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SOCIETY FOR RANGE MANAGEMENT

# *Awards*

**Board of Directors Approve SRM Fellow Award**

The Awards Committee is soliciting nominations for SRM Awards to be granted at the 1977 SRM Annual Meeting. Nominations for SRM Awards may be made by any member, Section or Chapter officer, or committee having actual knowledge of the nominees' achievements. The nominees will be expected to prepare and submit a documentary in support of their qualifications for the award for which they have been nominated. Nominees' qualifications are reviewed and rated by the Awards Committee and the awardees are selected by the SRM Board of Directors.

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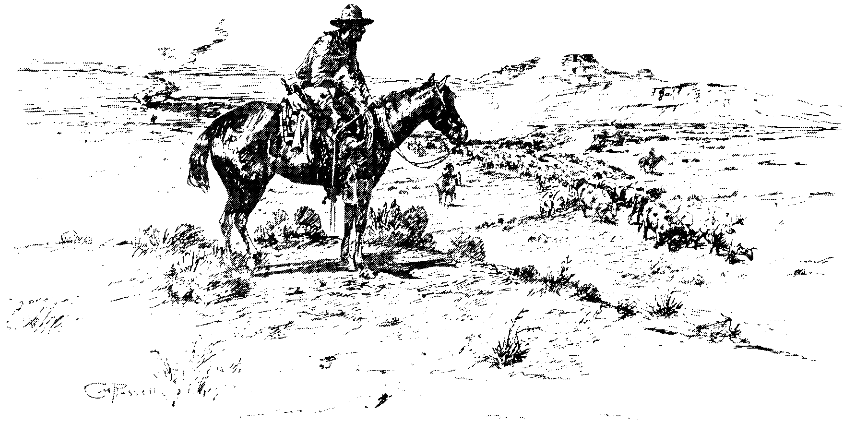
# SOCIETY FOR RANGE MANAGEMENT





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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: Root system of sand shin oak (*Quercus havardii*) exposed (see article by Roberto M. Bóo and R. D. Pettit, page 469).

# Water Harvesting: A Source of Livestock Water

GARY W. FRASIER

**Highlight**: *Water harvesting is a means of supplying stockwater in any area where precipitation is sufficient to grow forage. There are many types of methods and materials which can be used to collect precipitation. Knowledge of the advantages and disadvantages of each treatment is needed to select the method best suited for a given site. Costs of water collected from various treatments range from less than $0.20 per 1,000 gallons to over $6.00 per 1,000 gallons in a 20-inch precipitation zone.*

In many areas of our western rangelands, stockwater can be supplied by a method called water harvesting using structures called trick tanks, rain traps, or catchments to collect and store precipitation runoff. Properly designed water harvesting systems are potentially capable of supplying stock drinking water in any area where there is sufficient precipitation to grow forage. In many places, water harvesting is less costly than alternate means such as hauling or piping.

## Water Harvesting Methods

Water harvesting techniques can be divided into five basic methods: (1) vegetation management, (2) natural impervious surfaces, (3) land alteration, (4) chemical treatment of the soil, and (5) ground covers. These methods have a wide range of costs, performance, and durability, which can limit the potential applicability of a treatment (Cooley et al., 1970). Knowledge of the advantages and disadvantages of each method or treatment is needed to select the treatment best suited for a given site.

### Vegetation Management

Studies have shown that in some areas, surface runoff can be increased by converting scrub woodland to a grass forage cover (Gifford, 1973). In many places, this method cannot be used as a source of livestock water because of the necessity of constructing major dams or diversion structures in the watershed drainage channel. For some limited locations, it may be possible to collect the runoff water before it reaches the main channel.

### Natural Surfaces

The simplest and probably the most durable material for a catchment surface is a large rock outcropping (Fig. 1). Usually all that is necessary to convert the outcropping into a suitable catchment are some small diversion dikes along the lower edge which direct the runoff water into the storage facility. Runoff efficiencies from natural rock surfaces are variable, depending upon the porosity of the base rock and the number and extent of cracks in the surface. Burdass (1975) reported that in Australia, the common practice is to use 45% as the runoff efficiency for rock catchments. On some rock surfaces, the runoff efficiency can be improved by sealing the surface cracks with an asphaltic caulking compound. In some areas, it is possible to compensate for the relatively low runoff efficiency by simply increasing the size of the collection area. Total costs for preparing a rock catchment may be as low as $0.01 per square yard of collecting area (Table 1).

The highways and roads which cross the rangelands can also be used for collecting precipitation (Fig. 2). The full potential of using highways for water harvesting has not been realized because of the concern that the runoff water could be contaminated by oil droppings from the vehicular traffic. Chiarella and Beck (1975) describe a highway catchment system in Arizona used for collecting drinking water for livestock for over 15 years with no observed ill effects. Evans et al. (1975) reported that in Wyoming there are approximately 8 acres of pavement per mile of interstate highway. If we assume a catchment efficiency of 90%, a potential water supply of about 2 million gallons of water is available per mile of highway for every 10 inches of precipitation. The major cost of collecting this water is the expense of a conveyance system from the highway to the storage.

### Land Alteration

For the thousands of acres of land where highways or rock outcropping are not available, a livestock water supply can sometimes be developed by simple land alteration treatments which increase the quantity of runoff from the soil surface. Land clearing is the least expensive method of land alteration, but the increase in precipitation runoff is often negligible except for storms of high precipitation intensity and/or long duration. Because the small precipitation events do not always produce satisfactory runoff, it is usually necessary to have relatively large catchment areas and storage structures to provide adequate water to last between the runoff events.

On some soils, the runoff efficiency from land clearing treatments can be effectively increased by additional soil smoothing and/or soil compaction. Land alteration, soil smoothing, and compaction is presently used successfully in Australia in the form of roaded catchments (Frith, 1975). Soil smoothing and compacting treatments are usually more successful on loam or clay loam soils. Care must be taken in the design and construction of this type of treatment to minimize the soil slope and runoff water velocity to reduce any potential soil erosion (Hollick, 1975).

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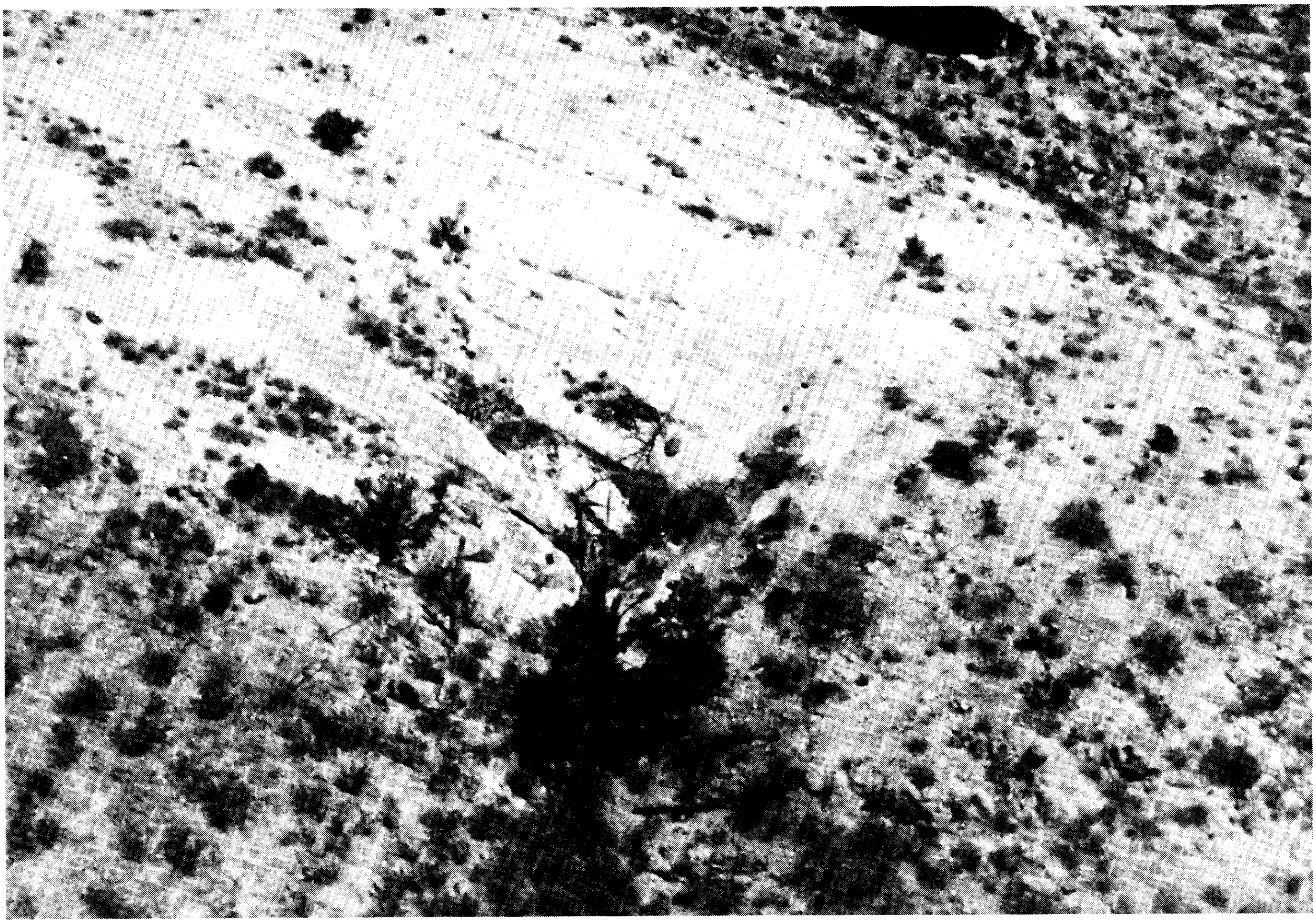

**Fig. 1.** *Large rock outcropping used as a water harvesting catchment.*

### Chemical Soil Treatments

On some soils it is possible to apply chemicals which induce a water repellency to the soil surface. The water-repellent soil surface reduces or stops infiltration, thereby increasing the quantity of runoff water. On a loamy sand soil in southern Arizona, a plot treated with a silicone water repellent yielded over 90-percent runoff during the first year (Myers and Frasier, 1969). Four years later, runoff had declined to about 60% as the treatment gradually deteriorated. Silicone-treated catchments may be damaged by erosion because of insufficient

**Table 1. Water costs for various water harvesting treatments.**

| Treatment | Runoff (%) | Estimated life of treatment (years) | Initial treatment cost ($/yd²) | Annual amortized cost[1] ($/yd²) | Water cost in a 20-inch rainfall zone ($/1,000 gal) |
|---|---|---|---|---|---|
| Rock outcropping | 20–40 | 20–30 | <0.01 | <0.02 | 0.22–0.45 |
| Land clearing | 20–30 | 5–10 | 0.01–0.02 | <0.01 | 0.30–0.45 |
| Soil smoothing | 25–35 | 5–10 | 0.05–0.07 | 0.01–0.02 | 0.25–0.71 |
| Sodium dispersant[2] | 40–70 | 3–5 | 0.07–0.12 | 0.01–0.02 | 0.13–0.45 |
| Silicone water repellents[3] | 50–80 | 3–5 | 0.12–0.18 | 0.02–0.04 | 0.22–0.71 |
| Paraffin wax[4] | 60–90 | 5–8 | 0.30–0.40 | 0.05–0.10 | 0.50–1.49 |
| Concrete | 60–80 | 20 | 2.00–5.00 | 0.17–0.44 | 1.89–6.53 |
| Gravel covered membranes | 70–80 | 10–20 | 0.50–0.70 | 0.04–0.10 | 0.45–1.27 |
| Asphalt fiberglass[5] | 85–95 | 5–10 | 1.00–2.00 | 0.14–0.48 | 1.31–5.00 |
| Artificial rubber[6] | 90–100 | 10–15 | 2.00–3.00 | 0.21–0.41 | 1.87–4.00 |
| Sheet metal[7] | 90–100 | 20 | 2.00–3.00 | 0.17–0.26 | 1.51–2.57 |

[1] Based on the life of the treatment at 6% interest.
[2] Cluff, 1975.
[3] Myers and Frasier, 1969.
[4] Fink, et al., 1973.
[5] Myers and Frasier, 1974.
[6] Lauritzen and Thayer, 1966.
[7] Lauritzen, 1967.

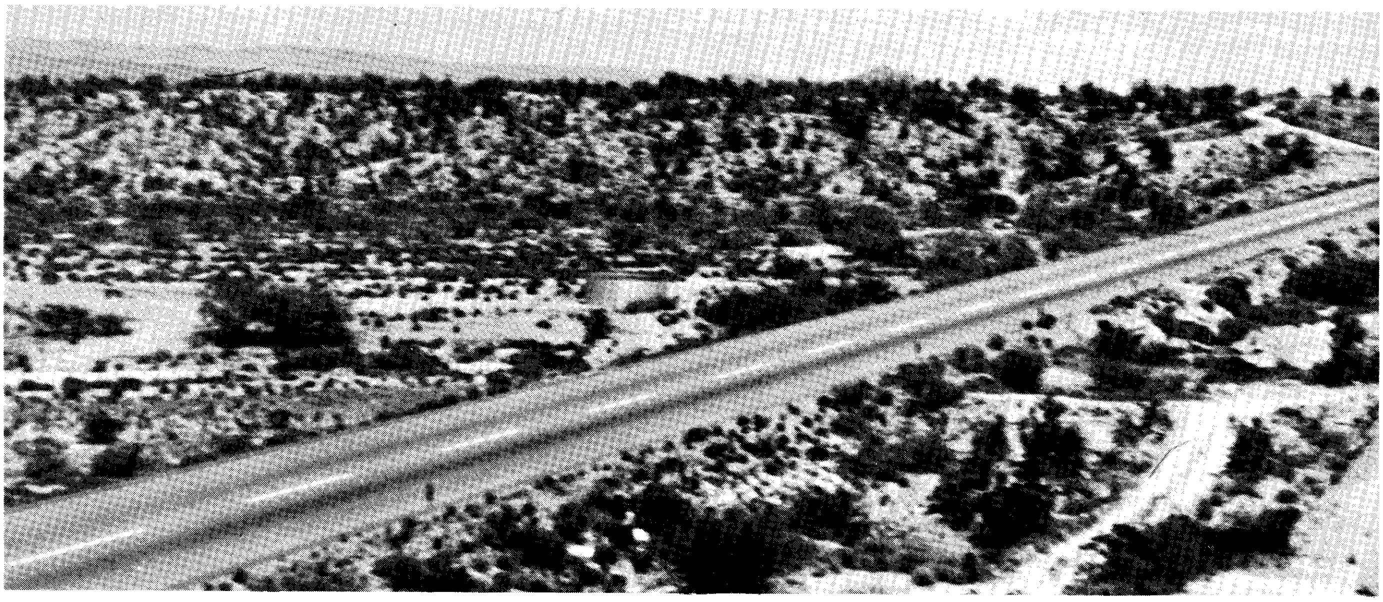

**Fig. 2.** *Highway used as a livestock water catchment on San Carlos Indian Reservation in Arizona.*

soil stabilization from the silicone treatment. Studies are being conducted to determine the possibility of adding a soil stabilizing compound to the silicone mixture to reduce soil erosion.

Recently, paraffin wax has been found to be effective in making soils water repellent (Fink et al., 1973) (Fig. 3). The paraffin wax treatment does partially stabilize the soil in addition to waterproofing the soil. Studies on a half-acre operational catchment treated with the paraffin wax indicate the treatment may lose its waterproofing ability, at least temporarily, if the soil freezes and thaws when there is a film of water on the soil surface. Subsequent studies with a laboratory freeze-thaw chamber confirmed the field data. These studies also showed the treatment effectiveness can be regenerated if the soil surface is reheated to a temperature above the melting point of the wax (128°F for the study). In many places, the surface soil temperatures will naturally exceed this temperature during warm summer days.

Another method of chemically reducing infiltration of water and increasing surface runoff is to disperse the clay in the soil to plug the soil pores. On some soils this can be accomplished by the application of a sodium salt such as

**Fig. 3.** *Application of paraffin wax to a catchment on the San Carlos Indian Reservation in Arizona.*

sodium carbonate. This type of treatment has been very successful for sealing of stock tanks (Reginato et al., 1973) and shows promise of working on some catchment areas (Dutt and McCreary, 1975). A sodium salt treatment requires a minimum quantity of expanding type clay in the soil, and soil erosion is a potential problem.

### Ground Covers

The remainder of the methods discussed for water harvesting are classified as ground covers. These are treatments where the soil surface is covered with some form of impermeable membrane.

Concrete has been used as a method of water harvesting for many years. Poured concrete slabs are quite durable but have the disadvantage of being relatively expensive and will crack from shrinkage unless properly designed expansion joints are provided. A simple and inexpensive method of sealing the cracks is to bond strips of fiberglass to the concrete over the cracks with an asphalt emulsion. Periodic maintenance and inspection will insure that the cracks will remain sealed. Even with sealed cracks, concrete will not yield 100-percent runoff because of a natural surface porosity that absorbs a measurable quantity of precipitation before runoff will occur (Frasier, 1975).

Gravel-covered membranes of various materials such as plastic or tar paper have been used as successful ground cover treatments (Cluff, 1967). The gravel covering reduces the deterioration of the impermeable plastic or paper membrane layer and provides some measure of protection from mechanical damage. The treatment is relatively easy to install and low cost if there is a source of clean gravel near the catchment site. Any damage to the membrane during the placement of the gravel can be serious if it occurs at a low spot in the catchment, but normal care during installation will usually suffice in insuring a satisfactory treatment. There is the possibility of plants growing on the gravel covering from windblown seeds if the gravel was not clean or if sufficient time has elapsed to permit dust to be deposited in the gravel layer. The gravel layer will retain a part of each rainfall event by retention. This retained water is then lost by evaporation into the air resulting in a reduced catchment efficiency (Frasier, 1975).

Ground covers of fiberglass or polypropylene matting saturated with asphalt are another durable method presently being used in various places for harvesting water (Myers and Frasier, 1974). The matting serves as a reinforcing fabric, and the asphalt is the waterproofing agent (Fig. 4). Application of protective paints to the surface of the covers reduces the problem of discolored runoff water from asphaltic surface and extends the time period between application of new seal coats (Frasier, 1970). Asphalt-fiberglass catchments have been successfully installed over surfaces too rough for the majority of membrane coverings. Although the rough surface retains some water, the membrane shows only minor deterioration after 5 years of use. Installation of asphalt-fiberglass catchments does require considerable labor.

Artificial rubber membranes have been used as water harvesting catchments for over 20 years at several locations in the United States (Lauritzen and Thayer, 1966) (Fig. 5). Correctly installed and maintained sheeting results in a good source of clean water. Many past failures of butyl catchments can be attributed to improper installation procedures, lack of maintenance, improper formulated material, or lack of protection from animals or rodents (Dedrick, 1973). Artificial rubber catchments are one of the simplest ground covers to install after the catchment site has been properly prepared.

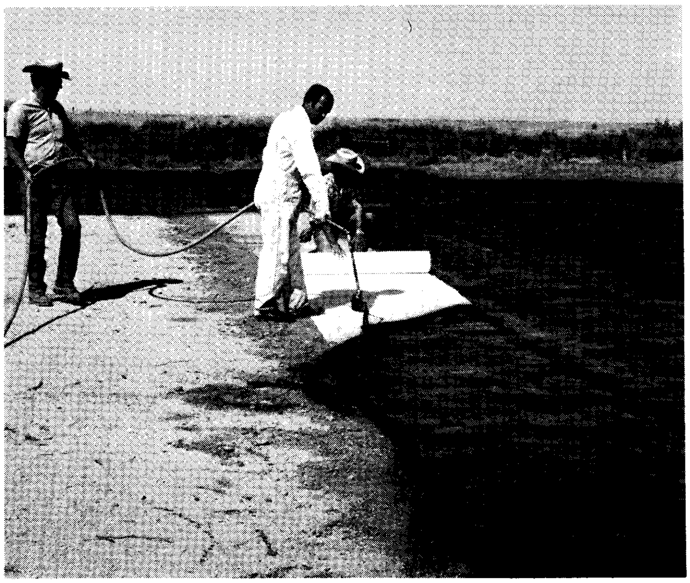

**Fig. 4.** *Installation of an asphalt-fiberglass water harvesting catchment.*

Sheet metal can be a very durable and effective catchment material. In the past, it was thought necessary to construct these catchments above ground on a framework similar to a roof of a building. The majority of these catchments performed satisfactorily until the support framework deteriorated and collapsed. Sheet metal catchments have been installed with the sheeting laid directly on the ground with a good undercoating of asphaltic paint to reduce corrosion (Fig. 6). Bolting the sheets into a continuous covering and adequate edge tiedowns are all that are required (Lauritzen, 1967).

**Fig. 5.** *Butyl rubber catchment.*

Table 2. **Advantages and disadvantages of various types of storage structures for water harvesting systems.**

| Storage method | Advantages | Disadvantages |
|---|---|---|
| Excavated pits | | |
| Unlined | a) Low cost<br>b) Allow direct animal access | a) May have excessive seepage losses<br>b) Must have sufficient soil depth |
| Chemically sealed | a) Low cost | a) Not suitable on all soil types<br>b) Some materials unable to withstand wetting and drying |
| Membrane linings | a) Eliminates all seepage losses | a) High cost<br>b) Potential damage by livestock |
| Tanks | a) Universally available | a) High cost |
| Bags | a) Eliminates evaporative losses<br>b) Easily installed | a) Damaged by rodents and livestock<br>b) Not suitable where snow drifts |

## Water Storage

A complete water harvesting system also includes some means of storing the collected water until it is needed (Dedrick, 1975). There are three basic ways of storing the water: (1) excavated pits, (2) above-ground tanks made from materials such as steel or wood, and (3) bags of plastic or rubber. Table 2 lists some of the methods which have been used for storing water and the advantages and disadvantages of each. The cost of constructing the water storage facility in remote sites is affected by the accessibility of the site for construction. On some sites the accessibility of men and equipment is the limiting factor in the selection of the water storage system.

## Maintenance

Maintenance cost for a water harvesting system is highly variable. Not all catchment treatments require the same quantity and kind of maintenance. For the smoothed soil treatments, weed growth must be eliminated and soil erosion prevented. Chemical treatments require similar attention. Maintenance of ground cover treatments primarily consists of repair of mechanical damage to the materials. The storage system and conveyance system between catchment and storage must be included in a maintenance program. This type of maintenance would usually be able to be completed by one man spending approximately 1 to 2 hours at each water harvesting system about 4 times a year.

## Water Costs

Runoff efficiency, initial costs, and amortized annual cost of the various treatments are shown in Table 1. The treatment life and runoff efficiencies are based on the results of 11 years of study at the Granite Reef test site and on 15 operational field units constructed in cooperation with private ranchers and governmental agencies. Water costs, shown in the last column, are based on a total annual precipitation of 20 inches per year and an amortized annual cost of 6% interest for the expected life of the treatment. They do not include any yearly maintenance costs. Computed water costs varied from less than \$0.20 per 1,000 gallons for the sodium salt treatment to over \$6.50 per 1,000 gallons for a concrete catchment. These costs will vary according to the local availability of the various construction materials and the remoteness of the catchment site. They can be used for comparative purposes in the selection of the type of catchment and material during the initial design stages.

It must also be remembered that the total cost of water from a water harvesting system must also include the cost of storing the water. Storage costs are highly variable, depending upon the type and size of structure required. Catchments with lower runoff efficiencies will often require larger water storage facilities to insure adequate water when needed (Frasier, 1975).

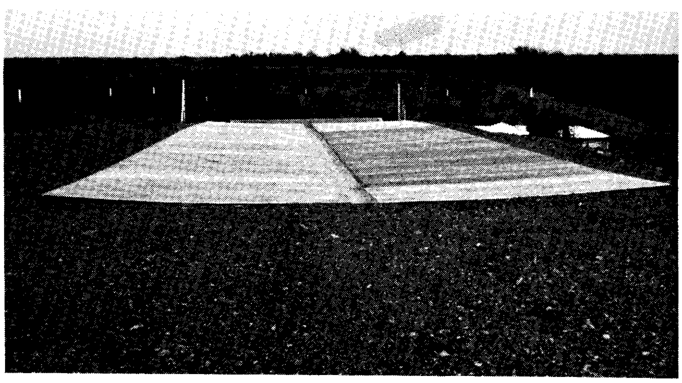

**Fig. 6.** *Sheet metal catchment.*

## Conclusions

Water harvesting is a means of potentially supplying stock drinking water in any area where there is sufficient precipitation to produce forage. Knowledge of the advantages and disadvantages of each of the many methods of water harvesting is needed to select the treatment best suited for a given site.

Large rock outcroppings and highways are potentially low-cost catchment surfaces which have not been utilized to full potential. Costs of water harvested in a 20-inch precipitation zone range from less than \$0.20 per 1,000 gallons for chemical treatments to over \$6.00 per 1,000 gallons for long-lasting materials such as concrete. The expected life, runoff efficiency, and yearly maintenance requirements are other factors which should be included when selecting the type of catchment surface to install. The water storage structure must also be matched to the catchment method to provide a satisfactory and complete water system.

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# Cattle Grazing and Wood Production with Different Basal Areas of Ponderosa Pine

WARREN P. CLARY, WILLIAM H. KRUSE, AND FREDERIC R. LARSON

**Highlight**: *Ponderosa pine stands were thinned to various basal areas on the Wild Bill Range near Flagstaff, Arizona, to determine the effects on beef and wood production. Beef gain potential was maximum at zero basal area and was one-third less when ponderosa pine was present at basal areas of 20 $ft^2$/acre. Physical relationships and the 1972 prices suggest that the combined economic value of grazing and saw log production would be maximum in tree stands having a basal area of about 45 to 60 $ft^2$/acre.*

Cattle grazing and timber production, two major uses of forested lands, are often competitive. Trees strongly influence livestock production through their effect on forage plants. Although the relationships of forage yields to tree overstory stocking have been documented in many locations (Ffolliott and Clary, 1972), little information is available on the direct relationship of livestock production to wood production or to an index of tree dominance such as tree basal area.

Production economics, which examines relationships among various resource values, provides a useful framework to determine the best use or combination of uses of public lands (Lloyd, 1969; O'Connell and Brown, 1972). Typical production economics procedures utilize production functions and product-product relationships, usually to optimize economic returns. While the primary goal of public land managers is rarely to optimize economic returns, these relationships can help form an effective framework for land management decisions.

Studies of the Wild Bill Range, established in the early 1960's near Flagstaff, Ariz., provide a basis to determine such product-product relationships. One of the objectives at Wild Bill was to determine the effects on beef production and timber production when tree stands are thinned to different basal area levels. This information should be useful for land managers, economic planners, and others who are interested in managing forested lands more effectively.

## Study Area and Methods

The Wild Bill study area is on a ponderosa pine (*Pinus ponderosa* Laws.)-bunchgrass range (Pearson and Jameson, 1967). Elevation is 7,600 ft, and the land is generally level to moderately sloping with a southwest aspect. Soils are gravelly silt loam, derived from basalt.

This study utilized one clearcut range unit, four thinned range units, and a control range unit. In 1967, approximately two-thirds of the original control unit was consumed by wildfire and another unit was substituted as the control. The principal forage species were Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* (Nutt.) Hitchc.).

Livestock management and forage measurements were described by Pearson (1972). Tree basal area was reduced to predetermined growing stock levels during 1963 and 1964. The tree stands were inventoried in 1971 by point sampling techniques (Grosenbaugh, 1958), the sample trees were bored to determine growth rates, and volumes (Ffolliott et al., 1971) were computed for the beginning and end of the study. The

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Table 1. Characteristics of the Wild Bill Range units–averages for 1965–1971.

| Characteristic | 2 (Clear) | 3 (Thin) | 4 (Thin) | 5 (Thin) | 6 (Thin) | 7 (Control to 1966) | 8 (Control from 1967) |
|---|---|---|---|---|---|---|---|
| Tree basal area (ft²/acre) | 0 | 21 ± 1 | 31 ± 3 | 50 ± 4 | 62 ± 6 | 130 ± 9 | 109 ± 8 |
| Tree crown cover (%) | 0 | 12 ± 1 | 21 ± 3 | 30 ± 3 | 33 ± 3 | 60 ± 5 | 58 ± 3 |
| Annual bolewood production | | | | | | | |
| Total (ft³/acre) | 0 | 17 ± 1 | 31 ± 3 | 29 ± 2 | 32 ± 3 | – | 49 ± 5 |
| Merchantable (ft³/acre) | 0 | 18 ± 3 | 31 ± 4 | 24 ± 3 | 31 ± 4 | – | 35 ± 5 |
| Merchantable (bd ft/acre) | 0 | 73 ± 6 | 68 ± 12 | 88 ± 11 | 120 ± 17 | – | 50 ± 9 |
| Annual understory production | | | | | | | |
| Grass (lb/acre) | 447 | 485 | 374 | 263 | 199 | 39 | 149 |
| Forb (lb/acre) | 540 | 77 | 87 | 77 | 48 | 17 | 23 |
| Shrub (lb/acre) | 2 | 7 | 2 | T | 1 | 0 | T |
| Total (lb/acre) | 989 ± 34 | 569 ± 29 | 463 ± 63 | 340 ± 50 | 248 ± 33 | 56 ± 6 | 172 ± 15 |
| Beef gain (lb/acre/year) | 31.8 ± 3.5 | 22.0 ± 4.4 | 17.0 ± 2.4 | 12.9 ± 1.7 | 10.6 ± 1.7 | 1.4 ± 0.2 | – |
| Yearling days/acre/year | 22.5 ± 3.1 | 15.8 ± 2.7 | 14.0 ± 1.5 | 10.5 ± 1.7 | 7.6 ± 1.3 | 2.0 ± 0.1 | – |

average tree diameter was 7½ inches although considerable variation was present.

Grazing studies were initiated in 1965 and continued through 1971. Yearling cattle, supplied by forest permittees, grazed the Wild Bill Range from June through September each year.

## Product Relationships

Beef gains on the different range units were closely related to the amount of tree overstory, due to differences in forage production (Table 1). One-third (29 to 34%) of the beef gain potential was lost as the tree basal area increased from 0 to 20 ft²/acre (Fig. 1). This relationship demonstrates the large differences in average annual beef gain potential at different levels of tree basal area.

Animal stocking rates were such that average forage utilization varied from 24 to 33% with an overall mean of 28%–close to rates required for maximum profit (Pearson, 1973). Since the average stocking rates were near optimum, they will be used as a direct indication of livestock carrying capacity at Wild Bill.

Beef gains among the range units were very closely related to animal stocking (indicated carrying capacity) with an average of 1.35±0.04 pounds of beef gain/yearling day. Average daily beef gains were similar because the differences in stocking rates per acre were due primarily to differences in forage production and not to differences in utilization levels.

Livestock carrying capacity was inversely and linearly related to *total* tree volume growth. A similar relationship has been described for central Arizona (Ffolliott and Clary, 1974). However, when only the increment of volume on *merchantable* stems is considered, the function is curvilinear (Fig. 2). The downward curve results from relatively little more merchantable volume growth on range units with greater tree stocking than on those units where tree stocking has been somewhat reduced. Range units with greater stand basal areas had more trees in small nonmerchantable sizes (<6 inches dbh) and a lower average tree diameter. Thinning operations tended to remove these smaller trees, thus increasing the average tree diameter of the residual stand, and merchantable volume growth more nearly equaled total volume growth in the thinned range units.

The relationship of livestock carrying capacity to board-foot volume growth has a quite different form. Board-foot growth, calculated from sawtimber-sized trees, reached a peak in range unit 6 (timber basal area 62 ft²/acre), but was much lower in the high tree basal areas of the control range unit. Since a considerable gap in tree basal area occurred

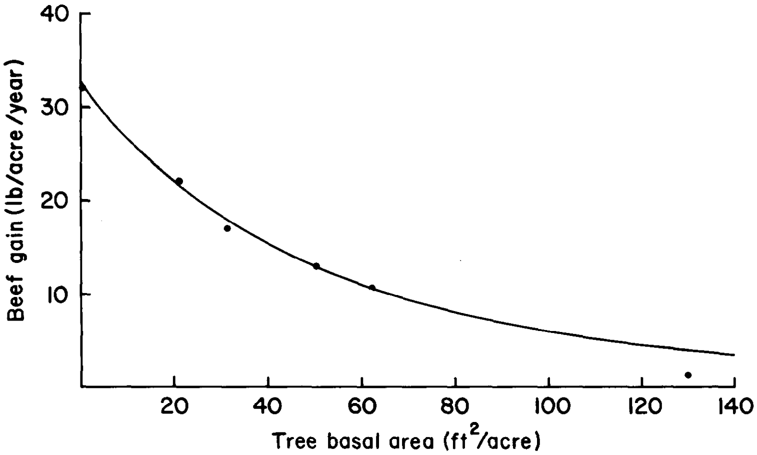


Fig. 1. *Relationship of beef gain to tree basal area.*

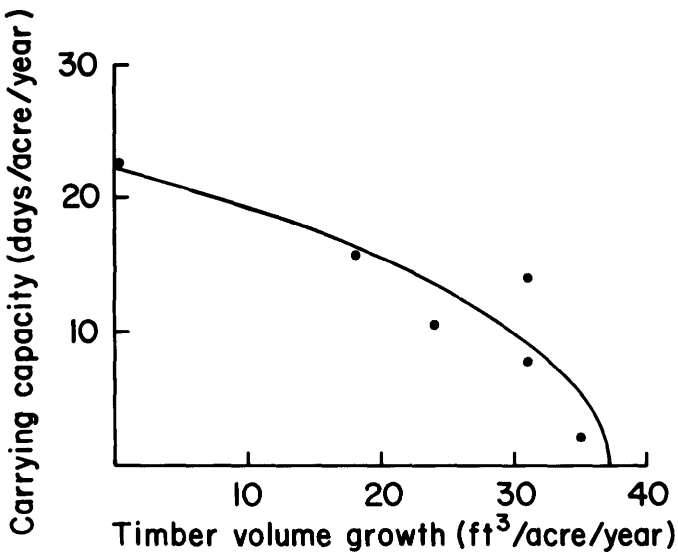


Fig. 2. *Relationship between livestock carrying capacity and merchantable timber volume growth.*

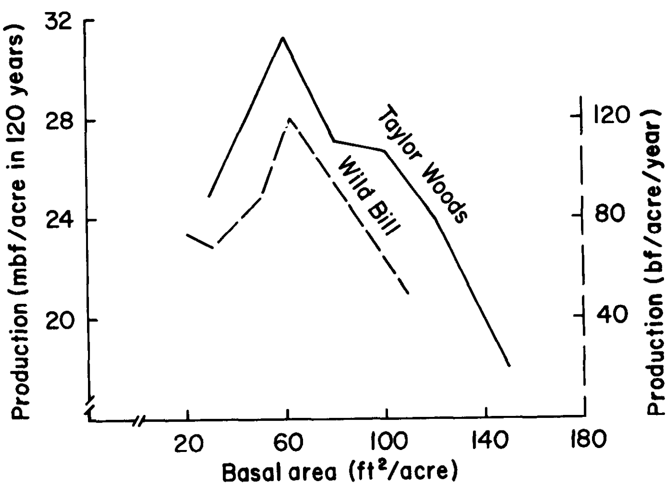


**Fig. 3.** *Board-foot production in relation to ponderosa pine basal area. (Taylor Woods data from Schubert 1974.)*

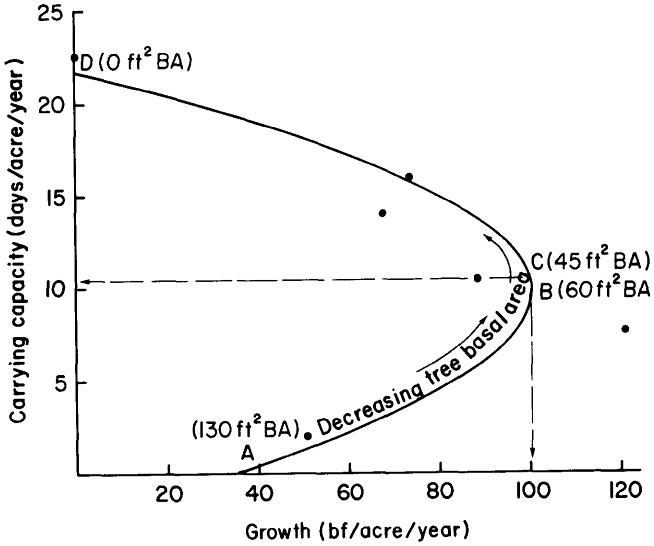


**Fig. 4.** *Relationship between livestock carrying capacity and board-foot timber volume growth.*

between range unit 6 and the control range unit, the pattern of tree growth was compared to that of nearby Taylor Woods (Schubert, 1974). Results from both areas demonstrate a pronounced peak of board-foot growth at about 60 ft$^2$ of tree basal area per acre (Fig. 3). Because average beef gain and livestock carrying capacity are closely correlated with tree basal area, and because the peak of board-foot growth appears to be fairly assured at about 60 ft$^2$ of tree basal area, we have fitted a curve to the data comparing livestock carrying capacity and board-foot growth (Fig. 4). The fit of the calculated relationship is not tight, but it is logical and is supported by the results described above.

At higher tree basal areas, the relationship between livestock carrying capacity and sawtimber growth is complementary (O'Connell and Brown, 1972) because production of both can be increased with a partial reduction in tree basal area. After a certain point, continued reductions in basal area reduce sawtimber growth, and grazing and timber production become competitive (Fig. 4).

## Economic Relationships

The shapes of these curves are important in determining economic optimum product mixes. In relationships where the two products substitute for one another at a constant rate, the best economic solution is usually to specialize in production of either one product or the other (Lloyd, 1969). In relationships of the type illustrated in Figs. 2 and 4, where the relationships are nonlinear and convex outward, the rates of substitution are variable. In such cases an economic optimum can usually be obtained only by producing some of both products.

Determining the true net economic values of different products having different cost inputs, such as livestock pasturage (which is used annually) and cubic feet of wood (which is produced annually, but harvested periodically), requires careful consideration. When considering public lands, the inputs of public monies should also be considered for each level of management.

The rental value of livestock carrying capacity (or pasturage), which excludes the additional cost of labor and capital to produce beef, is more easily determined and evaluated than is the net value of beef gain as such. Therefore, livestock carrying capacity was the range measure selected for comparison with wood production to ascertain which combination of these two forest outputs yield the greatest dollar value. The primary wood product from southwestern national forests is sawtimber; therefore board-foot volume growth was the wood product measure selected for the economic evaluation. Product values in 1972 were \$99.55/Mbf for saw log stumpage and \$5.82/animal unit month for grazing (O'Connell and Boster, 1974). Corresponding unit values are 10 cents/board-foot of timber and 12 cents/yearling-day.

