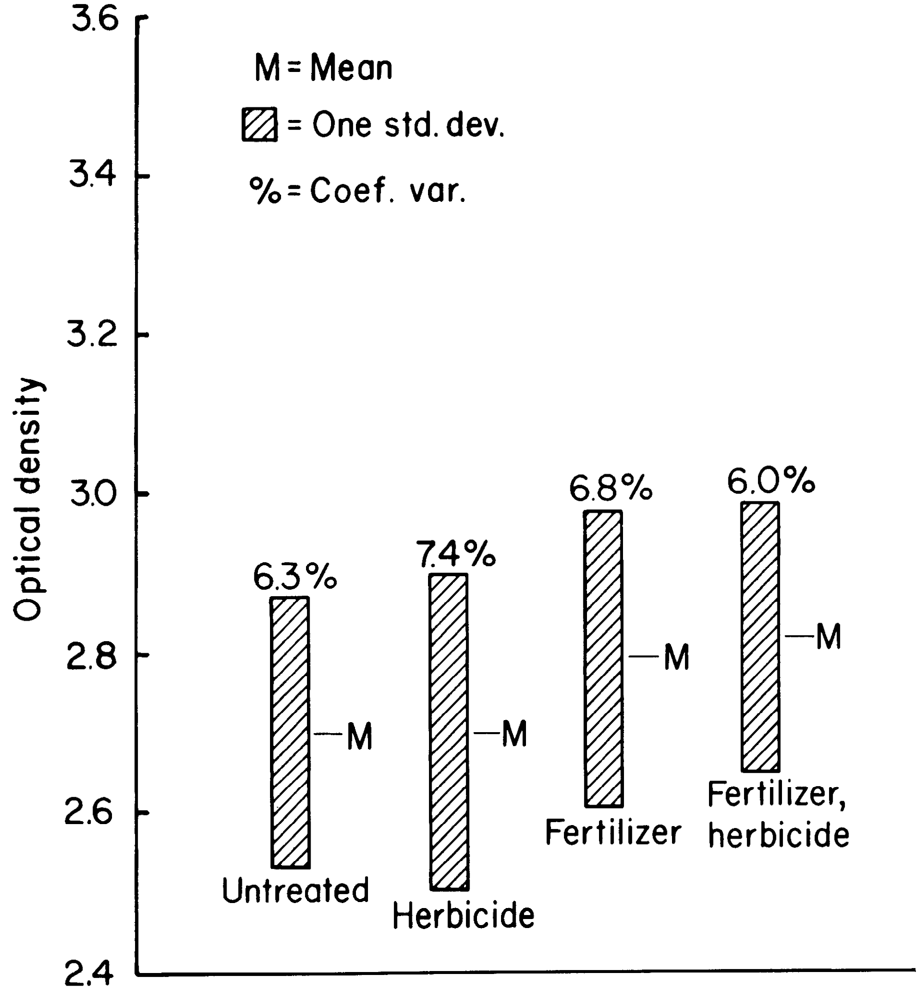

Fig. 6. *Optical film density of four cultural treatments, native grassland community. Manitou, photo scale 1:2,700, color infrared-8443, exposed August 8, 1968.*

Conclusions

Automated photointerpretation by microdensitometry is possible, although more research is needed to identify an operational procedure. The best season and scale, plus various film/filter combinations, need to be determined to optimize discrimination of particular plant communities and components.

To further improve separation, several characteristics from a single photo should be used: optical density, frequency, and amplitude of the scan lines. An effective procedure that uses the information from single-date photos would have widespread application and be relatively inexpensive.

Development of a system which incorporates sequential photographic coverage may further improve separation of wildland terrain features based on optical density and scan line patterns. The chance of misclassification may be reduced or eliminated by taking advantage of phenological changes in plant communities and sun angle effects. A sequential photo system would be especially suitable to inventory and monitor extensive plant communities and land use classes from earth-orbiting satellites.

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New Adjustable, Decimal, Collapsible Quadrat vs Three Old Quadrats – an Evaluation

CH. M. ANWAR KHAN

Highlight: *This paper presents an evaluation of a new adjustable, decimal, collapsible quadrat (ADCQ) of meter square size in comparison with three other quadrats employed for range vegetation sampling in Pakistan since 1966. In addition to size of quadrats, the different modes of subdivisions built in as an aid for estimation of vegetation cover within the same sized quadrats affected very significantly the different attributes of quadrats as well as quality of data recorded. The new quadrat was faster than other meter square quadrats to a highly significant extent and was as fast as canopy coverage quadrat (CCQ) with only 0.15 m² in size. The coefficient of variation for the new quadrat was significantly less than CCQ. The new quadrat was more precise in sampling major species than all other quadrats.*

Unlike the new quadrat, older meter square quadrats overestimated the cover values. Whereas CCQ was relatively better in estimating cover of minor species, the new quadrat was the best of all in estimating total vegetation cover, cover of major species and litter. It also was most efficient in sampling major species. Its efficiency computed over five vegetation criteria was significantly greater than older meter square quadrats. The constructional advantages of ADCQ over fractional quadrat (FQ) as well as the decimalized, collapsible, meter square quadrat (DCMSQ) are also of importance.

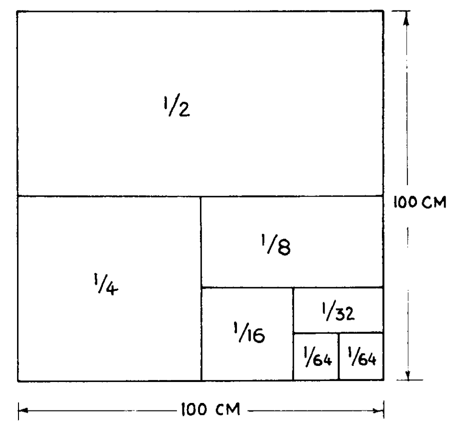

Fig. 2. *Fractional quadrat (FQ).*

Methods employing area as a sampling unit constitute one of most commonly used techniques for vegetation study. The size and shape of such a sampling unit, or a quadrat, have been a common subject of investigation, especially in study of range and pasture vegetation. Thus, quadrats employed for range analysis varied from 3/4 inch dia loop (Parker and Harris, 1959) to as big as 200 square feet (Stewart and Hutchings, 1936). The popular shapes of quadrats have been circular, rectangular, and square.

This paper presents a comparative study of four quadrats developed and used in Pakistan. A grass steppe vegetation was sampled. Whereas one of the quadrats was a rectangle of 0.15 square meter, the other three quadrats were meter square and had different subdivisions built in as an aid for cover estimation.

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Methods Compared

Canopy Coverage Quadrat (CCQ)

The canopy coverage quadrat employed for range vegetation sampling in Pakistan since 1966 (Goodwin, 1966) is 60 cm x 25 cm (Fig. 1). It was subsequently recommended by Hussain (1968) and described as modified from the Daubenmire (1959) quadrat of 50 cm x 20 cm. It has four adjustable legs of iron bars that move through iron tubes welded at four corners. Though unpartitioned, the sides of the quadrat are painted in red and white to indicate three sections of 25% each, with a fourth section indicating subdivisions of 12½%, 10%, and 5%.

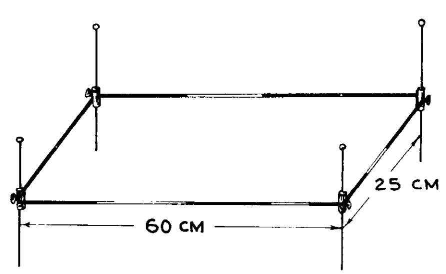

Fig. 1. *Canopy coverage quadrat (CCQ).*

Fractional Quadrat (FQ)

The fractional meter square quadrat employed for sampling of semidesert/desert vegetation of Thal rangelands in 1968 and described as "square meter method" (Higgins and Ibrahim, 1970) is legless, made of iron bar, welded, and partitioned into six successively bisective divisions to give 1/2, 1/4, 1/8, 1/16, 1/32 and 1/64th parts of a square meter (Fig. 2). The cover estimates are recorded as

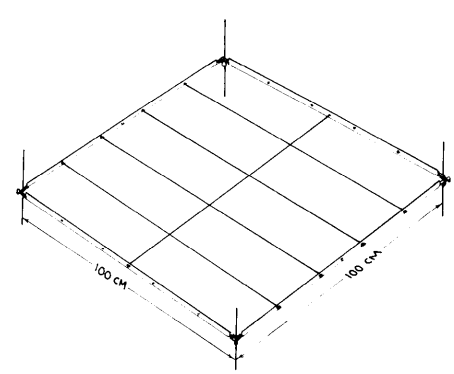

Fig. 3. *Meter square quadrat (DCMSQ).*

number of smallest square units (1/64 square meter). These cover units are subsequently converted into percent cover values.

Decimalized, Collapsible, Meter Square Quadrat (DCMSQ)

The decimalized, collapsible, meter square quadrat, designed in 1969 and used since then to sample steppe, semi-desert, and desert range communities, has four adjustable legs, movable through tubular corners (Fig. 3). The quadrat is partitioned by means of thin, iron partition bars fixable into opposite side strips of the quadrat with nuts, to give ten equal rectangles each 50 cm x 20 cm. All parts are collapsible. The cover estimates are made directly in percentages.

Adjustable, Decimalized, Collapsible Quadrat (ADCQ)

The adjustable, decimalized, collapsible quadrat is meter square and an improved but simpler version of DCMSQ (Fig. 4). To add sturdiness, the four side strips of quadrat are welded and hinged and make the quadrat foldable. Five of the ten equal rectangles are painted or corded through holes in opposite side strips, to indicate the subdivisions of 4, 4, and 2%. The central rectangle indicates an even 1%. The cover estimates are made directly in percentages. Incidentally, each of the ten rectangles is equal to Daubenmire's canopy coverage quadrat.