Assuming all points on the curve in Figure 4 represent equal costs to management over a planning horizon, the maximum economic output would be at 100 bd ft of timber/acre/year and 10.5 yearling-days of grazing/acre/year (point C). At this point the marginal rate of substitution of the two products is tangent with the ratio of the two product values. Animal carrying capacity is maximum at point D and sawtimber production is maximum at point B. Point A represents untreated conditions, or no tree removals. As more trees are removed in the initial treatment (moving up the curve from point A toward point D) more initial costs are incurred. The cost of completely converting a ponderosa pine stand to grass (point D) is \$30 to \$40/acre more expensive (Turner and Larson, 1974) than managing the stand at point C. When variations in costs for initial stand improvement are included, the economic optimum level of management moves to some point between points C and B, or between, say, about 45[1] and 60 ft$^2$ of tree basal area.

It does not appear that this economic optimum range of basal area is likely to change much over time. The point of optimum product-product yield will not occur at tree basal areas greater than that at point B (for conditions similar to Wild Bill) because it represents maximum timber yields. On the other hand, the value of animal products would have to increase substantially in relation to timber products in order to lower the economic optimum tree basal area level below that at point C, because of increasing costs to further reduce basal area levels. Therefore, it appears that the basal area range of approximately 45 to 60 ft$^2$ which was the economic optimum in 1972 may hold generally true for some time to come.

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[1] Estimated from the carrying capacity-tree basal area relationship.

## Summary

The presence of ponderosa pine in any density will probably decrease the beef gain potential or livestock carrying capacity. In fact, about one-third of the maximum beef gain potential on Wild Bill was lost as tree stands approached 20 $ft^2$ basal area/acre. Conversely, thinning dense tree stands can improve the livestock potential while at the same time maintaining or improving wood yields on merchantable stems. The economic optimum combination between animal production and wood production will vary according to whether the wood production is considered in all size classes or whether it is considered only in larger size classes.

The physical product-product relationship together with the 1972 unit prices suggest that the combination of product values would have peaked at approximately 45 to 60 $ft^2$ of tree basal area when managing for both livestock carrying capacity and board-foot yield in trees averaging 5 to 10 inches diameter.

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# Cost and Returns from Reseeding Plains Ranges in Wyoming

W. GORDON KEARL AND ROBERT V. CORDINGLY

**Highlight**: *Variable costs of reseeding 64 range sites totaling over 10,000 acres of plains type range in Wyoming averaged $14.26 per acre, and total costs averaged $16.31 per acre at 1972 cost levels. Information obtained from the ranch operators, together with experimental information from various sources and budgeting methods over time, were used to estimate a flow of returns. Investment costs of the reseeding occur immediately, as do costs for deferment. In the third year after reseeding, some beneficial effects are achieved. Full benefits of reseeding, including a higher percentage calf crop and a larger number of heavier yearlings available for sale, are not achieved until the fifth year. Allowing for the lag in response, the rate of return on reseeding Wyoming plains ranges is estimated at approximately 21.5% at 1972 cost and price levels.*

Over 80% of Wyoming's 62.4 million acres are classified as range and pasture land. Although the primary use of range in Wyoming is grazing, much of the land is not producing forage at its potential economic or physical level.

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The objectives of this study were to determine practices and inputs used, costs, and returns from reseeding ranges. Information was obtained from ranchers and farmers in the eastern or Great Plains counties of Wyoming through personal interviews. Usable responses were obtained from 30 ranch operators who had reseeded 64 range sites totaling about 10,000 acres prior to 1973.

The following criteria by C. W. Cook (1966) represent suggestions when converting sagebrush range into seeded grassland:

1) Annual precipitation should be at least 11 inches and 13-14 inches for best results.

2) Soils should be 24 inches deep to allow roots to become properly established.

It should be noted many of the sites where range reseeding was done on ranches in Wyoming met the precipitation requirement, but would be considered marginal with respect to these soil criteria.

## Inputs Required and Costs

Data were obtained on methods of seedbed preparation and planting, physical inputs used, and costs at the time reseeding was done. Costs were then calculated at 1972 price levels to

**Table 1. Input requirements and costs of range reseeding.**

| Item | Moldboard plow | Disk plow | Offset disk |
|---|---|---|---|
| Operators | 9 | 7 | 6 |
| Reseedings | 25 | 12 | 17 |
| Acres | | | |
| Total | 1,207 | 1,850 | 5,695 |
| Average | 48 | 154 | 335 |
| Man-hours, average per acre[1] | | | |
| Primary tillage | .96 | .64 | .64 |
| Other tillage | 1.10 | .30 | .25 |
| Planting | .37 | .33 | .26 |
| Cost per acre | | | |
| Labor | $6.22 | $3.22 | $2.93 |
| Fuel | 1.92 | .91 | 1.11 |
| Repairs | 3.23 | 1.67 | 2.54 |
| Seed | 5.00 | 5.16 | 4.64 |
| Other | .23 | 3.80 | .60 |
| Sub-total | 16.60 | 14.76 | 11.82 |
| Fixed costs | 2.98 | 1.28 | 1.55 |
| Total costs | 19.58 | 16.04 | 13.37 |
| Range | | | |
| From | 12.80 | 11.10 | 9.44 |
| To | 29.70 | 22.13 | 17.73 |

[1] Tractor and implement time are about 10% less than man-hours.

give a standard base for reference and comparisons. Fixed costs, including depreciation, interest on machinery investment, and taxes, were prorated between machinery use for reseeding and other uses for the machine on the ranch. Most of the machinery was used for other purposes also, reducing the fixed costs chargeable to reseeding.

Five tillage methods–moldboard plowing, disk plowing, chiseling, offset disking, and tandem disking–were used and data for three methods used by 22 operators were presented in Table 1. Two operators reseeded 190 acres using tandem disking as the primary tillage method at a total cost of $12.17/acre. Four operators reseeded 595 acres using a chisel for tillage at a cost of $13.09/acre. Two other operators used combinations of custom work and noncustom work. Elimination of competition through complete tillage and good seedbed preparation was important to successful reseeding. Any of the tillage methods which accomplished these things would be satisfactory from a biological standpoint.

Crested wheatgrass (*Agropyron desertorum* or *Agropyron cristatum*) was used on about 75% of the acreage. Other wheatgrasses were also seeded, as was Russian wildrye (*Elymus junceus*). Alfalfa and clovers (*Medicago media, Medicago sativa, Melilotus officinales,* or *Trifolium hybridum*) were seeded on 27 of the range sites and about 30% of the acreage. The average planting rate of grass and legumes seeded on the 64 sites surveyed was about 11 lb/acre. That amount of seed insured rapid establishment and productive stands.

A small grain nurse or cover crop was planted on seven of the reseeding sites to reduce wind or water erosion and protect sandy textured soils. The nurse crop was pastured or harvested as hay or grain, depending on the specific climatic and growing conditions.

## Effects on Forage and Livestock

### Forage Production

Estimates of forage production and carrying capacities before and after reseeding were also obtained. Percentage

**Table 2. Effect of reseeding on forage production.[1]**

| Item | Moldboard plow | Disk plow | Chisel | Offset disk |
|---|---|---|---|---|
| Operators | 10 | 7 | 5 | 6 |
| Reseedings | 26 | 12 | 7 | 17 |
| Acres | 1,337 | 1,850 | 1,235 | 5,695 |
| Production–AUMs/acre | | | | |
| Before | .29 | .20 | .37 | .29 |
| After | .76 | .81 | 1.00 | .69 |
| Percentage change | | | | |
| After/before | 262% | 405% | 270% | 238% |
| Increase | 162% | 305% | 170% | 138% |

[1] Includes results of the chisel method done on a custom basis and one moldboard plow method which was excluded from the cost summary because it was a combination of custom and operator performance.

increases in forage according to reseeding method varied from 138% to 305%. The average carrying capacities of native range before reseeding varied from .20 to .37 AUM/acre. Average carrying capacities of reseeded range varied from .69 to 1.0 AUM/acre (Table 2).

The increased forage production results were consistent with results found in many experiments and other studies of reseeding (Barnes and Nelson, 1950; Bedell, 1973; Campbell, 1963; Cook, 1966; Cook et al., 1967; Frischknecht and Harris, 1968; Houston and Urick, 1972; Hull, 1972a, 1972b; Hull and Klomp, 1966; Jeffries et al., 1967; Pingrey and Dortignac, 1959; Rauzi et al., 1971; Rumsey, 1961). Forage production results from a few of those studies are summarized in Table 3. Crested wheatgrass compared very favorably with other wheatgrasses or Russian wildrye in any of these studies where comparisons were made.

Reseeding was very successful, as only two seedings totaling 90 acres, or less than 1% of the 10,000 reseeded acres, failed. Both failures, one caused by a very heavy rain and one unexplained, were successfully established by replanting. Annual weed infestations the first year after seeding were a problem on some sites and were treated by spraying or mowing.

**Table 3. Summary of forage production results of selected crested wheatgrass range reseedings in the northern plains and Intermountain areas.**

| Location and time of experiment | Unit of measure | Native range | Reseeded |
|---|---|---|---|
| Utah, 1956–64[1] | | | |
| Eureka | lb/acre, air dry | 190 | 1,148 |
| Benmore | lb/acre, air dry | 199 | 965 |
| Miles City, 1964–68[2] | lb/acre, air dry | 410 | 1,680 |
| Idaho, 1955–64[3] | | | |
| Blackfoot | lb/acre, air dry | – | 1,187 |
| Raft River | lb/acre, air dry | – | 1,169 |
| Wyoming | | | |
| Archer, 1942–49[4] | ewe and lamb days | 60 | 143 |
| Gillette, 1959–62[5] | cow and calf days | 8 | 16 |
| Wheatland, 1971[6] | lb/acre, air dry | – | 701 |
| Archer, 1971–72[6] | lb/acre, air dry | – | 1,177 |
| Archer, 1965–69[7] | lb/acre, air dry | – | 762 |
| Gillette, 1965–69[7] | lb/acre, air dry | – | 513 |

[1] Cook, 1966.
[2] Houston and Urick, 1972. Crested wheatgrass-alfalfa mixture.
[3] Hull and Klomp, 1966.
[4] Barnes and Nelson, 1950.
[5] Jeffries et al., 1967.
[6] Bedell, 1973.
[7] Rauzi et al., 1971.

Table 4. Summary of cattle performance (lb/head, avg daily gain) factors for early spring grazing on selected range reseedings in the northern plains and Intermountain areas.

| Location, dates, and kind of animal | Native range | Reseeded |
|---|---|---|
| Benmore, Utah, 1956–64[1] | | |
| Cows | 1.02 | 1.73 |
| Calves | 1.37 | 2.02 |
| Cebolla Mesa, N. Mex., 1953–57[2] | | |
| Cows | 1.21 | 3.23 |
| Calves | 1.16 | 2.18 |
| No Agua, N. Mex.[2] | | |
| Yearlings | 1.50 | 2.15 |

Sources:
[1] Cook, 1966.
[2] Springfield, 1963.

Ranch operators generally did not give specific information on the amounts livestock gained and the percentage increases in calf crop due to grazing reseeded range. They did give general impressions that increased weight gains and increased calf crops were livestock benefits resulting from grazing reseeded ranges, which were consistent with experimental results.

Experimental results have shown calves and yearlings increased gains about 20 lb/season or more through grazing reseeded ranges from 4 to 6 weeks in the spring (Cook, 1966; Frischknecht and Harris, 1968; Springfield, 1963). The same studies showed large advantages in producing gains on cows between calving and breeding seasons (Table 4). That would suggest a flushing effect. A grazing trial at Fort Robinson, Nebr., did indicate beneficial effects (Anonymous, 1964). Higher percentages of 3-year-old cows were in heat within 50, 70, or 90 days after calving when grazing crested wheatgrass than when grazing native ranges (Table 5). Such performance should allow advancing calving dates and closer bunching of calf crop.

Grazing comparisons of reseeded and native ranges in southeastern Montana found that breeding herds grazing reseeded ranges in the spring weaned about 10% more calves than breeding herds grazing native spring ranges (Houston and Urick, 1972).

### Other Benefits or Problems

A number of operators reported the grazing season was lengthened because of earlier grazing of the reseeding before the native species were ready. Increased spring pasture forage reduced the winter feed requirements on some operations. Special use calving and breeding pastures were often developed through range reseeding programs.

Deferment of grazing on reseeded sites, a recommended practice, was generally used, and varied from 1 to 3 years.

Table 5. Percent of 3-year-old cows returning in heat within different periods after calving, Fort Robinson, Nebr.

| Days after calving | Post-calving pasture: Crested wheatgrass | Native range |
|---|---|---|
| 50 | 32 | 16 |
| 70 | 64 | 41 |
| 80 | 77 | 57 |
| 90 | 79 | 70 |
| 110 | 92 | 95 |

Source: Fort Robinson Beef Cattle Research Station, Field Day Report, April 30, 1964.

Accommodating the livestock inventory during reseeding and deferment caused some management and feed problems. Reducing livestock numbers, grazing other range more intensively, buying hay, or renting pasture are methods of providing for the effects of nonuse on the reseeded area. The latter two methods were considered in making the evaluations, and the results using purchased hay, the more costly alternative, are presented here. Deferment was accomplished without additional fencing or water development.

Grass tetany, an often feared cause of death loss sometimes associated with grazing reseeded pastures, was reported by only one of the operators. Perhaps fear of grass tetany is exaggerated.

Legume species were mixed with grass species on some reseeded sites to increase forage production. Bloat problems were not reported, although some operators expressed concern about the possibility. Also, legume mixtures on reseeded sites inhibit control of broad-leaf weeds by chemicals.

## Economics of Reseeding

Hypothetical ranch models based on northern plains cattle ranch studies were used to show forage and livestock effects and changes in net returns before, during, and after reseeding. A ranch model using a cow-yearling operation with 125 acres of crested wheatgrass pasture was compared to the same ranch model with an additional 951 acres of reseeded range to allow 35 days use between calving and breeding seasons. Reseeding was assumed to cost \$16.31 per acre, the average cost for 64 sites, and about 15% more than the average cost for the disk plow, chisel, and offset disk methods. Reseeded range was assumed to produce feed at .7 AUM/acre while native range produced at .29 AUM/acre. Other assumptions, data items, and conclusions stemming from the analysis are summarized in Table 6.

The critical assumptions with respect to increased calf crop and gains of calves and yearlings are well supported by research. The other data and results flow logically from them. Calf crop is based on calves weaned as a percent of cows in the herd at calving time.

### Comparisons Before and After Reseeding

Increasing a calf crop from 83.3% to 91.6% constitutes an 8% increase in calf crop. This assumption may seem optimistic but calf crop weaned in the northern plains and intermountain areas has been averaging under 80% and an 8% increase from 70%, 75%, or 80% would seem within reach and produce about the same results. Since requirements for replacements remain about the same, the number of heifers available for sale is increased by about 17% and the number of steers by about 10%. The weight of animals, regardless of age, is increased about 6%. The net effect of all changes is to increase gross incomes by 13%, even after allowing for slight reductions in price per pound for heavier animals. Since costs do not increase greatly, excluding the investment for the reseeding, the effect is to increase net ranch income by 26% and return to land by 64%.

## The Return Flow

The simple comparison of results before and after reseeding, although easily understood, ignores problems of time and transition from the initial to the reseeded operation. Cash flow budgeting and discounting were used to estimate changes through time.

Table 6. Assumptions and results of analysis of range reseeding—comparisons of before and after situations.

| Item | Before reseeding | After reseeding | Percent change |
|---|---|---|---|
| AUM equivalents | 6,287 | 6,676 | 6.2 |
| Percent calf crop | 83.3% | 91.6% | 8.3 |
| Weights (lb) | | | |
| Heifer calves | 355 | 375 | 5.6 |
| Steer calves | 375 | 395 | 5.3 |
| Yearling heifers | 650 | 690 | 6.2 |
| Yearling steers | 705 | 745 | 5.7 |
| Cull cows | 1,000 | 1,000 | |
| Inventories (No.) | | | |
| Cows to calve | 314 | 314 | |
| Yearlings | 262 | 288 | 10.0 |
| Number sold | | | |
| Cull cows | 47 | 47 | |
| Yearling heifers | 77 | 90 | 16.9 |
| Yearling steers | 129 | 142 | 10.0 |
| Weight sold (Cwt.) | | | |
| Cull cows | 470 | 470 | |
| Yearling heifers | 500 | 621 | 24.2 |
| Yearling steers | 909 | 1,058 | 16.4 |
| Price ($/Cwt.) | | | |
| Cull cows | $24.41 | $24.41 | – |
| Yearling heifers | $35.96 | $35.34 | −1.5 |
| Yearling steers | $40.01 | $38.88 | −2.8 |
| Value of sales | $65,858 | $74,550 | 13.2 |
| Operating expenses | $34,317 | $34,790 | 1.4 |
| Net ranch income | $31,541 | $39,760 | 26.1 |
| Operator's allowances[1] | $19,947 | $20,761 | 4.2 |
| Return to land | $11,594 | $18,999 | 63.9 |
| Return to land per AUM | $1.84 | $2.86 | 55.4 |

[1] Includes $6,000 for labor, 5% of gross receipts for management, and 6% interest on working capital.

Year-to-year changes for a hypothetical reseeding situation involve the following steps:

| Year | Actions and Effects |
|---|---|
| −1 | Normal operation the year before reseeding. |
| 0 | Reseeding year—951 acres are reseeded, $13,561 variable cost is incurred for reseeding and $2,324 for buying hay, because of deferment. There is no effect on output or gross receipts. |
| 1 | The year after reseeding and the second year of deferment. There are costs for buying hay, but no effect on output or gross receipts. |
| 2 | Very moderate grazing allowed. Costs and returns are as in the normal operation. |
| 3 | The first full-use year. There are beneficial effects on conception, and calf and yearling weights increased by 20 lb each. There are slight increases in gross receipts and net income as heavier yearlings are sold. |
| 4 | Calf crop increases to 91.6%. Yearling sale weights reach maximum, because increased gains were realized on calves in the previous year and on yearlings in the 2nd year. |
| 5 | Full benefits of increased calf crop, heavier yearling sale weights, and larger number of yearlings sold are achieved. |

Full productivity on the reseeded ranch situation was reached in 5 years after reseeding and was assumed to continue over 25- or 40-year life spans. Studies of seedings in Idaho in the 1930–40 era indicate this length of life is a reasonable expectation (Hull, 1972a). Effects on receipts, costs, and returns during the reseeding, deferment, and transition years are shown in Table 7. Changes in return to capital of the model ranches during these years are also shown.

Table 7. Flow of sales, expenses, net ranch income, return to capital and change in return to capital as a result of reseeding on the hypothetical ranch models over 25 and 40 year life spans.

| Year | Total sales ($) | Total expenses ($) | Net ranch income ($) | Return to capital ($) | Change in return to capital ($) |
|---|---|---|---|---|---|
| −1[1] | 65,858 | 34,317 | 31,541 | 22,248 | – |
| 0 | 65,858 | 50,202[2] | 15,656 | 6,363 | −15,885 |
| 1 | 65,858 | 36,641[3] | 29,217 | 19,924 | − 2,324 |
| 2 | 65,858 | 34,317 | 31,541 | 22,248 | – |
| 3 | 66,751 | 34,405 | 32,346 | 23,008 | 760 |
| 4 | 67,615 | 34,588 | 33,027 | 23,646 | 1,398 |
| 5[4] | 74,550 | 34,790 | 39,760 | 30,032 | 7,784 |
| 6 | 74,550 | 34,790 | 39,760 | 30,032 | 7,784 |
| 7–25 | 74,550 | 34,790 | 39,760 | 30,032 | 7,784 |
| 7–40 | 74,550 | 34,790 | 39,760 | 30,032 | 7,784 |

[1] Basic ranch model situation.
[2] Includes $34,317, operating expenses of basic ranch; $13,561 total variable costs of reseeding 951 acres; and $2,324, cost of purchasing extra hay.
[3] Includes $34,317 operating expenses and $2,324 cost of extra hay.
[4] Stable condition was reached in year 5 and continued to provide the same annual return to the end of the time period.

The present value of return to capital was discounted at 8% in order to account for uncertainty and time lapses between income expenditure and receipts resulting from the reseeding improvement practice (Table 8). The present value of the flow of returns was positive at the end of the 8th year after reseeding, indicating that the reseeding investment, costs, and an interest of 8% had been paid in full by that time. The true or internal rate of return was about 21.5% for the 25- or 40-year life.

## A Stepwise Approach to Range Reseeding.

The previous analysis assumes reseeding of 951 acres in a single year. The average size of reseeding as indicated by Table 1 was 156 acres, including the moldboard plow method, and 260 acres for the other two methods. It may be necessary or desirable to spread a reseeding as large as 951 acres over several years.

Requirements for AUM's and acreage for a stepwise

Table 8. Changes in return ($) to capital due to reseeding, undiscounted and discounted at 8% interest for 25 and 40 year periods.

| Year | Undiscounted returns | Present value of returns discounted at 8% | |
|---|---|---|---|
| | | Annual | Cumulated |
| 0 | −15,885 | −15,885 | −15,885 |
| 1 | − 2,324 | − 2,152 | −18,037 |
| 2 | – | – | −18,037 |
| 3 | 760 | 603 | −17,434 |
| 4 | 1,398 | 1,028 | −16,406 |
| 5 | 7,784 | 5,298 | −11,108 |
| 6 | 7,784 | 4,905 | − 6,203 |
| 7 | 7,784 | 4,542 | − 1,661 |
| 8 | 7,784 | 4,205 | + 2,544 |
| 9–25 | 7,784 | 38,361[1] | 40,905 |
| Total | 147,413 | – | |
| 9–40 | 7,784 | 48,089[1] | 50,633 |
| Total | 264,173 | – | |

[1] Discounted annual returns cumulated for the 9 through 25 or 9 through 40 year time periods.

approach to range reseeding are indicated in Table 9. One-half the total yearling heifer inventory for the hypothetical ranch operation used in the previous evaluation would require 74 acres of reseeded range for breeding pasture for 1.2 months of grazing. Two-year-old heifers to be rebred would require 107 acres. That 181 acres of reseeded range would likely return considerably more than 20% on investment.

The balance of the cow herd would require 560 acres of additional reseeded range, about 4% of the ranch rangeland, and produce a return at around 20% indicated in this analysis.

Steers and heifers to be sold would produce lower rate of return to reseeding investment, since the gain advantage on yearling steers and heifers is much less than the combined advantage of increased percent calf crop, and increased weight of calves expected from the cow herd and yearling heifers.

It is quite possible that a good level of returns would be realized on reseedings adequate to carry the livestock inventory for 1.6 to 1.7 months, instead of 1.2 months used in this analysis. If more reseeded range is provided, it will merely increase the ranch carrying capacity without further enhancing the livestock reproductive efficiency or rate of gain. Returns to such additional reseedings would likely be much less than a 20% return estimated by this analysis.

The stepwise approach to range reseeding for this hypothetical ranch would allow seeding over a period of 4 years with around 150 to 300 acres seeded each year. That would reduce the labor, machinery, and capital requirements in any 1 year, tend to reduce the risk of complete failure, reduce problems, and perhaps costs associated with deferment, allow for some learning experience in 1 year's seeding to be applied in subsequent years, and result in high rate of return to the range reseeding.

## Summary and Conclusions

Based upon the foregoing analysis, range reseeding appears to be a very profitable undertaking. The assumptions made in connection with the evaluation are consistent and well supported by research. Their application to actual ranch operations is quite plausible also.

Some economic evaluations of range reseeding done in the past have been based upon evaluating the effect of an increased carrying capacity without making any allowance for increased livestock gains or reproductive efficiency. When potential increases in reproductive efficiency or livestock gains are ignored, then evaluations have suggested that range reseeding is marginal from an economic point of view. This analysis would suggest that when those factors are considered and evaluated on a reasonable or perhaps even a conservative basis, then range reseeding appears to be highly profitable.

**Table 9. Reseeded acreage required for various classes of stock.**

| | | Requirements | | | |
|---|---|---|---|---|---|
| Kind | No. of cattle[1] | AUMs[2] | Reseeded acres[2] | Percent of range | Returns expected |
| Yearling heifers to breed | 72 | 52 | 74 | 0.5 | Much above 20% |
| Two-year-old heifers to rebreed | 50 | 75 | 107 | 0.8 | Much above 20% |
| Cows with calves | 260 | 391 | 560 | 4.0 | About 20% |
| Market steers and heifers | 216 | 147 | 210 | 1.5 | Below 20% |
| Extend grazing from 1.2 to 1.7 months | | | 396 | 2.8 | Below 20% |
| Extend grazing season further | | | | Any amount | Below 20% |

[1] Allows for death loss through the calving season.
[2] Allows also for bulls and nursing calves.

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# Resource Allocation through Goal Programming

KENNETH E. BOTTOMS AND E. T. BARTLETT

**Highlight**: *One of the major weaknesses of using linear programming in natural resource management is that only a single criterion for determining the optimal strategy is allowed. A goal programming model is presented that allows for multiple, conflicting goals. Results are provided for a management area in northern Colorado. The trade offs between goals are demonstrated by comparison of results from multiple runs in which the order of goal preferences is varied. Goal programming is shown to be a very flexible decision aiding tool which can handle any decision problem formulated by linear programming more efficiently.*

Public pressure and limited quantities of natural resources necessitate development of more reliable decision making techniques. Modern natural resource managers are rapidly becoming aware of new decision aiding techniques which are capable of reviewing, utilizing, and organizing vast quantities of resource data.

During the past decade, many models utilizing operation research techniques have been developed to aid range and other resource managers. To date, the most common technique used has been linear programming (Nielsen et al., 1966; McConnen et al., 1965; D'Aquino, 1974; Bartlett et al., 1974).

Decision makers realize, however, that linear programming models are single objective or single goal systems; the objective has commonly been profit maximization or cost minimization. Organizations seldom have a single goal; in fact, in public land management, the classical economic objective of maximum net revenue often rates only a low priority. Linear programming has been modified in order to allocate resources when multiple conflicting goals are present (Charnes and Cooper, 1961). The procedure is called goal programming.

The traditional method of solving multiple goal problems has been to define all goals in a common unit (usually dollars). Managers and most economists have been highly critical of this procedure as all goals cannot be translated into strictly economic terms. In goal programming, there is no requirement that the objectives be defined in the same value terms. In fact, multiple goals may be in terms of board feet of timber, number of cattle, or dollars, as well as number of sales and regional incomes.

The only requirement in goal programming is that the manager can attach ordinal priorities or rankings to the goals that reflect the importance of each goal. For example, if the manager has two goals, (1) red meat production and (2) economic efficiency, he must rank one above the other before using goal programming. Once goals have been defined and ranked according to importance, a solution via goal programming can be obtained. The decision maker can then change the goal priorities, and by examining the solutions, he can obtain an estimate of the trade offs between goals.

The general logic of goal programming will be discussed, and the application to natural resources explained. A discussion of an application to a forest in northern Colorado has been completed. The results of the goal program have been compared to the results of a linear program.

## Goal Programming

The concept of goal programming evolved as a result of unsolvable linear programming problems and the occurrence of conflicting multiple goals. Many allocation decisions arise in natural resource management because demands on the resource base exceed the supply capability of the ecosystems. In such instances, a linear programming model such as that developed by D'Aquino (1974) will provide the manager with three words, "no feasible solution." Goal programming will provide solutions to infeasible linear programs. In fact, the basic concept of goal programming is "whether goals are attainable or not, an objective may be stated in which optimization gives a result which comes 'as close as possible' to the indicated goals" (Lee, 1972). Goal programming provides the manager with estimates of achievement or nonachievement of his defined and ranked goals.

A simple example is needed to explain goal attainment. Let us assume a manager wanted to carry as close to 500 cow-calf units as possible on his ranch. Goal programming allows either overachievement or underachievement, depending on the particular decision problem. Overachievement would be any point above the 500 level, and underachievement, any point below this level. The objective of goal programming is to minimize the nonachievement of each actual goal level. If nonachievement is minimized to zero, the exact attainment of the goal has been accomplished. Using the example above, the manager might be concerned with minimizing the underachievement, while overachievement might be more than acceptable and therefore not minimized.

For a single-goal problem, the formulation and solution is similar to linear programming with one exception. If complete goal attainment is not possible, goal programming will provide a solution and information to

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the decision maker. In problems with more than one goal, the manager must rank the goals in order of importance. The procedure is to minimize the deviational variables of the highest priority goal, and proceed to the next lower goal. Deviation from this goal is then minimized with the additional constraint that attainment of the first goal cannot be lessened. The other goals are considered in order of priority but lower order goals are only achieved as long as they do not detract from the attainment of higher priority goals. Several solutions can be obtained by changing the priorities in order to indicate how the order of the goals affect planning strategies.[1],[2]

The goal programming model formulation used was a modification of the one developed by D'Aquino (1974). The difference between the two model formulations, of course, concerns the goals. D'Aquino's model was composed of constraints and a single objective function, in contrast to the goal programming formulation, which contains constraints and multiple objective functions.

Since goal programming requires that each goal be assigned an importance level, the concept results in a multiple objective function wherein the number of objectives is equal to the number of importance levels. Each goal does not, however, result in a separate objective function. If two or more goals can be expressed in the same units of measure, they can be within the same importance level. Dollars of budget and dollars of profit can therefore be represented in the same importance level.

In order to minimize either under- or overachievement of a particular goal, a variable called a "deviational variable" is assigned to the goal. This variable represents the magnitude by which the goal level is not achieved. If the value of the deviational variable is small, the goal is more nearly achieved than if the value is relatively large. Thus, the value of the deviational variable is minimized in an attempt to achieve the goal. Optimality occurs when the deviational variables of the different goals have been minimized to the smallest possible value in order of importance.

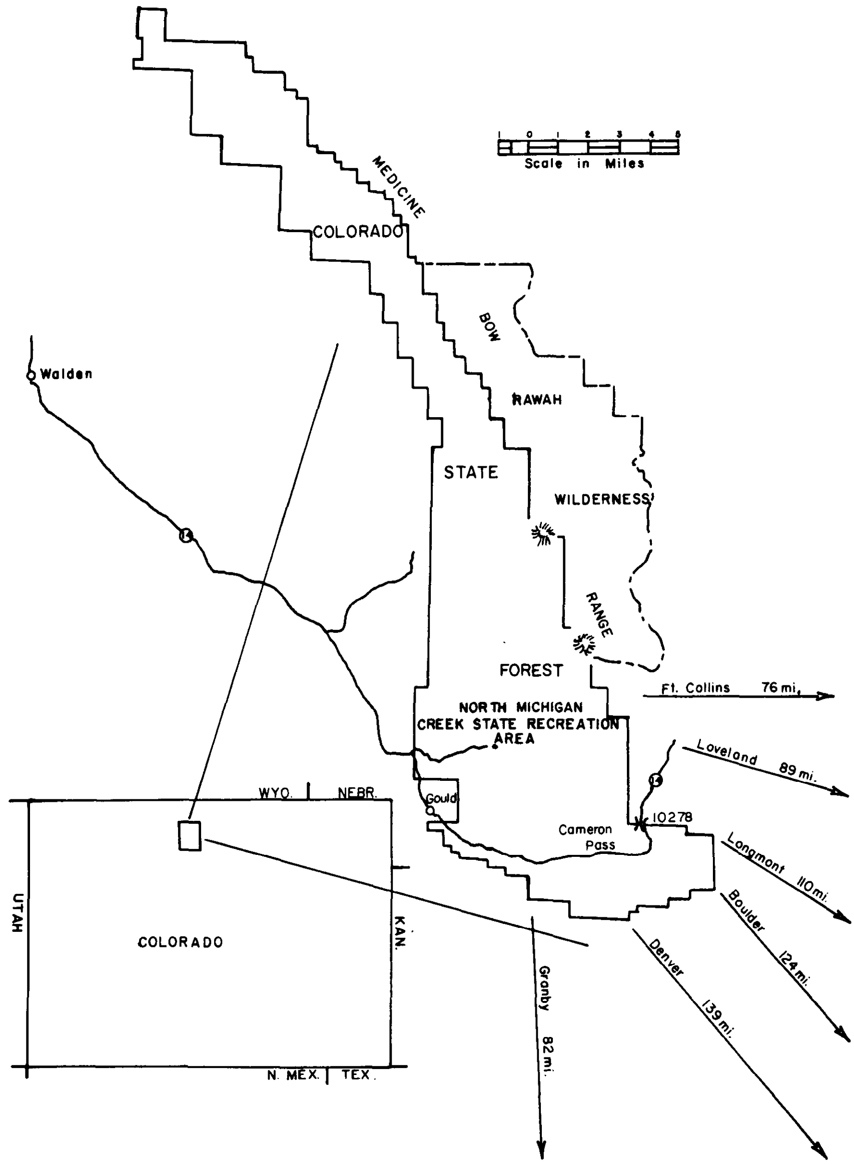


**Fig. 1.** *The geographic location of the Colorado State Forest.*

## Study Area

Goal programming was applied to a resource decision problem on the mountainous Colorado State Forest, located in northern Colorado (Fig. 1). The area is approximately 9,050 acres of the southern portion of the State Forest, which ranges in elevation from 8,500 feet to over 11,000 feet. The area has been, and may increasingly become, a conflict area due to its location and its basic resource composition.

Winter may begin the last of August and continue through May. Therefore, resource use is concentrated in the 3-month period from June to August. Average precipitation ranges between 18 and 21 inches annually, with most precipitation falling as snow.

Soils in this area vary greatly but are composed mostly of granitic residues on shale or slate. Soil depth varies from 15 to 25 inches. Most of the forest soils are very susceptible to slippage and tend to be somewhat acidic. Soils in this area are very susceptible to erosion; when used intensively, great care should be taken to prevent the potential erosion.

Vegetation of the study site is extremely diverse and can be broken into several distinct types: willow carrs and marshy meadows, grassland meadows, sagebrush meadows, spruce-fir forests, lodgepole pine forests, and sagebrush-lodgepole ecotones. Acreage for each type is shown in Table 1.

[1] Readers desiring an indepth discussion of goal programming should refer to *Goal Programming for Decision Analysis* by Sang M. Lee.

[2] Additionally *REACT II–A Goal Programming Computer Program* is available from the RANN Project, Department of Range Science, Colorado State University.

Table 1. Acreage by major vegetative types.

| Vegetative type | Area (acres) |
|---|---|
| Grassland meadows | 1950 |
| Sagebrush meadows | 2000 |
| Spruce-fir | 1450 |
| Lodgepole pine | 2600 |
| Willow bottomland | 570 |
| Sagebrush-lodgepole ecotone | 480 |
| Total acres | 9050 |

Lakes cover an additional 82 acres with approximately 10.4 miles of streams. The major streams are the North Fork of the North Michigan River, its tributaries, and Grass Creek. The annual discharge from the approximately 18-square-mile area of this watershed is nearly 12,500 acre feet. Sedimentation also occurs and an average production of 7.5 tons/acre/year is considered a reasonable limit.

Recreational resources are many. The 66-acre North Michigan Reservoir along with several miles of trout stream provides a varied trout fishery, including cutthroat, rainbow, and brook trout. Camping also accounts for a significant portion of the recreational use, in addition to hiking and backpacking.

The timber resource at present is capable of yielding approximately 1,275 cubic feet of lodgepole pine and 200 cubic feet of spruce-fir per acre in each of the respective ecosystems.

Results of pellet group counts give estimates of deer and elk populations that range between .12 and .15 days use per acre, which is typically related to total deer and elk population levels. Considering only areas on the site that are believed to be valuable to deer and elk, it was thought that approximately 50–60 deer and 50–60 elk frequent the area during the available season of 150 days.

## Model Formulation

Several products have been identified on the study area: cow-calf months of grazing, steer months of grazing, recreation user days of camping, board feet of lodgepole pine and spruce-fir timber, and deer and elk months of grazing. Each of the products is derived from one or more of the seven available resources of the study area: domestic forage, phosphorus, protein, wildlife forage, fish, lodgepole pine, and spruce-fir. Table 2 outlines the quantities of the resources needed to produce one unit of each product. These values are based on the best available research results for areas similar to the study area.

Within each of the six vegetation types, several management alternatives have been defined, each of which would be expected to change the levels of production and some of the resources. Estimates of the expected effect of the management alternatives of the yields of the various resources for each of the vegetation types, together with projected unit costs, are summarized in Tables 3 through 8. These estimates were based either on existing data in the area or research conducted on similar areas (Morrison, 1949; Stoddart and Smith, 1955; Vallentine, 1971; and Cook, 1968). The rates for the recreation user days were calculated on an opportunity cost basis in which the acreage was assumed used for recreational purposes and therefore removed from other resource production.

Non-product-oriented goals in Table 9 were identified for management. Goals as used here became linear equations, each of which must be composed of homogeneous units al-

Table 2. Quantities of resources needed to produce one unit of each product.

| | Products | | | | | | |
|---|---|---|---|---|---|---|---|
| Resources | Cow-calf months of grazing | Steer months of grazing | Recreation user days of camping | MBF lodgepole pine | MBF spruce-fir | Deer months of grazing | Elk months of grazing |
| Domestic forage (lb)* | 1209 | 776 | 0.042 | | | 753. | 3080. |
| Phosphorus (lb)** | 2.51 | 1.55 | | | | | |
| Protein (lb)** | 141.4 | 77.6 | | | | | |
| Wildlife forage (lb)* | | | 0.057 | | | 5270 | 5133 |
| Fish (lb) | | | 1.5 | | | | |
| Lodgepole pine (bd ft) | | | | 1000. | | | |
| Spruce-fir (bd ft) | | | | | 1000. | | |
| Revenue ($) | 5.40 | 4.50 | | 174. | 408. | | |

*Domestic and wildlife forage are considered only to be the amount that is usable under proper stocking rates.
**Phosphorus and protein amounts also included as part of domestic forage.