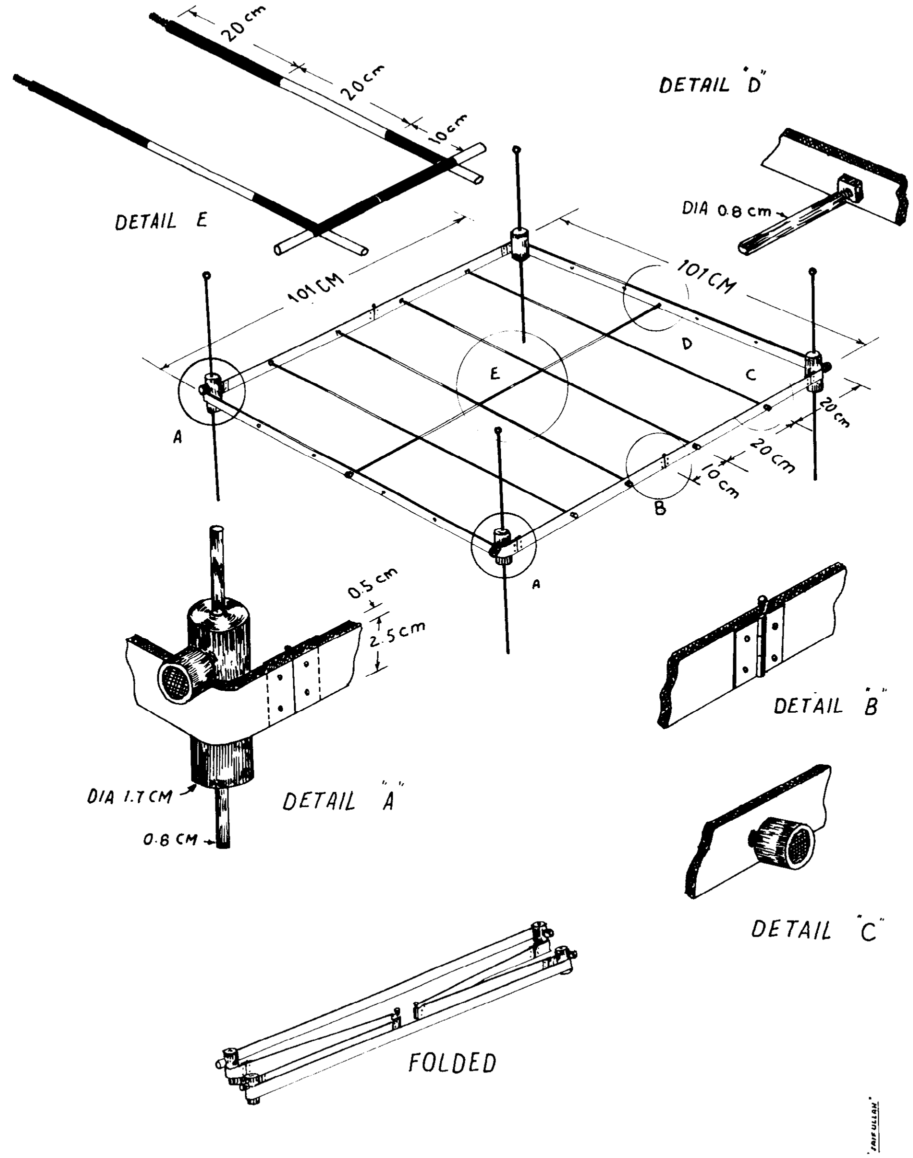

Fig. 4. *New adjustable decimal collapsible quadrat (ADCQ).*

Procedures

The *Cenchrus ciliaris* steppe was sampled with four experimental quadrats in July, 1972. Six persons studied vegetation with each of the quadrats in such a way that choice of observer and his quadrat were at random. To eliminate fatigue factor, the sampling was done in the morning, two hours (8.00 - 10.00) only. The quadrats were placed systematically at predetermined, 5-ft intervals along three transects permanently fixed by means of pegs and metallic tapes. The estimations were made for total aerial cover of vegetation (TAC), cover of *Cenchrus ciliaris,* cover of minor species, litter cover, and bare soil. Time taken by each observer to study 60 quadrats at a stretch was recorded. The data computations and analyses were done on electric calculators. The analyses of variance (ANOVA) and Duncan's new multiple range tests were done at significance levels of P=0.01 (VHS), P=0.05 (HS) and

Table 1. Mean values of eight test criteria for four different quadrats employed to sample grass steppe vegetation.

Test criteria	Quadrats compared[1, 2] CCQ	FQ	DCMSQ	ADCQ	ANOVA[3]
Field time (Tf) in minutes for 100 quadrats.	62.50 a	91.66 b	106.66 c	75.16 a	F (3,15) = 10.50 ***
Field time including conversion time for FQ in minutes (Tfc) for 100 quadrats.	62.50 a	138.00 c	106.16 b	75.16 a	F (3,15) = 17.56 ***
Equivalent number of quadrats (Ne).	20 b	15 a	14 a	15 a	F (3,15) = 10.56 ***
Equivalent field time (Tef) in minutes.	12.13 a	13.22 b	14.29 c	11.12 a	F (3,12) = 10.42 ***
Equivalent field time including conversion time for FQ in minutes (Tefc).	12.13 a	17.35 c	14.29 b	11.12 a	F (3,12) = 25.19 ***
Coefficient of variation (C V).	0.88 b	0.66 a	0.65 a	0.72 a	F (3,12) = 5.75 **
Precision (N/S²) for major species.	1.15 b	0.88 b	0.99 b	1.97 a	F (3,15) = 7.40 ***
Precision (N/S²) for minor species	48.28 a	13.08 b	16.51 b	18.83 b	F (3,15) = 2.43 *

[1] CCQ = canopy coverage quadrat; FQ = fractional quadrat; DCMSQ = decimalized, collapsible, meter square quadrat; and ADCQ = adjustable, decimalized, collapsible quadrat.
[2] Any two means followed by the same letter within a test criterion are not significantly different by Duncan's new multiple range test.
[3] *** VHS at P = 0.005 level; ** HS at P = 0.025 level; * S at P = 0.10 level.

P=0.10 (S).

Results and Discussions

Test Criteria

Table 1 presents summarised results for eight different test criteria along with analyses of variance and Duncan's new multiple range tests.

Field Time (Tf).

The analysis of variance (ANOVA) indicated very highly significant (VHS) differences among quadrats in field time required to study 100 quadrats. The differences among observers were nonsignificant (NS). Duncan's test (Table 1) showed that whereas Tf for CCQ was minimum there was no significant difference between CCQ and ADCQ. The CCQ was faster than FQ as well as DCMSQ at the VHS level. The ADCQ was faster than DCMSQ and FQ at VHS and significant levels, respectively. Thus, among three meter square quadrats, ADCQ was the fastest and was as fast as CCQ with only $0.15 m^2$ area.

Field Time including Conversion Time (Tfc)

Unlike the other three quadrats which estimate cover in percent, FQ estimates cover as number of unit squares (1/64 m^2). For comparable data additional time is required to convert units-data into percent cover values. The average time of conversion for six observers per 100 quadrats of FQ when calculated directly was 50 minutes. The minimum average time of 23.83 minutes per 100 quadrats was spent when already prepared conversion tables were provided to the computors. The field time for FQ, therefore, was computed by adding the minimum conversion time.

The ANOVA indicated differences in Tfc among four quadrats at the VHS level but differences among six observers were NS. Duncan's test (Table 1) showed that although CCQ took the minimum time, there was no significant difference between CCQ and ADCQ. Both CCQ and ADCQ were faster than DCMSQ as well as FQ at the VHS level. Even DCMSQ was faster than FQ at the VHS level. Thus FQ was the slowest of all.

Equivalent Number of Quadrats (Ne)

The number of quadrats required to estimate percent cover within 10% of true mean at 95% level of confidence were calculated for all quadrats, for each observer, and for each of the five vegetation criteria studied as recommended by International Biological Program (Milner and Hughes, 1968). Average number for six observers was called equivalent number (Ne). The ANOVA (Table 1) indicated differences in Ne among quadrats compared as well as vegetation criteria analysed at the VHS level. Duncan's test showed that Ne for CCQ was greater than for all other quadrats at VHS level. Differences among FQ, DCMSQ and ADCQ were nonsignificant. As compared to ADCQ, the additional number of CCQ required to sample various vegetation criteria were: Total cover of vegetation (33%), cover of *Cenchrus ciliaris* (64%), cover of minor species (24%), litter cover (14%) and bare soil (16%).

Equivalent Field Time (Tef)

The ANOVA (Table 1) indicated differences in Tef, i.e., time required to study equivalent number (Ne) of different quadrats in field, among quadrats compared as well as vegetation criteria analysed at the VHS level. The Duncan's test showed that ADCQ took the minimum time but there was no significant difference between ADCQ and CCQ. The ADCQ was faster than FQ and DCMSQ at VHS level. CCQ was found significantly faster than FQ and VHS faster than DCMSQ. The FQ was also significantly faster than DCMSQ. As compared to ADCQ, other quadrats took additional time: CCQ (9%), FQ (18%), and DCMSQ (27%).

Equivalent Field Time including Conversion Time for FQ (Tefc)

The field time in minutes required to study equivalent number (Ne) of quadrats, including conversion time for FQ (Tefc) was computed and averaged over six observers for comparisons. The ANOVA (Table 1) indicated differences in Tefc among quadrats as well as vegetation criteria at the VHS level. Duncan's test showed that ADCQ was the fastest but there was no significant difference in Tefc between ADCQ and CCQ. The ADCQ was faster than FQ as well as DCMSQ at the VHS level. CCQ was found to be faster than FQ at VHS level and significantly faster than DCMSQ. Even DCMSQ was faster than FQ at VHS level. Thus FQ was the slowest. As compared to ADCQ, on the average, the other three quadrats took additional time: CCQ (9%), DCMSQ (28.5%), and FQ (56%).

Coefficient of Variation (C V)

The coefficients of variation (C V) were computed for four categories of quadrats, for each observer and for different vegetation criteria. The ANOVA (Table 1) indicated highly significant differences among quadrats and nonsignificant differences among observers. The differences among vegetation criteria were at the VHS level. Duncan's test showed that CCQ had the highest C V, which was greater than those for DCMSQ as well as FQ at the VHS level and significantly more than that of ADCQ. Differences among DCMSQ, FQ, and ADCQ were nonsignificant.

For vegetation criteria, minor species (cover 1.21%) had higher C V than all other criteria at VHS level. Differences for total aerial cover (TAC), major species (CECI), and litter were nonsignificant. The C V for bare soil was minimum and lower than all others at VHS level.

Precision (N/S^2) of Quadrats for Major Species.

The precision values were computed for *Cenchrus ciliaris* constituting 86.44% of vegetation. The ANOVA (Table 1) indicated differences among quadrats at VHS level; nonsignificant differences were found among observers. Duncan's test showed that ADCQ was the most precise. Its precision was found greater than FQ and DCMSQ at the VHS level and greater than CCQ at the highly significant level. The differences in precision of CCQ, DCMSQ and FQ were nonsignificant. Their relative precision values were: FQ (100%), DCMSQ (113%), CCQ 131%), and ADCQ (223%).

Precision (N/S^2) of Quadrats for Minor Species:

The precision values were also computed for minor species (cover 1.21%) constituting 13.56% of vegetation. The ANOVA (Table 1) indicated significant differences in precision of quadrats compared, but differences among observers were nonsignificant. Duncan's test showed that CCQ was the most precise in estimating cover of minor species and FQ was the least precise. Whereas CCQ was more precise than FQ at a highly significant level, it was better than DCMSQ and ADCQ at a significant level. The differences among ADCQ, DCMSQ, and FQ were nonsignificant.

Estimates of Parameters

Table 2 presents summarised estimates of vegetation parameters, along with analyses of variance and Duncan's new multiple range tests.

Vegetation Cover

The analysis of variance (ANOVA) indicated very highly significant (VHS) differences among quadrats in estimation of percent total aerial cover (TAC) of vegetation. The differences among observers were also highly significant (HS). Duncan's test showed that mean TAC estimated with FQ or DCMSQ were VHS greater than those estimated with ADCQ or CCQ. The differences between ADCQ and CCQ, as well as between FQ and DCMSQ, were nonsignificant (NS). As compared to ADCQ, the overestimations by DCMSQ and FQ were 49.56% and 52.96%, respectively.

Cover of Major Species

The ANOVA indicated VHS differences among quadrats in estimation of percent aerial cover of major species. The differences among observers were nonsignificant. Duncan's tests showed that mean percent cover estimated with FQ or DCMSQ was greater than that estimated with ADCQ or CCQ. The differences between ADCQ and CCQ, as well as FQ and DCMSQ, were nonsignificant. As compared to ADCQ, the overestimations by DCMSQ and FQ were 46.66% and 51.66% respectively.

Cover of Minor Species

The ANOVA indicated HS differences among quadrats in estimation of percent aerial cover of minor species. The differences among observers were also highly significant. Duncan's test showed that FQ gave VHS higher estimates than CCQ or ADCQ, and significantly higher estimates than DCMSQ. The differences among other three quadrats were nonsignificant.

Litter Cover

The ANOVA indicated nonsignificant differences among quadrats in estimation of percent cover of litter. However the Duncan's test indicated that FQ estimated significantly higher than CCQ. Other differences among quadrats were nonsignificant. The differences among observers, however, were very highly significant.

Bare Soil

The ANOVA indicated nonsignificant differences among quadrats in estimation of percent bare soil area. The differences among observers were also nonsignificant. The Duncan's test also showed nonsignificant differences among quadrats.

Observers' Variations

The highly significant differences among observers for estimation of total vegetation cover, cover of minor species, and litter cover were consistently due to overestimation by two of the six observers who had no previous training in reading the vegetation. The variation, therefore, will normally be eliminated with practice and experience.

Reliability of Parameter Estimates.

Table 2 presents the mean values of parameters estimated through 360 quadrats of each category and averaged over six observers. The estimations of percent cover values for major as well as minor species provide contrasting comparisons. A reference to Table 1 indicates that whereas ADCQ was the most precise in sampling major species, CCQ was the highest in precision for minor species. Thus, respective quadrats gave the best estimates for major and minor species.

Both DCMSQ and FQ overestimated the percent cover values when compared to ADCQ. These corresponding overestimations were: DCMSQ (46.67%) and FQ (51.72%). The CCQ underestimated by 7.34%. As compared to CCQ, the corresponding overestimations of minor species were: DCMSQ (65.29%), FQ (138.84%), and ADCQ (18.18%).

Like quadrat precision, the length of confidence intervals at 95% level of probability computed around mean estimated parameters (Table 2) gives an indirect measure of quadrat accuracy. The four categories of quadrats were accurate in the decreasing order of ADCQ, DCMSQ, CCQ and FQ. For all five vegetation criteria, FQ was consistent in showing longest confidence intervals or was the least accurate. Whereas CCQ was relatively more accurate in estimating minor species (percent cover less than 2.00), ADCQ was the best for total vegetation, major species (percent cover more than 9.00), and litter.

Efficiency of Quadrats

The efficiency values of quadrats (QE) defined in terms of quadrat precision ($P=N/S^2$), equivalent quadrat number (Ne), and equivalent time (Tefc) as QE= P/Ne Tefc, were computed for different vegetation criteria as well as over-all criteria (Table 3).

All Criteria

The relative percent values of QE were: FQ (100), DCMSQ (105), CCQ (128), and ADCQ (174). Although differences among six observers were nonsignificant, Duncan's new multiple range test showed significant differences among quadrats' efficiencies. The differences among FQ, DCMSQ, and CCQ were nonsignificant. The ADCQ, though, just missed being more efficient than CCQ at 90% level of probability, it was significantly more efficient than FQ as well as DCMSQ. Thus, ADCQ, when compared with the other three quadrats, was more efficient by 46 to 74%.

Major Species.

Whereas differences among observers were nonsignificant, the analysis of variance indicated very highly significant differences in quadrat efficiency for sampling major grass species [$F(3,15)$ = 16.35]. The ADCQ was more efficient than all other quadrats at VHS level. The differences among other three quadrats were nonsignificant.

Other Criteria.

The analysis of variance and Duncan's tests indicated nonsignificant differences of QE among six observers as well as four quadrats in sampling total vegetation cover, minor species, litter, and bare soil.

Table 2. Population parameter estimates with 95% level of confidence intervals for four different quadrats employed to sample grass steppe vegetation.

Parameters	Mean values for quadrats[1, 2]				ANOVA
	CCQ	FQ	DCMSQ	ADCQ	[F(3,15)]
Percent total aerial cover.	9.34 a ±2.29	14.81 b ±2.77	14.48 b ±2.55	9.68 a ±1.65	18.07 ***
Percent cover of major species.	8.08 a ±2.02	13.23 b ±2.30	12.79 b ±2.22	8.72 a ±1.46	17.46 ***
Percent cover of minor species.	1.21 a ±0.44	2.89 b ±0.60	2.00 a ±0.52	1.43 a ±0.54	5.39 **
Percent cover of litter.	3.82 a ±0.74	5.42 b ±0.86	5.06 ab ±0.81	4.28 ab ±0.66	1.98 NS
Percent cover of bare soil.	76.41 a ±5.41	68.80 a ±5.80	76.35 a ±4.17	74.50 a ±5.58	2.15 NS
Average value of confidence intervals.	±2.18	±2.466	±2.05	±1.978	

[1] CCQ = canopy coverage quadrat; FQ = fractional quadrat; DCMSQ = decimalized, collapsible, meter square quadrat; and ADCQ = adjustable, decimalized, collapsible quadrat.
[2] Any two means followed by the same letter within a test criterion are not significantly different by Duncan's new multiple range test.
[3] *** VHS at $P = 0.005$ level; ** HS at $P = 0.025$ level; * NS at $P = 0.10$ level.

Table 3. Comparative quadrats efficiency (QE = P/Ne Tefc) in sampling grass steppe vegetation for its various criteria.

Analytic criteria	Quadrats compared[1,2]			
	CCQ	FQ	DCMSQ	ADCQ
Average over all criteria for six observers.	0.0319 ab	0.0249 b	0.0261 b	0.0433 a
Percent cover of major species.	0.0043 b	0.0036 b	0.0053 b	0.1679 a
Percent cover of minor species.	0.0493 a	0.0331 a	0.0355 a	0.0394 a
Percent cover of litter.	0.7853 a	1.1282 a	0.8456 a	1.1785 a
Percent total vegetation cover.	0.5102 a	0.4278 a	0.6233 a	0.1277 a
Percent area of bare soil.	0.0849 a	0.0256 a	0.0824 a	0.0555 a

[1] CCQ = canopy coverage quadrat; FQ = fractional quadrat; DCMSQ = decimalized, collapsible, meter square quadrat; and ADCQ = adjustable, decimalized, collapsible quadrat.
[2] Any two means followed by the same letter within a criterion are not significantly different by Duncan's new multiple range test.