Table 3. Yields of resources on willow bottomland (570 acres) under various management alternatives.

| | Alternative | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Resources | No action | Drainage of wet lands | Aerial spraying of willow land | Aerial spraying with grass seeding | Mechanical removal | Mechanical removal with grass seeding | Fertilization | Campground development | Units |
| Size of action | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | Acres |
| Sediment | 2.5 | 6.5 | 5.0 | 4.35 | 9.5 | 8.5 | 2.0 | 27.0 | Tons/acre/year |
| Domestic forage | 1270.0 | 1459.0 | 1647.0 | 1730.0 | 1786.0 | 2249.0 | 2006.0 | | Pounds/acre |
| Phosphorus | 2.54 | 2.92 | 3.30 | 3.46 | 3.57 | 4.50 | 4.01 | | Pounds/acre |
| Protein | 94.0 | 108.0 | 122.0 | 128.0 | 132.0 | 161.0 | 148.0 | | Pounds/acre |
| Wildlife forage | 1500.0 | 975.0 | 150.0 | 75.0 | 750.0 | 375.0 | 1875.0 | 2250.0 | Pounds/acre |
| Fish | | | | | | | | 2000.0 | Pounds stocked/year |
| Recreation | | | | | | | | 1750.0 | User days |
| Variable cost | 0.00 | 125.00 | 3.50 | 8.50 | 25.00 | 25.50 | 6.00 | 2700.0 | Dollars/unit action |

**Table 4. Yields of resources on sagebrush vegetation type (2,000 acres) under various management alternatives.**

| Resources | Alternative: No action | Mechanical removal | Mechanical removal with grass seeding | Mechanical removal grass seeding fertilization | Aerial spraying | Aerial spraying with grass seeding | Spraying grass seeding, fertilization | Grass interseeding | Units |
|---|---|---|---|---|---|---|---|---|---|
| Size of action | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Acres |
| Sediment | 9.75 | 10.0 | 9.25 | 7.00 | 5.75 | 5.5 | 5.0 | 6.5 | Tons/acre/year |
| Domestic forage | 825.0 | 1918.0 | 2475.0 | 2681.0 | 1031.0 | 1116.0 | 1256.0 | 947.0 | Pounds/acre |
| Phosphorus | .99 | 2.30 | 2.97 | 3.22 | 1.24 | 1.34 | 1.51 | 1.14 | Pounds/acre |
| Protein | 33.8 | 78.7 | 161.0 | 110.0 | 42.3 | 45.7 | 51.5 | 38.8 | Pounds/acre |
| Wildlife forage | 2500.0 | 1000.0 | 875.0 | 750.0 | 1500.0 | 1375.0 | 1125.0 | 2375.0 | Pounds/acre |
| Variable cost | 0.00 | 15.00 | 17.50 | 32.50 | 3.00 | 18.00 | 20.50 | 7.50 | Dollars/unit action |

though the units may differ between goals. The goal level is the amount of each goal unit desired, such as number of cow months, board feet of timber, acre feet of water, etc.

The initial results indicate that goal programming will mimic the linear programming solution if the objective function of the linear program is the lowest priority goal or if only one objective is considered in the goal program. Conventional linear programming requires all constraints be met before profit is maximized. The same requirement must be made of goal programming before it can mimic linear programming. Setting all goals at a higher priority than the linear programming objective or only using one objective accomplishes the same end. The goals, goal levels, and priorities are shown in Table 9. In the linear program, profit maximization was the objective function and the remaining eight goals were entered as minimum constraint requirements.

The results from the linear and goal programs were identical with all goals being met or exceeded. The number of steers and amount of lodgepole pine and spruce-fir timber were exceeded because of the contribution to the objective function of the linear program or the profit goal in the goal program. The ecosystems produced an ample amount of wildlife forage; consequently, animal numbers exceeded the minimum. With two exceptions the ecosystems were managed under the "no action" alternative. One campground was constructed in the sagebrush-lodgepole ecotone and four patchcuts for wildlife were indicated in the spruce-fir community.

The goal program was reexamined after raising the budget level to $90,500 and then to $135,750 (Table 9). Profit increased as a result of an increase in spruce-fir production and a slight increase in steers without an increase in cows. The only change in the management alternatives was an increase in the number of patchcuts in the spruce-fir ecosystem.

Some goals of the model were increased, as indicated in Table 10. A linear program will not aid the decision maker in this case, because the ecosystem is not capable of producing all of the goals simultaneously at the given budget levels.

**Table 5. Yields of resources on sagebrush-lodgepole ecotone (480 acres) under various management alternatives.**

| Resources | Alternatives: No action | Campground development | Wildlife habitat development | Units |
|---|---|---|---|---|
| Size of action | 1.0 | 3.0 | 1.0 | Acres |
| Sediment | 5.65 | 25.35 | 9.82 | Ton/acre/year |
| Domestic forage | 525.0 | | | Pounds/acre |
| Phosphorus | .79 | | | Pounds/acre |
| Protein | 28.4 | | | Pounds/acre |
| Wildlife forage | 1418.0 | 2979.0 | 2128.0 | Pounds/acre |
| Fish | | 3200.0 | | Pounds stocked/year |
| Recreation | | 2700.0 | | User days |
| Variable cost | 0.00 | 2500.00 | 350.00 | Dollars/unit action |

**Table 6. Yields of resources on lodgepole type (2,600 acres) under various management alternatives.**

| Resources | Alternatives: No action | Clearcut harvest | Clearcut replant nursery stock | Patch cutting | Campground development | Units |
|---|---|---|---|---|---|---|
| Size of action | 1.0 | 1.0 | 1.0 | 40.0 | 3.0 | Acres |
| Sediment | 6.5 | 9.05 | 7.65 | 350.0 | 27.75 | Tons/acre/year |
| Domestic forage | 225.0 | 786.0 | | 28064.0 | | Pounds/acre |
| Phosphorus | .38 | 1.34 | | 47.6 | | Pounds/acre |
| Protein | 15.0 | 52.6 | | 1880.0 | | Pounds/acre |
| Wildlife forage | 337.0 | 565.0 | 168.0 | 26941.0 | 606.0 | Pounds/acre |
| Fish | | | | | 1500.0 | Pounds stocked/year |
| Recreation | | | | | 2000.0 | User days |
| Lodgepole pine | 562.5 | 11250.0 | 14062.0 | 18000.0 | | Board feet |
| Variable cost | 0.00 | 400.00 | 489.00 | 11000.00 | 2700.00 | Dollars/unit action |

Table 7. Yields of resources on spruce-fir type (1,450 acres) under various management alternatives.

| Resources | Alternatives: No action | Clearcut | Clearcut replant nursery stock | Selective cut | Patchcut for wildlife | Campsite development | Units |
|---|---|---|---|---|---|---|---|
| Size of action | 1.0 | 1.0 | 1.0 | 1.0 | 40.0 | 3.0 | Acres |
| Sediment | 7.0 | 9.25 | 9.7 | 9.75 | 350.00 | 28.5 | Tons/acre/year |
| Domestic forage | 40.0 | 1.0 | | 348.0 | 14744.0 | | Pounds/acre |
| Phosphorus | 0.39 | 0.78 | | 0.59 | 25.2 | | Pounds/acre |
| Protein | 15.4 | 30.9 | | 23.2 | 988.0 | | Pounds/acre |
| Wildlife forage | 125.0 | 200.0 | 100.0 | 250.0 | 12480.0 | 112.5 | Pounds/acre |
| Fish | | | | | | 1200.0 | Pounds stocked/year |
| Recreation | | | | | | 500.0 | User days |
| Spruce-fir | 350.0 | 7000.0 | 7700.0 | 2100.0 | 280000.0 | | Board feet |
| Variable cost | 0.00 | 452.00 | 510.00 | 376.00 | 10000.00 | 2700.00 | Dollars/unit action |

Table 8. Yields of resources on grassland type (1,950 acres) under various management alternatives.

| Resources | Alternatives: No action | Interseeding | Disking and interseeding | Disk, interseed and fertilizer | Disk | Units |
|---|---|---|---|---|---|---|
| Size of action | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Acres |
| Sediment | 1.5 | 3.5 | 8.25 | 8.0 | 8.5 | Tons/acre/year |
| Domestic forage | 2450.0 | 2817.0 | 3062.0 | 3552.0 | 2940.0 | Pounds/acre |
| Phosphorus | 3.92 | 4.51 | 4.90 | 5.63 | 4.7 | Pounds/acre |
| Protein | 66.2 | 76.1 | 82.7 | 95.9 | 79.4 | Pounds/acre |
| Wildlife forage | 625.0 | 469.0 | 250.0 | 125.00 | 312.0 | Pounds/acre |
| Variable cost | 0.00 | 6.50 | 7.95 | 12.45 | 7.00 | Dollars/unit action |

Table 9. Results of linear and goal programs with varying budget levels.

| | Constraint (LP) or goal level (GP)[1] | Priority for goal program | Results: Linear program | Goal programs 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| Budget ($) | – | – | 45,250. | 45,250. | 90,500. | 135,750. |
| Cow-calf months of grazing | 200. | 1 | 200. | 200. | 200. | 200. |
| Steer months of grazing | 50. | 2 | 3,846. | 3,846. | 3,868. | 3,890. |
| Recreation user days | 3,000. | 3 | 3,000. | 3,000. | 3,000. | 3,000. |
| Lodgepole pine (MBF) | 240. | 4 | 1,463. | 1,463. | 1,463. | 1,463. |
| Spruce-fir (MBF) | 120. | 5 | 1,618. | 1,618. | 2,821. | 4,025. |
| Sediment (tons) | 67,875. | 6 | 53,916. | 53,916. | 54,233. | 54,549. |
| Elk months of grazing | 50. | 7 | 1,647. | 1,647. | 1,648. | 1,649. |
| Deer months of grazing | 25. | 8 | 73. | 73. | 79. | 85. |
| Profit ($) | 2,000,000. | 9 | 887,608. | 887,608. | 1,333,545. | 1,779,481. |

[1] LP = linear programming; GP = goal programming.

Table 10. Results of goal program as goal priorities change.

| Goal | Goal level | Run 1 Goal priority ranking | Run 1 Level achieved | Run 2 Goal priority ranking | Run 2 Level achieved | Run 3 Goal priority ranking | Run 3 Level achieved | Run 4 Goal priority ranking | Run 4 Level achieved |
|---|---|---|---|---|---|---|---|---|---|
| Profit ($) | 2,000,000. | 1 | 926,337. | 4 | 434,500. | 4 | 434,500. | 4 | 2,000,000. |
| Cow-calf months of grazing | 200. | 2 | 0. | 2 | 200. | 2 | 200. | 2 | 200. |
| Steer months of grazing | 50. | 3 | 4,214. | 3 | 3,808. | 1 | 3,808. | 3 | 5,229. |
| Recreation user days | 45,000. | 4 | 0. | 1 | 38,613. | 3 | 38,613. | 1 | 45,000. |
| Lodgepole pine (MBF) | 240. | 5 | 1,463. | 5 | 1,463. | 5 | 1,463. | 5 | 1,153. |
| Spruce-fir (MBF) | 120. | 6 | 1,711. | 6 | 508. | 6 | 508. | 6 | 7,759. |
| Sediment (tons) | 67,875 | 7 | 53,929. | 7 | 53,764. | 7 | 53,764. | 7 | 64,139. |
| Elk months of grazing | 500. | 8 | 1,107. | 8 | 1,096. | 8 | 1,096. | 8 | 1,418. |
| Deer months of grazing | 600. | 9 | 600. | 9 | 600. | 9 | 600. | 9 | 600. |
| Budget ($) | 45,250. | – | – | – | – | – | – | 10 | 1,391,089. |

Conflict for scarce resources forces the manager to sacrifice some of his goals in order to meet others. Multiple runs using linear programming would not show any trade offs between goals and would be many times more expensive. In such a situation, information concerning the trade off between goals would greatly aid the resource manager. To provide such information, the goal programming model was solved using several different orders of goal priorities. Such varying of the order of goals will be defined as parametric goal programming.

Table 10 outlines the results of the three parametric goal programming runs, each of which has a different top priority goal. Table 10 also shows how the results differ if the budget is entered as a goal instead of a fixed constraint.

Run one was based on profit maximization as the top priority goal. Steers were favored over cow-calf units, spruce-fir over lodgepole pine with no user days produced. The only alternative other than "no action" alternatives was 4.5 forty-acre patchcuts in spruce-fir. The profit generated was $926,337. All goals, whether completely achieved or not, were met to the fullest possible extent given the priority ranking.

The second test had user day production as the highest priority goal with priority of profit dropping to fourth. User day production increased to 38,613, which is the maximum given a fixed budget of $45,250. Eighteen campgrounds were indicated on the sagebrush-lodgepole ecotone. The cow-calf goal was met in this run because profit was no longer overriding this alternative. Steer production dropped because of recreation and the presence of cow-calves. Spruce-fir production dropped because the budget was consumed in recreation development instead of timber harvesting; thus no patchcuts were indicated. Elk numbers decreased slightly because of the overall decrease in wildlife forage being produced on the area. The profit was approximately one-half that of the first run.

The third test had steer production as the highest goal, followed by cow-calf, recreation, and profit. The results are the same as when recreation was the highest goal because the low goal level is met on all runs. This indicates to the manager that steer production is not a critical goal except as it relates to profit.

In the last test, the budget constraint was changed from a constraint to the last priority goal (tenth). In this case, all levels of the other goals were met but at a cost of $1,391,089. This is over 30 times the budget level of $45,250. The management alternatives indicated in the solution are shown in Table 11.

## Conclusions

The public ideally views the soundness of a decision-making process by the degree that goals are achieved by a decision. Goal programming measures the degree of goal attainment and has the ability to solve problems involving multiple conflicting goals according to an ordinal priority structure.

Goal programming enables the manager to program multi-objective problems. Goal programming is particularly applicable as a planning aid to agencies such as the Forest Service and the Bureau of Land Management, where multiple resource management is essential.

The goal-programming procedure is one more tool available to natural resource decision makers. We, as resource managers, must strive to improve our decision-making processes. Any tool which can, in any way, aid the decision maker in arriving at good solutions to complex problems should be reviewed, evaluated, and used when feasible.

Model formulations have shown great promise as effective decision-aiding tools for natural resource allocation (D'Aquino, 1974; Bartlett et al., 1974). The idea of using the level of goal attainment as objective functions rather than the conventional profit or cost seems to more closely approximate the actual thinking process of the manager. Quantification of this nature sets the foundation for an iterative updating system so necessary if operation research tools are to be used in practical applications to natural resource allocation processes.

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**Table 11. Management alternatives selected under the goal program with budget as a last priority rather than a constraint goal.**

| Alternative | Amount |
|---|---|
| Fertilization of willow bottomland (acres) | 570. |
| Campgrounds in sagebrush-lodgepole ecotone (3 acres) | 0. |
| Wildlife habitat development in sagebrush-lodgepole ecotone (3 acres) | 480. |
| Patchcut for wildlife in lodgepole pine (40 acres) | 64. |
| Campgrounds in lodgepole pine (3 acres) | 12.3 |
| Selective cut in spruce-fir (acres) | 313. |
| Patchcut for wildlife in spruce-fir (40 acres) | 25. |
| Campgrounds in spruce-fir (3 acres) | 41. |

# Soil Ingestion by Cattle on Semiarid Range as Reflected by Titanium Analysis of Feces

H. F. MAYLAND, A. R. FLORENCE, R. C. ROSENAU, V. A. LAZAR, AND H. A. TURNER

**Highlight:** *Soil ingestion was determined for cattle grazing a* Bromus tectorum *range in southern Idaho by measuring titanium concentrations in animal feces collected at 2-week intervals during the droughty 1973 grazing season. The experiment was based on the premise that titanium, which is abundant in soils, is contained only in small quantities (less than 1 ppm) in plants not contaminated with soil.*

*Fecal-soil values averaged 14%, with values ranging from 3 to 30% of fecal dry matter, increasing as forage availability decreased. Soil ingestion levels were estimated to range from 0.1 to 1.5 kg with a median of 0.5 kg soil/animal-day. This soil was ingested primarily with the roots of* Bromus tectorum, *which were often pulled up and consumed with the aboveground plant parts. Dust on leaves and stems accounted for only a small portion of the ingested soil.*

*Measurements of acid-insoluble residue concentration in feces overestimated soil ingestion because of the probable presence of $SiO_2$ of plant origin. Large changes in forage $SiO_2$ concentrations of the diet reduce the effectiveness of this method compared to the Ti method.*

*Ingested soil may be a possible source of trace minerals, pesticides, heavy metals, and radionucleides that may be sorbed to surface soil particles.*

Ingested soil may be a source of minerals to the grazing ruminant. Its importance depends on the amount of soil ingested, the ratio of the mineral concentration in soil to that in herbage, and the ability of the ruminant to solubilize and absorb the soil-derived minerals.

We were motivated to consider ingested soil as a dietary zinc (Zn) source because we did not find visual Zn deficiency symptoms in cattle whose diet did not otherwise appear to contain adequate Zn. The possibility that ingested soil may be a source of dietary minerals for grazing sheep and cattle has been investigated in New Zealand (Healy, 1967, 1968, 1973). Healy et al. (1970) reported that about 14% of the radioactive $^{65}Zn$ adsorbed to soil was absorbed by experimental sheep after they were drenched with 100 g of the $^{65}Zn$ labelled soil.

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The objective of this study was to determine soil ingestion rates for cattle grazing on a semiarid range in southern Idaho.

## Field Methods

The study was conducted on the Saylor Creek Experimental Range, 7 miles southwest of Glenns Ferry, Ida. It is a mesic, upland site with a coarse silty, xerollic durorthid soil classified in the Minidoka silt loam soil series. The area receives 130 to 330 mm annual precipitation with a mean of 220 mm. Precipitation during 1973 was 200 mm, with only 80 mm occurring between March 1 and October 31. The native big sagebrush-Thurber needlegrass complex (*Artemisia tridentata-Stipa thurberiana*) has been largely replaced by cheatgrass (*Bromus tectorum*).

In mid-June 1973, four groups of 25 cow-calf pairs each were assigned to individual 32.4 ha (80 acre) pastures (Fig. 1F). After each group utilized an estimated 70% to 80% of the forage in that pasture, it was given access to an additional pasture(s). A fifth group, also having 25 cow-calf pairs, was assigned to a large 150-ha pasture for the entire study (Pasture LP, Fig. 1F). Feces, distinguished as to cow or calf origin, were sampled from the five groups at 2-week intervals from July 3 through November 6. Fecal subsamples were taken from the center of approximately 10 fresh dung pats, carefully avoiding soil and dust contamination; subsamples were composited by group.

Forage, clipped at a 2-cm stubble height, was collected at regular intervals. During the grazing season, six forage samples were pulled in a sweeping motion and shaken to simulate material eaten by cattle. The simulated samples contained attached crowns, roots, and soil. The forage and fecal samples were dried at 65°C for 72 hours and ground in stainless steel equipment to pass a 20-mesh screen.

Soil samples representing less than 0.58 mm material in the 0- to 2-cm depth were collected from Pastures 47, 50, 54, 57, and 61 (Fig. 1F) and air dried.

## Laboratory Methods

### Titanium Method

The experimental approach was based on the premise that titanium (Ti), which is abundant in soils (1,000 to 3,000 ppm Ti), is contained only in small quantities (less than 1 ppm Ti) in plants not contaminated with soil (Healy, 1968). Soil concentration in fecal and plant material was, therefore, determined by spectrographically measuring the amount of Ti present. Samples were loosely packed in aluminum frames, backed with 0.06 mm mylar film, and subjected to an x-ray fluorescence instrument with a tungsten target tube and a sodium chloride analyzing crystal. Samples and optical path were bathed with a helium atmosphere.

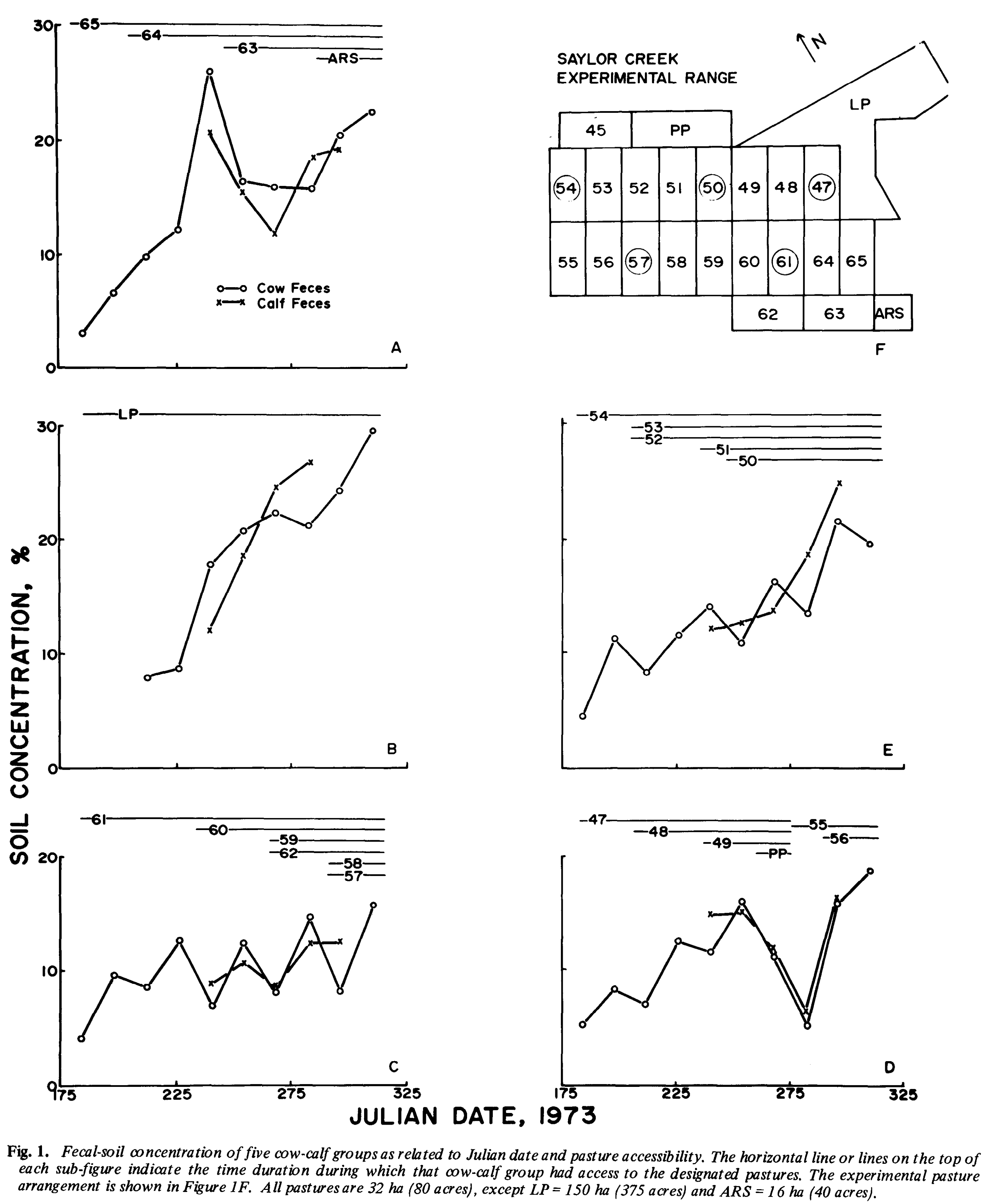


**Fig. 1.** *Fecal-soil concentration of five cow-calf groups as related to Julian date and pasture accessibility. The horizontal line or lines on the top of each sub-figure indicate the time duration during which that cow-calf group had access to the designated pastures. The experimental pasture arrangement is shown in Figure 1F. All pastures are 32 ha (80 acres), except LP = 150 ha (375 acres) and ARS = 16 ha (40 acres).*

The ratio F/S, where F is the counting rate at the Ti K$\alpha$ emission line ($\lambda$ = 2.750 Å, $2\theta$ = 58.34°), and S is the counting rate at the background ($\lambda$ = 3.267 Å, $2\theta$ = 71.00°) was used as a measure of the Ti concentrations in fecal, plant, and soil samples. In previous studies, this ratio was found to be a better measure of the concentrations of elements in the parts per million range than either the counting rate at the Ti K$\alpha$ line less rounting rate at the background (F − S), or the counting rate at the Ti K$\alpha$ line (F) by itself (Kubota and Lazar, 1971).

### Calibration for Titanium Method

The Ti concentration in soils was determined by the method of additions. The spectrographic parameter F/S was linearly related to $TiO_2$ additions in the range of 0 to 6,000 ppm Ti ($r$ = 0.99, standard error = 30 ppm Ti). Soils from Pastures 50, 54, and 57 were calculated to contain 2,400 ppm Ti, while those from Pastures 47 and 61 contained 2,100 and 2,200 ppm Ti, respectively. The soil from Pasture 57 was chosen for further calibration, realizing that estimates of soil content in forage and feces collected from the eastern part of the experimental area would be underestimated by 5 to 10%.

A standard fecal-soil series was prepared by thoroughly mixing known amounts of soil from Pasture 57 (Fig. 1F) with a dry "control" fecal sample obtained from a stall-fed cow receiving cured timothy hay. Since only a trace of Ti was measured in the "control" by x-ray spectrographic scan, it was ascertained to contain less than 0.1% soil. Fecal-soil concentration was curvilinearly related to the spectrographic expression F/S (Fig. 2) having an error of 0.35% soil. Soil concentration in field samples would have an expected standard error of 0.7% soil because unknowns had been thoroughly mixed 1:1 with the "control" feces to reduce the errors derived from differences in matrix effects between field and "control" samples.

A standard forage-soil series was prepared as above, except that a wheatgrass (*Agropyron desertorum*) sample was used instead of the "control" feces. The Ti concentration in the wheatgrass sample was determined by the method of soil additions. Clipped plant samples were mixed 1:1 with the wheatgrass sample before analysis.

### Acid-Insoluble Residue Method

The acid-insoluble residue content of plant and fecal samples was determined by dry-ashing 10-g samples at 550°C for 6 hours. The cooled ash was moistened with water, acidified with 20 ml concentrated HCl to remove carbonate, taken to dryness on hot plate, redissolved in 50 ml 2*N* $HNO_3$, and diluted to approximately 100 ml with water. The sample was washed onto Whatman No. 1 filter paper and the residue washed with about 50 ml additional water. The filter paper and residue were ashed at 550°C for 4 hours and the cooled ash was moistened with water, acidified with 2 ml concentrated HCl, and taken to dryness. The residue was weighed and calculated as percent acid-insoluble residue of the original sample.

Forage dry matter digestibility was determined by the in vitro technique of Tilley and Terry (1963) as modified by Kartchner (1975).

## Results and Discussion

Clipped grass samples of wheatgrass, cheatgrass, bluegrass (*Poa secunda*), needleandthread (*Stipa comata*) and squirreltail (*Sitanion hysterix*) contained up to about 0.4% soil, with several samples having as much as 0.7% soil. Animal consumption of clipped forage with an assumed 66% dry matter digestibility would yield feces containing up to 2% soil. Thus, soil attached to aboveground plant parts does not seem to have contributed much to fecal-soil concentrations in this study.

Soil concentrations in the pulled cheatgrass samples ranged from 13 to 18%. Ingestion of the forage samples pulled to simulate livestock grazing would, under the above conditions, produce feces containing about 30% soil. Thus, fecal-soil concentrations in excess of 2% probably originate from soil adhering to ingested stem bases and roots or from direct soil ingestion.

Fecal-soil concentrations ranged from 3 to 30% during the droughty 1973 season (Fig. 1A-E), and generally increased as the amount of available forage decreased. When animals were given access to previously ungrazed pastures, fecal-soil concentrations would decrease. For example, cows grazing Pastures 64 and 65 on day 240 were excreting feces containing 26% soil (Fig. 1A). However, after cattle were given access to Pasture 63, average soil concentrations in the feces decreased to about 16%. The abundant forage in this pasture was probably responsible for maintenance of similar soil ingestion levels for two additional sampling periods. Cattle in the LP pasture had access to more feed than did other groups, but it is believed that they may not have used it efficiently because of the irregular pasture perimeter (Fig. 1B). The calf data for fecal-soil concentrations were generally similar to those for cows (Fig. 1A-E).

Healy (1967, 1968), who reported on soil ingestion studies in sheep and dairy cows grazing humid pastures in New Zealand, found that cows ingested from 0.25 to 1.25 kg soil/animal-day. The amount was roughly proportional to stocking intensity and closeness of grazing, and inversely proportional to available forage and soil structure. Muddying of forage by trampling, raindrop splash, and earthworm casts was an indirect factor affecting soil ingestion levels in the New Zealand studies.

Muddying of forage was definitely not a contributing factor in the Idaho study since soils remained dry during the July to November period. Grass forage was mature and cured during much of this period. Dry soil particles may have been attached to the leaves and stems but would not have accounted for more than 2% soil concentration in the feces (see previous discussion). Fecal-soil concentrations in this study are likely related to closeness of grazing, forage availability, and shallow rooted plants. Cattle easily pulled the shallow-rooted cheatgrass plants from the dry silty soils along with portions of

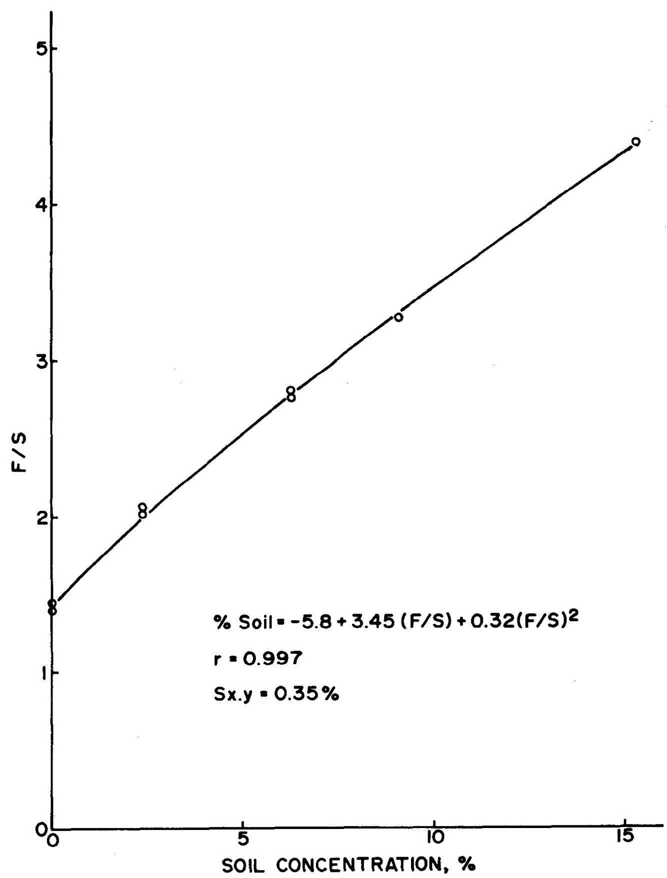


**Fig. 2.** *Fecal-soil concentrations in relation to the spectrographic expression F/S.*

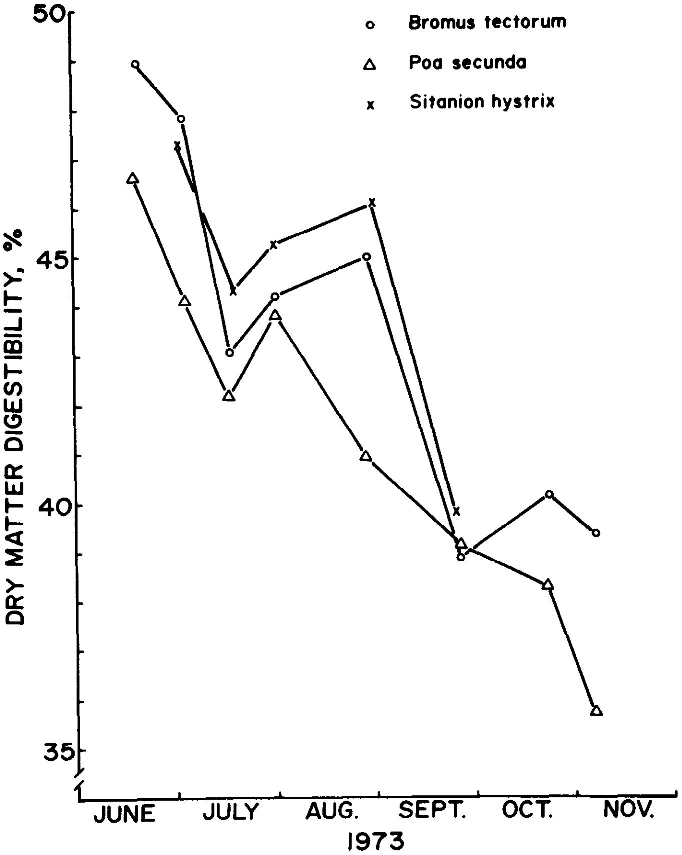


**Fig. 3.** *In vitro dry matter digestibility values for three forage species grazed on the Saylor Creek Experimental Range in 1973.*

roots and attached soil. Animals would occasionally drop that portion of the bite having a large amount of soil. Forage samples pulled from the soil to simulate grazing were calculated to produce a fecal soil concentration of about 35% (assuming a 50% dry matter digestibility). This value is considerably greater than the maximum values shown in Fig. 1A-E, indicating some discrimination against the ingestion of plant parts containing the amount of soil normally adhering to crowns and roots.

The data presented thus far represent soil concentration measured in the feces. Dry matter intake and digestibility must also be known in order to calculate actual soil ingestion levels. In vitro dry matter digestibility of forage samples collected throughout the 1973 grazing period (Fig. 3) and in vivo data obtained from a 1970 study of steers grazing Pasture 65 (Olsen, 1971) will be used to provide this additional information. Steer weights were 222, 248, and 274 kg; dry matter intake was 5.0, 5.0, and 6.8 kg per day; and dry matter digestibility was 72, 63, and 66% for early, mid-, and late summer periods, respectively (Olsen, 1971). Cows used in the present study weighed 300 to 450 kg and were assumed to have a dry matter intake of 7 to 9 kg/cow-day. Forage in the 1973 study was probably less digestible than that reported by Olsen, especially for the early summer period because of earlier forage maturity in 1973. This contention is supported by the in vitro dry matter digestibility data obtained on the 1973 clipped forage samples (Fig. 3).

The following example is given for calculating soil ingestion levels when forage dry matter digestibility is 50%. The non-soil fecal mass is calculated as:

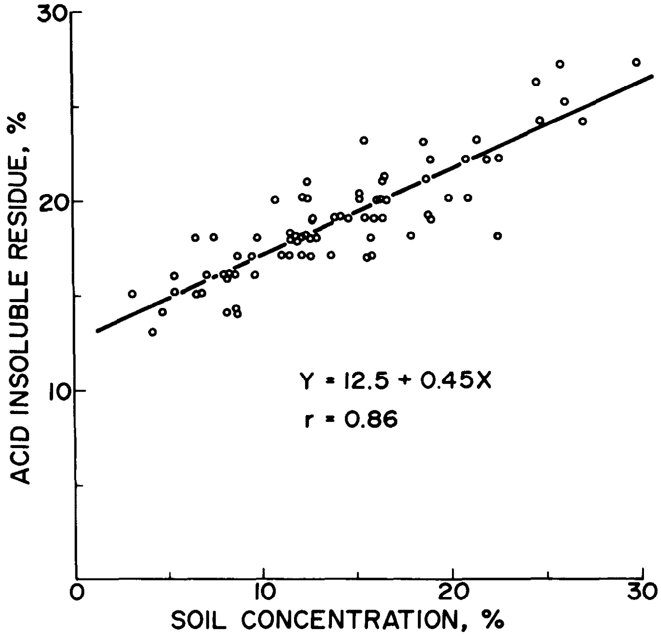


**Fig. 4.** *Acid-insoluble residues in fecal samples as related to soil concentration values determined by the titanium method.*

$$(9 \text{ kg DM intake}) - [(0.50 \text{ digestible})(9 \text{ kg DM})] = 4.5 \text{ kg fecal mass of plant origin} \quad [1]$$

Fecal-soil concentrations given in Figure 1A-E are based on soil plus organic matter. Therefore, if the fecal sample contains 10% soil (organic matter fraction = 0.9), the total fecal excretion is:

$$(4.5 \text{ kg fecal organic matter})/0.9 = 5.0 \text{ kg fecal-soil plus fecal mass of plant origin} \quad [2]$$

The mass of soil ingested is:

$$5.0 \text{ kg total excretion} - 4.5 \text{ kg excreted fecal mass of plant origin} = 0.5 \text{ kg soil ingested} \quad [3]$$

Table 1 gives soil ingestion levels for two dry matter intake rates and four dry matter digestibilities. The calculated values range from a low of 0.1 (early in the season) to as much as 1.5 kg soil ingested/animal-day (later in the grazing season). These values compare reasonably well to those of Healy (1968), who reported a range of 0.25 to 1.25 kg soil/animal-day for dairy cows on humid pastures.

Silica ($SiO_2$) concentrations or acid-insoluble residues (Healy, 1973) in feces are possible indicators of soil ingestion levels. Acid-insoluble residue of feces versus soil concentration values determined by the Ti method are given in Figure 4. The $Y$ intercept of about 13% represents a residue of plant origin, largely $SiO_2$. That the regression coefficient is not 1.0 indicates large variations in the dietary intake of insoluble plant residue.

**Table 1. Soil ingestion levels (kg/animal-day) for a 10% soil increment found in feces calculated for two dry-matter intake levels and four dry-matter digestibility levels.**

| Dry matter intake | Dry matter digestibility 40% | 50% | 60% | 70% |
|---|---|---|---|---|
| 7 | 0.47 | 0.39 | 0.31 | 0.23 |
| 9 | 0.60 | 0.50 | 0.40 | 0.30 |

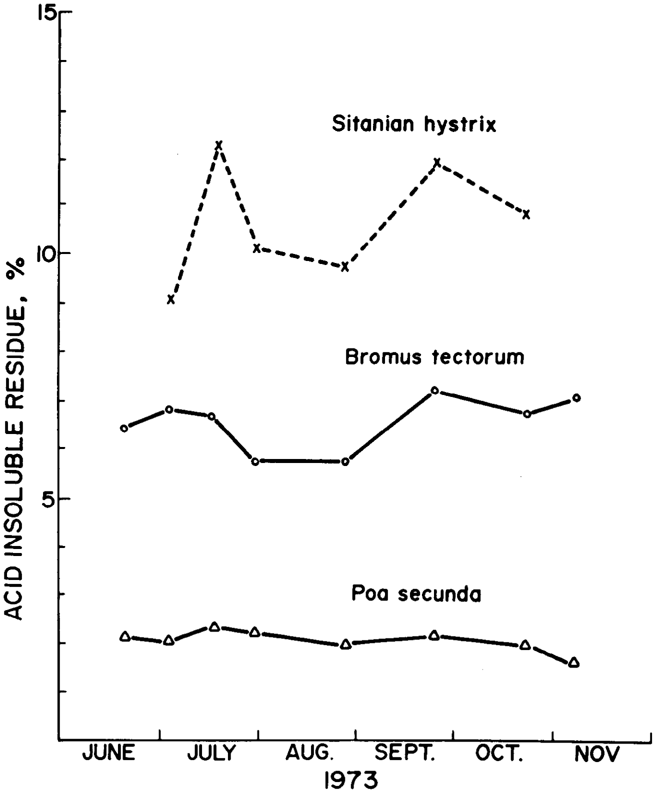


**Fig. 5.** *Acid-insoluble residues in three forage species grazed on the Saylor Creek Experimental Range in 1973.*

Significant differences in the acid-insoluble residue of the three major forage species from the study area are shown in Figure 5. A diet of *Bromus tectorum* having a 50% dry matter digestibility would result in a 12 to 14% acid-insoluble residue predicted at the 0% fecal soil concentration (Fig. 4), but does not explain the 0.5 regression coefficient. About 75 to 85% of the forage in the study area was *Bromus tectorum*, but the inclusion of other grasses in the diet could greatly change the amount of insoluble residue of plant origin which would then appear in the feces.

Thus the acid-insoluble residue or $SiO_2$ concentrations in feces are subject to large changes in forage $SiO_2$ concentrations of the diet. These changes reduce the effectiveness of these two methods for determining soil concentrations in feces and ultimately the level of soil ingestion by animals.

The cattle in this study were ingesting significant amounts of soils. How important this soil ingestion is in contributing to the trace mineral requirement will depend on soil properties (Healy, 1973). Soil ingestion may also be important for uptake of toxic elements, i.e., cadmium, lead, mercury, pesticides, and radionucleides, which are concentrated in the upper few centimeters of soil.

The overall impact of these findings is that a direct soil-animal interrelationship must be considered.

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# THESIS: NEW MEXICO STATE UNIVERSITY

**Effects of Type and Rates of Nitrogen Fertilizers on Blue Grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) Rangeland Production**, by Kenneth Owen Fulgham. MS, Animal, Range, and Wildlife Science. 1972.

A study was conducted on the Fort Stanton Experimental Research Station in Lincoln County, New Mexico, to determine the effects of four types of nitrogen fertilizers applied at two rates on production of a blue grama rangeland.

Ammonium nitrate, ammonium sulfate, sulfur coated urea and urea were applied at rates of 40 lb of nitrogen per acre annually and 80 lb nitrogen per acre biennially.

Fertilization increased production for carruth sagewort, grasses and other forbs ($P < .01$) during the study. The drouth experienced during the study influenced plant composition and production. Production of other forbs increased from 1970 to 1971 while the carruth sagewort and grass production decreased. This was a result of the decreased precipitation. Urea was the most effective nitrogen source over the 2 years. The 80 lb nitrogen per acre rate was more effective the first year while the inverse was true the second year.

Inflorescence production was not significantly influenced by fertilization except that there was a significant response to the low rate of urea in 1970 on blue grama culm heights. Crude protein was increased almost 1% for all fertilizer treatments combined when compared to the control.

# Vegetative Changes on Protected versus Grazed Desert Grassland Ranges in Arizona

DAVID A. SMITH AND ERVIN M. SCHMUTZ

**Highlight:** *Comparison of vegetative changes between a protected and closely grazed desert grassland range in southeastern Arizona showed that velvet mesquite was rapidly invading both ranges at almost equal rates. Arizona cottontop, sideoats grama, and wright buckwheat were dominant in the understory on the protected range while rothrock grama, poverty threeawns, burroweed, and annuals dominated the understory on the grazed range. The grazed range was classed in a low stage of range condition, the protected range in an intermediate stage. Without a change in treatment and management, it is postulated that mesquite will continue to increase on both ranges.*

Conservative stocking is one of the practices recommended to improve depleted desert grassland ranges to a higher state of forage productivity. The question is: How effective is conservative stocking or even complete protection without other treatment in improving desert grassland ranges?

In 1941, Haskell (1945) measured the contrast between a desert grassland range conservatively grazed since 1923 and an adjacent heavily grazed range. Haskell concluded that the conservatively grazed range was in a subclimax stage, undergoing progressive succession toward the climax.

The present study, a follow-up of Haskell's study, was designed to measure the contrast between the same two desert grassland ranges in 1969 and to interpret the effects of grazing, competition, fire, drought, soil, and time on the vegetation.

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## Study Areas

The study areas are northwest of the Santa Catalina mountains in southeast Pinal County, approximately 8 miles west of Oracle, Ariz., at an elevation of 3,700 feet.

The areas consist of two half sections of land, 320 acres each. One of the half sections, a part of the Page-Trowbridge Experimental Ranch, was conservatively grazed from 1923 to 1941 and has been protected from grazing since. The other half section is part of a heavily grazed range on the east.

The areas were mapped as desert grassland by Nichol (1952) and Brown (1973). Presently the vegetation consists of an overstory of trees and shrubs, predominantly velvet mesquite,[1] and an understory of half-shrubs, perennial grasses and forbs, and numerous annuals such as filaree (*Erodium cicutarium*).

The climate of the desert grassland is characterized by low cyclic precipitation and usually high temperatures. Humidity is generally low and water evaporation from soils and surface water is high. Gusty winds accentuate drought conditions in early summer before the summer rainy season begins.

Comparison of longterm rainfall records for Oracle, Ariz., and short-term records on the Page-Trowbridge ranch, indicate that precipitation at the study site averages 15 to 16 inches per year (Haskell, 1945). Approximately half of this precipitation falls during the summer and half in the winter (Smith, 1956). Summer precipitation comes from the Gulf of Mexico in the form of convective thunderstorms during the months of July, August, and September. Winter precipitation comes from the Pacific Ocean in the form of frontal systems during the months of December, January, and February.

Temperatures on the desert grassland are usually adequate for some plant growth. This makes vegetative growth almost entirely dependent on rainfall during the summer months for warm-season plants and during the winter and early spring months for cool-season plants.

The study areas are located on a flat to nearly flat alluvial fan, with a westerly slope not exceeding 5%. Soils are reddish-brown, friable, mostly deep upland loams or sandy loams of granitic origin, slightly acid in reaction and underlain by a distinctly calcareous layer at a depth of 2 to 3 feet (Haskell, 1945).

Soils on the grazed range are undoubtedly in a lower state of productivity than on the protected range due to overgrazing and exposure of the surface horizon to erosion of soil, organic matter, and nutrients. It was

[1] See tables for scientific names of species measured.

observed that filaree dried up quicker on the grazed range than on the protected range. It was also noted that soils on the grazed range were much more compacted due to trampling by livestock.

## Methods

To provide more uniform sampling, each area was divided into eight 40-acre blocks and samples taken in each block. Samples were systematically taken from a random start. Fifty-foot line transects were used. Within each block 10 samples were taken, making a total of 80 samples per pasture. Measurements were made by the line intercept method of Canfield (1941). Perennial grasses and forbs were measured at ground level, trees and shrubs at the crown intercept. Basal cover of perennial grasses and forbs and crown cover of trees and shrubs were used to calculate percentage of cover and percentage composition for each group of plants. A species presence on a line transect was used to determine percentage frequency.

## Results and Discussion

Trees and shrubs produced the highest cover measurements, followed by grasses then forbs (Fig. 1). However, the higher tree and shrub measurements can not be directly compared to the grass and forb measurements since tree and shrub measurements are crown cover measurements and grasses and forbs are basal cover measurements.

Crown cover of shrubs and trees was greatest on the grazed range, while basal cover of grasses was greatest on the protected range. Both grasses and trees and shrubs increased significantly over time, being higher on both grazed and protected ranges in 1969 than in 1941. However, part of these differences over time could be due to climatic differences prior to and during the years of each measurement (Martin and Cable, 1974). The basal cover of forbs was insignificant on both protected and grazed ranges on both dates.

### Trees and Shrubs

The crown cover of trees and shrubs on the protected range was more than twice as great in 1969 as in 1941 (Fig. 1). This resulted because velvet mesquite was nearly six times and wright buckwheat four times as abundant in 1969 (Fig. 2). In contrast to these species, burroweed and other shrubs made no significant changes or

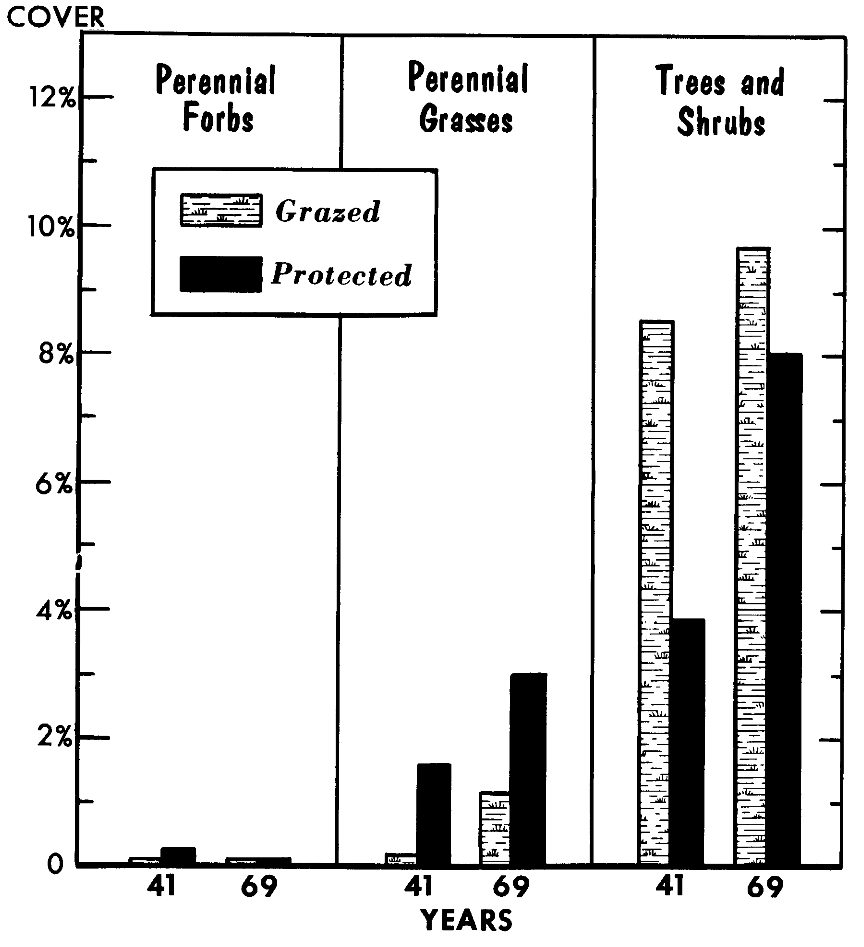


**Fig. 1.** *Basal cover of perennial forbs and grasses and crown cover of trees and shrubs on grazed and protected desert grassland ranges in 1941 and 1969. The 1941 data is from Haskell (1945).*

decreased in crown cover. Because of these changes, velvet mesquite tripled, wright buckwheat doubled, and burroweed declined 60% in species composition (Table 1).

On the protected range mesquite made up only 17% of the tree and shrub cover in 1941 but had increased to 48% in 1969, becoming the dominant species (Table 1). This indicates that protection from grazing alone will not control mesquite and that some other factor such as fire is needed to control mesquite under

**Table 1. Percentage composition and frequency of tree and shrub on the protected and grazed desert grassland ranges in 1941[1] and 1969.**

| Species | Range | Composition 1941 | Composition 1969 | Frequency 1941 | Frequency 1969 |
|---|---|---|---|---|---|
| Burroweed | Grazed | 74.9 | 23.8 | 98.0 | 62.5 |
| (*Haplopappus tenuisectus*) | Protected | 52.1 | 21.2 | 59.3 | 37.5 |
| Sticky snakeweed | Grazed | 9.9 | 11.4 | 45.0 | 51.2 |
| (*Gutierrezia lucida*) | Protected | – | T | – | 7.5 |
| Velvet mesquite | Grazed | 8.9 | 55.0 | 16.2 | 31.2 |
| (*Prosopis juliflora* var. *velutina*) | Protected | 17.4 | 47.7 | 13.1 | 26.2 |
| Wright buckwheat | Grazed | .2 | 1.6 | 1.2 | 3.8 |
| (*Eriogonum wrightii*) | Protected | 16.8 | 31.1 | 25.0 | 6.2 |
| Others | Grazed | 6.1 | 8.2 | 3.3[2] | 3.0[2] |
| | Protected | 13.7 | T | 2.5[2] | 2.8[2] |
| Total | Grazed | 100.0 | 100.0 | – | – |
| | Protected | 100.0 | 100.0 | – | – |

[1] 1941 data is from Haskell (1945).
[2] Average of species recorded.

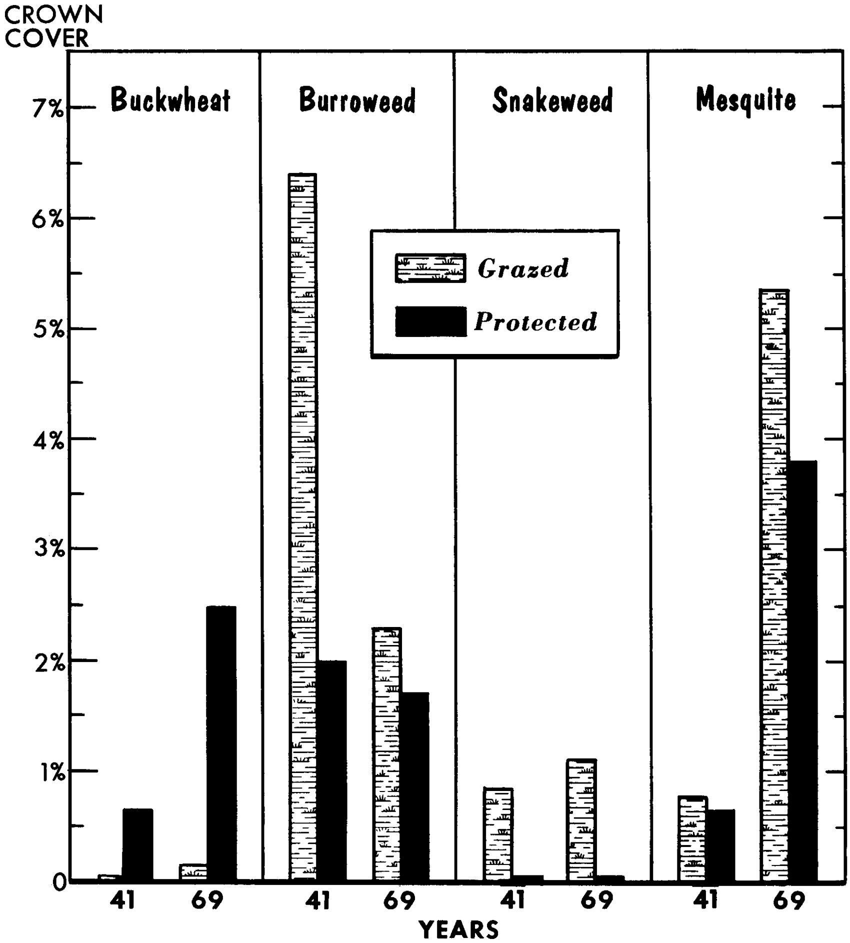


**Fig. 2.** *Crown cover of tree and shrub species on grazed and protected desert grassland ranges in 1941 and 1969. The 1941 data is from Haskell (1945).*

pristine conditions (Humphrey, 1949; Parker and Martin, 1952; Glendening and Paulsen, 1955; Reynolds and Bohning, 1956). However, after mesquite gets established and over 1 to 2 inches in diameter, fire is not very effective (Glendening and Paulsen, 1955; Blydenstein, 1957; Cable, 1961) and the mesquite plants increase rapidly because of their extensive, competitive root system and height dominance.

On the grazed range burroweed was the dominant shrub in 1941 making up 75% of the tree and shrub composition (Table 1). By 1969 composition of burroweed on the grazed area had declined to 24%. This resulted because burroweed declined about two-thirds in crown cover and other trees and shrubs, particularly mesquite, increased in crown cover. As a result, in 1969 mesquite was the dominant shrub on both the grazed and protected range and was increasing at a faster rate than any other tree or shrub.

The sharp decline in crown cover of burroweed on the grazed range, while only slightly declining on the protected range (Fig. 2), is the complete reverse of what usually happens (Humphrey, 1937; Tschirley and Martin, 1961). Reasons for this reversal are not apparent. Grass competition was certainly not a major factor since that would have caused a greater decline on the protected range. Also, Cable (1969) found only moderate competition between grass and mature burroweed plants because of differences in root systems and growing seasons. However, Humphrey (1937) found severe competition between seedling burroweed plants and perennial grasses in the dry spring months when both root systems occupy the same root zone and compete for the same moisture. Mesquite competition could have been a factor in reducing burroweed cover on the grazed range, but mesquite cover was almost as high on the protected range. Furthermore, mesquite and burroweed commonly grow together because the burroweed begins growth on winter and early spring moisture and is well established before the mesquite begins growth. Fire could have caused a difference in burroweed reaction if it burned the grazed range and not the protected range, but this is unlikely since the protected area would have burned more readily. Burroweed stands are known to decline after maturity (Reynolds and Martin, 1968) but greater reductions would be expected on the protected range. Drought could have had a greater effect on burroweed on the closely grazed range than the protected range because of greater runoff and evaporation from more barren soil, but no measurements were made to determine these effects.

Wright buckwheat was insignificant on the grazed range in both years but increased greatly on the protected range both in crown cover and percentage composition (Fig. 2 and Table 1). This response would be expected since it is an aggressive, moderately palatable plant. This would favor an increase in composition on the protected range in the lower stages of improvement and slow or prevent its recovery on the grazed range.

On the protected range both crown cover and percentage composition of sticky snakeweed were insignificant in both 1941 and 1969 (Fig. 2 and Table 1). However, on the grazed range it made up about 10% of the shrub composition in 1941 and had increased only slightly by 1969. From this it appears that close grazing increased the snakeweed, and plant competition, probably competition from the perennial grasses, crowded it out and/or prevented its establishment on the protected range.

The frequency data (Table 1) shows that burroweed was the most widely distributed shrub, occurring on 98% of the transects on the grazed range in 1941 and 62% of the transects in 1969. Burroweed was also most prevalent on the protected range, occurring on almost 60% of the transects in 1941 and almost 40% in 1969. Sticky snakeweed was second in frequency on the grazed range but nearly absent on the protected range. Velvet mesquite was third in frequency, being about evenly distributed on the protected and grazed range; wright buckwheat was fourth in frequency of distribution. Most frequency data were correlated with crown cover. However, on the protected range, buckwheat frequency declined sharply with an increase in crown cover, indicating that its density increased on restricted areas and died out on other areas.

### Perennial Grasses

On the protected area the cover of perennial grasses was twice as high in 1969 as in 1941 (Fig. 1). This was due primarily to an increase in the midgrasses Arizona cottontop, sideoats grama, cane beardgrass, and the poverty threeawns (Fig. 3). These are generally considered climax plants on this site. Another grass increasing was the introduced Lehmann lovegrass, a plant well adapted to reseeding in the area. This plant is spreading from areas in the southern part of the Page-Trowbridge ranch, where it was seeded in experimental trials during the 1950's. Red threeawn decreased significantly on the protected range in both cover and percentage composition (Fig. 3 and Table 2). This is expected on an improving range. The cover of Rothrock grama on the protected range remained about the same (Fig. 3), but there was a marked decrease in composition as the other grasses increased (Table 2).

Perennial grasses also increased markedly on the grazed range (Fig. 1). However, the big change resulted from an increase in Rothrock grama and the poverty threeawns (Fig. 3), species that appear in the earlier stages of improvement on this site. Substantiating this observation is the fact that both these species were more abundant on the protected range than on the grazed range in 1941. Red threeawn was also more abundant on the protected range in 1941 but had declined by 1969 (Fig. 3). This indicates that it was a pioneer species in the early stages of improvement on this site. Cane beardgrass and sideoats grama were also more abundant on the protected than the grazed range in 1941. However, they continued to increase from 1941 to 1969, indicating that they become established in the early stages of range improvement, and continue through the intermediate stages. Arizona cottontop, not found on any transects in 1941, was abundant in 1969, indicating that it becomes established in an intermediate


**Fig. 3.** *Basal cover of perennial grasses on grazed and protected desert grassland ranges in 1941 and 1969. The 1941 data is from Haskell (1945).*

**Table 2. Percentage composition and frequency of perennial grass on the protected and grazed desert grassland ranges in 1941[1] and 1969.**

| | | Composition | | Frequency | |
|---|---|---|---|---|---|
| Species | Range | 1941 | 1969 | 1941 | 1969 |
| Arizona cottontop | Grazed | – | 7.1 | – | 11.2 |
| (*Digitaria californica*) | Protected | – | 23.3 | – | 35.0 |
| Cane beardgrass | Grazed | 16.7 | 1.8 | 1.9 | 3.7 |
| (*Bothriochloa barbinodis*) | Protected | 11.8 | 9.0 | 24.4 | 30.0 |
| Lehmann lovegrass | Grazed | – | 0.9 | – | 2.5 |
| (*Eragrostis lehmanniana*) | Protected | – | 10.0 | – | 15.0 |
| Poverty threeawns | Grazed | T | 28.6 | 1.2 | 47.5 |
| (*Aristida divaricata* and *hamulosa*) | Protected | 9.9 | 12.3 | 21.9 | 35.0 |
| Red threeawn | Grazed | T | 6.2 | 3.7 | 12.5 |
| (*Aristida longiseta*) | Protected | 42.8 | 11.3 | 85.3 | 36.2 |
| Rothrock grama | Grazed | 50.0 | 46.4 | 39.4 | 51.2 |
| (*Bouteloua rothrockii*) | Protected | 19.7 | 11.7 | 75.6 | 53.7 |
| Sideoats grama | Grazed | – | .9 | – | 1.2 |
| (*Bouteloua curtipendula*) | Protected | 7.9 | 17.7 | 10.6 | 27.5 |
| Others | Grazed | 33.3 | 8.1 | 2.0[2] | 3.4[2] |
| | Protected | 7.9 | 4.7 | 2.4[2] | 3.7[2] |
| Total | Grazed | 100.0 | 100.0 | – | – |
| | Protected | 100.0 | 100.0 | – | – |

[1] 1941 data is from Haskell (1945).
[2] Average of species recorded.

stage of improvement and becomes more abundant in the higher stages of succession.

Grass frequency data (Table 2) are difficult to interpret at these stages of range condition. Distribution of species on an improving range may be largely restricted to areas in close proximity to a seed source so it is difficult to tell whether establishment is limited to this cause or to site restrictions such as on ridgetops in the case of red threeawn or in swales in the case of cane beardgrass and sideoats grama. However, it is quite clear that the reduction in distribution of red threeawn on the protected range is due to a similar reduction in plant cover. On the other hand Rothrock grama showed a substantial reduction in distribution on the protected range without any substantial change in basal cover. This indicates that it was being crowded out of some sites by the taller perennials but continuing to increase on other sites on about one-half of both areas. In fact the data indicate that it was the most widely adapted grass species on both areas under 1969 range conditions. This contrasts with the two other most abundant species, Arizona cottontop and sideoats grama, which occurred on only about one-third of the protected area. These species became most abundant in the swales and better soil areas, where they rapidly increased in basal cover and percentage composition on limited areas. This was probably due to their growth in favored site conditions and in close proximity to seed source.

**Table 3. Percentage composition and frequency of perennial forb on the protected and grazed desert grassland ranges in 1941[1] and 1969.**

| Species | Range | Composition 1941 | Composition 1969 | Frequency 1941 | Frequency 1969 |
|---|---|---|---|---|---|
| Fleabane | Grazed | T | T | 1.9 | 8.7 |
| (*Erigeron* sp.) | Protected | 71.4 | T | 8.7 | 32.5 |
| Gaura | Grazed | T | – | .6 | – |
| (*Gaura* sp.) | Protected | 17.9 | – | 24.4 | – |
| Senna | Grazed | 50.0 | T | 10.6 | 2.5 |
| (*Cassia bauhinioides*) | Protected | – | – | – | – |
| Western ragweed | Grazed | – | T | – | 10.0 |
| (*Ambrosia psilostachya*) | Protected | T | T | .6 | 42.5 |
| Others | Grazed | 50.0 | T | 1.4[2] | 1.6[2] |
| | Protected | 10.7 | T | 1.2[2] | 4.3[2] |
| Total | Grazed | 100.0 | T | – | – |
| | Protected | 100.0 | T | – | – |

[1] 1941 data is from Haskell (1945).
[2] Average of species recorded.

### Perennial Forbs

Fleabane was the most abundant perennial forb in 1941, making up over 70% of the forb composition (Table 3). However, no perennial forb occurred in more than a trace in 1969. Although occurring in only insignificant amounts, perennial forbs were most widely distributed on the protected range. Ragweed, fleabane, and gaura were the most widely distributed species on the protected range; senna, ragweed, and fleabane were most widely distributed on the grazed range.

## Conclusions

Both grazed and protected ranges showed signs of improvement toward and deterioration from the desert grassland climax. The grazed range was in a seriously depleted stage of development in 1941. It was dominated by trees and shrubs (particularly mesquite, burroweed, and snakeweed) and annuals (not recorded in the survey) and had virtually no perennial forbs or grasses, (Fig. 1 and 2). By 1969, Rothrock grama and the poverty threeawns had increased significantly in cover and distribution, indicating an improving trend. Decline in the undesirable burroweed and the moderate increase in the moderately palatable buckwheat between 1941 and 1969 also indicate an improving trend. However, between 1941 and 1969 the more desirable plants, such as Arizona cottontop, cane beardgrass, and sideoats grama, did not increase in significant amounts, indicating a static condition. In contrast, the moderate increase in snakeweed and rapid increase in mesquite indicate a declining condition. Therefore, in 1969 the close-grazed range was still low in range condition although improving slowly. Furthermore, it is not likely to improve much more without the control of mesquite and/or installation of an improved grazing system.

The protected range is in better condition. It has gone through the early stages of improvement where the pioneer species red threeawn and Rothrock grama have increased and are now decreasing or leveling off. The poverty threeawns, are still increasing in cover and distribution but haven't leveled off or decreased. Also, the midgrasses, sideoats grama, cane beardgrass, and Arizona cottontop, are increasing in cover and frequency; the moderately palatable buckwheat is increasing in locally adapted niches; the undesirable burroweed is decreasing in cover, composition, and frequency; and the undesirable snakeweed is not invading. All of these conditions indicate that the range is intermediate in range condition and improving.

The major sign of deterioration on the protected range is the continued rapid increase in velvet mesquite. Although not quite as rapid as on the grazed range, it still represents a threat to continued range improvement. Another threat to climax succession is the invasion of Lehmann lovegrass. On this site it has the ability to grow in association with mesquite better than the native grasses (Cable, 1971). These two species, mesquite and Lehmann lovegrass, may eventually take over the site unless mesquite is controlled. What will happen to the lovegrass if the mesquite is controlled is uncertain at this point on this site, although studies at the Santa Rita Experimental Range indicate that at this elevation on grazed desert grassland ranges the lovegrass will eventually crowd out the native grasses (Cable, 1971). However, lovegrass may not be able to replace the native climax species as readily on a protected range.

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# Long-term Effects of Pocket Gopher Control on Vegetation and Soils of a Subalpine Grassland

W. A. LAYCOCK AND B. Z. RICHARDSON

**Highlight:** *In the half of an exclosure where pocket gopher populations were uncontrolled, dandelion was eliminated from the community and the aboveground peak standing crop of slender wheatgrass, mountain brome, Michaux sagewort, and Rydberg penstemon increased between 1942 and 1973. In the half of the exclosure where gophers were controlled yearly, most species of annuals were absent in 1973, Letterman needlegrass decreased, and slender wheatgrass increased. Tall forbs, mainly Oregon fleabane and sticky geranium, increased in both areas, but the greatest increase occurred where gophers were controlled. Soils within the exclosure were significantly higher in total porosity and significantly lower in bulk density in 1973 than soils in the adjacent area grazed by sheep. Organic matter, nitrogen, and phosphorus contents of the soil were significantly higher where gophers were present in the exclosure than where gophers had been controlled.*

Pocket gophers play a dual and sometimes conflicting role on mountain rangelands. Gopher populations usually are low on ranges in good condition, and their burrowing activities are believed to be largely beneficial through the mixing and deepening of soils (Grinnell, 1923). They also may improve infiltration rates (Ellison, 1946) and possibly increase fertility through excrement deposits and decay of underground food caches (Taylor, 1935).

Gopher populations often increase on ranges depleted by overgrazing and the resulting high populations have been reported to perpetuate large amounts of ephemeral and annual plants because of excessive soil disturbance (Richens, 1965); increase soil erosion (Ellison, 1946); harvest large amounts of forage and thus compete with livestock (Julander et al., 1969); destroy range seedings (Garrison and Moore, 1956; Julander et al., 1959); and keep ranges in poor condition even after grazing pressure has been reduced or eliminated.

Several studies have shown effects on vegetation of reducing or eliminating pocket gophers from native mountain rangelands. Periods of control have been 13 years (Branson and Payne, 1958); 11 years (Turner, 1969, 1973); and 9 years (Moore and Reid, 1951; Ellison and Aldous, 1952).

This paper reports the effects of the presence and absence of northern pocket gophers (*Thomomys talpoides*) on the vegetation and soil of a subalpine grassland in central Utah protected from livestock grazing for 31 years. Ellison and Aldous (1952) reported the results of the first 9 years of the study.

## Methods

The study site was located at an elevation of about 10,000 ft (3,050 m) near the top of the Wasatch Plateau in central Utah. A 4-acre (1.6 ha) area was fenced in 1942 to exclude livestock on a subalpine grassland type previously grazed heavily by domestic sheep for years. The exclosure was divided into two parts; in the north half, gophers were removed by

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trapping at least twice yearly from 1942 through 1956. Since that time gophers have been poisoned at least once a year by bait placed in active burrows. The south half of the exclosure remained untreated. In 1948, a gopher-proof fence was constructed between the two areas. Control in the north half never completely eliminated gophers, but reduced populations markedly. For convenience, the north half will be referred to as "gophers absent" and the south half as "gophers present."

Vegetation was sampled on permanent 1- by 3-m plots, 41 in the "gopher absent" area and 36 in the "gopher present" area. Plots were sampled by the weight estimate method (Pechanec and Pickford, 1937) to determine aboveground peak standing crops of herbage in the late summer of 1942, 1944, 1950, 1956, 1972, and 1973. The 1942 records were obtained before gopher control and thus represent pretreatment conditions. Only 1942, 1956, and 1973 data are presented here. Herbage samples of each of the major species were dried to convert weights to an air-dry basis. A more detailed description of the study site, methodology, and trends in vegetation during the first 9 years of the study was reported by Ellison and Aldous (1952).

In 1973 the vegetation of the adjacent range, which had been grazed yearly by domestic sheep, was sampled using the weight estimate method on 50 temporary plots, each 0.45 $m^2$. The outside plots were adjacent to the exclosure, but at least 15 m from the fence to avoid any influence from the fence or from the gopher control operations in the north half of the exclosure. In 1973, in addition to the weight estimates, the percentage of the surface covered by the aerial projection of plants, exposed litter, total bare ground, and fresh gopher mounds formed the current summer was estimated on all plots.

In October 1972, soils were sampled at 30 locations: 10 in the area where gophers were present, 10 in the area where gophers had been controlled, and 10 in the area grazed by sheep outside the exclosure. At each location, core samples were taken at the 0- to 5-cm and 5- to 10-cm level to determine bulk density and soil porosity (Hoover et al., 1954). The same number of bulk soil samples also were taken at depths of 0–5, 5–10, 10–15, and 15–30 cm to determine soil texture and organic matter, total nitrogen, total phosphorus, and potassium contents. Although the lack of replication of treatments limited interpretations, the various soil properties were subjected to variance analysis considering depth and treatment as fixed effects. Differences among treatment means ($P<.05$) were compared using Duncan's (1955) multiple range test.

## Results and Discussion

### Vegetation in Exclosure, 1942–1973

When the study was started in 1942, Ellison and Aldous (1952) characterized the site as having been degraded by years of heavy sheep grazing because of the preponderance of Letterman needlegrass (*Stipa lettermani*),[1] dandelion (*Taraxacum officinale*), and rhizomatous species such as Rydberg penstemon (*Penstemon rydbergi*), Michaux sagewort (*Artemisia michauxiana*), and yarrow (*Achillea millefolium*) on the site. Ellison (1954) believed that the original "mixed upland-herb association" of the Wasatch Plateau consisted of 70% to 88% perennial forbs, 1% to 21% grasses and sedges, and few annuals.

Total aboveground peak standing crops of herbage in both areas inside the exclosure were essentially the same in 1973 as in 1942, but the 1973 data indicated an upward trend in vegetal composition (Table 1). Trends for some classes of vegetation were the same: amount of herbage of tap-rooted and ephemeral species decreased and amount of tall forbs increased in both areas. Total standing crops of grasses and grasslike species and rhizomatous forbs increased where gophers were present but remained unchanged where gophers were absent.

In the absence of sheep grazing, the trend in vegetation composition has been toward the climax community described by Ellison (1954), but even after 31 years of protection, progress has been slow. The short growing season and other severe climatic factors, and possibly the heavy clay soils, make secondary succession slow on these high elevation rangelands. Tall forbs, which Ellison (1954) believed dominated the original community, have increased in both areas in the exclosure, but even in 1973 they comprised only 8% to 15% of the total peak standing crop. Amounts of almost all species of tall forbs increased in both areas in the exclosure. Where gophers had been controlled, Oregon fleabane (*Erigeron speciosus*) and sticky Geranium (*Geranium viscosissimum*) increased the most both in standing crop and frequency of occurrence. Feeding by gophers may have been a factor in slowing the increase of tall forbs. Even though sticky geranium, Oregon fleabane, Porter ligusticum (*Ligusticum porteri*), and leafy polemonium (*Polemonium foliosissimum*) are not highly preferred gopher foods in the area, they are eaten (Aldous, 1951). When they occur infrequently on the range, even light feeding pressure from gophers may slow their spread. These species are also palatable to deer (personal communication, O. J. Julander), and feeding by deer in the exclosure also could be a factor in slowing their spread.

Dandelion showed the greatest change in amount of herbage for any one species. Gophers in the absence of grazing almost eliminated dandelion from the community, probably because of selective feeding. Dandelion roots are a preferred food of gophers on mountain rangelands (Aldous, 1951; Ward, 1973). Ellison and Aldous (1952) reported that, in the first 9 years of this study, amount of dandelion herbage increased where gophers were absent and decreased drastically where gophers were present. The decline where gophers were present continued; amount of dandelion herbage was less than 1 lb per acre in 1973 compared with 289 lb in 1942 and 241 lb in 1944. Frequency of occurrence on the permanent plots dropped from 100% in 1942 to 6% in 1973. Large reductions of dandelion by gophers in the absence of grazing have also been reported by Branson and Payne (1958), Moore and Reid (1951), and Turner (1969, 1973).

Where gophers were controlled, the peak standing crop of dandelion increased from 1942 through 1956, but then decreased. Frequency of occurrence on the permanent plots where gophers were absent dropped slightly from 95% in 1942 to 85% in 1973. The other main tap-rooted species, pale agoseris (*Agoseris glauca*), increased in both areas until 1956 and then decreased to slightly below original levels.

The doubling of peak standing crops of grass and grasslike plants by 1973 where gophers were present was the result of a large increase in slender wheatgrass and a smaller increase in mountain brome (*Bromus carinatus*). Amount of Letterman needlegrass decreased in both areas between 1942 and 1973, but the decrease was greatest where gophers were controlled.

For rhizomatous forbs the pattern of change was quite different in the two areas. Where gophers were present, peak standing crop increased, largely due to a doubling of amount

[1] Nomenclature of vascular plants follows Holmgren and Reveal (1966).

**Table 1. Amount of herbage (lb/acre aboveground peak standing crop) in 1942, 1956, and 1973, and species frequency (%) in 1942 and 1973 in an exclosure where gophers were allowed to remain in one half and controlled yearly in the other half; and production in 1973 on grazed range outside the exclosure where gophers were not controlled.**

| | Herbage production (lb/acre) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Exclosure | | | | | | Grazed range | Frequency (%) on plots (exclosure) | | | |
| | Gophers absent | | | Gophers present | | | Gophers present | Gophers absent | | Gophers present | |
| Species | 1942 | 1956 | 1973 | 1942 | 1956 | 1973 | 1973 | 1942 | 1973 | 1942 | 1973 |
| Grass and grasslike | | | | | | | | | | | |
| *Agropyron trachycaulum* | 14 | 3 | 85 | 26 | 62 | 175 | 97 | 73 | 98 | 94 | 100 |
| *Bromus carinatus* | 0 | 0 | 1 | 1 | 5 | 27 | 2 | 0 | 7 | 6 | 36 |
| *Stipa columbiana* | 7 | 18 | 14 | 6 | 77 | 15 | 12 | 56 | 73 | 75 | 75 |
| *Stipa lettermani* | 230 | 166 | 142 | 69 | 86 | 33 | 110 | 100 | 100 | 100 | 92 |
| Others | 3 | 1 | 2 | 9 | 5 | 8 | 7 | – | – | – | – |
| Total grass | 254 | 188 | 244 | 111 | 235 | 258 | 228 | – | – | – | – |
| Tap-rooted | | | | | | | | | | | |
| *Agoseris glauca* | 9 | 36 | 5 | 10 | 38 | 8 | 29 | 71 | 68 | 72 | 61 |
| *Taraxacum officinale* | 65 | 125 | 13 | 289 | 5 | T[1] | 19 | 95 | 85 | 100 | 6 |
| Others | 4 | 12 | 2 | 6 | 2 | 14 | 1 | – | – | – | – |
| Total tap-rooted | 78 | 173 | 20 | 305 | 45 | 22 | 49 | – | – | – | – |
| Rhizomatous | | | | | | | | | | | |
| *Achillea millefolium* | 77 | 6 | 30 | 131 | 6 | 14 | 21 | 100 | 98 | 100 | 97 |
| *Artemisia michauxiana* | 336 | 147 | 314 | 167 | 257 | 380 | 157 | 95 | 95 | 97 | 100 |
| *Penstemon rydbergi* | 149 | 128 | 200 | 300 | 396 | 307 | 132 | 66 | 80 | 97 | 97 |
| *Vicia americana* | 15 | 18 | 11 | 5 | 21 | 19 | 16 | 98 | 98 | 97 | 100 |
| Others | 6 | 19 | 26 | 15 | 60 | 68 | 24 | – | – | – | – |
| Total rhizomatous | 583 | 318 | 581 | 618 | 740 | 788 | 350 | – | – | – | – |
| Tall forb | | | | | | | | | | | |
| *Erigeron speciosus* | 2 | 2 | 39 | 1 | 0 | 5 | 0 | 10 | 46 | 17 | 6 |
| *Geranium viscosissimum* | 1 | 9 | 49 | T | 4 | 14 | 8 | 17 | 61 | 3 | 17 |
| *Ligusticum porteri* | 1 | 8 | 8 | 1 | 10 | 11 | 0 | 7 | 29 | 7 | 31 |
| *Potentilla gracilis* | 4 | 11 | 16 | 4 | 10 | 15 | 38 | 27 | 34 | 41 | 44 |
| *Thalictrum fendleri* | 19 | 41 | 25 | 28 | 58 | 31 | 40 | 66 | 66 | 67 | 72 |
| Others | 1 | T | 8 | 2 | T | 12 | T | – | – | – | – |
| Total tall forbs | 28 | 71 | 145 | 36 | 82 | 88 | 86 | – | – | – | – |
| Annuals & ephemerals | | | | | | | | | | | |
| *Collomia linearis* | 4 | T | 0 | 13 | 2 | 16 | 4 | 85 | 0 | 97 | 67 |
| Other annuals | 5 | 0 | T | 10 | T | T | 5 | – | – | – | – |
| *Viola nuttalli* | 40 | 48 | 2 | 17 | 2 | 0 | 3 | 100 | 37 | 78 | 0 |
| Other ephemerals | 9 | 1 | 3 | 8 | 1 | 2 | 4 | – | – | – | – |
| Total annuals & ephemerals | 58 | 49 | 5 | 48 | 5 | 18 | 16 | – | – | – | – |
| Shrubs | | | | | | | | | | | |
| *Chrysothamnus viscidiflorus* | T | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| Total production | 1,001 | 800 | 996 | 1,118 | 1,107 | 1,174 | 729 | – | – | – | – |

[1] T=Trace (< .5 lb/acre).

of herbage of Michaux sagewort. The presence of gophers apparently favored Michaux sagewort and the widespread occurrence and high production of this species may have inhibited other more desirable forbs. Where gophers were controlled, rhizomatous species declined almost 50% from 1942 through 1956, but then increased to their original level by 1973. Both Michaux sagewort and Rydberg penstemon followed this pattern where gophers were controlled. As reported by Ellison and Aldous (1952), Rydberg penstemon increased where gophers were present, but the increase continued only until 1956; then amount of herbage of this species dropped to its original level. Yarrow decreased in both areas, but the largest change occurred where gophers were present.