Conclusions

Various analytic criteria established statistically significant differences among four quadrats compared. In addition to size of quadrats, the different modes of subdivisions built in as an aid for estimation of vegetation cover within the same sized quadrats affected very significantly the different attributes of quadrats as well as quality of data recorded.

In respect to field time, ADCQ was faster than other meter square quadrats and was as fast as CCQ with its 0.15 m^2 area. The FQ was the slowest. The number of quadrats required to constitute a sample of the same adequacy level was greater for CCQ than for the other three quadrats. A similar number was needed for the three meter-square quadrats. The time required to study an equivalent number of different quadrats differed. Whereas ADCQ took the minimum time, the difference with CCQ was not significant. The ADCQ was faster than FQ and DCMSQ. As compared to ADCQ, on the average, the other three quadrats took additional time of: CCQ (9%), DCMSQ (28.5%), and FQ (56%).

Whereas differences in coefficients of variation among three meter-square quadrats were nonsignificant, ADCQ had significantly less value than CCQ. For sampling major species, the ADCQ was more precise than FQ, DCMSQ, or CCQ. Their relative precision values were: FQ (100%), DCMSQ (113%), CCQ (131%), and ADCQ (223%). The CCQ, however, was more precise than other quadrats in sampling minor species. Differences among FQ, DCMSQ, and ADCQ were nonsignificant.

Statistically different estimates of vegetation parameters were made by different quadrats. Estimates of total vegetation cover and cover of major species were higher by FQ and DCMSQ. Both ADCQ and CCQ gave similar estimates. Whereas similar estimates of minor species were made by other three quadrats, FQ gave higher estimates. All quadrats gave nonsignificantly different estimates of bare soil.

Though observer differences were generally nonsignificant, the differences in estimation of total vegetation cover, minor species cover, and litter by two of the six observers were due to lack of previous training. This variation can be eliminated with experience and training.

Because of statistically higher precisions, the best estimates of vegetation parameters for major and minor species were given by ADCQ and CCQ, respectively. Based on length of confidence intervals calculated around all parameter estimates, the four quadrats were accurate in the decreasing order of ADCQ, DCMSQ, CCQ and FQ. For all five vegetation criteria, FQ was consistent in giving longest confidence intervals or was the least accurate. Whereas CCQ was relatively more accurate in estimating minor species, ADCQ was the best for total vegetation, major species, and litter.

The ADCQ was the most efficient in sampling major species. The differences among quadrats' efficiency for sampling bare soil, litter and minor species, however, were nonsignificant. The quadrat efficiency of ADCQ computed over all vegetation criteria was significantly greater than DCMSQ or FQ. The ADCQ was more efficient than CCQ, DCMSQ and FQ by 46%, 66%, and 74%, respectively.

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I certify that the statements made by me above are correct and complete.—*Francis T. Colbert,* Managing Editor.

Using a Grid to Estimate Production and Utilization of Shrubs

H. W. SPRINGFIELD

Highlight: *Production of fourwing saltbush plants was estimated from photographs against a 1-inch grid. All squares partially or completely obscured by plant material were counted. Utilization of several shrub species was estimated from photos taken before and after browsing by deer. With modification, the technique could be used for other species and situations.*

The most accurate method for determining production and utilization of shrubs is clipping and weighing, but this method is costly, time consuming, and affects the physiology of the plant. Visual estimates also are used, especially for extensive surveys. The most common procedure, however, involves determining (1) production by measuring the length and/or weight of the current year's twigs, and (2) utilization from counts or lengths of twigs before and after browsing (Schuster, 1965; Shafer, 1963; Smith and Urness, 1962; and Stickney, 1966).

Occasionally the problems are rather unique in that only a few plants of a species are available; plants may be in the ground or in containers; or the main concern may be with growth over a

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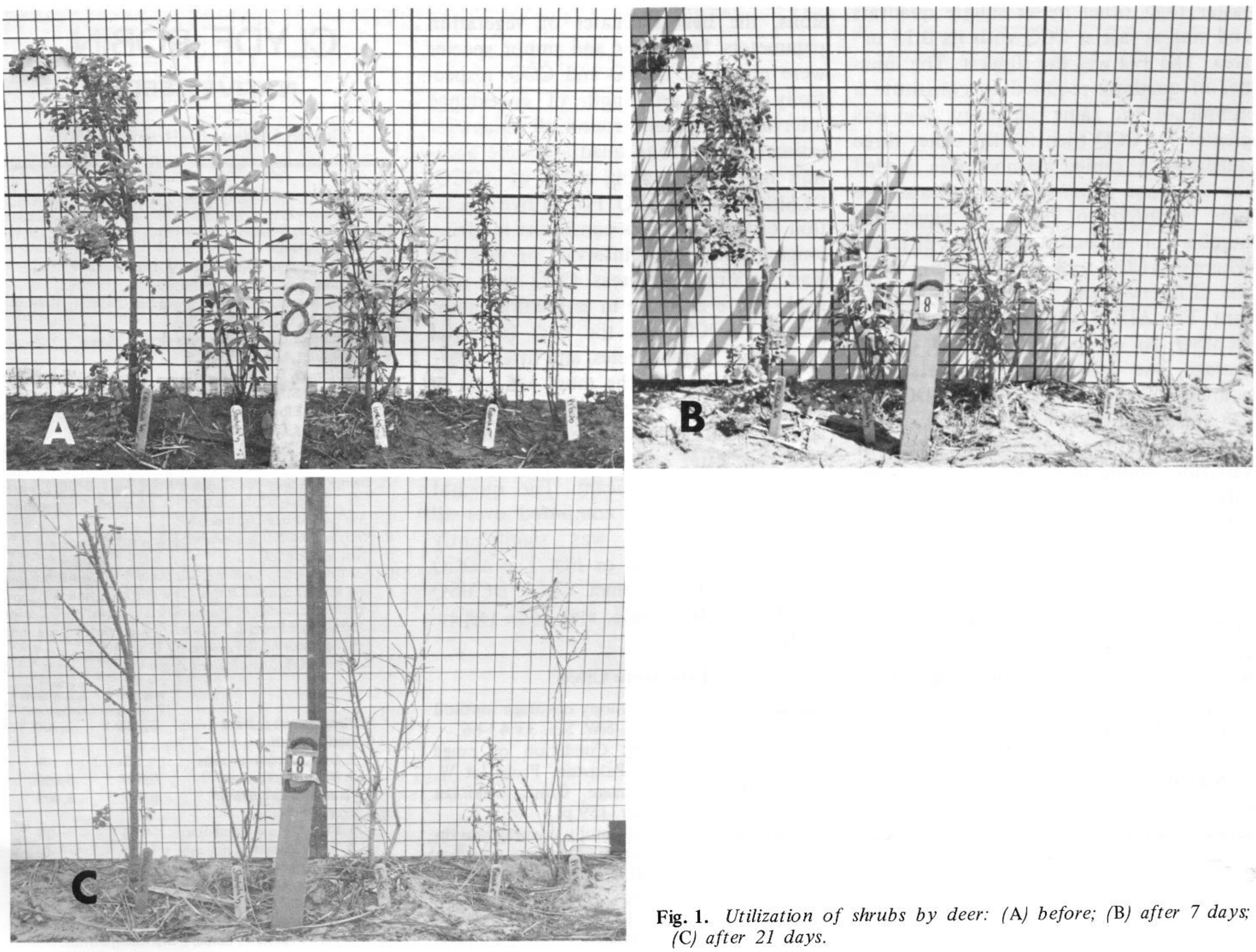

Fig. 1. *Utilization of shrubs by deer: (A) before; (B) after 7 days; (C) after 21 days.*

period of years, from seedling to mature plant. Moreover, the size or weight of the whole plant (above ground) may be needed, not just the current year's growth. In these situations, it is not feasible to clip the whole plant, or even a few twigs, for fear of inducing undesirable physiological changes.

The technique briefly described and illustrated here was developed in response to a special need. Six plants each of 16 different species were planted in an enclosure to determine browsing preferences by adult deer. A method was needed that was easy to use, yet sufficiently precise to detect daily utilization by the deer. The technique, which was used for several weeks in 1966, and again in 1967, gave reasonably reliable estimates of utilization (Lamb, 1968). During subsequent years essentially the same technique has been used for estimating production of different sizes and species of shrubs.

The principal feature of the technique is a 3-ft-square piece of 3/8-inch masonite painted white and marked off in 1-inch squares (Fig. 1). Though not necessary, a hinged brace fastened to the back of the board makes it convenient for one person to set up the grid and take photos. To facilitate handling, the board can be cut in to two 1-1/2- by 3-ft pieces joined by a piano hinge.

In the deer preference tests, all 1-inch squares even slightly obscured or intercepted by plant material were counted. Utilization estimates determined from grid counts compared favorably with visual estimates. No data comparing the grid technique against ocular-estimate methods were analyzed, however.

The photos (Fig. 1) illustrate how the grid was used to estimate utilization. The first photo taken before deer had a chance to browse the shrubs gave us a base count. Photos taken at intervals thereafter with the grid the same distance behind all plants furnished grid counts from which utilization was estimated. Here is an hypothetical example:

	1-inch squares obscured (number)	Plant material missing (1-inch squares) (number)	Utilization (%)
First day	200	0	0
Second day	184	16	8
Third day	176	24	12
Fifth day	150	50	25

During the past 4 years, the grid also has been used for estimating production. Pot tests with fourwing saltbush (*Atriplex canescens*), involving different ecotypic strains grown in different soils, provide an example. Twenty-eight saltbush plants were photographed against the grid (Fig. 2), then harvested and weighed air-dry. All plants were less than 2 years old and less than 3 ft tall.