The number of plant species recorded on the quadrats totaled:

| | 1942 | 1956 | 1973 |
|---|---|---|---|
| Gophers present | 44 | 31 | 33 |
| Gophers absent | 38 | 31 | 35 |

Rockjasmine (*Androsace septentrionalis*), which produced little aboveground biomass, was present on more than 70% of the quadrats in both areas in 1942 and completely absent in 1973. Other species which occurred in both areas in 1942 but were absent in 1973 were yellow evening primrose (*Oenothera flava*) and tuber starwort (*Stellaria jamesiana*). Mountain spring parsley (*Pseudocymopteris montanus*), blue pennycress (*Thlaspi fendleri*), and Nuttall violet (*Viola nutalli*) were present in 1942 but were not found on the quadrats in 1973 in the area where gophers were present.

The annuals, narrowleaved collomia (*Collomia linearis*), lambsquarters (*Chenopodium album*), and Douglas knotweed (*Polygonum douglasi*) were abundant in 1942 in both areas, but were not found on the quadrats in 1973 where gophers were absent. Others have reported the role of pocket gopher disturbance in maintaining native annuals in the community (Moore and Reid, 1951; Laycock, 1958). Annuals remained a part of the vegetal composition where gophers were present inside the exclosure but amount of herbage decreased from 1942 to 1973. Species which had not been recorded in 1942 but were found in 1973 in the area where gophers had been controlled were mountain brome, showy elkweed (*Frasera speciosa*), and skyrocket gilia (*Gilia aggregata*).

Table 2. Summary of ground cover (%), 1973.

| | Exclosure | | Grazed |
|---|---|---|---|
| Type of cover | Gophers absent | Gophers present | Gophers present |
| Plant | 68 | 70 | 51 |
| Litter | 15 | 11 | 14 |
| Bare ground | 17 | 19 | 35 |
| Fresh gopher mounds[1] | 4 | 11 | 18 |

[1] Mounds were a subdivision of the bare ground figure.

### Vegetation of Area Grazed by Sheep, 1973

No direct comparisons since 1942 could be established for the grazed area, because it was sampled only in 1973. However, if we assume that the vegetation in the grazed area was similar to that inside the exclosure when it was built in 1942, some conclusions can be drawn. Changes have occurred under continued sheep grazing which has been at a much lower intensity than in the early years of the century and in the presence of a rather high population of gophers. These trends generally were in the direction of the mixed upland-herb association described by Ellison (1954), but did not represent a very large change.

Aboveground peak standing crops and species composition of grasses and grasslike species were nearly the same on the grazed area in 1973 as they were in the area where gophers were absent inside the exclosure (Table 1). Slender wheatgrass appears to have increased considerably and Letterman needlegrass appears to have decreased since 1942, both on the grazed area and inside the exclosure. Comparison with the 1942 data indicates that rhizomatous and tap-rooted forb species probably have decreased on the grazed area. Peak standing crops of ephemerals and annuals on the grazed range in 1973 were similar to those in the area where gophers were present inside the exclosure.

### Ground Cover

Where gophers had been controlled, only 4% of the gound surface was covered by fresh (current summer) gopher mounds in 1973, indicating a small population of gophers (Table 2). Where gophers had not been controlled, fresh mounds covered 11% of the ground inside the exclosure and 18% on the grazed area. Plant and litter cover estimates were similar for the two areas inside the exclosure. The area grazed by sheep had considerably less plant cover and more total bare ground than either area protected from grazing.

### Soil

The soil was classified as a clay texture with particle sizes ranging from 41% to 57% clay, 27% to 43% silt, and 11% to 24% sand. The averages were 49% clay, 34% silt, and 17% sand. Gravel content (particles larger than 2 mm) ranged from 9% to 12%. All areas had similar soil texture but with some differences in percentages of sand, clay, and gravel (Table 3).

Regardless of the presence or absence of gophers, soils within the exclosure were significantly higher in total porosity and significantly lower in bulk density than soils in the area grazed by sheep. The presence of gophers and their burrowing activities in the absence of grazing apparently helped maintain soil tilth. Ellison and Aldous (1952) made the following observations about the study site: "The soil of the south side of the experimental area, where gophers are present, is much looser and softer than the soil of the north side where gophers are absent. . . . The difference is even more marked between the south side and the adjacent range where gophers are also present."

The soil samples taken in 1972 confirmed and quantified these differences. Bulk density was significantly lower and noncapillary porosity was significantly higher where gophers were present in the exclosure than where they were absent. On the grazed area, compaction caused by sheep grazing on these clay soils evidently more than offset the loosening effects of the burrowing activities of gophers and resulted in lower total porosity and higher bulk density on the grazed range.

In the absence of grazing, gophers apparently had other beneficial effects on the soil. Organic matter, total nitrogen, and total phosphorus were significantly higher where gophers

Table 3. Summary of soil data, 1972.

| Site | Depth (cm) | Organ. matter (%) | Total N (%) | Total P (%) | K (ppm) | Bulk density (g/cc) | Capillary porosity (%) | Non-capillary porosity (%) | Total porosity (%) | Texture: Sand (%) | Texture: Silt (%) | Texture: Clay (%) | Gravel (> 2 mm) (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exclosure– gophers absent | 0–5 | 7.5 | .34 | .15 | 8,800 | .86 | 41.8 | 20.0 | 61.8 | 20.5 | 33.1 | 46.4 | 12.0 |
| | 5–10 | 6.0 | .28 | .14 | – | .99 | 41.9 | 15.1 | 57.0 | 16.5 | 34.6 | 48.9 | 11.8 |
| | 10–15 | 5.1 | .25 | .13 | – | – | – | – | – | 15.3 | 34.7 | 50.0 | 11.8 |
| | 15–30 | 5.0 | .24 | .13 | – | – | – | – | – | 14.5 | 34.8 | 50.7 | 11.3 |
| Average | | 5.9a[1] | .28a | .14a | 8,800a | .92b | 41.8a | 17.6a | 59.4a | 16.7a | 34.3a | 49.0ab | 11.7a |
| Exclosure– gophers present | 0–5 | 8.7 | .38 | .16 | 9,600 | .82 | 38.3 | 25.0 | 63.3 | 17.0 | 32.6 | 50.3 | 9.2 |
| | 5–10 | 7.4 | .34 | .16 | – | .84 | 39.0 | 19.6 | 58.6 | 15.2 | 34.6 | 50.2 | 10.5 |
| | 10–15 | 5.9 | .31 | .16 | – | – | – | – | – | 16.3 | 34.3 | 49.4 | 9.0 |
| | 15–30 | 6.0 | .29 | .15 | – | – | – | – | – | 14.2 | 34.3 | 51.5 | 9.5 |
| Average | | 7.0b | .33b | .16b | 9,600a | .83a | 38.6b | 22.3b | 60.9a | 15.7ab | 33.9a | 50.4b | 9.6b |
| Grazed– gophers present | 0–5 | 7.9 | .35 | .14 | 9,400 | 1.01 | 39.2 | 15.6 | 54.8 | 19.3 | 33.3 | 47.4 | 9.2 |
| | 5–10 | 6.7 | .31 | .15 | – | 1.03 | 37.5 | 15.5 | 53.0 | 17.2 | 35.3 | 47.5 | 9.9 |
| | 10–15 | 5.6 | .27 | .14 | – | – | – | – | – | 16.0 | 36.8 | 47.2 | 7.6 |
| | 15–30 | 4.3 | .24 | .14 | – | – | – | – | – | 16.8 | 33.8 | 49.4 | 10.2 |
| Average | | 6.1a | .29a | .14a | 9,400a | 1.02c | 38.3b | 15.6a | 53.9b | 17.3b | 34.8a | 47.9a | 9.2b |

[1] For each column, treatment means were averaged over all depths sampled and compared using Duncan's (1955) multiple range test. Means followed by the same letter are not significantly different at the 5% level.

were present inside the exclosure than in the other two areas. This may have been the result of burial of plant material and litter as mounds were formed, decay of unused underground food caches, and distribution of excrement throughout the burrow system. Taylor (1935) and Greene and Reynard (1932) reported similar changes in soil due to the burrowing activities of other rodents.

The increase in soil fertility was not reflected in the total amount of herbage produced; both areas inside the exclosure had similar aboveground peak standing crops in 1942 and in 1973. Perhaps the disturbance to the vegetation by the burrowing activities plus the material harvested and consumed by the gophers offset the increased fertility of the soil.

Organic matter, total nitrogen, and total phosphorus were not significantly different between the area grazed by sheep and the area where gophers had been controlled inside the exclosure. Potassium content at the 0–5 cm depth did not differ significantly among areas.

Organic matter and total nitrogen decreased significantly with depth of sampling, but the total phosphorus content remained relatively constant with depth. Silt and clay increased significantly with depth but gravel content was unchanged. Bulk density was significantly lower and noncapillary and total porosity were significantly higher at the 0–5 cm than at the 5–10 cm depth. The interaction between treatment and depth of sampling was not statistically significant for any of the soil properties measured.

## Summary

Pocket gophers were controlled in one half and left undisturbed in the other half of an exclosure built in 1942 on depleted subalpine grassland on the Wasatch Plateau in central Utah. Total aboveground peak standing crop in both areas inside the exclosure was the same in 1973 as it had been in 1942. Trends in vegetal composition were generally toward the "mixed upland-herb association" described by Ellison (1954). Tall forbs, mainly Oregon fleabane and sticky geranium, were quite scarce in the area in 1942 and have since increased in both areas inside the exclosure. Selective feeding by gophers may have been a factor in the rate of increase because tall forbs increased more in the area where gophers were absent than where gophers were present.

Total peak standing crop of grasses increased where gophers were present in the exclosure as a result of increases in slender wheatgrass and mountain brome. Letterman needlegrass decreased in both areas inside the exclosure and on the grazed range, but where gophers had been controlled, the decrease was offset by an increase in slender wheatgrass.

The peak standing crop of dandelion decreased on both ungrazed areas and on the grazed range but, where gophers were present inside the exclosure, feeding pressure almost eliminated dandelion from the community, Michaux sagewort increased in the exclosure where gophers were present. Where gophers had been controlled, Michaux sagewort and other rhizomatous forbs decreased from 1942 through 1956 but then increased to original levels by 1973. Ephemeral species declined in all areas. Annuals were scarce in 1973 in the exclosure where gophers had been controlled but were maintained in the stand by the digging activities where gophers were present.

The clay soils of the study site varied only slightly in texture among the areas sampled. Exclusion of sheep grazing resulted in significantly higher total porosity and lower bulk density of the soil. Where gophers were present in the exclosure, noncapillary porosity, organic matter, total nitrogen, and total phosphorus were higher and bulk density was lower than where gophers were absent or on the grazed area. Potassium content of the soil did not differ among areas.

The increased soil fertility where gophers were present was not reflected in total peak standing crops. Damage to vegetation by consumption or burrowing activities of the pocket gophers may have offset the increased fertility.

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# Environmental Factors Related to Medusahead Distribution

B. E. DAHL AND E. W. TISDALE

**Highlight:** *Sites particularly susceptible to medusahead invasion in the more arid portions of Idaho were either those with well-developed soil profiles, particularly those with high clay content either at or near the surface; or those occupying topographic positions that received additional run-off from adjacent sites. In more mesic climates moderately well developed soils appeared as highly susceptible as the well-developed soils. Conversely, soils with little profile development, particularly those which were well drained, remained dominated by cheatgrass in early seral stages regardless of whether they were in the more arid or mesic areas. The nature of the surface geology as it influenced the soil texture derived therefrom was a valuable aid to identifying sites susceptible to medusahead. Maintaining a good stand of perennial vegetation appeared the best barrier to medusahead invasion into susceptible soils.*

The introduction and subsequent rapid spread of medusahead wildrye (*Taeniatherum asperum* Nevski) in Idaho is an increasing cause of concern to all who manage rangelands adapted to this plant. Torrell et al. (1961) regarded this annual grass as the worst range weed in Idaho because of its rapid migration, vigorous competitive nature, and low forage value. It is a serious problem on more than 700,000 acres of rangeland in the 10–20-inch precipitation zone of southwestern Idaho (Hironaka, 1963) where grazing capacity has been reduced as much as 80% in some infested areas (Hironaka, 1961).

McKell et al. (1962) suggest that if the site requirements of medusahead completely overlap those of cheatgrass (*Bromus tectorum* L.), it could spread widely in the Intermountain Region. Cheatgrass is also an exotic annual invader of rangelands, but unlike medusahead, it has distinct value for livestock forage. Although medusahead is reported best adapted to soils that contain considerable clay (Major et al., 1960; Young and Evans, 1970) it was feared that it could replace much of the cheatgrass on rangelands in Idaho.

If site characteristics that favor successful medusahead establishment were known, range improvement efforts could be concentrated on those sites most likely to be invaded. Therefore, the primary objective of this study was to ascertain and describe those site characteristics most favorable to the establishment and growth of medusahead.

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## Description of the Study Area

Major medusahead infestations occur in Gem, Payette, and Washington counties, while less extensive but sizeable areas exist in Ada, Adams, Boise, Idaho, Nez Perce, and Owyhee counties. Spot infestations were found in Canyon, Clearwater, Elmore, and Latah counties (Fig. 1).

The study area has considerable variation in relief, slope, and type of landscape. Squaw Mountain in Washington County, at approximately 5,850 feet elevation, is the highest point within the medusahead-infested region. In the northern portion the Lewiston Basin is only 747 feet above sea level; in

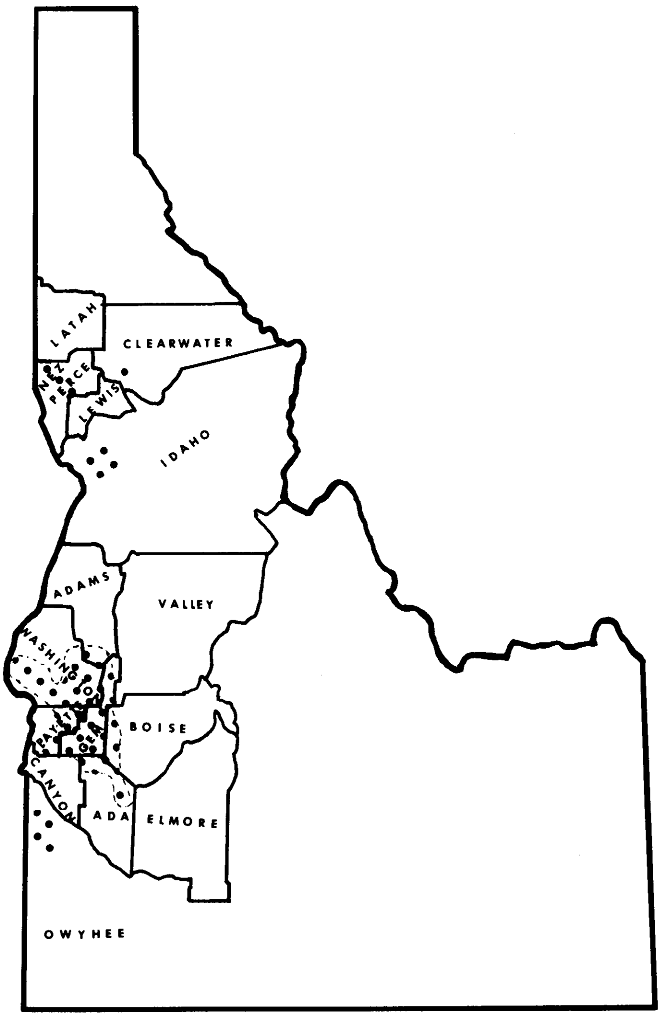


**Fig. 1.** *Map of medusahead infestation and the study areas in Idaho. Dots indicate extent of infestation in 1964.*

the southern portion the regional low of 2,010 feet occurs on the Snake River north of Payette. Local differences in relief of 900 to 1,200 feet are common throughout the area.

The climate is characterized by a modified maritime type of seasonal precipitation, with over half of the annual total occurring from October through April. The amount of precipitation during July and August is normally very low. Temperatures in the northern portions of the area are relatively mild for the latitude, especially in the lower valleys. Data from representative stations are shown in Table 1.

Native vegetation ranges from Pacific Northwest bunchgrass in the north to sagebrush-grass in the south. Most sites studied were occupied by seral communities composed primarily of annuals. With the exception of two sites in Nez Perce County and one near Orofino in Clearwater County, the study was conducted south of the Clearwater River. In the northern portion two principal vegetation zones, the *Festuca/Agropyron* and *Agropyron/Poa*, can be distinguished. The former is associated with soils of the Chernozem and Prairie Great Soil Groups (Xerolls), and the latter zone with Chestnut soils (Xerolls). Due to cultivation of the more mesic areas, the bulk of the remaining grasslands are in the *Agropyron/Poa* zone (Tisdale et al., 1959).

All sites studied in southern Idaho are in the sagebrush-grass vegetation zone characterized by dominance of a woody species of *Artemisia* and one or more perennial grasses (Tisdale et al., 1969). Much of the perennial vegetation of the area has been replaced by annuals, especially cheatgrass. It is these stands that have been invaded more recently by medusahead. Types of the original sagebrush vegetation involved include several dominated by one of the subspecies of big sagebrush (*Artemisia tridentata*), as well as communities in which dwarf sagebrushes (*A. arbuscula* and *A. rigida*) are dominant. Specifically, medusahead infestations have been found in the *Artemisia tridentata vaseyana/Agropyron spicatum; A. tridentata tridentata/Agropyron spicatum/Poa sandbergii; A. arbuscula/Agropyron spicatum;* and *A. rigida/Poa sandbergii* communities. It is possible that other sagebrush communities have become or will be invaded by this annual grass.

## Methods and Procedures

Study sites were chosen throughout the major area of rangeland in Idaho infested by medusahead. Emphasis was placed on areas where sites heavily infested by medusahead occurred closely adjacent to areas similar in degree of depletion (i.e., mostly without perennial species) but occupied by species other than medusahead. On each site at least two macroplots, each 10 feet square, were permanently marked and studied intensively. One plot was placed on that portion of the site occupied by medusahead and another on the area where medusahead was rare or lacking. Occasionally, plots intermediate between these conditions were chosen. Data on elevation, aspect, percent slope, position on slope, vegetation, and soils were obtained at each plot.

The current year's growth of vegetation was clipped at ground level from five square-foot subplots on each macroplot. Density and frequency were also determined for all species. However, only the air-dry weight of medusahead and cheatgrass were used to indicate the degree of dominance of each species on the study sites. Adjacent to each intensively sampled plot a soil pit was excavated and a standard profile description made. Analyses performed on samples taken from each horizon included texture, bulk density, total pore space, organic matter, air space, moisture retention at 1/3 and 15 atmospheres and at 60 cm tension, and a clay mineral index.

The clay mineral index was calculated as 100 less percent air space. Subtraction of the percent air space from 100 was done to eliminate negative values. The method used to obtain percent air space (% total pore space less % total water held at 60 cm tension) often results in negative values if expanding lattice clay minerals are important in the soil. This results because clods used for bulk density determination are in a dry, shrunken state giving high bulk density values. The amount of moisture held by these clay soils at 60 cm tension is very high due to their expansion on wetting, and often exceeds the calculated percent total pore space. Values from this formula give reasonable indexes of the amount of expanding lattice clay minerals in the soil horizon and were used for this purpose.

**Table 1. Climatological data for representative stations in medusahead-infested portions of Idaho (through 1972).**

| Station | Elevation (feet) | Latitude | Mean annual precipitation (inches) | Mean annual temperature (°F) July | Mean annual temperature (°F) Jan. |
|---|---|---|---|---|---|
| Southern portion | | | | | |
| Mountain Home | 3,180 | 43°07′ | 8.78 | 73.7 | 28.3 |
| Boise (airport) | 2,842 | 43°34′ | 11.43 | 75.2 | 29.1 |
| Parma Exp. Sta. | 2,215 | 43°48′ | 9.34 | 73;6 | 28.3 |
| Emmett | 2,500 | 43°52′ | 12.43 | 73.7 | 29.5 |
| Weiser | 2,120 | 44°14′ | 11.31 | 75.4 | 27.5 |
| Cambridge | 2,650 | 44°34′ | 19.71 | 74.1 | 22.3 |
| Northern portion | | | | | |
| Grangeville | 3,355 | 45°55′ | 22.65 | 67.0 | 27.7 |
| Lewiston Airport | 1,413 | 46°23′ | 13.24 | 73.8 | 30.7 |
| Orofino | 1,027 | 46°29′ | 25.93 | 73.8 | 31.0 |

A topographic position index was also recorded for each site. Bare ridges and steep convex slopes were considered dry positions and given a rating of one, while wet meadows were rated ten. Positions between these extremes were given intermediate ratings.

## Results and Discussion

To determine site characteristics that were or were not associated with vigorous medusahead stands, the plots were grouped according to degree of dominance of medusahead. Each group is briefly discussed in the following section, with the characteristics of selected sites shown in Table 2.

### Areas with Grumusols and Other Related Soils of High Clay Content

Ten of the plots studied were either Grumusols (Table 2, Plot 18) or closely related types (Table 2, Plot 1) having characteristic large vertical cracks when dry, and high clay content. Medusahead grew well on all of these regardless of precipitation zone. Clay content of the most developed horizons in these soils varied from 43 to 64%. Study sites with Grumusol soils ranged from the Camas Prairie near Grangeville with 23 inches of precipitation to the Weiser area with 11 inches of precipitation. To illustrate the apparent importance of this type soil, one plot had a Grumusol type clay overlying a speckled white and yellow sandy textured decomposing rock. Where the clay attained a thickness of 6 inches, medusahead was abundant, but it was almost absent where the clay was only 2 inches thick. Young and Evans (1970) indicated that once medusahead fully occupied Grumusol sites in Nevada they were effectively closed to invasion by naturally or artificially introduced species.

### Sites with Mounded Relief

Where medusahead occurred in mounded terrain it was usually confined as a dominant to the intermound areas with cheatgrass remaining dominant on the mounds (Table 2, plots 1 and 27). These mounds were 1 to 3 feet higher than the

**Table 2. Site and soil characteristics for selected study sites.**

| Plot No. | Description | Precipitation | Topographic index | Yield (g/ft$^2$) Medusahead | Cheatgrass | Horizon | Depth (inch) | Texture 1/ | Particle size distribution Sand(%) | Silt(%) | Clay(%) | Structure 2/ | Clay Mineral index | Wilting Coefficient (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | Grumusol | 12 | 2 | 62 | 0 | A1 | 0-1.5 | l | 47 | 38 | 15 | 1cpl | 93 | 8 |
| | | | | | | A3-B1 | 1.5-4 | cl | | | | 1cpl | 131 | 29 |
| | | | | | | B21 | 4-18 | c | 14 | 22 | 64 | 3msbk | 143 | 35 |
| | | | | | | B22 | 18-24 | c | | | | 2csbk | 133 | 31 |
| | | | | | | B3ca | 24-32 | c | | | | 2csbk | 138 | 34 |
| | | | | | | Cmca | 32+ | | | | | | | |
| 1 | Intermound | 10 | 4 | 47 | 4 | A1(A2) | 0-3 | sil | 23 | 57 | 20 | 2fpl | 94 | 12 |
| | | | | | | B21 | 3-9 | c | 9 | 32 | 59 | 3mpr | 147 | 39 |
| | | | | | | B22 | 9-17 | c | 11 | 37 | 52 | 3cabk | 140 | 38 |
| | | | | | | B3ca | 17-24 | sil | 31 | 51 | 18 | 2fsbk | 137 | 41 |
| | | | | | | Cca | 24+ | | | | | | | |
| 3 | Mound | 10 | 3 | 0 | 118 | A11 | 0-1 | sil | 20 | 55 | 25 | 1vfgr | 105 | 16 |
| | | | | | | A12 | 1-6 | sicl | 15 | 57 | 28 | 1fpl | 101 | 14 |
| | | | | | | B21t | 6-16 | sicl | 19 | 46 | 35 | 1mpr | 103 | 17 |
| | | | | | | B22 | 16-23 | sil | 24 | 51 | 25 | 1mpr | 101 | 16 |
| | | | | | | B3ca | 23+ | sil | 19 | 71 | 10 | 1msbk | 101 | 17 |
| 27 | Intermound | 17 | 3 | 93 | 1 | A1 | 0-6 | l | 45 | 35 | 20 | 1mpl | 95 | 12 |
| | | | | | | A3 | 6-10 | l | 44 | 36 | 20 | 1mgr | 87 | 13 |
| | | | | | | B1 | 10-14 | l | 42 | 36 | 22 | 2msbk | 92 | 13 |
| | | | | | | B21 | 14-16 | l | 43 | 33 | 24 | 3csbk | 97 | 14 |
| | | | | | | B22b | 16-21 | cl | 42 | 29 | 29 | 3csbk | 103 | 17 |
| | | | | | | IIB23 | 21-28 | cl | 40 | 28 | 32 | 3cpr | 104 | 16 |
| | | | | | | B3 | 28-31 | scl | 52 | 22 | 26 | 3csbk | 115 | 24 |
| 28 | Mound | 17 | 3 | 2 | 64 | A11 | 0-8 | l | | | | 1cpl | 91 | 22 |
| | | | | | | A12 | 8-11 | l | 35 | 47 | 18 | 1cpl | 90 | 12 |
| | | | | | | A3 | 11-16 | l | 35 | 45 | 20 | 1msbk | 89 | 12 |
| | | | | | | B1 | 16-24 | l | 36 | 45 | 19 | 1msbk | 95 | 13 |
| | | | | | | B2 | 24-36 | l | 36 | 46 | 18 | 1mpr | 98 | 11 |
| 17 | Alluvial fan | 12 | 8 | 46 | 13 | A11 | 0-7 | sl | 53 | 31 | 16 | 1vfgr | 90 | 10 |
| | | | | | | A12 | 7-11 | l | | | | 1cgr | 87 | 7 |
| | | | | | | B(C1) | 11-19 | l | 49 | 39 | 12 | 1sbk | 91 | 9 |
| | | | | | | Bca(C2ca) | 19-22 | l | | | | 2sbk | 87 | 10 |
| | | | | | | Bca(C3ca) | 22-32 | l | | | | 2sbk | 90 | 11 |
| 16 | Alluvial fan | 12 | 8 | 1 | 24 | A11 | 0-2 | ls | 83 | 11 | 6 | 1fpl | 80 | 5 |
| | | | | | | A12 | 2-10 | ls | 83 | 11 | 6 | 1fgr | 73 | 3 |
| | | | | | | C | 10-13 | ls | | | | 1fgr | 76 | 4 |
| | | | | | | A1b | 13-16 | ls | 83 | ~~10~~ | 7 | 1fgr | 83 | 6 |
| | | | | | | C1b | 16-26 | ls | 83 | 10 | 7 | 1fgr | 83 | 5 |
| 25 | Clay pan soil | 11 | 5 | 42 | 6 | A1 | 0-2.5 | sil | 52 | 38 | 10 | 1fpl | 86 | 7 |
| | | | | | | A21 | 2.5-7 | sil | 52 | 38 | 10 | 1cpl | 84 | 8 |
| | | | | | | A22 | 7-11 | sl | | | | 1msbk | 88 | 8 |
| | | | | | | B21 | 11-17 | c | 16 | 38 | 46 | 3cpr | 124 | 32 |
| | | | | | | B3 | 17-21 | sic | | | | 1cpr | 120 | 32 |
| | | | | | | B3ca | 21-25 | sic | | | | 1fsbk | 115 | 32 |
| 26 | Adjacent to clay pen (well drained soil) | 11 | 3 | 1 | 54 | A11 | 0-4 | sil | 74 | 15 | 11 | 1vfgr | 84 | 6 |
| | | | | | | A13 | 4-19 | sil | 74 | 15 | 11 | 1mpl | 80 | 5 |
| | | | | | | C1 | 19-23 | sl | | | | 1msbk | 84 | 6 |
| | | | | | | C2 | 23-28 | sl | 70 | 17 | 13 | 1msbk | 87 | 9 |
| | | | | | | C3 | 28-33 | sl | | | | 1msbk | 89 | 9 |
| 19 | Favorable topography | 10 | 5 | 59 | 16 | A11 | 0-4 | sil | 22 | 65 | 13 | 1fgr | 92 | 14 |
| | | | | | | A12 | 4-10 | sil | 22 | 65 | 13 | 1mpl | 88 | 12 |
| | | | | | | A3 | 10-19 | sil | | | | 1msbk | 93 | 12 |
| | | | | | | B2 | 19-34 | sil | 15 | 61 | 24 | 1mabk | 102 | 15 |
| 20 | Unfavorable topography | 10 | 2 | 0 | 47 | A11 | 0-4.5 | sil | 33 | 63 | 4 | 1fpl | 79 | 5 |
| | | | | | | A2 | 4.5-13 | sil | | | | 1fsbk | 80 | 6 |
| | | | | | | B2 | 13-15 | sil | 36 | 58 | 6 | 1fsbk | 90 | 11 |
| | | | | | | C1m | 15-19 | sil | 36 | 58 | 6 | ? | 96 | 21 |
| | | | | | | C2mca | 19-24 | | | | | | 94 | 15 |
| | | | | | | C3ca | 24-40 | l | | | | | | |
| 23 | Favorable climate (intermediate soil) | 19 | 5 | 49 | 1 | A11 | 0-9 | l | 27 | 49 | 24 | 1fpl | 98 | 16 |
| | | | | | | A+B | 9-11 | sil | | | | 1msbk | 103 | 13 |
| | | | | | | B2 | 11-19 | sil | 21 | 54 | 25 | 2fpr | 99 | 12 |
| | | | | | | B31 | 19-23 | sil | | | | 2msbk | 97 | 11 |
| | | | | | | B32 | 23-30 | sil | | | | 1msbk | 94 | 9 |
| 24 | Favorable climate (well drained soil) | 19 | 3 | 3 | 64 | A11 | 0-3 | l | 42 | 44 | 14 | 1fgr | 91 | 8 |
| | | | | | | A12 | 3-6 | l | | | | 2cpl | 88 | 8 |
| | | | | | | A+B | 6-10 | l | | | | 1msbk | 91 | 9 |
| | | | | | | B | 10-14 | l | 39 | 46 | 15 | 1msbk | 91 | 9 |
| | | | | | | R | 14+ | | | | | | | |
| 9 | Perennial dominated site | 12 | 2 | 6 | 1 | A11 | 0-2 | l | 48 | 39 | 13 | 3fpl | 86 | 6 |
| | | | | | | A12 | 2-11 | l | 43 | 41 | 16 | 3mpl | 84 | 6 |
| | | | | | | B1+A2 | 11-14 | l | 44 | 39 | 17 | 1cpr | 91 | 8 |
| | | | | | | IIB21b | 14-23 | c | 30 | 23 | 47 | 3cpr | 116 | 20 |
| | | | | | | IIB22b | 23-26 | cl | | | | | | |
| 7 | No perennial domination | 12 | 5 | 37 | 1 | A11 | 0-2 | sil | 32 | 50 | 18 | 3fpl | 94 | 8 |
| | | | | | | A12 | 2-8 | l | 33 | 47 | 20 | 3cpl | 92 | 10 |
| | | | | | | A3 | 8-11 | cl | 34 | 36 | 30 | 1fsbk | 91 | 11 |
| | | | | | | B2-A2 | 11-15 | c | 32 | 24 | 44 | 3mp4 | 112 | 17 |
| | | | | | | IIB2 | 15-30 | scl | 47 | 19 | 34 | 3cpr | 110 | 14 |
| | | | | | | IICca | 30+ | | | | | | | |

1/ Texture abbreviations: s = sand or sandy; si = silt; c = clay; l = loam.

2/ Structure abbreviations: c = coarse; m = medium; f = fine; vf = very fine; gr = granular; pl = platy; bk = blocky; pr = prisimatic; a = angular; s = subangular.

intermound areas and had little profile development. The soil from all horizons was mixed (Table 2, plots 3 and 28) at least partially from rodent burrowing, as rodent excavations were common. The mounds often had textural but seldom structural $B_2$ horizons. Conversely, the intermound areas had well-developed profiles with an $A_1$ or often an $A_2$ overlying a textural and structural $B_2$ horizon. Soils of the A horizons were of silt loam to loam texture, with clay loam or clay in the $B_2$ horizons. Depth to the $B_2$ horizon seemed critical in the drier portions and less so in areas of greater precipitation. In the Black's Creek area south of Boise with 10–11 inches annual precipitation, medusahead stands were most dense on soils with clay $B_2$ horizons within 2 to 3 inches of the surface (Plot 1). Where depth to the $B_2$ reached 11 inches, medusahead was absent. On the other hand, this species grew well on intermound areas with a clay $B_2$ horizon at 14–16 inches (Plot 27) in the Riley Butte area of Washington County where annual precipitation averages 16–17 inches.

**Well-developed Soil Profiles vs Soils with Weak Profile Development**

In southwestern Idaho, disturbed sites with well-developed soil profiles were dominated by medusahead, while adjacent areas with weakly developed profiles were generally dominated by cheatgrass (Table 2, plots 25 and 26; Fig. 2). Sites lacking medusahead often had the same soil horizon sequence as those with medusahead, but differed in degree of structural development, clay content of the $B_2$, or depth to the strongest developed horizon. For example, plots 7 and 8 were similar in texture and profile development, but the strongest developed horizon was at a depth of 11 inches on Plot 7 and 33 inches in Plot 8. Plots 10 and 11 had similar horizon depths, but Plot 10 had greater structural B development and the clay content was several percentage points higher. Plots 25 and 26 were within 150 feet of each other and the first 10 inches of each profile were similar silt loams with 10% clay. However, the soil of Plot 25 changed abruptly at 10 inches to a strongly developed columnar structure with 46% clay content (Fig. 2, left) while Plot 26 had little structural development to 33 inches and its maximum clay content was 13% throughout (Fig. 2, right).

Another example of the effect of soil profile development on susceptibility to invasion by medusahead was observed in the case of sites belonging in *Artemisia arbuscula* communities. Over much of the sagebrush region this species of low sagebrush is confined to soils in which strongly developed $B_2$ horizons, usually high in clay content, occur within 12 inches of the soil surface (Fosberg and Hironaka, 1964). Big sagebrush (*A. tridentata*) grows in the same general areas, but on deep, well-drained soils of weak to moderate profile development. From data presented earlier, depleted stands of the *A. Arbuscula* type should offer suitable conditions for the invasion of medusahead.

In 1963, personnel of the Owyhee District, Bureau of Land Management reported infestations of medusahead in a portion of Owyhee County where *A. arbuscula/Agropyron spicatum/Poa sandbergii* community was the type concerned. On stands with fair range condition or better, only scattered plants of medusahead were found, but a dense stand of medusahead had developed on a badly depleted stand of this type. The soil profile revealed a 6-inch $A_2$ horizon of silt loam texture resting on a strongly developed $B_2$ clay horizon extending from 6 to 19 inches in depth. Approximately 100 feet away, a similarly depleted area was dominated by cheatgrass and Sandberg bluegrass, with remnants of *A. tridentata.* The main difference between the soils of the two sites was depth to the $B_2$ horizon, which was 13 inches on the big sagebrush site. It would appear that badly depleted sites of the *A. arbuscula* type are among those in the region susceptible to invasion by medusahead. Young and Evans (1970) report similar findings in Nevada.

**Medusahead-dominated Sites with Weakly Developed Soil Profiles**

While the examples just cited would suggest a clear-cut relationship between degree of profile development and suitability for occupation by medusahead, such was not always the case. Several areas were found where medusahead was abundant on the soils whose profile development, taken alone,

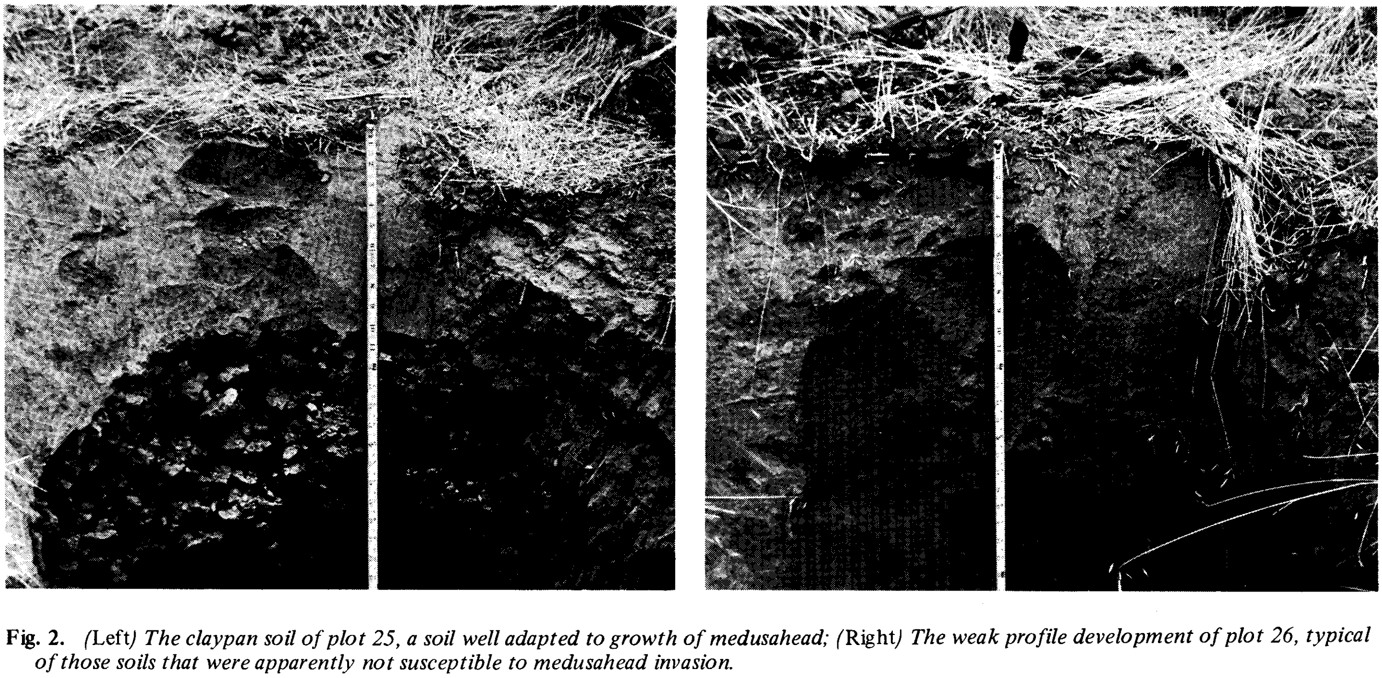

**Fig. 2.** (Left) *The claypan soil of plot 25, a soil well adapted to growth of medusahead;* (Right) *The weak profile development of plot 26, typical of those soils that were apparently not susceptible to medusahead invasion.*

would have seemed poorly suited for this species. These included four study sites in southwestern Idaho, plus a number of areas in the northern portion of the state for which no formal site descriptions were made.