Three methods of estimating production from grid counts were compared:

(a) Total number of 1-inch squares obscured or intercepted by plant material, even if only slightly.

(b) Number of squares intercepted by main stem plus squares 1/2 or more obscured.

(c) Number of squares intercepted by main stem plus squares 1/4 or more obscured.

Analyses showed the correlations were highest for methods (a) and (c). The regression equations (Fig. 3) proved useful, not only for estimating yields of plants in the pot tests but also for the yields of other fourwing saltbush plants growing in field plots or in containers.

Certain precautions need to be mentioned. The grid should be placed the same distance behind all plants in a particular study, and the distance from the camera lens to the plants should be approximately

Fig. 2. *Fourwing saltbush plants photographed against grid for estimates of production.*

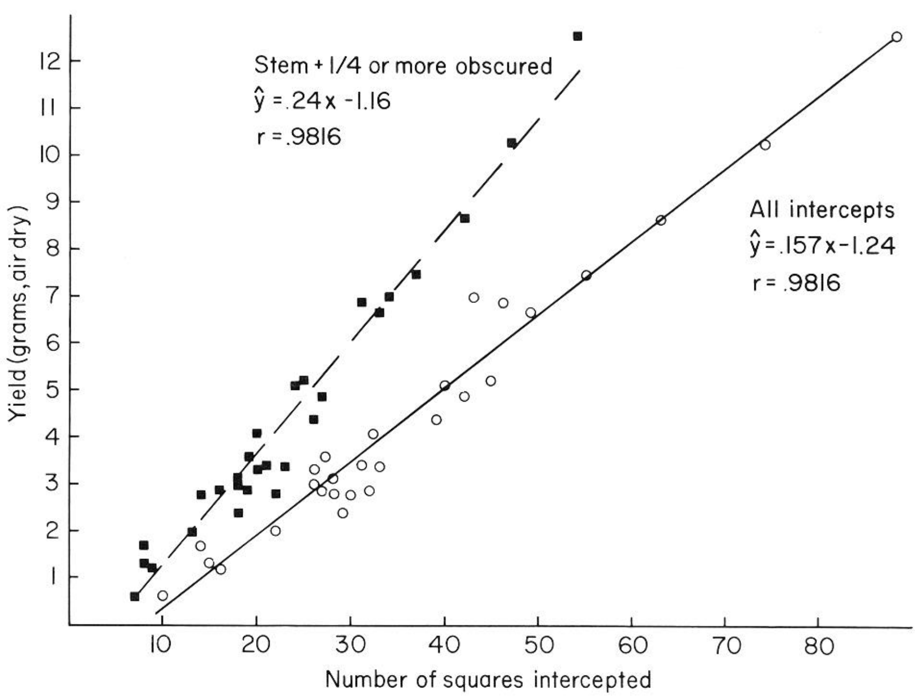

Fig. 3. *Relationships between grid counts and weights of fourwing saltbush plants.*

the same. Photographs should be taken when no strong shadows are cast on the board.

An obvious limitation is the size of the board. This limitation could easily be overcome by using a larger board together with correlation analyses developed from larger plants. Differences in growth form—particularly short, compact plants or those with considerable horizontal spread—might cause complications. The technique could be modified, however, to fit many different species and situations.

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Winterfat Seeds Viable after 8 Years Refrigerated Storage

H. W. SPRINGFIELD

Highlight: *Five collections of winterfat seeds from New Mexico were stored in cans under refrigeration (34–42°F) and ordinary temperatures (55–95°F). After 8 years of storage, viability ranged from 51 to 80% for the refrigerated seeds, but practically no seeds remained viable under the warmer storage temperatures.*

Although the early literature states winterfat (*Eurotia lanata* (Pursh) Moq.) seeds lose most of their viability in 1 or 2 years (Hilton, 1941; U. S. Forest Service, 1948), our preliminary results showed viability is retained 2½ to 3 years under cold storage (Springfield, 1968).

The purpose of this note is to report the results of storing five collections of winterfat seeds under refrigeration for 8 years.

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Table 1. Percent germination of five sources of winterfat seeds after 2½ and 8 years of storage under refrigeration and at ordinary temperatures.

	Stored at 55–95°F		Stored at 38–42°F	
Seed source	2½ yr	8 yr	2½ yr	8 yr
Mountainair	80	0	94	80
Silver Hill	64	4	92	71
Willard	80	0	88	60
Santa Fe	71	0	88	73
Corona	68	0	86	51
Average	73	1	90	67

Winterfat fruits were collected at five sites in New Mexico during November, 1964. Half of the fruits were stored in a heated garage (55 to 95°F) and half in a refrigerator (34 to 42°F) beginning in December, 1964. Storage was in 1-quart metal cans with quarter-turn lids; these containers were not airtight.

Viability was checked after 2½ years (as reported in Springfield, 1968), and again after 8 years. At the start of each viability check, whole fruits were threshed by hand to insure comparability among collections; percentage of fruits with seeds varied from 67 to 95 among the five collections. For each storage situation and each collection, four replications of 50 seeds were put in petri dishes filled with 100 ml vermiculite and 60 ml distilled water. Two layers of germination blotter were put on top of the vermiculite. Seeds were placed on the blotters, which remained moist throughout the test. All tests were made in a refrigerator modified to provide a temperature of 56 ± 2°F without light.

Seedlings were counted at 1- or 2-day intervals. Seeds were considered germinated when cotyledons and radicles together measured at least one inch and both were detached from the seedcoat.

Viability of refrigerated winterfat seeds stored 8 years remained much higher than expected (Table 1). Declines in viability between the 2½-year-check and the 8-year-check averaged only 23 percent. The Santa Fe collection, in fact, dropped only 15% during the additional 5½ years of storage. On the average, about two-thirds of the seeds still were viable after 8 years of refrigerated storage. More than half the seeds of even the poorest of the five collections—the Corona collection—were viable the 8th year.

As expected, viability of seeds stored at 55-95°F was practically zero after 8 years. Viability of these seeds already had begun to decline at the time of the 2½-year check.

Results of this study clearly show the advantage of refrigerated storage of winterfat seeds for long-term retention of viability.

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Effect of pH on Germination of Three Grass Species

J. STUBBENDIECK

Highlight: *Hydrogen-ion concentration (pH) affected the percent germination of weeping lovegrass, sand bluestem, and blue panic in laboratory tests. The latter two species exhibited the ability to germinate over a wide pH range but showed repressed germiantion at pH levels near neutrality. Tests using water of unknown pH may not provide a true indication of potential germination.*

Many factors influence the processes of germination and seedling establishment. One factor that has received little attention is the effect of hydrogen-ion concentration (pH). Soil pH was found to determine species distribution by affecting germination (Justice and Reece, 1954). A slightly acidic condition was found to be most favorable to germination of several forage crops (Promsy, 1911). Breazeale and LeClerc (1912) concluded that the depressant effect of acidity was greater on the germination than the subsequent growth of wheat. Salter and McIlvaine (1920) germinated seeds of

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Effect of pH on Germination of Three Grass Species

J. STUBBENDIECK

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alfalfa, corn, red clover, soybeans, and wheat on filter paper with solutions adjusted to pH values between 2 and 8. Values of 3 through 8 produced equal germination results for all five kinds of seeds. At pH 2, no alfalfa seeds germinated, and low percentages were recorded for the other species. However, they found that a solution with pH 4 did not exert a depressing effect on the germination of the seeds studied, but did depress growth. They concluded that the optimum solution for germination was somewhere above pH 3 and below pH 8.

Seeds of sunflower and tomato were germinated in solutions which had been adjusted in unit steps of pH 2 through 10 by adding citric acid and potassium hydroxide (Malhotra, 1930). Maximum germination was obtained at pH 6. Solutions of pH 2, 3, 8, 9, and 10 gave inferior rates of germination. Seeds of heather (*Calluna vulgaris),* subjected to unit intervals between pH 2 and 10 by using sulfuric acid and sodium hydroxide, expressed maximum germination at pH 4 (Poel, 1949).

Within species variation in germination response to pH is also evident. Bohmont and Legg (1953) reported that maximum germination of halogeton (*Halogeton glomeratus*) occurred at pH 4, while Jansen and Cronin (1953) reported that maximum germination for the same species occurred at pH 6. In addition, Bohmont and Legg received 72% germination at pH 9, while Jansen and Cronin reported a sharp drop in germination as pH increased and only 2% germination at pH 8 and 8.5.

Materials and Methods

Weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), sand bluestem (*Andropogon hallii* Hack. cv. Elida), and blue panic (*Panicum antidotale* Retz.) were selected for germination at various pH levels because they commonly grow on acidic, neutral, and basic soils, respectively. Florets that had been in storage for 18 months were reduced to caryopses, fractionated in a seed blower, and the heaviest fraction of caryopses saved. Each caryopsis was visually examined under a magnifier for soundness before germination.

The range of hydrogen-ion concentrations was established by adding hydrochloric acid or potassium hydroxide to distilled water. The pH levels of the solutions used were 2.5, 4.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 10.0, and 11.5. Petri dishes were used as germination containers. Two Whatman No. 3 filter papers were placed in the bottom of each petri dish. Six ml of a solution was added to each petri dish and 100 caryopses of a species were placed in the petri dish.

Table 1. Percent germination as affected by pH of the water used during germination.[1]

pH level	Species: Weeping lovegrass	Sand bluestem	Blue panic
2.5	0 b	27 c	0 d
4.0	88 a	48 b	66 b
5.5	86 a	59 a	66 b
6.0	85 a	59 a	66 b
6.5	85 a	54 ab	51 c
7.0	88 a	50 b	51 c
7.5	87 a	53 b	53 c
8.0	83 a	55 ab	69 ab
8.5	83 a	54 ab	74 a
10.0	88 a	53 b	71 ab
11.5	88 a	54 ab	73 a
Species means	78	51	58

[1] Means within a column followed by the same letters are not significantly different at the .05 level of probability.

Three replications of each species in each of the 11 pH solutions were established as a split-plot design within species as main plots and pH levels as split plots.

The petri dishes were covered and placed in a germinator programmed for 16 hours at 20° C and 8 hours at 30° C out of each 24 hours. They were exposed to light during the period of high temperature.

The Association of Official Seed Analysts (1970) defines germination as: "... the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions." In this experiment, this stage was said to have been reached when both the root and the shoot had attained a length of 5 mm. The germinated seedlings were counted weekly for 4 weeks.

Results and Discussion

Each of the grasses tested showed a different response to pH during germination. Differences in mean percent germination for each species as affected by pH are presented in Table 1. No germination of weeping lovegrass occurred at pH 2.5, while germination was high at all other levels. The highest percent germination of sand bluestem was at the slightly acidic levels of pH 5.5 and 6.0. The lowest percent germination for this species occurred at pH 2.5. It was the only species that germinated at the highly acidic condition.

The highest percent germination for blue panic occurred at pH 8.0 to 11.5 (Table 1). The percent germination near neutrality were the lowest. Perhaps neutrality does not favor the synthesis or action of an enzyme necessary for germination.

Conclusions

The germination of some grasses is affected by pH; however, all species tested germinated well over a large range of pH levels. The critical level of basicity for germination of all species tested was over pH 11.5. The critical level of acidity for sand bluestem germination was under pH 2.5 and for weeping lovegrass and blue panic germination was under a pH of 4. The percent germination of sand bluestem and blue panic was somewhat lower near neutrality than under slightly acidic or basic conditions.

The rules for seed testing of the Association of Official Seed Analysts (1970) call for the use of "water" for moistening the germination substratum. The pH of water varies greatly; therefore, the use of water of unknown pH may not give a true indication of the seed's viability.

Many ions can be toxic at relatively low concentrations. Therefore, care must be taken in interpreting and comparing results when different chemicals are used to adjust pH levels.

The species tested responded differentially to varying pH of the germination substratum. It could be postulated that varieties of ecotypes within a species may also respond differentially. This may furnish another criterion for selection of plant materials.

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BOOK REVIEWS

Wildflowers of Louisiana and Adjoining States by Clair A. Brown. Louisiana University Press, Baton Rouge, Louisiana, 70803. 247 p. illus., 1972. $10.00.

This book, which culminates Dr. Brown's career of almost a half-century, contains color photos and descriptions of some 430 plants. Currently professor emeritus of botany at Louisiana State University, Dr. Brown is eminently qualified by his long association with the Louisiana flora to select these relatively few plants to represent the state's approximately 4,000 species. Eliminating plants from the included group, however, was probably more vexing to him than it would have been to one less knowledgeable of Louisiana plants. The book has a hard cover and 6- by 9-inch pages of a high-quality, low-gloss paper. In addition to native herbaceous plants with pretty flowers, as some define wildflowers, Dr. Brown also included woody species and common plants which have escaped from cultivation, such as Cherokee rose (*Rosa laevigata*) and the clovers (*Trifolium* spp.). His principal criterion was that the included plants be a conspicuous part of the flora. Thus, he included the rare and beautiful red penstemon (*Penstemon murrayanus*) as well as the ubiquitous, but hardly showy, poison ivy (*Rhus radicans*).

Plant photos and descriptions are arranged by families in the familiar Engler and Prantl order, with two (occasionally one) plants to the page. With only one exception, all of the photos were made by Dr. Brown, whose proficiency as a botanist is at least equalled by his skill with the 35-mm camera. Where natural backgrounds were unsuitable, plants were very effectively posed against black velvet. Flowers or fruits are shown for each of the illustrated plants, and include the seldom-seen winter flowers of witch hazel (*Hamamelis virginiana*) and swamp privet (*Forestiera acuminata*). An inset or additional photo showing mature foliage would have enhanced the identification value of these illustrations as well as those of other dormant-season bloomers, but might have cluttered the pleasant format. Plant descriptions include a common name or names, a Latin name with author citation, plant measurements in feet and inches, relative abundance and distribution in the state, overall range, and flowering period. Dr. Brown collected specimens of each plant photographed and deposited them at the U. S. National Herbarium and the New York Botanical Garden to ensure positive identification. Plant nomenclature follows that of the New York Botanical Garden.

A 30-page introduction includes nontechnical discussions of plant values, nomenclature and classification, and flower structure and functions. About half of the introduction is a summary of the ecological features of Louisiana, including a description of the vegetative regions of the state, with an accompanying colored map. Dr. Brown also discusses endangered plant species, flower photography, and ways to use the book in plant identification.

Only one serious printing error was found: the photos and descriptions of *Liatris pycnostachya* and *L. squarrosa* were mismatched. The common name "blazing star" is used for both species, however, so those who match plant with picture and use common names only may never notice the switch. Several minor typographical errors were found, mainly in author citations and index page references.

This book adds Louisiana to a small, elite group of southeastern states with wildflower books illustrated in color. As it includes an area not fully covered by taxonomic manuals, its technical contribution is substantial, particularly in the genera *Baptisia* and *Solidago* which have several species of fairly local distribution. But the book's greatest value, to professional botanist or novice, is in the excellence of the illustrations, which others hopefully may equal but are not likely to surpass.—*Harold A. Grelen*, Pineville, Louisiana.

Men Who Matched the Mountains. By Edwin A. Tucker and George Fitzpatrick. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. 293 p. 1972. $3.85 postage paid.

The subject matter and style of this book should appeal to many people – not only those who have worked in the Forest Service or ranched in the Southwest, but also to outdoor recreationists of many kinds and to those interested in the early history of the Southwest. The material for this book was collected largely by Ed Tucker, long-time Region 3 employee, from the early rangers themselves and from written records and reports.

The first two-thirds of the book (15 chapters) tells the story of the early years of the Forest Service while it attempted to bring the forests and ranges of the Southwest under a level of management that would restore or maintain the resources in optimum productive condition. The story is told from the point of view of the Rangers who were charged with the responsibility of implementing management policies. And the story is a very personal one in terms of the problems and frustrations of day to day living – the hardships they had to meet due to physical problems (poor roads, bad weather, etc.) and also to the people problems of trying to change long-established patterns of land use.

To anyone who has worked in the forests of the Southwest, many of the names will be familiar. Several of the men who are mentioned went on to positions of national prominence, such as Aldo Leopold, Will C. Barnes, Arthur C. Ringland, Raymond E. Marsh, and Earl Loveridge.

The last third of the book (12 chapters) brings the story up to date by briefly describing the increasing complexity of Forest Service operations in the Southwest in terms of organization, function, and improved technology, to provide a well-rounded view of the Service from its earliest beginnings up till 1972. Numerous photographs, some dating back to 1900, are included showing people, places, and activities discussed.

This book cannot be considered a definitive history of the Forest Service in the Southwest (and it was not meant to be). It does, however, admirably capture the flavor of the times and will be enjoyable reading for anyone interested in resource management or history of the Southwest. A special bonus, too, is the low price of $3.85, possibly because the book is a U.S. Department of Agriculture publication.—*Dwight R. Cable*, Tucson, Ariz.

Conversion Tables for Metric and U. S. Weights and Measures

E. WILLIAM ANDERSON

The following conversion tables are useful in studying current scientific and technical reports which commonly cite data expressed in the metric system.

The figures in the central of the three columns in each table represent either one or the other of the side columns, as required. For example, 1 centimeter equals 0.394 inch; 1 inch equals 2.540 centimeters.

The idea for the format of these tables was obtained from *The Journal of the Soil Conservation Service of New South Wales*, Sydney, Australia.

AREA

Square centi-meters	cm² or inches²	Square inches	Square meters	m² or ft²	Square feet	Square meters	m² or yd²	Square yards	Square kilo-meters	km² or miles²	Square miles
6.452	1	0.155	0.099	1	10.764	0.836	1	1.196	2.59	1	0.386
12.904	2	0.310	0.186	2	21.528	1.672	2	2.392	5.18	2	0.772
19.356	3	0.465	0.279	3	32.292	2.508	3	3.588	7.77	3	1.158
25.808	4	0.620	0.372	4	43.056	3.344	4	4.784	10.36	4	1.544
32.260	5	0.775	0.465	5	53.820	4.181	5	5.980	12.95	5	1.931
38.712	6	0.930	0.557	6	64.584	5.017	6	7.176	15.54	6	2.317
45.164	7	1.085	0.650	7	75.348	5.853	7	8.372	18.13	7	2.703
51.616	8	1.240	0.743	8	86.112	6.689	8	9.568	20.72	8	3.089
58.068	9	1.395	0.836	9	96.876	7.525	9	10.764	23.31	9	3.475
64.52	10	1.55	0.929	10	107.64	8.361	10	11.96	25.90	10	3.861
129.04	20	3.10	1.858	20	215.28	16.722	20	23.92	51.8	20	7.722
193.56	30	4.65	2.787	30	322.92	25.083	30	35.88	77.7	30	11.583
258.08	40	6.20	3.716	40	430.56	33.444	40	47.84	103.6	40	15.444
322.60	50	7.75	4.645	50	538.20	41.805	50	59.80	129.5	50	19.305
387.12	60	9.30	5.574	60	645.84	50.166	60	71.76	155.4	60	23.166
451.64	70	10.85	6.503	70	753.48	58.527	70	83.72	181.3	70	27.027
516.16	80	12.40	7.432	80	861.12	66.888	80	95.68	207.2	80	30.888
580.68	90	13.95	8.361	90	968.76	75.249	90	107.64	233.1	90	34.749
645.2	100	15.50	9.29	100	1,076.4	83.61	100	119.6	259.	100	38.61