For the southern sites, favorable topographic position for moisture appeared to compensate in large part for weak development of the $B_2$ horizon. The soil at one such site had a textural $B_2$ at 19 inches, but minimal structural development. The site was located in a depression at the head of a drainageway which received extra run-off moisture. An adjacent site with similar soil but located outside the depression was devoid of medusahead (Table 2, plots 19 and 20).

In the northern part of the state, most sites dominated by medusahead were on soils intermediate in profile development (Table 2, plots 23 and 24). More precipitation (14–18 inches annually), plus a relatively mild climate with precipitation mainly in the winter months, produced an environment where medusahead flourished without the strong soil profile development usually required in southern Idaho. Even mounded soils were found to support medusahead in the northern areas.

**Alluvial Fans**

The degree of profile development and the clay content appeared to be primary determinants of medusahead adaptability on alluvial fans. Plots 16 and 17 were on similar appearing fans, yet on Plot 16 red threeawn (*Aristida longiseta*) and cheatgrass dominated, while medusahead and some squirreltail grass (*Sitanion hystrix*) dominated Plot 17. The soil on Plot 16 showed no profile development, had 83% or more of sand, and was well drained by a gully through the fan. Plot 17 had weak profile development with a maximum of 53% sand, and was less well drained (Table 2). Apparently, the combination of more favorable topographic position, lower sand content, and greater profile development offset the need for the well-developed clay B required for medusahead occupation on many sites. However, medusahead did not dominate this site as completely as at many other sites studied. Plots 21 and 22 were also on an alluvial area. Plot 21 was similar to Plot 16, but Plot 22 had a strongly developed $B_2$ horizon at 14 inches with 39% clay and was completely dominated by medusahead.

**Influence of Perennial Competition**

Stands in which medusahead could be rated as anything more than sparse were all seral. In virtually every case, the sites invaded by medusahead had been occupied previously by seral species, mainly annuals, which had in turn replaced climax perennials depleted by overgrazing, fire, or cultivation.

The influence of a remnant perennial stand is shown by a comparison of sites 7 and 9 (Table 2). Site 9 was similar to Site 7 (dominated by medusahead) in soil type, and would also have been expected to be dominated by medusahead if it had not been occupied by the perennial, squirreltail grass. Medusahead had invaded Site 9, but constituted only a small part of the total vegetation, largely replacing other annuals which had grown sparsely in spaces between the perennial grass clumps.

Meadows in the sagebrush-grass, stands of *Artemisia arbuscula* with perennial grasses, and seedings of intermediate wheatgrass on clay soils in Washington County all exhibited this type of perennial control over medusahead and other annuals.

Apparently perennial competition is an effective deterrent to both medusahead and cheatgrass invasion. This does not mean that perennial cover is a total barrier to these annual species. Robocker (1961) has pointed out that some exotic annuals such as cheatgrass have invaded even long-protected native vegetation in semiarid regions and remain as a small part of the total plant cover.

**Relations to Soil Taxonomic Units**

The normal system of soil classification did not allow for soil groupings according to medusahead susceptibility *per se* at the Great Soil Group level, or the Order level of the 7th Approximation (Soil Conservation Service, 1960). However, we found that Grumusols (Vertisols) in the study area were universally susceptible, and that Azonal (Entisol) soils were nonsusceptible. If one were to construct a soil gradient of susceptibility to invasion of medusahead with these two groups at the extremes, he would find that soils having intermediate characteristics represent almost all stages of susceptibility. As Heerwagen and Aandahl (1961) indicate, probably the most meaningful soil-plant relationships occur at the series and type levels. Except for Gem County, formal soil surveys were not available, and even in that county the data were not sufficiently detailed to designate series for all study sites.

**Relation to Geology and Soil Parent Materials**

The pattern of infestation by medusahead in the study area showed strong relationships to the nature of the surface geology and soil parent materials. Generally, the finer the soil texture produced by decomposition of the parent rock, the more suitable were the resulting soils for the growth of medusahead.

Soil developed on basalts (Columbia River basalts, Snake River eruptives) or fine-grained sedimentaries from the Payette and Idaho formation supported the more dense and most extensive stands of medusahead. On the other hand sites whose soils were derived from the Idaho Batholith, Tenmile gravels, eolian and fluviatile sediments and the course-textured Caldwell and Nampa sediments were unlikely to be invaded by this species.

A striking example of the influence of fine soil materials on medusahead invasion was provided in the case of soils derived from the Idaho Batholith. This is the oldest geological formation in the area, and covers large portions of Boise, Valley, and Idaho counties. It consists primarily of granodiorite and quartz monzonite with dikes of aplite and pegmatite. These materials weather rapidly to form deep soils of coarse sandy texture and weak profile development. In rare cases, clays are formed as products of late stage decomposition of feldspars and accessory minerals (Peebles, 1962). Depleted areas on patches of these clay soils were consistently found to be dominated by medusahead, which was otherwise lacking on soils derived from the Batholith.

The other extreme of soil suitability for medusahead was shown in the area west of the Idaho Batholith, in Gem, Payette, and Washington counties. Here the major soil forming material is Columbia River basalt, which produces soils high in montomorillonite-type clays. The most extensive and vigorous stands of medusahead in Idaho occur on this parent material.

## Conclusions

This study indicated that medusahead plants required from 2 to 3 weeks longer than cheatgrass to mature in the spring, hence they require a source of moisture for a longer period. The apparent requirement of medusahead for a soil with a high clay content is probably a function of the soil's water-holding potential rather than the water content *per se*. Where other combinations of site factors provides the needed wet environment, neither an abnormally high clay content nor a clay pan near the soil surface was required for medusahead domination of sites in seral stages. Sites occupying topographic positions where extra water is received from run-off, sites with soils of high clay content either at or near the surface, or regions with a distinct mediterranean pattern of winter precipitation with moderately well-developed soils may be highly susceptible to medusahead invasion if the perennial vegetation has been lost. Conversely, soils with little profile development, particularly those which are well drained, will probably remain dominated by cheatgrass in the early seral stage, and medusahead invasion should be of little consequence. The nature of the surface geology as it influences the soil texture derived therefrom is a valuable aid to identifying sites susceptible to medusahead. Evidence supporting these conclusions comes from a similar study with *Aristida longiseta* and *Agropyron spicatum* by Evans and Tisdale (1972). They found *Aristida* confined to the well-drained sites and soils of loam texture or coarser, whereas *Agropyron* occurred on a wider range of soil textures and topographic positions. *Aristida* replaced the *Agropyron* following heavy grazing use, except that medusahead dominated those soils with high moisture-holding capacity or areas of restricted drainage. Thus medusahead can apparently spread throughout the sagebrush-grass zone of the Intermountain Region on sites here described as susceptible if a seed source becomes available and perennial vegetation is lost. Maintaining good management on nondeteriorated sites in this region should assume new importance.

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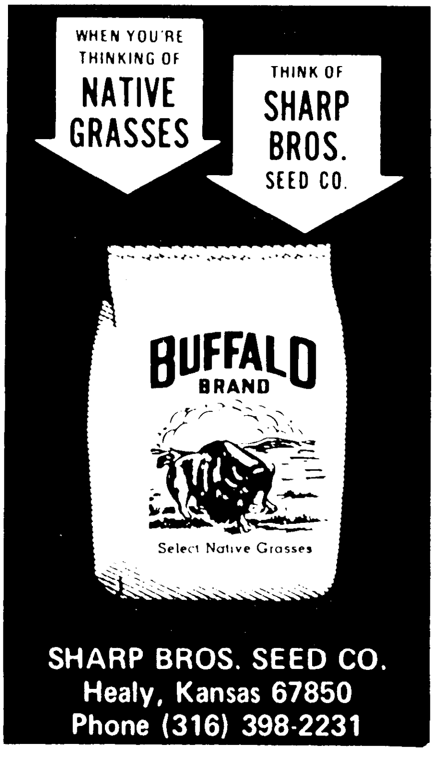
## Position Announcement

**Manager of Biological Station**: The Nature Conservancy is seeking a qualified individual to manage and direct a biological station on a 7,600 acre prairie preserve located in McPherson County, South Dakota, 50 miles northwest of Aberdeen. Must have broad training in grassland ecology, preferably with degree in natural sciences. Experience in and motivation toward the development and establishment of research programs necessary. Will be responsible for all management aspects, including construction, fence repair, and necessary maintenance. Must show ability and willingness to work with minimum of supervision, skill in coordinating volunteers, and responsiveness to local community needs. Salary dependent upon qualifications. Immediate opening. Contact: *Grace M. McDermott, Director of Preserve Management, The Nature Conservancy, 325 W. 15th St., Minneapolis, MN 55403, Phone: (612) 871-6231.*





# Carbohydrate Reserves in Roots of Sand Shin Oak in West Texas

ROBERTO M. BÓO AND R. D. PETTIT

**Highlight:** *Total nonstructural carbohydrate (TNC) concentrations in the root system of sand shin oak (*Quercus havardii*) were analyzed from January, 1972, through December, 1973. Effects of shredding on root reserves were also explored. In both years root TNC varied with the different phenological growth stages. Reserves were gradually depleted throughout the dormant season, November to April, until the low of 6.5 and 7.0% was reached in early May of 1972 and 1973, respectively. TNC then began to accumulate in the roots when the leaves were from 1/3 to 1/2 full size. Shredding significantly reduced root reserves for 6 months. Early leaf expansion is a good indicator of downward carbohydrate translocation and may be the best guideline available for the application of systemic herbicides to effect oak control.*

Seasonal variations of carbohydrate reserves have been analyzed for many plants, and in many cases results have been similar. Some of the variability between species has been attributed to growth behavior and environmental conditions (Cook, 1966). Coyne and Cook (1970) concluded that the most important factor influencing carbohydrate reserves in plants is stage of growth.

McConnell and Garrison (1966) working with bitterbrush (*Purshia tridentata*) reported root carbohydrate reserves to be depleted during the early growing season and during seed formation. Root carbohydrates then accumulated until leaf fall. Similar results were found by Woods et al. (1959) with turkey oak (*Quercus laevis*) and bluejack oak (*Q. incana*). Jones and Laude (1960) found a decrease in root reserves of chamise (*Adenostoma fasciculatum*) coinciding with early spring twig growth.

Carbohydrate reserves are rapidly utilized to produce growth in early spring. If the species is defoliated during growth, reserve carbohydrates are further utilized to promote photosynthetic organs. When root reserves are limited, the rate of growth may be reduced. Donart and Cook (1970) analyzed carbohydrate reserve levels in snowberry (*Symphoricaropos vaccinioides*) and rabbitbrush (*Chrysothamnus viscidiflorus*) after foliage was removed. Rabbitbrush produced fewer stems and regrowth was slower when it was clipped at the low reserve level. Both shrubs were able to replenish root reserves if allowed to produce 20% of their anticipated regrowth. Berg and Plumb (1972) further stated that vigor of sprouting is lowest if shrubs are cut at the time reserves are lowest.

Sand shin oak (*Quercus havardii*) is a low-growing, rhizomatous, deciduous shrub seldom growing more than 1 m tall. The root system consists of both taproots and widespread laterals capable of sprouting along their entire length (McIlvain, 1956). The lateral roots have been described as rhizomes which assume a vertical growth upon reaching the soil surface (Muller, 1951). Root:shoot ratios approach 10:1 (Pettit and Deering, 1971). An example of the root mass is found in Figure 1 (top) while typical aboveground shin oak growth is noted in Figure 1 (bottom).

Herbicide effectiveness in killing this oak has been eratic, and at times very little top kill has occurred. Objectives of this research were to study seasonal variations in sand shin oak root reserve carbohydrates and to monitor the effects of shredding upon these reserves.

## Methods and Materials

The study area, owned by Robert Beasley, was located 15 km north of Plains in Yoakum County, Texas. Climate of the area is continental with an average precipitation of 49 cm. Much of this precipitation results from brief but intense spring and late summer thunderstorms. Topography is level to slightly undulating with numerous wind-eroded pockets up to 30 cm deep.

Dominant soils of the area are Patricia fine sand with inclusions of Brownfield fine sand. They are characterized by having an A horizon with over 90% fine sand to a depth of 40 to 50 cm. A well-developed argillic horizon is found in the subsoil. These soils are Aridic Paleustalfs of the fine mixed thermic family. Water infiltration and percolation are rapid until the wetting front reaches the subsoil.

This sandyland range site supports in addition to the sand shin oak, varying densities of sand sagebrush (*Artemisia filifolia*), broom snakeweed (*Xanthocephalum sarothrae*), fall witchgrass (*Leptoloma cognatum*), little bluestem (*Schizachyrium scoparium*), purple threeawn (*Aristida purpurea*), sand dropseed (*Sporobolus cryptandrus*), and sideoats grama (*Bouteloua curtipendula*).

On each sampling date, stems from five oak plants were randomly selected, then excavated to obtain root materials. From January, 1972, through December, 1973, roots were collected at weekly or biweekly intervals during the growing season and at

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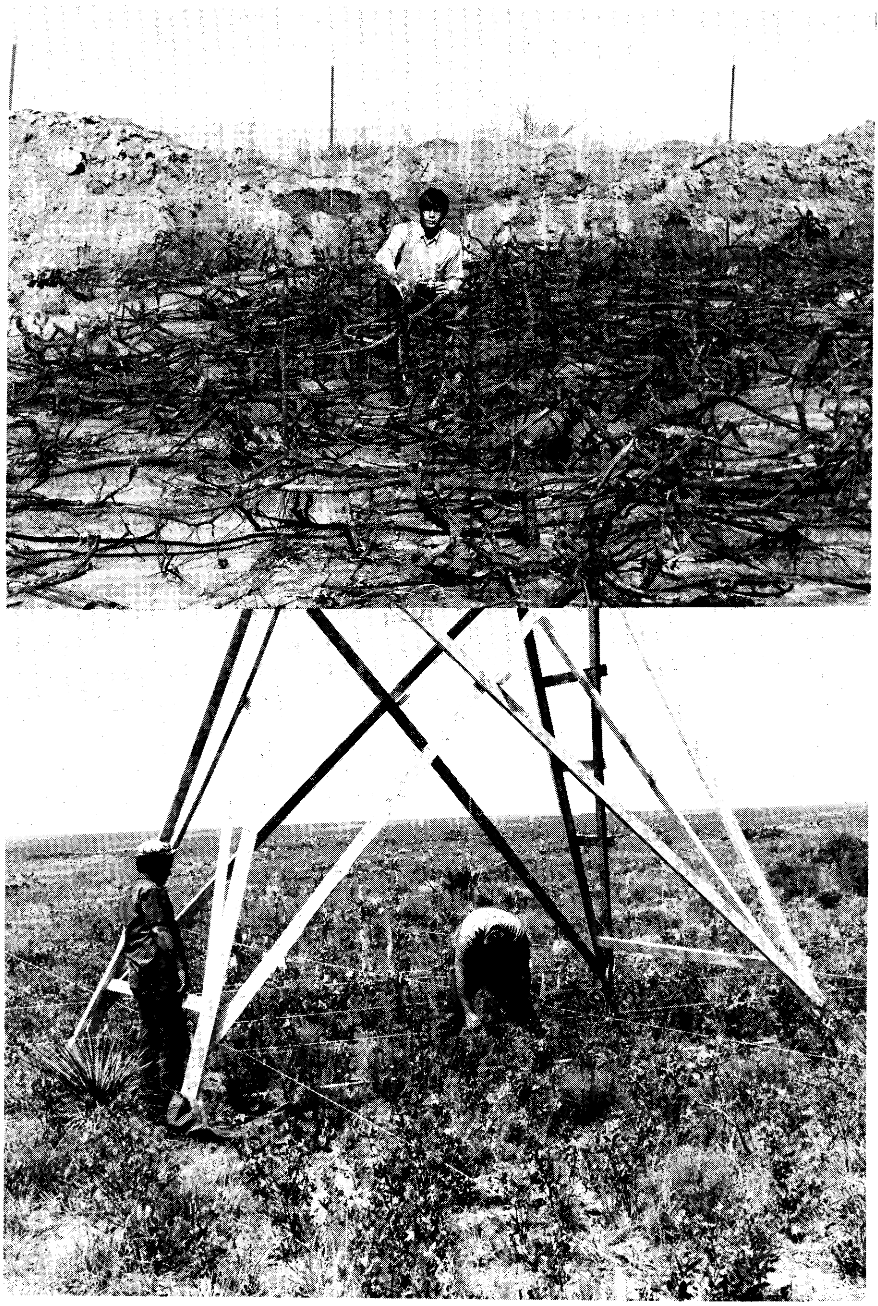

**Fig. 1.** (Top) *Water was used to expose roots within the sand shin oak community. These roots are capable of producing new shoots along their entire length. Only soil in the A horizon has been removed.* (Bottom) *Typical sand shin oak community in West Texas. This view corresponds to plot where roots were exposed* (Top).

monthly intervals in the dormant season. Two size classes of roots were taken from each plant and separated using the following criteria: (a) small; roots directly connected to the aerial portion of the plant with a diameter of 0.5 to 1.0 cm, (b) large; ramifications of roots defined as small and larger than 1 cm in diameter. The roots were excised into 10 to 15 cm sections and placed upon dry ice in an airtight container. They were kept here for at least 5 hours before being transferred to a forced-air drying oven set at 65°C. After drying for a minimum of 2 days, the samples were cleaned to remove rhytidome and wood appearing dead. They were then ground with a Wiley Mill to pass a 1-mm screen before storing in hermetic containers.

On June 1, 1973, 2 ha of the study area were shredded with a power-take-off driven "flail-type" shredder. After regrowth occurred, samples were taken and processed similarly to the unshredded samples.

Samples weighing 0.5 g were hydrolized and extracted with 0.2 *N* hydrochloric acid. Total nonstructural carbohydrates (TNC) contained within this extract were assayed using the anthrone method described by Yemm and Willis (1954).

On each sampling date aboveground stems were collected to accurately describe the phenological growth stage. Anatomical development of each leaf could also be studied. Experimental units used in this study were completely randomized with five replications of each treatment. Data were analyzed as a split-plot factorial, and the means were compared using Duncan's multiple range test. Level of precision used was 0.05.

## Results and Discussion

Data analyses comparing carbohydrate concentrations of the large and small roots showed that they were not significantly different. For this presentation, all datum points for each sampling date represents the average of 10 analyses of root material collected on each date.

### Root Carbohydrate Concentrations

Shin oak root TNC concentrations varied throughout both years in response to phenological changes. With few exceptions this finding is coincident with those already cited for other species (Jones and Laude, 1960; Cook, 1966; and McConnell and Garrison, 1966).

Data from 1972 showed no significant change in root TNC during the first five sampling dates (Fig. 2). On March 16, buds began to enlarge and open. This corresponded to a TNC concentration of 10.7% on a dry weight basis. After this date, root TNC's decreased significantly to a low of 6.5% on May 6. Carbohydrate concentration within the roots were below 7.5% for a month, which is atypical in woody plant roots. This prolonged low TNC level is believed to be due to a killing freeze on March 21. This freeze, 5 days after bud break, delayed the phenological progression.

From May 6 until June 29, TNC's accumulated to 13.8% as photosynthate was rapidly being translocated from leaf tissue into the roots. Root carbohydrates decreased from 12.9 to 8.0% between the July 6 and July 20 sampling dates. No new aboveground growth occurred during this time. Also no acorn production was observed as most flowers had aborted much earlier. Perhaps the most plausible explanation for this decrease would be rapid root growth into a moister subsoil. The upper portion of the soil profile was very dry at this time. It has been suggested that drought could convert all TNC's into mono-saccharides (Stocker, 1961); respiratory losses, then, could be large. We feel, without evidence, that this conversion did not occur within this species.

Between July 20 and August 17 root TNC's increased to over 17%, which was the highest concentration recorded this year. Root carbohydrates were then again utilized for new aboveground growth. Typically, no new top growth of this species occurs in late summer; however, between August 17 and September 15, 16.8 cm of precipitation were received. This precipitation was instrumental in initiating new growth from shallow rhizomes. TNC's then increased slightly until November 11 at which time leaf fall was occurring.

During the dormant season from January 19 to March 30, 1973, no significant difference in root carbohydrates was found (Fig. 2). Root reserves decreased until April 13 after which they again accumulated in the roots. On April 28 plants were visibly breaking dormancy, which accounted for the carbohydrate depletion until May 12. Leaf expansion was then sufficient to produce enough photosynthate to accumulate in the roots until November.

The increase in TNC's before the plants broke dormancy is difficult to explain as this is contradictory to other carbohydrate research. Environmental factors such as water, temperature, light, and possibly soil oxygen levels may affect the physiology of the plant and reduce or stop growth. According to Wardlaw (1968), this could lead to an accumulation of carbohydrates in the storage organs. This, however, appears not to be a tenable explanation for the apparent anomaly in our data. Because of very limited perennial aboveground living tissue, carbohydrate translocation to the roots from aboveground stem storage does not seem plausible. Perhaps there were roots in the soil that act as carbohydrate sinks which could provide a continuum of carbohydrate flow into the root samples.

Prior to bud swelling in the spring it is difficult to differentiate between living and recently dead roots. The xylary tissue varies from white to light brown, thus color is not a good indicator of root condition. Variability between samples on each date during dormancy was greater than was obtained during the growing season. However, this variation was also present in the first 3 months of the year.

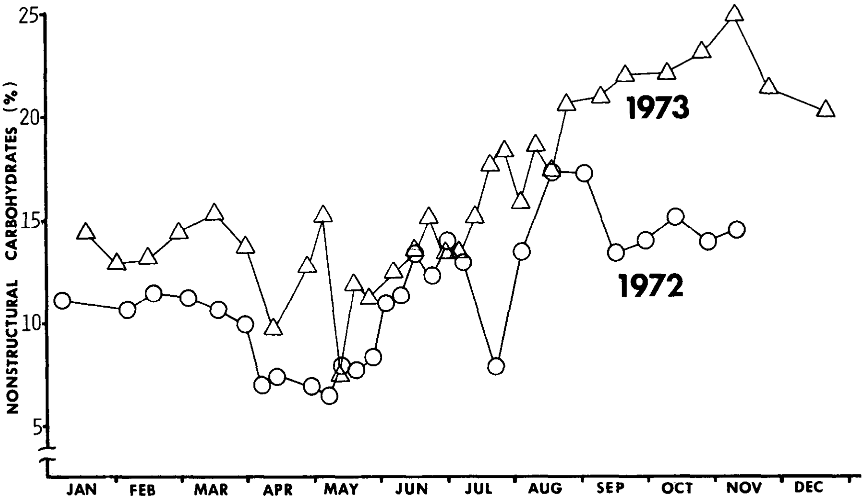


Fig. 2. *Averaged TNC concentration of sand shin oak roots collected in 1972 and 1973 from a west Texas sandyland range site.*

### Relationship of Root Carbohydrates to Leaf Blade Expansion

Leaf blade expansion in relationship to net downward translocation of photosynthate is often used as a guideline for systemic herbicide applications. On many undesirable shrub species, it has often been assumed that to get downward translocation of these herbicides, they should not be applied until leaves were fully expanded. Herbicide application time suggested for sand shin oak is from May 1 to June 15 or when plants are fully leaved.

Our data in 1973 showed that roots began accumulating TNC's when leaves were only 20 mm long, or approximately 1/3 full size (Fig. 3). Similarly root carbohydrates began accumulating in 1972 when leaves were only 1/2 full size. As the leaves expand, wax accumulates very rapidly on the adaxial side which might make the leaf less penetrable by chemicals. Second, all stomata are located on the bottom (abaxial) side of the leaf. Perhaps, then, we might be able to maximize

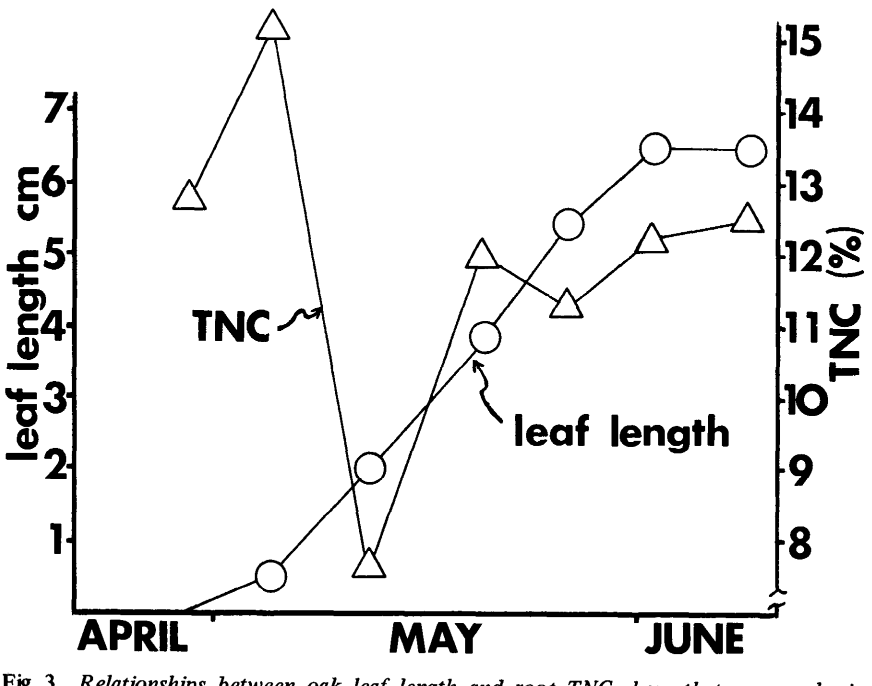


Fig. 3. *Relationships between oak leaf length and root TNC show that reserves begin accumulating in oak roots when leaves are only partially expanded.*

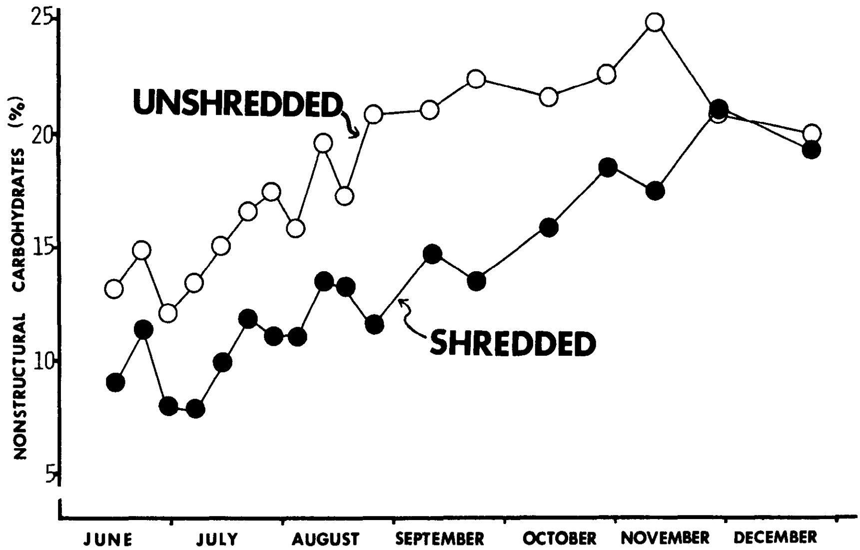


**Fig. 4.** *Shredding the oak once to near ground level effectively has reduced the roots' TNC content until near leaf fall in November.*

downward translocation of systemic herbicides into this plants root system by applying herbicides when leaves are from 1/3 to 1/2 of full size.

### Effect of Shredding on Root Reserves

On June 15 or 2 weeks after 2 ha of the oak was shredded, oak roots were collected and analyzed for TNC's. The average TNC concentration of root tissue on this date was 8.9% as compared to 13.2% in the nontreated oak roots (Fig. 4). Root carbohydrates in the shredded oak roots decreased until July 6; then accumulation of reserves began and continued until leaf fall in late November.

On each sampling date, except late November and December, root carbohydrate concentration in the unshredded oak was significantly higher than in the roots of shredded oak. For the most part, both TNC curves paralleled each other until late summer. Shredded oak roots then accumulated reserves at a more rapid rate than roots of the nonshredded plants. These results demonstrated that shredding can effectively reduce energy reserves in sand shin oak; however, the effect can only be described as ephemeral.

### Management Implications

Over 3 million acres of sand shin oak are found on west Texas rangelands. On many of these acres this oak has essentially formed a monoculture–most forages have been grazed out. In these areas the oak should not be completely controlled in order to prevent active sand dune formation. The oak also provides livestock and wildlife forage; but because of its toxic properties, particularly during budding and new leaf formation, alternative forage resources must be made available.

Personal observations of herbicide application to this oak in June show it to be very resistant to these chemical applications. If ranchers are going to expend monies for oak brush control, we suggest that the chemical be applied before leaves are fully developed. We will begin testing the effectiveness of herbicide applications as related to leaf size in the spring of 1975. Then specific application recommendations can be made.

We do not recommend shredding as a sand shin oak control technique. Rapid and prolific rhizome sprouting following top removal further complicates the rancher's brush problem.

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# Response of Root and Shoot Growth of Three Grass Species to Decreases in Soil Water Potential

MARK E. MAJERUS

**Highlight**: *Native grass species show differences in leaf and root growth response to soil water potential. Soil water potential developed by blue grama at the time of leaf growth stoppage ranged from < -80.0 bars at 5 cm depths to -8.4 bars at 35 cm depths, while corresponding values for little bluestem were -24.3 and -3.0 bars, and -30.0 and -15.3 bars for western wheatgrass. Soil water potentials at the time of root growth cessation were somewhat lower with a minimum of -16.6 bars at the 5 cm depth of blue grama and a maximum of -5.0 bars at the 25 cm and 35 cm depths of little bluestem. The* $R^2$ *values indicate a lower level of correlation between soil water potential and root growth than between soil water potential and leaf growth. In ranking the three mixed prairie grass species as to their growth tolerance to decreasing soil water potential, blue grama ranks the highest followed by western wheatgrass and little bluestem, respectively.*

In natural vegetation the position of plant species does not occur at random but the plants are intermixed or controlled by the impact of the environment over a series of years. Within the mixed prairie of central Montana, blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and little bluestem (*Schizachyrium scoparium*) each appear to have different and distinct site requirements. The soil moisture requirements of these three species have been characterized as low for blue grama, moderate for western wheatgrass, and moderately good for little bluestem (U.S. Dep. Agr., 1971).

Daubenmire (1956) stated that each vegetation type differs from its neighbor in the degree of summer drought, except at the wet end of the climatic gradient, where low temperature is more the decisive factor. McMinn (1952) supports this by showing that in the northern Rocky Mountains, where most precipitation occurs in the winter months and there are summer droughts, different plant associations are correlated with different extents of soil drought. The time and extent of summer drought serves to limit the spread of some species while favoring the spread of others.

The amount and rate of water uptake depends on the ability of the roots to absorb water from the soil with which they are in contact, as well as the ability of the soil to supply and transmit water toward the root. These, in turn, are defined by properties of the plant: rooting density, root depth, and rate of root extension, as well as the physiological ability of the plant to increase its own water suction sufficiently to continue drawing water from the soil at a rate needed to avoid wilting; and by properties of the soil: hydraulic conductivity-diffusivity-matric suction-wetness relationships (Hillel, 1970). According to Brown (1970) the concept of the energy status of water in a system best explains the availability of the water. The free energy of the water in the soil can be expressed as the difference between the free energy of pure free water and the free energy of the water in the system at the same pressure and temperature, better known as water potential. Water potential is affected by factors that change the free energy of water molecules in the system. The presence of solutes, colloids, large particles such as sands, silts, and clays all decrease the water potential. The water molecules interact with these factors and decrease the free energy of the water below that of pure free water. Therefore, the total water potential is a combination of osmotic, matric, and gravitational pressures (Hillel, 1970; Brown, 1970).

There are implications that temperature and relative humidity of the atmosphere also play a significant role in the physiological ability of grasses to maintain water suction (Eddleman and Nimlos, 1972).

The thermocouple psychrometer method of measuring soil water potential is relatively new and is proving itself in many fields of science. Because the relative vapor pressure of soil water and plant tissue, which is directly proportional to water potential, lies very close to the saturated vapor pressure (95 to 100%), the method used to measure this must be capable of detecting very small changes in vapor pressure of water. This measurement can be made with small sensitive thermocouples (Spanner, 1951).

The objectives of this study were: (1) to test the hypothesis that there is a direct correlation between decreasing soil water potential and decreases in daily root and leaf growth, (2) to determine the water potentials of the soil system at the time of root and leaf growth cessation, and (3) to test the general hypothesis that differences exist between blue grama, western wheatgrass, and little bluestem in their ability to remove water from the soil.

## Methods and Procedures

Specimens of blue grama, western wheatgrass, and little bluestem were collected from the Judith River valley 15 miles

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west of Lewistown, Mont. Clonal material was used to minimize the genetic variation between replications of each treatment. Specimens were collected in early spring before any evidence of new growth. Once growth started the plant clusters were removed from the sod and broken into smaller plants, which were used as individual replications in the study.

The study was conducted in a greenhouse using glass-front root observation boxes. Each root box contained approximately 6.5 liters of sandy loam soil (48% sand, 41% silt, and 11% clay).

Three replications of control and treatment plants of each species were used. The treatment plants were not watered after the initial saturation. Photosynthesis and respiration of the plant as well as evaporation were allowed to drain the soil of available moisture. The control plants were watered every 3 or 4 days to maintain a high water potential (greater than −1 bar).

The glass surface of the root boxes was divided vertically into four equal soil levels each 10 cm deep. Thermocouple psychrometers were inserted through the back of the boxes and centered at 5, 15, 25, and 35 cm in each of the four soil levels.

Soil water potential, soil temperature, root elongation, and leaf elongation measurements were taken at 24-hour intervals. All measurements started when the plant began to produce new visible roots along the glass surface of the root boxes. Measurements continued until there was no further elongation of roots in any of the four soil levels and no further leaf elongation in the treatment boxes.

## Results

The soil water potential at the time of leaf growth cessation was used to rank the three species in their ability to extract moisture from a drying soil system (Table 1).

Blue grama extracted more moisture from the surface soil level than either western wheatgrass or little bluestem, to beyond the measuring capabilities of the thermocouple psychrometer (−80 bars). In the second soil level, blue grama and western wheatgrass developed lower soil water potentials than did little bluestem. In the lower two soil levels western wheatgrass extracted moisture to the lowest potential, followed by blue grama and little bluestem, respectively. As seen in Table 1, western wheatgrass extracted moisture more evenly from the entire soil profile than did the other two species. In all species the moisture was extracted first and to the greatest extent from the upper soil level and to a lesser degree from each successively lower level. Using various cool-season forage grasses and legumes, Bennett and Doss (1960) found that when plants wilted there usually was available moisture in the lower soil levels, but the plant was incapable of extracting this moisture. Such was the case with blue grama and little bluestem, where moisture was available in the lower soil levels at the time of leaf growth cessation.

**Table 1. Soil water potential when leaf growth terminated.**

| Soil depth | Blue grama (Bars) | | Western wheatgrass (Bars) | | Little bluestem (Bars) | |
|---|---|---|---|---|---|---|
| Level 1 | <−80.0 b,c[1] | 2,3,4[2] | −30.0 a,c | 2,3,4 | −24.3 a,b | 2,3,4 |
| Level 2 | −26.0 c | 1,3,4 | −23.6 c | 1,3,4 | − 9.8 a,b | 1,3,4 |
| Level 3 | −11.0 b,c | 1,2 | −16.8 a,c | 1,2 | − 3.4 a,b | 1,2 |
| Level 4 | − 8.4 b,c | 1,2 | −15.3 a,c | 1,2 | − 3.0 a,b | 1,2 |

[1] Letters indicate the species that have significantly different water potential at the 5% level using a *t*-test of the replication means.
[2] Numbers indicate the soil levels within each species that have significantly different water potential at the 5% level using a *t*-test of replication means.

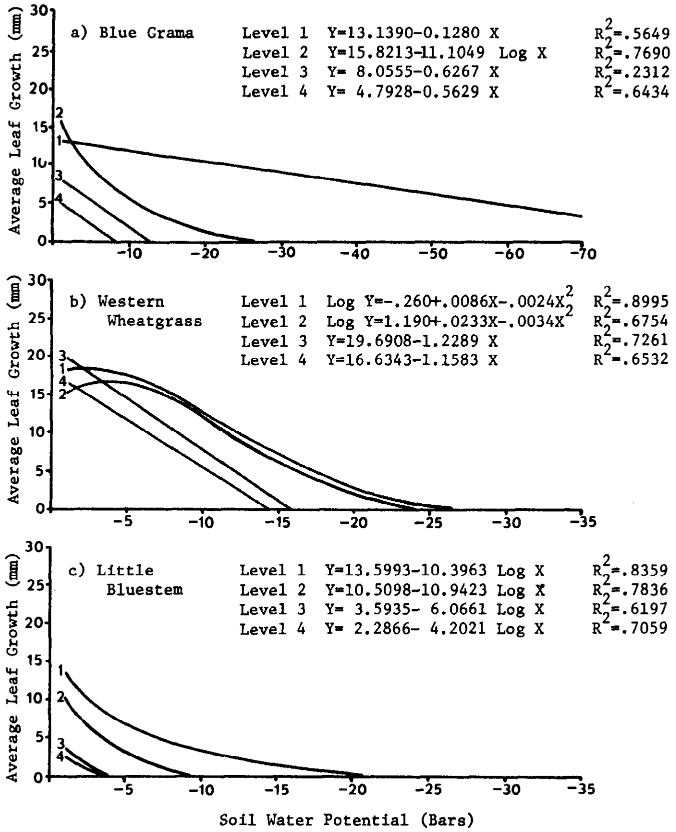


**Fig. 1.** *Correlation between average daily leaf elongation and soil water potential in the four soil levels for all three species.*

The correlation between soil water potential in all soil levels and leaf growth cannot be used to pinpoint the region of the soil that is the most critical in controlling leaf growth, but the slope and position of the regression lines can be used to support some theories (Fig. 1).

The decline in the soil water potential of the upper soil level corresponds with very small reductions in leaf growth of blue grama, suggesting that the upper soil level contributes little to the reduction of leaf growth (Fig. 1a). The leaf growth was reduced to nearly 50% of the original growth rate before the soil water potential dropped below −1 bar in the third soil level. Because there was apparent available soil moisture in the lower levels at the time of leaf growth cessation, the soil moisture availability in the second soil level seemed to have the closest correlation with decreases in leaf growth.

As illustrated in Figure 1b, all regression lines originated at points where leaf growth was at or near its maximum growth rate. This indicates that water potential decreased below −1 bar in all levels before any reduction in leaf growth occurred. The upward sloping of the first two lines indicates that leaf growth was actually increasing as the soil water potential decreased to as low as −5 bars in the upper soil levels. The similarity of the slopes of all four lines suggests that the water potential of all four levels contributed rather uniformly to the reduction of leaf growth.

The presence of decreasing leaf growth of little bluestem was apparent before there was any decrease in water potential of the second soil level (Fig. 1c). Leaf growth was reduced to one-third that of the original growth rate before the water potential decreased below −1 bar in the third soil level. The water potential reached in the lower two levels, before leaf growth terminated, remained very high compared to that in

**Table 2. Soil water potential when root growth terminated.**

| Soil depth | Blue grama (Bars) | Western wheatgrass (Bars) | | Little bluestem (Bars) | |
|---|---|---|---|---|---|
| Level 1 | −16.6 b,c[1] | − 7.8 a | 2,3,4[2] | − 9.2 a | 3,4 |
| Level 2 | −14.7 | −10.6 | 1 | −11.1 | 3,4 |
| Level 3 | −10.7 c | − 9.6 c | 1 | − 5.0 a,b | 1,2 |
| Level 4 | −14.5 c | −13.8 c | 1 | − 5.0 a,b | 1,2 |

[1] Letters indicate the species that have significantly different water potential at the 5% level using a $t$-test of the replication means.
[2] Numbers indicate the soil levels within each species that have significantly different water potential at the 5% level using a $t$-test of the replication means.

the upper soil levels.

The growth characteristic of the root system of many grass species is firmly fixed by their genetics. This, in turn, has an important bearing on the plant's ability to absorb water and, hence, survive drought. In most cases, upon encountering dry soil, root growth ceases and the roots become suberized to prevent moisture loss.

Blue grama developed similar water potentials at all levels at the time of root growth cessation (Table 2). For western wheatgrass the water potentials of the lower three levels were similar and significantly lower than that found in the upper level. The roots of little bluestem that tolerated the lowest water potential were in the upper two levels.

In the first soil level blue grama had the lowest soil water potential, which was significantly lower than the soil water potentials at the same level of the other two species. The soil water potentials of all three species were similar in the second soil level. In the third and fourth soil levels blue grama and western wheatgrass were similar but significantly lower than little bluestem. The total range of soil water potential at the

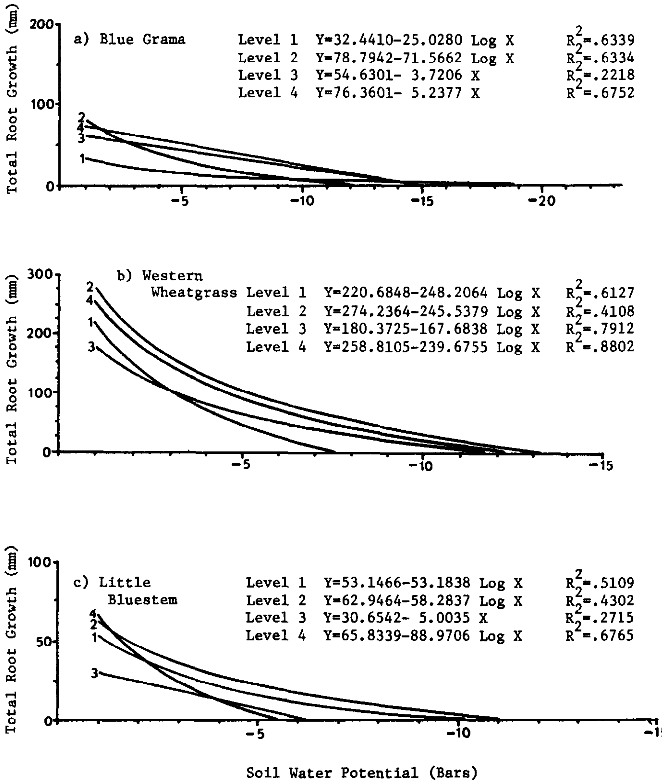


**Fig. 2.** *Correlation between average daily root elongation in each soil level and soil water potential in each of the respective soil levels for all three species.*

time of root growth cessation (−5.0 to −16.6) is quite small. Roots of the three species responded similarly to decreasing soil water potential.

The correlation between the soil water potential of each individual soil level and the root growth in that level is relatively consistent in all soil levels of the three species as indicated by the regression lines in Figure 2. The $R^2$ values indicate a lower level of correlation between soil water potential and root growth than between soil water potential and leaf growth. Some correlation between moisture and root growth may be purely coincidental, as indicated by a comparison of the growth pattern of the roots in the control and treatment boxes. Root growth, in both control and treatment, reached an early peak and decreased to a very low rate. The drying cycle developed in the soil of the treatment plants may have actually stimulated root growth to a greater rate than that for control plants. Canon (1926) and Weaver and Clements (1929) believed that a relatively low water content, provided there is enough to insure good growth, stimulates the roots to greater development, resulting in a greatly increased absorbing surface.

## Summary and Conclusion

The three species involved in this study were deliberately chosen because of the habitats they occupy. Blue grama is usually the dominant species on low moisture sites. Little bluestem appears to thrive on damp, north-facing slopes. Western wheatgrass is found on a variety of sites ranging from xeric to mesic and appears to be an intermediate species in its moisture requirements. The soil water potentials that these species are capable of enduring, both in terms of leaf growth and root growth, appear to correlate with the apparent habitats they generally occupy.

One characteristic of these species that must be considered is their season of growth and maturation. Blue grama and little bluestem have both been termed "warm-season" grasses, while western wheatgrass is a "cool-season" grass. This, in part, may explain the different moisture extraction patterns, i.e., the relatively uniform moisture extraction by western wheatgrass and the inability of little bluestem and blue grama to effectively extract available moisture from the lower soil levels.

Soil water potentials at the time of root growth cessation varied no more than 6.1 bars throughout the soil profiles of these three species; blue grama ranged from −16.6 to −10.7 bars, western wheatgrass −13.8 to −7.8 bars, and little bluestem −11.1 to −5.0 bars. This indicates the need for a relatively moist soil profile to facilitate root penetration.

The increase in some species such as blue grama during extended dry periods can be partially explained by soil water potential tolerances found in this study, whereas higher precipitation and management systems that establish good soil moisture conditions appear necessary for maintaining western wheatgrass and little bluestem stands.

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# Soil Fertility and Production Parameters of *Andropogon scoparius* Tillers

S. S. WALLER, C. M. BRITTON, AND J. D. DODD

**Highlight:** *Inherent soil fertility substantially influenced selected production parameters of little bluestem tillers. Net aerial production, heights of tallest flowering culm, and number of flowering culms of tillers grown in clay soil were significantly higher than those grown in sand. Second year survival and regrowth was also greater on the clay soil. Apparently, tillers grown on the sand are highly dependent on a rapid mineral cycle.*

Soil fertility is a major influence on plant production. Most fertility studies have been concerned with major agronomic crops where fertilizer applications have resulted in increased production. Rangeland fertilization has been investigated only on a limited scale. Few studies have been concerned with inherent soil fertility levels and plant production.

The effect of fertilizers on native forage grasses has received recent attention. Growth and development of grasses and forbs in the northern Great Plains was greater with 67 lb/acre of applied nitrogen as opposed to 33 or 100 lb/acre (Goetz, 1970). The maximum yield occurred with the highest rate of fertilizer application on Coastal Prairie rangeland (Drawe and Box, 1969). Holt and Wilson (1961) reported a doubling of forage production on a desert grassland in response to ammonium phosphate and ammonium nitrate. Fertilizer application resulted in a 50% increase in little bluestem (*Andropogon scoparius*) forage production on a Tabor fine sandy loam in the Post Oak Savannah of Texas (Reardon and Huss, 1965). Results from such studies often reflect treatment effects on a single soil type. This does not allow examination of variations among inherent fertilities of various soil types and plant production.

Studies comparing plant production with inherent soil fertility are uncommon. Caird (1945) reported that a fine sandy loam produced 1,101 lb/acre while a clay soil supporting a similar grassland community produced 2,116 lb/acre. Van Amburg and Dodd (1970) reported that little bluestem clones from a clay soil were generally larger in circumference and contained more tillers than those from a fine sandy loam. However, number of roots produced per tiller was greater from the fine sandy loam.

Little bluestem is one of the most important forage species of the United States (Gould, 1968). It is widespread in North America and occupies a wide variety of habitats (Hitchcock, 1950). This wide range of distribution results from adaptive characteristics. Weaver and Fitzpatrick (1934) have reported extensive grassland areas dominated by 55 to 90% little bluestem. It has a wide tolerance to variation in soil texture (Nixon and McMillan, 1964). Soil fertility may be the most important factor in species distribution on clay textured soils (White, 1961). However, Hubbard (1917) stated that little bluestem has a variable growth habit in response to both environmental and edaphic factors. The objective of this study was to quantitate differences in growth parameters of little bluestem resulting from differences in inherent soil fertility.

## Methods

The effects of inherent soil fertility on selected production parameters of little bluestem tillers were evaluated in a greenhouse utilizing surface soils of a Tabor fine sandy loam and a Heiden-Hunt clay. The soils vary considerably in inherent fertility, texture, and water retention (Mowery et al., 1958). The A horizon of both soils contains approximately 80% of the root system of little bluestem under field conditions (Van Amburg and Dodd, 1970).

The Tabor fine sandy loam soil (Alfisol) developed from a sandy clay. The surface soil texture is 6.5% clay, 27.5% silt, and 66.0% sand. X-ray diffraction indicated highly weathered clay minerals in the A horizon. The surface soil was characterized as having an exchangeable Ca content of 1.50 meq/100g, CEC 4.99 meq/100g, and base saturation 38.08% (Van Amburg and Dodd, 1970). Reardon and Huss (1965) reported this soil to be deficient in nitrogen, phosphorus, potassium, and calcium. Inherent fertility is low and the soil usually exhibits low to moderate productivity of native plants (Mowery et al., 1958).

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The Heiden-Hunt clay soil (Vertisol) developed from a calcareous clay. The surface soil is 32% clay, 35% silt, and 33% sand. The clay soil is not as highly weathered and contains a larger quantity of montmorillonitic clay than the Tabor soil with a reported exchangeable Ca content of 8.81 meq/100g, CEC 28.59 meq/100g, and base saturation 45.23% (Van Amburg and Dodd, 1970). This soil has moderate productivity resulting from moderate to high inherent soil fertility (Mowery et al., 1958).

On February 28, 1972, little bluestem clones and surface soil were collected from each soil site located in the Post Oak Savannah near College Station, Tex. A transition zone with one exposed tiller was planted in a 4-liter can containing approximately 3,000 g of surface soil. The soil moisture was maintained without leaf wetting throughout the study to minimize the effect of moisture stress. Litter did not accumulate on the soil surface during the study. Volunteering plants were removed periodically by hand. These practices were employed to remove major return avenues for minerals in a nutrient cycle. Adequate growing temperatures were maintained in the greenhouse.

Total number of flowering culms and height of the tallest flowering culm per transition zone was recorded at 41 weeks after planting. Tillers were then harvested by clipping 2.5 cm above the soil surface. Plant material was dried at 82°C for 24 hours and weighed to the nearest tenth of a gram. Data are reported as net aerial production per transition zone. Fifty-nine tillers were measured from the Tabor fine sandy loam and 61 from the Heiden-Hunt clay. Unequal numbers resulted from failure of transition zones to establish. Eighty-four tillers were originally planted on each soil type.

Regrowth as number of tillers per transition zone and length of longest leaf was recorded 3 weeks post-harvest. Survival and net aerial production were determined 25 weeks after the initial harvest.

Data were analyzed using a two sample $t$ test to determine significant differences among sample means. Confidence intervals about the sample means were computed and a correlation matrix for each soil type was generated using the various tiller attributes.

## Results and Discussion

Initial transition zone establishment was similar between soil types. Sixty-one transition zones out of the 84 planted were established in the Heiden-Hunt clay and 59 in the Tabor sand. These surviving transition zones were the basis of this study.

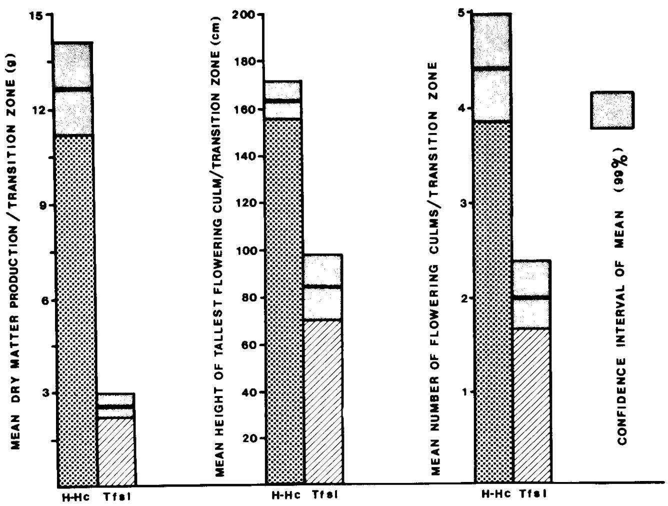


Fig. 1. *Mean dry matter production, height of tallest flowering culm, and number of flowering culms per transition zone for Tabor fine sandy loam (Tfsl) and Heiden-Hunt clay (H-Hc), 41 weeks after planting.*


Fig. 2. *Comparison of growth in Tabor fine sandy loam (left) and Heiden-Hunt clay (right) at maturation.*

Higher ($P < 0.01$) mean dry matter production (12.6 g/transition zone) on Heiden-Hunt clay than on the Tabor sand (2.6 g/transition zone) resulted at 41 weeks after planting (Fig. 1). Mean height of the tallest flowering culm (163.3 cm) from the Heiden-Hunt clay was taller ($P < 0.01$) than Tabor sand (84.3 cm) (Fig. 2). All transition zones had at least one flowering culm. Difference in the mean number per transition zone, 4.4 on Heiden-Hunt clay and 2.0 on Tabor sand, was significant ($P < 0.01$).

Three weeks after initial harvest, 77.1% of the transition zones in the Heiden-Hunt clay and 35.6% in the Tabor sand had initiated regrowth. At this time, length of the longest leaf per tiller and number of live tillers per transition zone were measured (Fig. 3). Of the plants developing regrowth, difference in mean length of the longest leaf, 6.5 cm on Heiden-Hunt clay and 7.2 cm on the Tabor sand, was not significantly different ($P > 0.05$). Difference in the mean number of tillers per live transition zone, 4.9 on Heiden-Hunt clay and 4.0 on Tabor sand, was significant ($P < 0.05$).

Twenty-five weeks after initial harvest, dry matter production was measured on those transition zones with

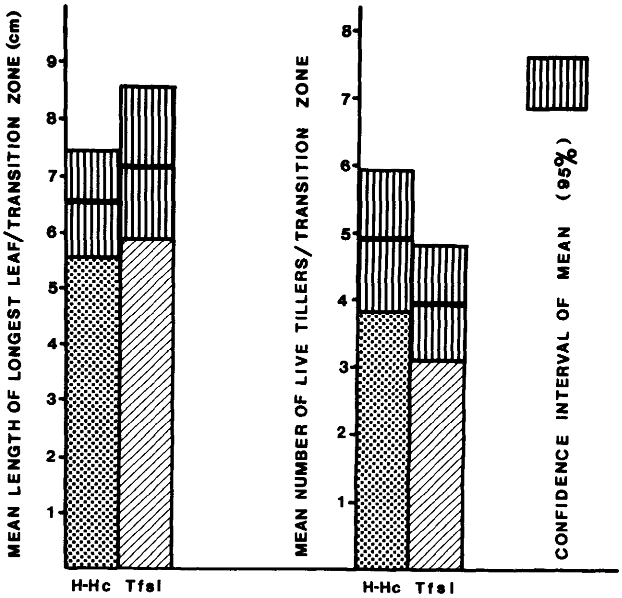


Fig. 3. *Mean length of longest leaf and number of live tillers per transition zone for Tabor fine sandy loam (Tfsl) and Heiden-Hunt clay (H-Hc), 3 weeks after initial harvest.*

regrowth (Fig. 4). Mean production from the Heiden-Hunt clay was 3.9 g per transition zone while only 0.3 g per transition zone was produced on the Tabor sand (significant at $P < 0.01$). At this time, 90.2% of the transition zones grown on Heiden-Hunt clay were alive while only 1.7% of those grown on Tabor sand were alive (Fig. 4).

Establishment of transition zones of little bluestem was similar in both soil types under greenhouse conditions. The greatest difference between the two soils was production of dry matter during the 41 weeks after planting. Production from Heiden-Hunt clay was five-fold greater than from Tabor sand. There is approximately a two-fold increase in production from Heiden-Hunt clay as compared to Tabor sand under field conditions (Waller, Unpublished data). Another contrast of tillers grown on these different soils was a doubling of average height of the tallest flowering culm and number of flowering culms per transition zone. Difference in development in field and greenhouse indicates that plants growing on Tabor sand are dependent on rapid mineral cycles.

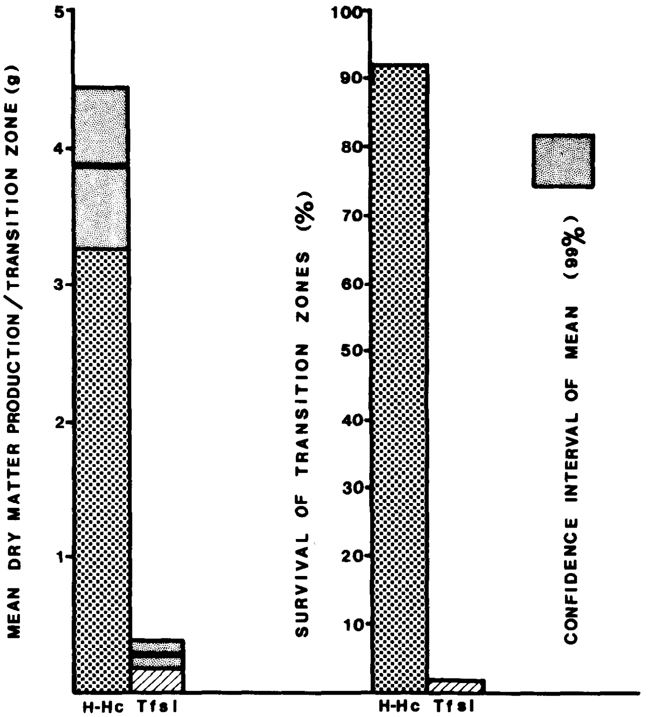


Fig. 4. *Mean dry matter production per transition zone and percent survival of transition zones for Tabor fine sandy loam (Tfsl) and Heiden-Hunt clay (H-Hc), 25 weeks after initial harvest.*

Litter decomposition and throughfall are two major avenues for nutrient return to the soil. By eliminating these avenues of return, the tillers are dependent on the available nutrient reservoir in the soil. The difference in production between sand and clay grown tillers expresses the inherent nutrient status of the soil when the mineral cycle is eliminated. Tiller growth on sand is dependent on a rapid mineral cycle to maintain adequate nutrient concentrations in the tiller root zone. This was verified by $^{134}$Cs research on mineral cycling of little bluestem on both of these soil types (Dodd and Van Amburg, 1970). Sixty percent of the cesium was maintained in the upper 10 cm of soil on the Tabor fine sandy loam. Tillers grown on the Tabor sand maintained a high, constant level of the isotope over time while those in the Heiden-Hunt clay exhibited a general loss over time. This was correlated with a more rapid movement through the soil of $^{134}$Cs indicating a lack of dependence by the clay grown tillers on a rapid mineral cycle. The Heiden-Hunt clay has adequate nutrient concentrations to support growth of little bluestem tillers. However, the nutrient status of the Tabor sand is marginal requiring some type of nutrient return to maintain growth over time.

A correlation matrix (Table 1) of measured plant attributes provides further information. Variation in growth habit is illustrated by the relationship of height of tallest flowering culm, initial harvest (HGTA) and dry matter production, initial harvest (WGTA) for the different soils. The correlation for Heiden-Hunt clay was only 0.2847 while for Tabor sand it was 0.6145, indicating that most changes in dry matter production from Tabor sand were contributed by the inflorescences. However, on Heiden-Hunt clay the major contribution was from leaves and sheaths.

**Table 1. Correlation matrix of measured production attributes of little bluestem tillers grown in Heiden-Hunt clay and Tabor fine sandy loam in the greenhouse.**

| | HGTA[2] | NFLC[3] | LTIL[4] | NTIL[5] | WGTB[6] |
|---|---|---|---|---|---|
| Correlation coefficients– Heiden-Hunt clay | | | | | |
| WGTA[1] | 0.2847 | 0.2252 | 0.1707 | 0.2005 | 0.2197 |
| HGTA | | −0.4826 | 0.1518 | −0.1432 | −0.0158 |
| NFLC | | | −0.0224 | 0.1938 | 0.3201 |
| LTIL | | | | 0.5713 | 0.3159 |
| NTIL | | | | | 0.3632 |
| Correlation coefficients– Tabor fine sandy loam | | | | | |
| WGTA[1] | 0.6145 | 0.5268 | −0.1868 | −0.2694 | 0.0401 |
| HGTA | | 0.2541 | −0.0258 | −0.1640 | 0.0843 |
| NFLC | | | −0.0752 | −0.0544 | 0.0978 |
| LTIL | | | | 0.6877 | 0.4870 |
| NTIL | | | | | 0.6958 |

[1] WGTA = Dry matter production, initial harvest.
[2] HGTA = Height of tallest flowering culm, initial harvest.
[3] NFLC = Number of flowering culms, initial harvest.
[4] LTIL = Length of longest leaf, 3 weeks after initial harvest.
[5] NTIL = Number of surviving tillers, 3 weeks after initial harvest.
[6] WGTB = Dry matter production, 25 weeks after initial harvest.

Three weeks after the initial harvest, tillers from Tabor sand had slightly longer leaves than did those from Heiden-Hunt clay. However, tillers from the Heiden-Hunt clay had more leaves and about twice as many shoots as the Tabor sand. Also, from the correlation matrix, it can be noted that for Heiden-Hunt clay a positive correlation existed between WGTA and number of surviving tillers, 3 weeks after initial harvest (NTIL) while for Tabor sand there is a negative correlation. This suggests that tillers grown on Tabor sand depleted the available nutrients for dry matter production before the initial harvest. This resulted in reduced tiller regrowth following harvest.

Dry matter production measured 25 weeks after the initial harvest illustrated a large decrease in production from both soils. There was a substantial 10-fold increase in the ratio of dry matter production on Heiden-Hunt clay with that on Tabor sand. There was virtually no correlation between the amount of dry matter produced prior to the initial harvest (WGTA) and that produced 25 weeks after the initial harvest (WGTB), regardless of soil type. However, Tabor sand exhibited a high correlation between WGTB and NTIL while Heiden-Hunt clay showed a low correlation. This illustrated that on the less fertile Tabor sand, dry matter production was more dependent on the number of surviving tillers than on the fertile Heiden-Hunt clay.

Data indicate that production, regrowth, and survival of little bluestem were greater on the more fertile Heiden-Hunt clay soil than on the Tabor fine sandy loam. This implies that range forage grasses, such as little bluestem, could be utilized more frequently or in different grazing systems on the more fertile range sites than on sites of low soil fertility. Vegetation on range sites of low soil fertility would require more intensive management to insure sustained production, regrowth, and survival of the desirable species.

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# Influence of Maturity on Digestibibility and Nutrient Accumulation of Amclo Clover Foliage

A. E. SMITH, E. R. BEATY, H. F. PERKINS, AND R. L. STANLEY

**Highlight:** *Cultivars of arrowleaf clover (*Trifolium vesiculosum *Savi.) are becoming important interseeded components of the pasture ecosystem in the humid southeast. This research was conducted to determine the seasonal change in digestibility and mineral composition of "Amclo" arrowleaf clover at various stages of crop development. Three previously unclipped plots of Amclo clover were clipped per week from mid-March until mid-May during 1965 and 1966 to determine the influence of stand maturity on foliar in vitro dry matter digestibility (IVDMD) and nutrient accumulation. Percent IVDMD generally decreased over the 1965 harvest period from 70% to 48%. However, over the same period in 1966 percent IVDMD increased from 48% in mid-March to a maximum of 72% in mid-April and gradually declined to 48% in mid-May. Foliar potassium (K) appeared to be the only element to change over the experimental period. Foliar K content increased until the middle of the vegetative stage of growth. This increase was followed by a gradual decline in foliar K content through the mature stage of crop development.*

Because of high yield and quality and the absence of grazing animal disorders, the arrowleaf clovers (*Trifolium vesiculosum* Savi.) (Fig. 1) are becoming important constituents in forage systems in the southeast.

'Amclo' arrowleaf clover is a high yielding annual legume that readily reseeds in the southeast. At least three accessions have been released (Ahlrich and Byrd, 1966; Beaty et al., 1965; Hoveland, 1967) with differences primarily in length of growing season and date of maturity. Total yields of arrowleaf clover varieties have averaged two to three times those of crimson clover (*Trifolium incarnatum* L.) when cut only once during the flowering stage of development (Knight, 1971). Most annual clovers recover rapidly following clipping or grazing. However regrowth of arrowleaf clovers is slow especially if the harvest occurs after April 15 (Hoveland et al., 1972).

Stanley et al. (1968) showed that, during early stages of crop development, the arrowleaf clover plants are composed primarily of leaves and petioles. Over a 10-week period beginning in mid-March, they determined that Amclo arrowleaf clover growth increased three-fold and the cell wall content increased from approximately 30 to 50%.

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The research is a contribution of the University of Georgia, College of Agriculture Experiment Stations; Georgia Experiment Station, Experiment, Ga.; and College Station, Athens, Ga.

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**Fig. 1.** *A uniform stand of Amclo arrowleaf clover seeded into permanent pasture.*

The purpose of this research was to determine the influence of crop maturity on digestibility and nutrient content of Amclo clover foliage.

## Materials and Methods

An area, at Americus, Ga., of established Amclo clover was allowed to reseed during the fall of 1964. In October after the seedlings were established, the area was fertilized with 896 kg/ha of a fertilizer containing 6.16 and 11.6% phosphorus (P) and potassium (K), respectively. Starting on March 22, 1965, and March 16, 1966, duplicate unclipped plots of 0.84 $m^2$ were clipped at a rate of three per week until May 21. The clover plants were clipped to ground level and dried at 80°C in a forced-draft dryer. After weighing, the dried samples were ground through a 20-mesh screen and stored in a dessicator at room temperature until analyzed. In vitro dry matter digestibility (IVDMD) was determined by methods described by Tilley and Terry (1963). Mineral nutrient content was assayed on forage samples dried in a convection oven at 70°C and digested in a $HCl$-$H_2SO_4$-$HClO_4$ mixture (Piper, 1944). P was determined, colorimetrically, in an acid system (Jackson, 1958) and the other cations were determined by atomic absorption spectrophotometry.

## Results and Discussion

Forage yields and tissue cell-wall content for these

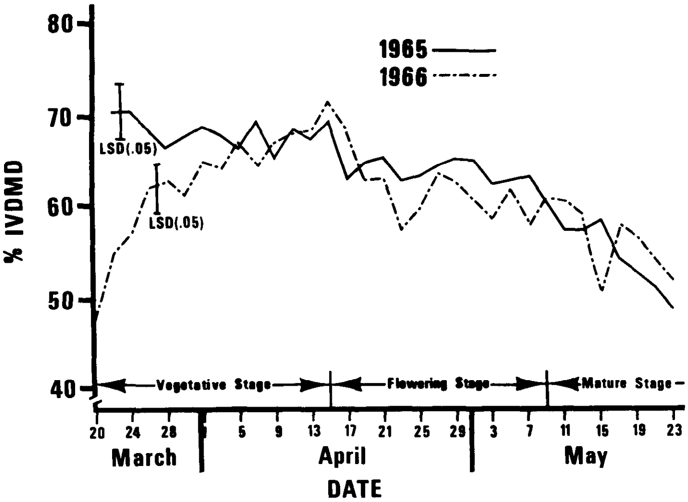


**Fig. 2.** *Percent in vitro dry matter digestibility (IVDMD) of Amclo clover foliage harvested, periodically, during 1965 and 1966 growing season.*

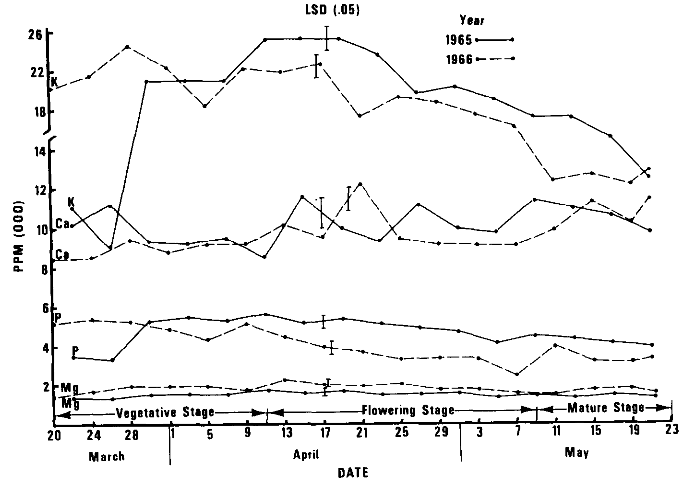


**Fig. 3.** *Macronutrient content of Amclo clover foliage during the 1965 and 1966 growing season.*

experiments have been reported previously (Stanley et al., 1968) and will be discussed only in relation to other findings. The IVDMD remained fairly constant throughout the vegetative and flowering stages of crop development in 1965 (Fig. 2). However, the IVDMD began to decrease, sharply, at the beginning of the mature stage and dropped to a low of 48% for the May 23, 1965 harvest. The cell-wall content of these samples increased steadily from 29% up to 57% through the three stages of crop development (Stanley et al., 1968). This increase in percent cell-wall content was much greater than the change in IVDMD during the first two stages of crop development.

IVDMD of clover harvested in 1966 (Fig. 2) varied considerably from the 1965 harvest data during the vegetative stage of crop development. In general, IVDMD increased throughout the vegetative stage of development from 48% to a maximum of 72% on April 11, after which it decreased to 50% in samples harvested on May 23, 1966. During the same year maximum yield (7,182 kg/ha) was obtained from plots harvested on May 1, and the cell-wall content remained fairly constant through the first two stages of crop development and increased from 42 to 54% during the mature stage (Stanley et al., 1968).

The major differences between IVDMD, production, and cell-wall data obtained in 1965 and 1966 during the vegetative stage were probably a response to major differences in rainfall patterns for the 2 years. During March and April of both years, the cumulative rainfall was similar. However, in 1965 the March rainfall was distributed evenly through the month and in 1966 most of the rainfall occurred the first 2 days of March and was followed by hot dry weather. In 1966, April rainfall amounted to 49 mm and May rainfall was 153 mm. However, between April 5 and May 13, 1966, only 12 mm of rain were recorded. The drier conditions in March, 1966, caused severe leaf drop and forage harvested was primarily stem. The high stem content is probably responsible for the lower initial digestibility (48%) and the reported higher cell-wall content and lower maximum dry-matter production (Stanley et al., 1968) from plots harvested in 1966, compared to similar data from 1965. Major decreases in IVDMD of forage harvested during the middle of April and May, 1966, are probably due to the lower rainfall and higher temperatures compared to 1965.

Macronutrient content of Amclo clover foliage was similar for both years except K in samples harvested between March 20 and 28 (Fig. 3). In general, magnesium (Mg), P, and calcium (Ca) fluctuated very little over both growing seasons. The minor increase in Ca content throughout crop development, especially during 1966, was probably a result of increasing cell-wall content. Potassium content fluctuated more than other macronutrient elements, reaching a maximum of approximately 25,000 ppm in April, 1965, and 24,900 ppm the last of March, 1966. The K content decreased from 25,000 ppm during the vegetative stage to 12,500 ppm in the mature stage. Hanway and Weber (1971) reported that K content of soybean (*Glycine max* (L.) Merr.) foliage reflected leafiness. They found that fallen leaves and petioles accounted for 20% of the total foliar K content. This would explain the drop in K content from the flowering stage to the mature stage of crop development in our study. However, the lower foliar K content during March 1965, a period of more desirable rainfall distribution, compared to March 1966, a period of severe leaf drop, was probably not a response to leafiness.

**Table 1. Seasonal change in micronutrient content (ppm) of Amclo clover foliage at 3 stages of maturity and 16 harvest dates. Reported values are means for two growing seasons.**

| Morphological stage and harvest date | Elements | | | | |
|---|---|---|---|---|---|
| | Zn | Mn | Fe | Cu | Na |
| Vegetative stage | | | | | |
| March 20-22 | 29 | 73 | 188 | 5 | 113 |
| 24-26 | 34 | 110 | 155 | 4 | 96 |
| 28-30 | 40 | 101 | 129 | 5 | 137 |
| April 1-3 | 24 | 104 | 187 | 5 | 130 |
| 5-7 | 26 | 97 | 105 | 3 | 86 |
| 9-11 | 35 | 119 | 150 | 6 | 142 |
| 13-15 | 37 | 93 | 137 | 5 | 100 |
| Flowering stage | | | | | |
| April 17-19 | 35 | 92 | 104 | 5 | 77 |
| 21-23 | 27 | 84 | 105 | 5 | 99 |
| 25-27 | 23 | 79 | 115 | 3 | 132 |
| 29-1 | 24 | 74 | 88 | 3 | 79 |
| May 3-5 | 22 | 65 | 89 | 4 | 116 |
| 7-9 | 16 | 63 | 94 | 5 | 67 |
| Mature stage | | | | | |
| May 11-13 | 20 | 70 | 87 | 3 | 58 |
| 15-17 | 21 | 50 | 107 | 3 | 120 |
| 19-21 | 21 | 83 | 130 | 5 | 101 |
| LSD | 8 | 27 | 25 | 3 | 33 |

Data from analyses of the micronutrient content of Amclo clover foliage (Table 1) indicate that the general trend for all elements, except copper (Cu), was a slight decrease from the middle of the vegetative stage to the latter part of the flowering stage or middle of the mature stage. These data varied considerably between harvests within the developmental stages. Foliar-Cu content remained fairly constant for the duration of this study.

Data in this report indicate Amclo clover to be highly digestible throughout most of the growing season. Hoveland et al. (1970) reported higher digestibility percentages for 'Yuchi' arrowleaf clover than included in this report. The difference is probably due to the analytical methods utilized as their data were obtained by the in vivo nylon bag method (Burton et al., 1967). Another advantage of Amclo clover over the other strains of *T. vesiculosum* is that it normally completes a major part of its growth before the onset of severe drought in Georgia (Ahlrich and Byrd, 1966). Data in our study indicate that differences in seasonal rainfall and stage of crop development did influence forage quality. Vaugh and Marten (1971) reported decreased IVDMD with increased moisture stress. They concluded that the reduced digestibility was due to a reduced leaf to stem ratio rather than decreased IVDMD of either type of tissue. Gifford and Jensen (1967) also have shown that soil moisture stress will reduce the yield of Alsike clover (*T. hybridum* L.).

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## THESIS: THE UNIVERSITY OF WYOMING

**Carrying Capacity of Elk Summer Range, by James E. Guest. PhD, Range Management. 1971.**

A research project designed to determine carrying capacity of elk summer range was conducted during the springs and summers of 1969 and 1970. Huckleberry Ridge, located near the south entrance of Yellowstone National Park in northwestern Wyoming, was chosen as the site for the intensive sampling.

Type mapping and acreage calculations were obtained from aerial photographs of a 1:12,000 scale. A modification of a double sampling system employing weight-estimate was used to estimate forage production. Approximately 3000 square-foot migrogrids were randomly placed on sites previously observed to be used by elk to obtain data on utilization, cover, and species composition. Utilization estimates were made to provide an index rating of forage preference for individual plant species. A season-long utilization of 35% was recorded for grass and grass-like vegetation and 25% for forbs.

Six habitat or forage types were found to be important on the savannahs of Huckleberry Ridge. These included: perennial forb, riparian (stream bank), dry meadow, wet meadow, snowbank, and forest (shelter). The forb community was the most extensive and occupied approximately 73% of the region. Three periods of production were recognized throughout the course of a grazing season and each was represented by a specific flora. These were designated spring, early summer, and late summer based on phenology. The late summer period produced the highs, 430 lb per acre on July 22, 1969, and 450 lb per acre on August 4, 1970.

To calculate carrying capacity, the summer grazing season was divided into four components corresponding to stages of growth. Proper use was based primarily on watershed values and site classification, as limited information was obtained on preference and availability of individual plant species. The results showed that sufficient potential was available to provide adequately for the number of elk observed to summer in this region, but poor distribution and use early in the season had limited the site capabilities. A mechanism or management system which would provide wide and even distribution was needed to realize the full benefits. Even more important than proper distribution was the concept of readiness. A proper use of zero was judged necessary for the first 2 weeks of the growing season because of the wetness of the soil and the limited protection provided by the sparse cover of vegetation and litter. Observation notes kept on migration, shelter, animal numbers, bear and gopher activity, trailing and trampling, salt licks, wallows, ant hills, other ungulate activity, insects, and recreational use were used to help evaluate the carrying capacity for elk.