Hectares	ha or acres	Acres	Hectares	ha or miles²	Square miles
0.405	1	2.471	258.99	1	0.00386
0.809	2	4.942	517.98	2	0.00772
1.214	3	7.413	776.97	3	0.01158
1.619	4	9.884	1,035.96	4	0.01544
2.023	5	12.355	1,294.95	5	0.01930
2.428	6	14.826	1,553.94	6	0.02316
2.833	7	17.297	1,812.93	7	0.02702
3.237	8	19.769	2,071.92	8	0.03088
3.642	9	22.240	2,330.91	9	0.03474
4.047	10	24.711	2,589.9	10	0.0386
8.094	20	49.421	5,179.8	20	0.0772
12.140	30	74.132	7,769.7	30	0.1158
16.187	40	98.842	10,359.6	40	0.1544
20.234	50	123.553	12,949.5	50	0.1930
24.281	60	148.263	15,539.4	60	0.2316
28.328	70	172.794	18,129.3	70	0.2702
32.375	80	197.684	20,719.2	80	0.3088
36.422	90	222.395	23,309.1	90	0.3474
40.469	100	247.105	25,899.	100	0.386

NOTE: Reprints of these tables may be obtained from the author, E. Wm. Anderson, Soil Conservation Service, Washington Bldg., 1218 S.W. Washington Street, Portland, OR 97205, or from Society for Range Management, 2120 S. Birch St., Denver, CO 80222. *(Reprints of other articles are available ONLY from authors.)*

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VOLUME AND CAPACITY

Cubic centimeters	cm³ or inches³	Cubic inches	Cubic meters	m³ or ft³	Cubic feet	Cubic meters	m³ or yard³	Cubic yards
16.39	1	0.061	0.028	1	35.314	0.765	1	1.308
32.78	2	0.122	0.057	2	70.628	1.529	2	2.616
49.17	3	0.183	0.085	3	105.942	2.294	3	3.924
65.56	4	0.244	0.113	4	141.256	3.058	4	5.232
81.95	5	0.305	0.142	5	176.570	3.823	5	6.540
98.34	6	0.366	0.170	6	211.884	4.587	6	7.848
114.73	7	0.427	0.198	7	247.198	5.352	7	9.156
131,12	8	0.488	0.226	8	282.512	6.116	8	10.464
147.51	9	0.549	0.255	9	317.826	6.881	9	11.772
163.9	10	0.61	0.283	10	353.14	7.645	10	13.08
327.8	20	1.22	0.566	20	706.28	15.290	20	26.16
491.7	30	1.83	0.849	30	1,059.42	22.935	30	39.24
655.6	40	2.44	1.132	40	1,412.56	30.580	40	52.32
819.5	50	3.05	1.415	50	1,765.70	38.225	50	65.40
983.4	60	3.66	1.698	60	2,118.84	45.870	60	78.48
1,147.3	70	4.27	1.981	70	2,471.98	53.515	70	91.56
1,311.2	80	4.88	2.264	80	2,825.12	61.160	80	104.64
1,475.1	90	5.49	2.547	90	3,178.26	68.805	90	117.72
1,639.	100	6.1	2.83	100	3,531.4	76.45	100	130.8

1 liter equals 61.023 cu inches

28.32 liters equals 1 cu ft

LIQUID VOLUME

Liters	l or qt	Quarts	Liters	l or gal	Gallons	Cubic meters	m³ or gal	Gallons
0.946	1	1.057	3.785	1	0.264	0.004	1	264.17
1.893	2	2.113	7.571	2	0.528	0.008	2	528.34
2.839	3	3.170	11.356	3	0.793	0.011	3	792.51
3.785	4	4.227	15.142	4	1.057	0.015	4	1,056.68
4.732	5	5.284	18.927	5	1.321	0.019	5	1,320.85
5.678	6	6.340	22.712	6	1.585	0.023	6	1,585.02
6.624	7	7.397	26.498	7	1.849	0.027	7	1,849.19
7.570	8	8.454	30.283	8	2.114	0.030	8	2,113.36
8,517	9	9.510	34.069	9	2.378	0.034	9	2,377.53
9.463	10	10.567	37.854	10	2.642	0.038	10	2,641.7
18.926	20	21.134	75.708	20	5.284	0.076	20	5,283.4
28.389	30	31.701	113.562	30	7.926	0.114	30	7,925.1
37.852	40	42.268	151.416	40	10.568	0.152	40	10,566.8
47.315	50	52.835	189.270	50	13.210	0.190	50	13,208.5
56.778	60	63.402	227.124	60	15.852	0.228	60	15,850.2
66.241	70	73.969	264.978	70	18.494	0.266	70	18,491.9
75.704	80	84.536	302.832	80	21.136	0.304	80	21,133.6
85.167	90	95.10	340.686	90	23.778	0.342	90	23,775.3
94.63	100	105.67	378.540	100	26.42	0.38	100	26,417.

Grams	g or grain	Grains
0.0648	1	15.432
0.1296	2	30.864
0.1944	3	46.296
0.2592	4	61.728
0.3240	5	77.160
0.3888	6	92.592
0.4536	7	108.024
0.5184	8	123.456
0.5832	9	138.888
0.648	10	154.320
1.296	20	308.64
1.944	30	462.96
2.592	40	617.28
3.240	50	771.60
3.888	60	925.92
4.536	70	1,080.24
5.184	80	1,234.56
5.832	90	1,388.88
6.48	100	1,543.2

Grams	g or oz	Ounces
28.35	1	0.0352
56.70	2	0.0704
85.05	3	0.1056
113.40	4	0.1408
141.75	5	0.1760
170.10	6	0.2112
198.45	7	0.2464
226.80	8	0.2816
225.15	9	0.3168
283.50	10	0.352
567.0	20	0.704
850.5	30	1.056
1,134.0	40	1.408
1,417.5	50	1.760
1,701.0	60	2.112
1,984.5	70	2.464
2,268.0	80	2.816
2,551.5	90	3.168
2,835.0	100	3.52

Kilo-grams	kg or lb	Pounds
0.454	1	2.205
0.907	2	4.409
1.361	3	6.614
1.814	4	8.819
2.268	5	11.023
2.722	6	13.228
3.175	7	15.432
3.629	8	17.637
4.082	9	19.842
4.536	10	22.046
9.072	20	44.092
13.608	30	66.139
18.144	40	88.185
22.680	50	110.231
27.216	60	132.277
31.752	70	154.324
36.287	80	176.370
40.823	90	198.416
45.369	100	220.462

Metric tons	mt or t	Net tons (2,000 lb)
0.9072	1	1.1023
1.8144	2	2.2046
2.7216	3	3.3069
3.6288	4	4.4092
4.5360	5	5.5115
5.4432	6	6.6138
6.3504	7	7.7161
7.2576	8	8.8184
8.1648	9	9.9207
9.072	10	11.023
18.144	20	22.046
27.216	30	33.069
36.288	40	44.092
45.360	50	55.115
54.432	60	66.138
63.504	70	77.161
72.576	80	88.184
81.648	90	99.207
90.72	100	110.23

Kilo-gram/square centi-meter	kg/cm² or lb/inch²	Pounds/square inch
0.070	1	14.233
0.141	2	28.446
0.211	3	42.669
0.281	4	56.892
0.352	5	71.115
0.422	6	85.338
0.492	7	99.561
0.562	8	113.784
0.633	9	128.007
0.703	10	142.230
1.406	20	284.46
2.109	30	426.69
2.812	40	568.92
3.515	50	711.15
4.218	60	853.38
4.921	70	995.61
5.624	80	1,137.84
6.327	90	1,280.07
7.030	100	1,422.3

Kilo-grams/meter	kg/m or lb/ft	Pounds/foot
1.488	1	0.672
2.976	2	1.344
4.465	3	2.016
5.953	4	2.688
7.441	5	3.360
8.929	6	4.032
10.417	7	4.704
11.906	8	5.376
13.394	9	6.048
14.882	10	6.720
29.764	20	13.440
44.646	30	20.160
59.528	40	26.880
74.410	50	33.600
89.292	60	40.320
104.174	70	47.040
119.056	80	53.760
133.938	90	60.480
148.82	100	67.20

Kilo-grams/square meter	kg/m² or lb/ft²	Pounds/square foot
4.883	1	0.205
9.765	2	0.410
14.648	3	0.614
19.530	4	0.819
24.413	5	1.024
29.295	6	1.229
34.178	7	1.434
39.060	8	1.638
43.943	9	1.843
48.825	10	2.048
97.650	20	4.096
146.475	30	6.144
195.300	40	8.192
244.125	50	10.240
292.950	60	12.288
341.775	70	14.336
390.600	80	16.384
439.425	90	18.432
488.25	100	20.48

Kilo-gram/cubic meter	kg/m³ or lb/ft³	Pounds/cubic foot
16.019	1	0.062
32.038	2	0.125
48.058	3	0.187
64.077	4	0.250
80.096	5	0.312
96.115	6	0.374
112.134	7	0.437
128.154	8	0.499
144.173	9	0.562
160.192	10	0.624
320.384	20	1.248
480.576	30	1.872
640.768	40	2.496
800.960	50	3.120
961.152	60	3.744
1,121.344	70	4.368
1,281.536	80	4.992
1,441.728	90	5.616
1,601.92	100	6.24

Kilo-grams/hectares	Kg/ha or lb/acre	Pounds/acre
1.12	1	.891
2.24	2	1.782
3.36	3	2.673
4.48	4	3.564
5.60	5	4.455
6.72	6	5.346
7.84	7	6.237
8.96	8	7.128
10.08	9	8.109
11.20	10	8.910
22.40	20	17.820
33.60	30	26.730
44.80	40	35.640
56.00	50	44.550
67.20	60	53.460
78.40	70	62.370
89.60	80	71.280
100.80	90	81.090
112.00	100	89.100

Ton (Metric)/hectares	Ton (M)/ha or Ton (E)/acre	Ton (English)/acre
2.24	1	.446
4.48	2	.892
6.72	3	1.338
8.96	4	1.784
11.20	5	2.230
13.44	6	2.676
15.68	7	3.122
17.92	8	3.568
20.16	9	4.014
22.40	10	4.460
44.80	20	8.920
67.20	30	13.380
89.60	40	17.840
112.00	50	22.300
134.40	60	26.760
156.80	70	31.220
179.20	80	35.680
201.60	90	40.140
224.00	100	44.600

LENGTH

Centimeters	cm or inches	Inches	Meters	m or ft	Feet	Meters	m or yd	Yards	Kilometers	km or miles	Miles
2.540	1	0.394	0.305	1	3.281	0.914	1	1.094	1.609	1	0.621
5.080	2	0.787	0.610	2	6.562	1.829	2	2.187	3.218	2	1.243
7.620	3	1.181	0.914	3	9.842	2.743	3	3.281	4.827	3	1.864
10.160	4	1.575	1.219	4	13.123	3.658	4	4.374	6.436	4	2.486
12.700	5	1.969	1.524	5	16.404	4.572	5	5.468	8.045	5	3.107
15.240	6	2.362	1.829	6	19.685	5.486	6	6.562	9.654	6	3.728
17.780	7	2.756	2.134	7	22.966	6.401	7	7.655	11.263	7	4.350
20.320	8	3.150	2.438	8	26.246	7.315	8	8.749	12.872	8	4.971
22.860	9	3.543	2.743	9	29.527	8.230	9	9.843	14.481	9	5.593
25.400	10	3.937	3.048	10	32.808	9.144	10	10.936	16.09	10	6.214
50.800	20	7.874	6.096	20	65.616	18.288	20	21.872	32.18	20	12.428
76.200	30	11.811	9.144	30	98.424	27.432	30	32.808	48.27	30	18.642
101.600	40	15.748	12.192	40	131.232	36.576	40	43.745	64.36	40	24.856
127.000	50	19.685	15.240	50	164.040	45.720	50	54.681	80.45	50	31.070
152.400	60	23.622	18.288	60	196.848	54.864	60	65.617	96.54	60	37.284
177.800	70	27.559	21.336	70	229.656	64.008	70	76.553	112.63	70	43.498
203.200	80	31.496	24.384	80	262.464	73.152	80	87.489	128.72	80	49.712
228.600	90	35.433	27.432	90	295.272	82.296	90	98.425	144.81	90	55.926
254.000	100	39.370	30.480	100	328.080	91.444	100	109.361	160.90	100	62.140

TEMPERATURE

Celsius (C)				Fahrenheit (F)		
Equivalent reading		Equivalent increment	C or F	Equivalent increment	Equivalent reading	
F above zero	F below zero				C above zero	C below zero
minus 17.78			0		plus 32.0	
17.72	minus 18.33	0.5556	1	1.8	33.8	plus 30.2
16.67	18.89	1.1112	2	3.6	35.6	28.4
16.11	19.44	1.6668	3	5.4	37.4	26.6
15.56	20.00	2.2224	4	7.2	39.2	24.8
15.00	20.56	2.7780	5	9.0	41.0	23.0
14.44	21.11	3.3336	6	10.8	42.8	21.2
13.89	21.67	3.8892	7	12.6	44.6	19.4
13.33	22.22	4.4448	8	14.4	46.4	17.6
12.78	22.78	5.0004	9	16.2	48.2	15.8
12.22	23.33	5.5560	10	18.0	50.0	plus 14.0
6.67	28.89	11.112	20	36.0	68.0	minus 4.0
minus 1.11	34.44	16.668	30	54.0	86.0	22.0
plus 4.44	40.00	22.224	40	72.0	104.0	40.0
10.00	45.56	27.780	50	90.0	122.0	58.0
15.56	51.11	33.336	60	108.0	140.0	76.0
21.11	56.67	38.892	70	126.0	158.0	94.0
26.67	62.22	44.448	80	144.0	176.0	112.0
32.22	67.78	50.004	90	162.0	194.0	130.0
plus 37.78	minus 73.33	55.560	100	180.0	plus 212.0	minus 140.0

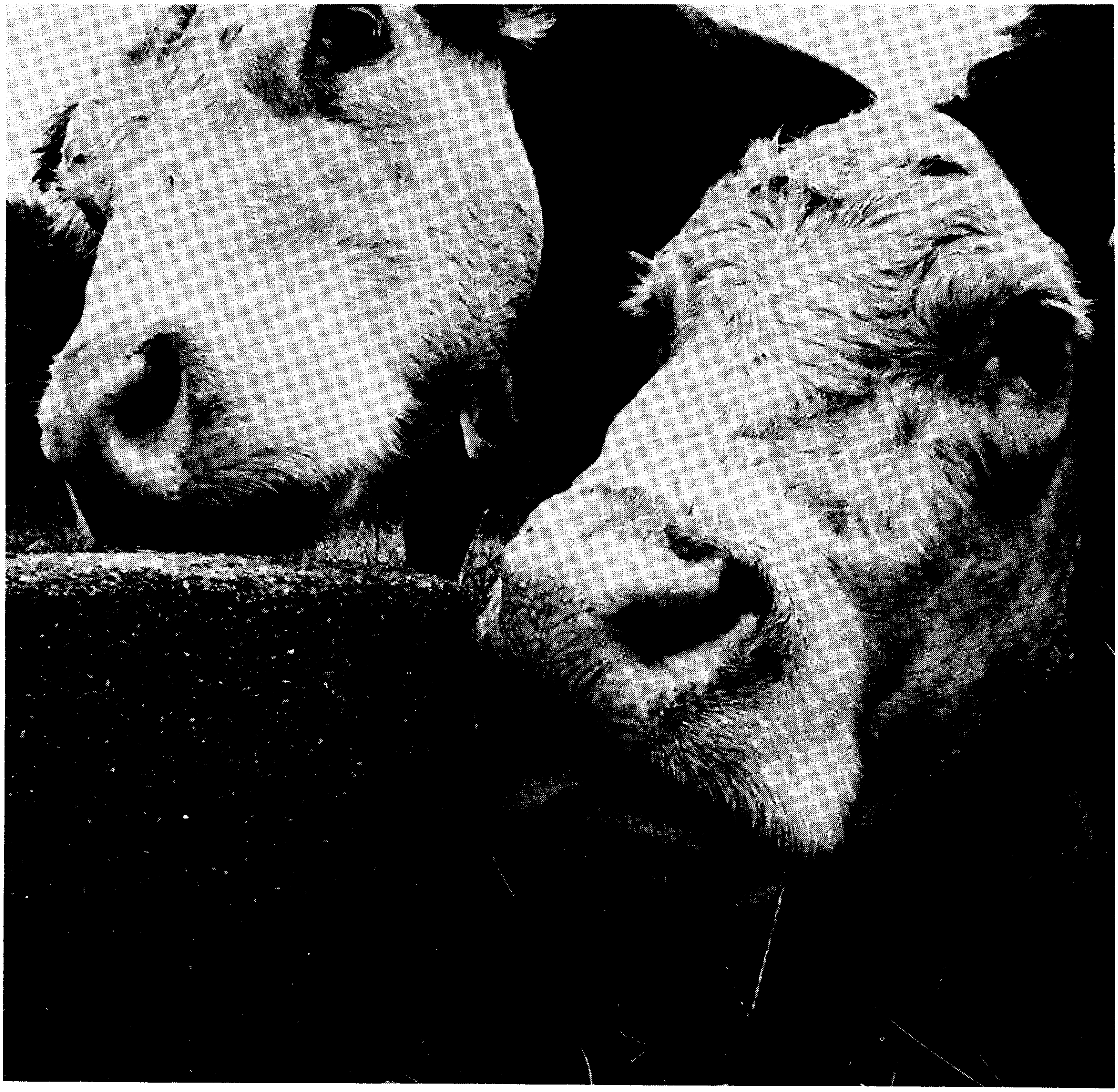
1°F equals 0.556°C
1°C equals 1.8°F

F equals (9/5 × C) plus 32
C equls 5/9 × (F minus 32)

The figures in the central column represent either Celsius or Fahrenheit, as required, to obtain equivalent temperature readings or equivalent increments. For example:

1. A change in temperature of 1°C is equivalent to a change in temperature of 1.8°F; a change of 1°F is equivalent to a change of 0.556°C.
2. A temperature reading of 1°C above zero is equivalent to a reading of 33.8°F above zero; a reading of 1°F above zero is equivalent to a reading of 17.72°C below zero.
3. A temperature reading of 1°C below zero is equivalent to a reading of 30.2°F above zero; a reading of 1°F below zero is equivalent to 18.33°C below zero.
4. A temperature reading of 73°C above zero is equivalent to a reading of 163.4°F. This is obtained by adding 158.0°F (the conversion for 70°C) and 5.4°F (the conversion for 3°C).

   A reading of 73°F above zero is equivalent to a reading of 22.78°C above zero. This is obtained by adding 21.11°C (the conversion for 70°F) and 1.67°C (the conversion for 3°F).



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