Assuming no further increase in elk numbers, Huckleberry Ridge has the potential to support adequately the animals which now use it as a summer range. Early use and poor distribution have created definite problems, but these have not yet become irreversible. Manipulation through salting or other appropriate techniques is needed to improve existing conditions and retard any further deterioration of the existing resources.

# Fall Application of Herbicides Improves Macartney Rose-infested Coastal Prairie Rangelands

C. J. SCIFRES

**Highlight**: *Picloram combined with 2,4,5-T (1:1) at 0.56 or 1.12 kg/ha was the most effective of several herbicides and herbicide combinations applied in the fall for control of Macartney rose. Aerial application of the 2,4,5-T/picloram combination at 1.12 kg/ha reduced Macartney rose canopies on Texas Coastal Prairie rangeland by 70 to 80% after a year. The same rate of 2,4-D, the standard treatment, reduced the canopies by 40 to 50%. The herbicide combination was equally effective whether applied in water containing 0.5% (v/v) of commercial surfactant or in a diesel oil:water (1:4) emulsion. Herbicides more effectively controlled undisturbed Macartney rose than plants that previously had been shredded or sprayed. Increasing the volume of carrier from 47 to 94 liters/ha did not adequately increase Macartney rose control to justify extra application costs associated with the higher spray volume.*

Macartney rose (*Rosa bracteata*) is a severe range management problem on over 200,000 ha of highly productive rangeland in southeast Texas. It reaches greatest proportions in the humid Gulf Prairies and western portions of the Post Oak (*Quercus stellata*) Savannah. Also called "Cherokee rose," "hedge," "wild-rose," or "Chickasaw rose" (Hoffman et al., 1964), it is estimated to have increased to the present level of infestation from about 16,000 ha in 1948 (Hoffman, 1966). Native to China, Macartney rose was evidently introduced into the United States in the early 1800's for use as hedge. Macartney rose has some value as food and cover for wildlife. At certain periods, the young shoots are browsed by cattle.[1] Unless controlled, however, Macartney rose spreads until grazing of livestock is severely limited. It not only competes with desirable species but restricts accessibility of grazing animals to herbage.

Macartney rose is spread by livestock, birds, and wildlife, which eat the mature rose hips. The seeds readily germinate after passage through the digestive tracts of most birds and animals (McCully, 1951). The long spreading canes of Macartney rose may also take root at the nodes after being trampled into damp soil. Undisturbed individual Macartney rose plants form dense clumps that may exceed 3 meters in height and several meters wide. As the infestations thicken, the clumps merge, forming dense thickets (Fig. 1). Macartney rose occurs on a range of soil types but is most common on heavy clays.

Upon disturbance of the topgrowth, Macartney rose sprouts profusely from the base, cane sections, and from shallow lateral roots (Haas, et al., 1970). Livestock tend to avoid grass near the Macartney rose plants or about the long trailing canes which may extend several meters from the parent clumps. Mechanical methods such as shredding or bulldozing generally have not been found effective for permanent control of Macartney rose. Repeated annual mowing may increase the area occupied by the dense thorny growth which further reduces the amount of usable grazing land. This may result from the canes being cut and spread over moist soil where they take root and increase the Macartney rose stand density.

From early research (McCully et al., 1959), 2,4-D [(2,4-dichlorophenoxy) acetic acid] was developed as the primary herbicide treatment for Macartney rose control. A single application of 2,4-D as an individual-

Fig. 1. *Macartney rose is a severe range management problem on the Texas Coastal Prairie. If not controlled, the clumps rapidly increase in size forming almost impenetrable thickets.*

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Cooperation of P. H. Welder, Victoria, Texas, in allowing use of resources on the Greenlake Ranch near Bloomington and his participation in the research are gratefully acknowledged. Assistance by J. L. Mutz and H. G. McCall in installation and evaluation of various experiments is greatly appreciated.

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[1] Durham, A. J., and M. M. Kothmann. 1974. Unpublished data.

plant treatment or ground broadcast will control seedlings and young plants. However, older growth usually requires several successive annual treatments for effective control.

Mowed Macartney rose should have at least 6 months but no more than 3 years to develop topgrowth following disturbance before herbicides are applied (Hoffman et al., 1964). Amine formulations of 2,4-D at 2.24 kg/ha may be used effectively from March 1 to May 1 for Macartney rose control. If treatment is delayed until May 1 through June 15, a low volatile ester should be applied. The ester formulation is also used in the early fall, from early September to mid-October, when growing conditions are conducive to herbicide effectiveness. The initial 2,4-D application usually must be followed by a minimum of two consecutive annual applications of at least 1.12 kg/ha to effectively control the Macartney rose.

Chemical control of Macartney rose significantly increases forage production (Hoffman, 1966; Hoffman et al., 1968). However, many area ranchmen have applied 1.12 kg/ha of 2,4-D annually for the past 7 to 10 years without completely controlling severe infestations.[2] These repeat annual applications progressively increase the hazard of damaging adjacent agricultural crops, reduce the economic feasibility of Macartney rose control, and virtually eliminate forbs from the rangeland. Therefore, research was initiated in 1970 to a) develop more effective herbicide treatments which could reduce the herbicide load introduced into the range ecosystem and b) concentrate on fall applications when hazard to nontarget agricultural ecosystems is minimal.

## Materials and Methods

Initial chemical control studies were installed near Benchley in Robertson County, Texas, with ground spraying equipment. The study area had not been grazed by livestock for 5 years. Topography was level to gently rolling and the soil was Wilson clay. The area supported about 250 Macartney rose plants/ha which had been shredded 3 years previous to initiation of the experiments described herein. The Macartney rose plants averaged 1 meter tall and 2.5 meters in diameter.

[2] Personal communication with P. H. Welder, Welder Greenlake Ranch, Bloomington, Texas.

Herbicides and herbicide combinations evaluated at 1.12 kg/ha for Macartney rose control near Benchley were: 2,4-D, 2,4-D combined with picloram (4-amino-2,3,6-trichloropicolonic acid) or dicamba (3,6-dichloro-*o*-anisic acid); 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] and silvex [(2,4,5-trichlorophenoxy) propionic acid] each alone or combined with picloram or dicamba; and dicamba combined with picloram. Combinations contained equal amounts of each herbicide and all but 2,4,5-T + picloram were tank mixed in the field. Herbicides were applied broadcast in 94 liters/ha of water plus 0.5% (v/v) commercial surfactant to 10- by 35-meter plots. Treatments were applied on September 26, 1970, in a randomized complete block experiment with three replications. This date of treatment was chosen based on previous study of spray dates for Macartney rose control (Haas et al., 1970). At 1 and 2 years after treatment, reduction of live canopy of each plant within the plots was estimated.

On October 3, 1972, and October 11, 1973, various herbicides, herbicide combinations, application rates, and formulations were aerially applied to dense stands of Macartney rose near Bloomington, Tex. Soils of the nearly level grassland are predominately Lake Charles and Victoria clays. The area is poorly drained such that standing water is common from late fall through the winter. However, conditions are usually droughty during July and August. Herbaceous vegetation was dominated by little bluestem (*Schizycharium scoparium*) with scattered clones of switchgrass (*Panicum virgatum*). Knotroot bristlegrass (*Setaria geniculata*), dallisgrass (*Paspalum dilatatum*) and longtom (*Paspalum lividium*) were also common. During the study, the area was grazed by cows and calves at approximately 1 AU/4 ha from late October or early November to late March.

Herbicides applied in 47 liters/ha of a diesel oil:water (1:4) emulsion in 1972 to disturbed (topgrowth previously removed by shredding, treated with 2,4-D at 4.48 kg/ha the following year and with 1.12 kg/ha each year thereafter for 7 years) Macartney rose included 2,4-D, dicamba and 2,4-D + dicamba (1:1) at 1 kg/ha and 2,4,5-T + picloram (1:1) at 0.28, 0.56, and 1.12 kg/ha. In addition, the 2,4,5-T + picloram combinations were applied in water containing 0.5% (v/v) of the commercial surfactant, 86% *a*-(*p*)-nonylphenyl-*w*-hydroxypoly (oxyethylene). The 2,4,5-T + picloram combinations in the two carrier systems were also applied to undisturbed Macartney rose to compare the reaction to that of disturbed growth. Using the diesel oil:water emulsion and 0.56 kg/ha of 2,4,5-T + picloram, carrier volumes of 47 and 94 liters/ha were compared on disturbed growth. The 2,4,5-T + picloram in combination were formulated as triethylamine salts, 2,4-D and 2,4,5-T were applied as the propyleneglycol butyl ether esters and dicamba as the dimethylamine salt. All herbicide combinations except 2,4,5-T + picloram were tank mixed at the application site. In 1973, all herbicides were applied in 47 liters/ha of water and 0.5% commercial surfactant.

In most cases, aerially applied treatments were duplicated or triplicated although plots were randomly located over the study area. Data analysis was handled as a completely random design. Plots ranged from 8 to 20 ha. Average percentage canopy reduction of Macartney rose was estimated after 30 days. At 1 and 2 years after treatment, two to five belts, 15 cm wide and 31 m long, were systematically located down the center of each plot. Macartney rose occurring in the belts was evaluated as to percentage canopy reduction and area occupied by new growth.

## Results and Discussion

Environmental conditions were excellent for application of herbicides to Macartney rose in all experiments. Application was usually preceded by 5 to 7 days of bright, warm weather. The air temperature was usually around 23°C at the time of herbicide application and the Macartney rose was actively growing.

### Ground Herbicide Application

Silvex was less effective than 2,4-D or 2,4,5-T at 1.12 kg/ha applied with ground broadcast equipment for the control of disturbed Macartney rose near Benchley, Tex. (Table 1). Dicamba, 2,4-D and 2,4,5-T reduced Macartney rose canopies from 40 to 50% at a year after treatment. Canopy reduction with combinations of 2,4-D or 2,4,5-T with dicamba a year after application was as expected from either herbicide used alone at the same application rate. The additive effect of 2,4,5-T + dicamba has also been demonstrated with honey mesquite (*Prosopis glandulosa* var. *glandulosa*) (Scifres and Hoffman, 1972) and sand shinnery oak (*Quercus havardii*)

**Table 1. Canopy reduction (%) of disturbed Macartney rose 1 year after broadcast application of various herbicides alone and in 1:1 combinations at 1.12 kg/ha with ground equipment on September 26, 1970, near Benchley, Tex.**

| Phenoxy herbicide | Herbicide in combination[a] | | |
|---|---|---|---|
| | None | Dicamba | Picloram |
| None | 0 a | 38 cd | 62 e |
| 2,4-D | 53 de | 42 cd | 50 de |
| 2,4,5-T | 40 cd | 31 bc | 40 cd |
| Silvex | 22 b | 5 a | 44 cd |

[a]Means followed by the same letter are not significantly different at the 95% level.

(Scifres, 1972). Combinations of silvex with dicamba were ineffective for Macartney rose control. Picloram at 1.12 kg/ha was the most effective single herbicide applied with ground broadcast equipment near Benchley. Combining picloram with 2,4-D, 2,4,5-T or silvex reduced the level of Macartney rose control as compared to picloram alone. Based on results from Benchley, silvex was not included in subsequent experiments and treatments containing picloram were expanded.

### Aerial Applications

Canopy reduction of disturbed Macartney rose from aerial application of 2,4-D at 1.12 kg/ha in the fall of 1972 near Bloomington, Tex. (Table 2) was roughly equivalent to that resulting from ground broadcast application near Benchley (Table 1). Dicamba or 2,4-D + dicamba were no more effective than 2,4-D alone for Macartney rose control (Table 2). The most effective herbicide treatment aerially applied at 1.12 kg/ha was 2,4,5-T + picloram.

In another experiment, as the rate of 2,4,5-T + picloram was increased from 0.28 kg/ha to 1.12 kg/ha, disturbed Macartney rose canopies were reduced proportionally based on evaluations 1 year after treatment (Table 3). At 0.28 kg/ha, only about 40% canopy reduction occurred at a year after treatment. By 2 years after aerial application of the low rate, less than 15% canopy reduction was apparent. New canes had grown over the sprayed growth such that area occupied, as compared to original canopy cover, had actually increased. Increasing the herbicide rate to 0.56 kg/ha resulted in a 60% canopy reduction at 1 year after application (Table 3) and 50% by 2 years after treatment. Where 1.12 kg/ha of the herbicide combination was applied, Macartney rose canopies were reduced, on the average, by 80%. Level of control was maintained at about 60% canopy reduction by 2 years after treatment. However, less than 20% of the disturbed Macartney rose plants were completely defoliated and not resprouting 2 years after treatment with the high rate of the herbicide combination, indicating the need for subsequent treatment.

**Table 2. Canopy reduction (%) of disturbed Macartney rose a year after aerial application of various herbicides and combinations of 1.12 kg/ha on October 3, 1972, near Bloomington, Tex.[a]**

| Herbicide(s)[b] | Canopy reduction |
|---|---|
| 2,4-D | 39 |
| Dicamba | 21 |
| Dicamba + 2,4–D[b] | 26 |
| 2,4,5-T + picloram | 71 |

[a]Applied in 46 liters/ha of a diesel oil:water emulsion.
[b]Herbicide combinations were applied with components in equal proportions.

**Table 3. Canopy reduction (%) of disturbed Macartney rose 1 year after aerial spraying with various rates of 2,4,5-T + picloram (1:1) on October 3, 1972, near Bloomington, Tex.[a]**

| Rate (kg/ha) | Canopy reduction[b] |
|---|---|
| 0 | 0 a |
| 0.28 | 38 b |
| 0.56 | 60 c |
| 1.12 | 78 d |

[a]Applied in 46 liters/ha of a diesel oil:water emulsion.
[b]Means followed by the same letter are not significantly different at the 95% level.

Regardless of herbicide rate, disturbed Macartney rose was generally more tolerant of 2,4,5-T + picloram treatments than were the original undisturbed stands (Table 4). The differential reaction was similar to that described by McCully et al. (1959) from applications of 2,4-D. Comparing the average response to 2,4,5-T + picloram at 0.56 kg/ha at 1 year after treatment, canopies of disturbed Macartney rose were reduced by about 50% whereas reduction of undisturbed canopies exceeded 70%. This reaction was presumably due to the greater foliar area in relation to the root mass on undisturbed as compared to disturbed plants. Within a growth type regardless of herbicide rate, there was little difference in reaction of Macartney rose whether the herbicides were applied in 47 liters/ha of a diesel oil:water emulsion or with water containing surfactant (Table 4).

**Table 4. Canopy reduction (%) of Macartney rose growth types 1 year after aerial application of various rates of 2,4,5-T + picloram (1:1) in water containing surfactant or in diesel oil:water emulsions on October 3, 1972, near Bloomington, Tex.[a]**

| | Disturbed growth[b] | | Undisturbed growth | |
|---|---|---|---|---|
| (kg/ha) | Diesel oil: water | Water | Diesel oil: water | Water |
| 0 | 0 a | 0 a | 0 a | 0 a |
| 0.28 | 29 b | 29 b | 45 c | 50 c |
| 0.56 | 48 c | 50 c | 74 de | 71 d |
| 1.12 | 76 de | 71 d | 83 e | – |

[a]Means followed by the same letter are not significantly different at the 95% level.
[b]Initially shredded, sprayed with 4.48 kg/ha of 2,4-D two years later, and then treated with 1.12 kg/ha of 2,4-D for 7 consecutive years.

In previous work, the importance of carrier volume in providing complete coverage of Macartney rose foliage with herbicide was stressed (Haas et al., 1970). Where 0.56 kg/ha of the 2,4,5-T + picloram mixture was applied in 47 liters/ha of total solution, Macartney rose canopies were reduced by about 75% at a year after treatment. Where the carrier volume was doubled, canopy reduc-

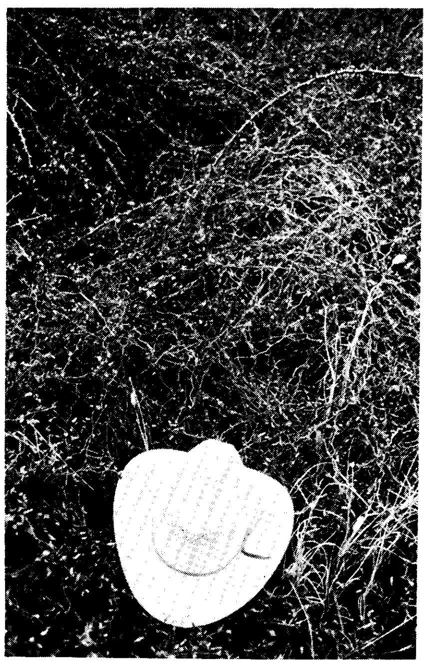

Fig. 2. *Spraying will control much of the above-ground Macartney rose growth, but standing dead canes present management problems. Prescribed burning effectively removed Macartney rose debris following the sprays.*

Fig. 3. *Rangeland in Figure 1 after spraying with 2,4,5-T + picloram at 1.12 kg/ha in October, 1970, followed by a prescribed burn 18 months later. Photo taken 7 months following burn.*

tion was about 85% from the same herbicide treatment. Considering internal variation in the study, it is doubtful that the increase provided by the additional carrier would justify the reduction in application time and increased application cost.

Although combinations of 2,4,5-T and picloram (1:1) at 0.56 and 1.12 kg/ha total herbicide were more effective than other treatments evaluated for Macartney rose control, in no case was complete control achieved. Also, application of the herbicide mixture does not remove the mechanical hindrance resulting from dead standing canes (Fig. 2). In subsequent studies, these canes have been removed by a prescribed burn in the winter 18 months after herbicide application. The prescribed burn eliminated the old dead Macartney rose debris (Fig. 3) and increased oven-dry native grass production to over 2,000 kg/ha as compared to 690 kg/ha with no treatment and 1,790 kg/ha from areas sprayed only (Scifres, 1975). Also, in burned areas, forbs such as Texas croton (*Croton texensis*) reappeared in abundance where previously they had been greatly reduced by the sprays. The combination of prescribed burning following herbicide application appears promising for extending the herbicide effectiveness for Macartney rose control.

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# Control of Honey Mesquite by Shredding and Spraying

DANNY L. BECK, RONALD E. SOSEBEE, AND E. B. HERNDON

**Highlight**: *Simultaneous shredding and spraying of honey mesquite were studied in the Rolling Plains of Texas. Mature trees were shredded and sprayed monthly, May, 1972, through October, 1972 (September was omitted). Herbicide treatments consisted of 2,4,5-T amine, 2,4,5-T ester, and Tordon 225 Mixture applied alone and in combination with naphthalene acetic acid (1, 5, 10, 50, and 10,000 ppm). Very high percentage root mortality was obtained when the trees were shredded and sprayed in May, with somewhat lower percentages obtained from treatments applied in June and October. Root mortality obtained from treatments applied in July and August was generally lower than that obtained from treatments applied during any other month. However, results from treatments applied any month of the study exceeded the results one could expect from either shredding or spraying applied alone during a comparable period. Tordon 225 Mixture was consistently most effective in controlling shredded mesquite. Therefore, shredding accompanied by a simultaneous herbicide application has potential in control programs.*

Conventional methods (such as aerial spraying, rootplowing, chaining, etc.) of controlling honey mesquite (*Prosopis glandulosa* var. *glandulosa*) are often impractical because of small acreages involved or proximity to susceptible cultivated crops. In such areas, shredding mesquite has received considerable attention, especially in the Rolling and High Plains of Texas (Fisher et al., 1959; Schuster, 1968; Herndon, 1970). Although shredding was effective for temporary control of honey mesquite, it must be repeated every year or two (Fisher et al., 1959; Rechenthin et al., 1964).

Most often shredding produces a pruning effect which causes sprouts to grow at a faster rate than growth prior to shredding (Carpenter, 1970). Weddle and Wright (1970) reported no root mortality of honey mesquite from shredding alone. Ames (1966) used various chemical and mechanical methods to control mesquite, but found that all methods required periodic maintenance treatments. Follow-up treatments involving a herbicide for controlling 2- and 3-year-old mesquite resprouts were largely ineffective (Karr, 1971). However, addition of thiamine (3.4 ppm), niacin (1.6 ppm), biotin (2.4 ppm), or pyridoxin (2.1 ppm) to 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T) significantly enhanced the control of 1- and 2-year-old mesquite resprouts (Sosebee, 1974). Naphthalene acetic acid (NAA) added to 2,4,5-T and picloram increased control of trunk sprouting of nine tree and shrub species in California (Harris et al., 1971). Generally, shredding without a follow-up treatment has neither been popular nor recommended.

Because shredding alone kills few trees and requires some type of follow-up treatment, an effective herbicide applied simultaneously with shredding could increase root mortality and reduce the number of maintenance treatments necessary for control. This study was designed to measure the effectiveness of honey mesquite control with shredding accompanied by a simultaneous herbicide application.

## Experimental Procedures

Shredding and spraying honey mesquite simultaneously were studied on the Bethel Ranch located 7 miles south of Quanah, Tex., in the Rolling Plains. The site was transitional between deep hardland and shallow clay characterized by clay to clay loam soils of the Tillman-Vernon series (Lofton et al., 1972). The soil is deep to shallow with a clay loam surface layer. It is slowly to moderately permeable in the lower layers. The topography is nearly level to gently sloping. Vegetation on the site was predominantly honey mesquite and tobosa grass (*Hilaria mutica*).

Trees (8 to 10 ft tall) were shredded monthly May 15 through October 15, 1972 (September was omitted) with a 65-hp farm type tractor and a 7-ft rotary shredder. Each herbicide treatment was randomly applied to the stumps of 15 mesquite trees (replications) immediately after shredding.

Herbicide treatments consisted of 2,4,5-T trimethylamine salt (Veon 245[1]), 2,4,5-T propylene glycol butyl ether esters (Esteron 245[1]), and 4-amino-3,5,6-Trichloropicolinic acid (picloram) plus 2,4,5-T (Tordon 225 Mixture[1]) applied either alone or in combination with 1, 5, 10, 50, or 10,000 (1%) ppm α-NAA. The herbicides were mixed according to the manufacturer's recommendations and applied with a compressed air garden sprayer. Basically, the Esteron 245 (4 lb A.E./gal) mixture consisted of 1 oz of herbicide dissolved in 1 oz of diesel fuel with water added to a volume of 1 gallon. One ounce of Veon 245 (4 lb A.E./gal) and 2 oz of Tordon 225 Mixture (2 lb A.E./gal) were dissolved in 1 gal of water. All mixtures were equivalent to 3 lb of herbicide per 100 gal of solution. A surfactant (Tronic[1]) was added to each herbicide solution to approximate 0.02% of the total volume. Each stump and the immediately surrounding area received a maximum of 0.1 gallon.

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

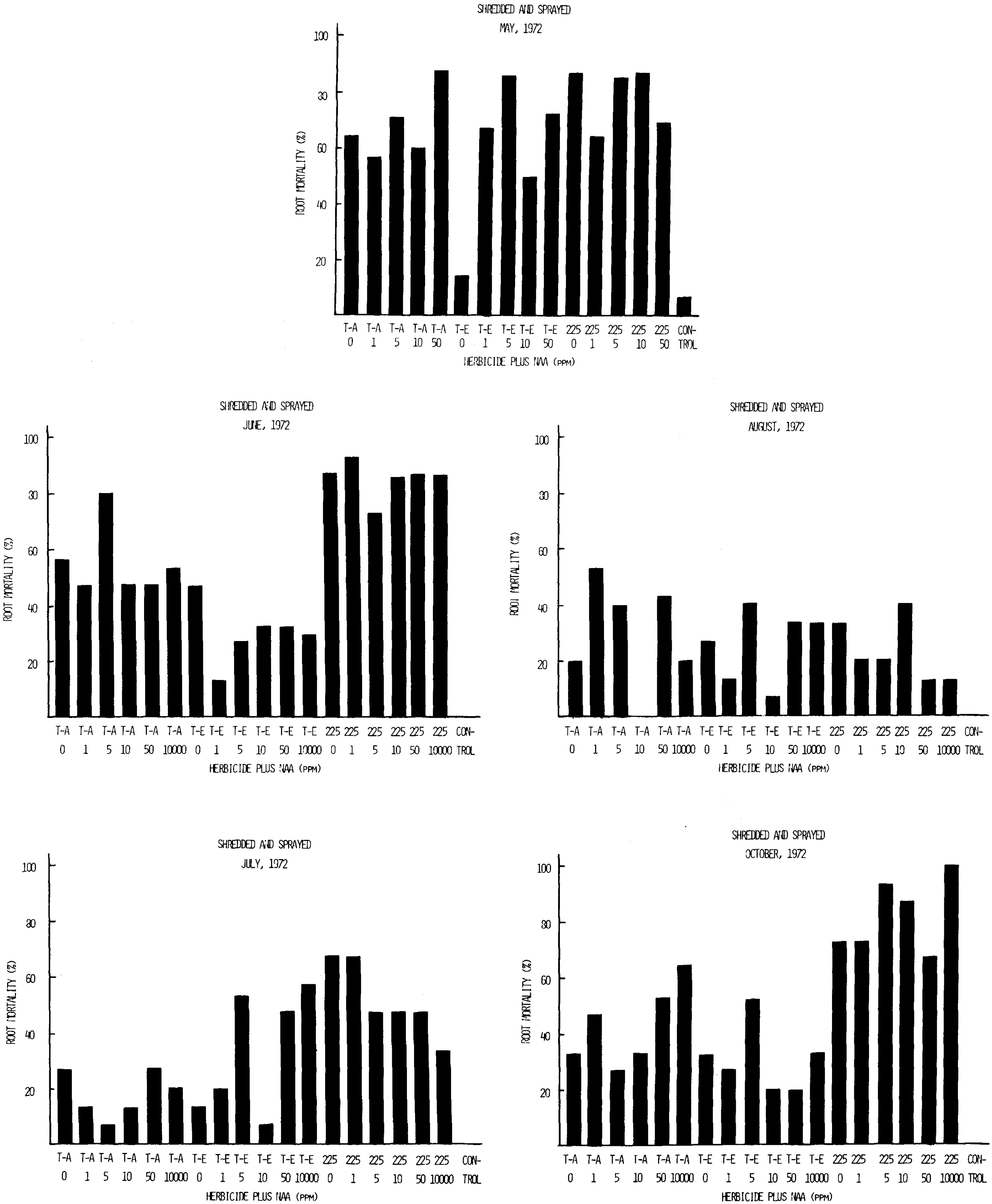


**Fig. 1.** *Average root mortality of honey mesquite shredded and sprayed with 2,4,5-T amine (T-A), 2,4,5-T ester (T-E), and Tordon 225 Mixture (225) plus NAA (0, 1, 5, 10, 50, and 10,000 ppm) at various times during 1972.*

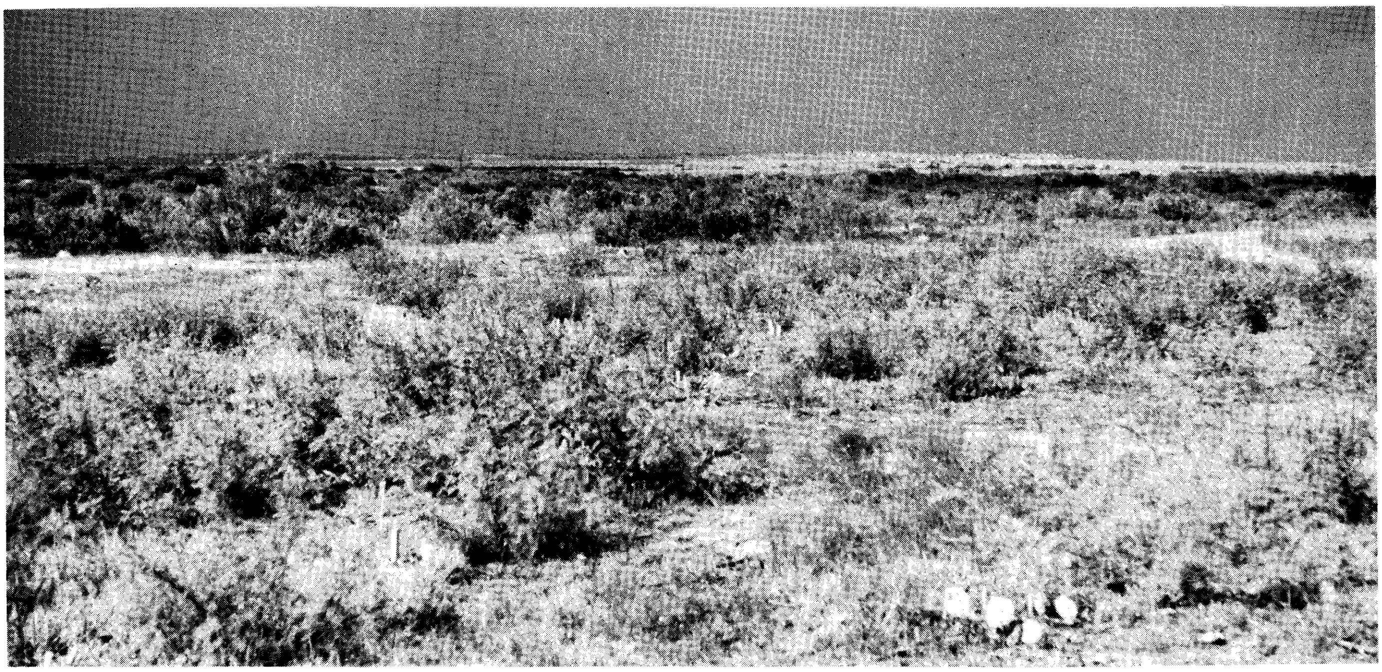

**Fig. 2.** *Resprouts from trees shredded May 15, 1972, but not sprayed (photo was taken June 13, 1972).*

Soil temperature, soil water content, air temperature, and relative humidity were measured at the time of herbicide application. Soil temperature was measured with a mercury-filled laboratory thermometer inserted into a 3/8-inch hole in the soil to depths of 6, 12, 18, and 24 inches. Soil water content (percent) was measured by gravimetric samples taken in 6-inch increments from the soil surface to a depth of 24 inches. Relative humidity was measured with a sling psychrometer. The stage of mesquite phenological development was evaluated at the time of shredding and spraying. Root mortality of stumps of trees shredded and sprayed in 1972 were evaluated in the fall of 1973. Any resprouting constituted live trees. The data were analyzed by chi-square analysis and statistical differences were denoted at the 95% confidence level.

## Results and Discussion

Herbicides simultaneously applied with shredding have tremendous potential in the control of honey mesquite (Fig. 1). All herbicide treatments applied in May except 2,4,5-T ester (applied alone) resulted in much higher root mortality than was found in the control. This coincides with the results reported by Wright (1968). Herbicide solutions involving Tordon 225 Mixture when applied during June and October resulted in more than 80% root mortality and killed 40–70% of the trees treated in July. Trees shredded and sprayed with solutions of 2,4,5-T amine also had a large percentage (35 to 80%) root mortality in June and October. Goen and Dahl (unpublished data) also obtained good control from shredding and spraying mesquite in the fall.

Percentage root mortality obtained from 2,4,5-T ester solutions was generally lower than that obtained from the other herbicide solutions. However, 2,4,5-T ester plus 5, 50, or 10,000 ppm NAA resulted in total root kill of 50–60% of the trees treated in July. NAA (5 ppm) increased the effectiveness of 2,4,5-T ester (vs applied alone) during every month of application except June. NAA did not significantly increase the effectiveness of either 2,4,5-T amine or Tordon 225 Mixture.

Percentage root mortality obtained from shredding and spraying in August generally was lower than that obtained from treatments applied during the other months. However, the results from simultaneously shredding and spraying most often exceeded the average results (about 20 to 25% root mortality) one could expect to obtain from aerial spraying during a comparable period.

The live control trees were easily detected by their vigor and lush growth (Fig. 2). Only one control tree out of 75 marked was killed by shredding alone.

Root mortalities obtained from May and June treatments indicated that the trees were more easily killed by shredding and spraying because of their stage of phenological development. In May they had mature leaves and mostly white and yellow flowers (a few immature flower spikes were present). By June 15, a few flower spikes were blooming but the trees mainly possessed immature pods 1 to 6 inches long. Root carbohydrates had apparently been depleted to a minimum level through spring growth (Wilson, 1972). Wilson also found a decline in total available carbohydrates (TAC) in mesquite roots in late summer following rains in August. Kramer and Kozlowski (1960) reported that some tree species have a period of maximum root growth in May and June followed by a second peak of growth in the autumn. The soil water content had substantially increased in October (from an average 8.5% in the summer to 22% in October); thus resumption of root growth might account for the mortalities obtained from treatments during this period. The other environmental factors apparently did not significantly influence the effectiveness of any of the treatments applied in this study.

The effectiveness of herbicides applied with shredding to honey mesquite is somewhat difficult to explain since the chemical is not dependent upon foliar absorption with subsequent translocation to the basal bud zone. Since shredding removes the top growth, the herbicides must enter the plant some other way than foliar absorption. Leonard and Harvey (1965) reported that the effectiveness of chemical

**Fig. 3.** *Prototype shredder designed to spray the shredded stump and the area immediately surrounding the stump. Designed and built by Robert Koziol of Midland, Texas*

control may be increased by cutting into the stump near the base and immediately applying the herbicide. When phenoxy herbicides are applied to the base of the tree, they possibly penetrate the soil and envelop the bud zone and prevent subsequent sprouting (Ames, 1966).

## Conclusions

Shredding honey mesquite without follow-up control is not a recommended practice. However, herbicidal application simultaneously with shredding can effectively increase mesquite control beyond the capabilities of either shredding or aerial spraying when applied alone. May is the best time to control mesquite by shredding and spraying and good results can be obtained from treatments applied in either June or October.

Herbicide mixtures of 3 lb of either 2,4,5-T amine, 2,4,5-T ester, or Tordon 225 Mixture per 100 gal of solution applied directly to the stump and its surrounding area effectively controlled resprouting in honey mesquite following shredding. The herbicide(s) from which the best results can be expected depends upon the month of application. However, Tordon 225 Mixture produced the greatest percentage root mortality consistently throughout the entire study.

Because a prototype shredder (Fig. 3) with the capability of spraying only the shredded stump and the immediately surrounding area has been developed, the method of shredding and spraying simultaneously has tremendous potential on large acreages of brush infested rangelands.

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# Improvement of Seed Germination in *Atriplex repanda* Phil.

SERGIO LAILHACAR-KIND AND HORTON M. LAUDE

**Highlight**: *Sereno saltbush (*Atriplex repanda *Phil.) is a valuable browse producer in arid coastal regions of central Chile. Direct seeding has been impractical using the heavily indurated fruits, which in laboratory germination tests yield zero to 2%. Among treatments which have been reported, manually clipping off the bracts has been the most beneficial. Debracted fruits which had not germinated would do so once the testa was ruptured. Bract removal without rupturing the testa was ineffective. Virtually 100% germination was obtained after fruits had been debracted and the testa pierced without damage to the embryo which encircles the endosperm. Germination approaching 10% was obtained from 3000-utricle samples after treatment in a modified small legume-seed scarifier which broke the pericarp and freed the seed. Higher values appear possible and the technique may have application to other small fruits with hard coverings.*

Sereno saltbush (*Atriplex repanda* Phil) is an evergreen shrub endemic to arid regions of Chile, primarily from 30° to 32° south latitude. Annual precipitation in this Mediterranean-type climate varies from 100 to 300 mm during the rainy period of 4 to 6 months. The species appears to be favored by the higher humidity of coastal areas and possesses the ability to absorb water through its leaves (Arentsen, 1972). The plant grows to a meter in height and branches profusely with flexible and leafy stems. During the critical period from late spring to early fall when annual vegetation is dry, Sereno saltbush maintains a satisfactory protein level and produces green forage much desired for browse.

The potential for greater use of this plant in Chile and elsewhere in arid to semiarid climates is presently limited by very low seed germination. Whereas a number of *Atriplex* species may be expected to give from 15 to 80% germination in laboratory tests without seed treatment, only 0 to 2% has been reached in repeated trials with Sereno saltbush. Until germination is improved, little progress can be made on studies of seeding and establishment. To date the information on establishment and utilization has been obtained mostly from seedlings transplanted to the field from the nursery or greenhouse.

The objectives of this investigation were to determine more precisely the causes for the poor seed germination in Sereno saltbush and to attempt to identify a type of treatment adaptable to the preparation of seed in quantity for direct seeding.

Sereno saltbush produces a one-seeded indehiscent fruit called a utricle. The principal parts of this fruit are shown in Figure 1. Two winged bracts enclose the seed in a locule or cavity. These bracts are fused at the base and together form the pericarp. They are extremely indurated and are not abraded, cut, or broken easily. The testa, embryo, and endosperm comprise the true seed, and it is this that is termed the seed in this paper. Once the bracts are removed, the seed is released, but it is difficult to remove the hard bracts without injuring the embryo which curves around the endosperm like a ring. Therefore it is the entire fruit which is harvested and usually sown.

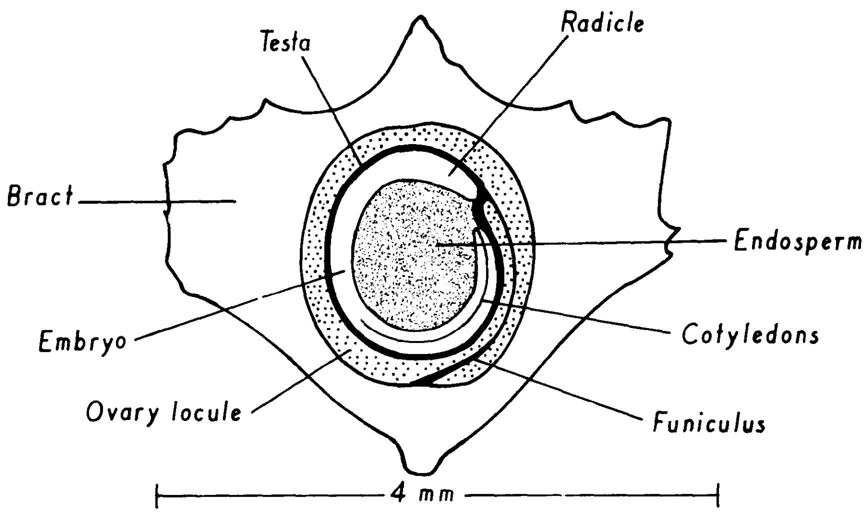


**Fig. 1.** *Diagrammatic sketch of the utricle in a lateral longitudinal section.*

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Mention of trade names in this paper is for identification only and does not constitute endorsement of the product.

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Two recent Chilean publications on Sereno saltbush have provided information useful to this study. Cristi and Gastó (1971) reported the effect on germination of a number of treatments applied to the utricles. An 18-day germination test revealed little to no benefit from immersion in running tap water or in hot water, from fire, or scarification. Forty-five minutes in sulfuric acid proved to be the best chemical treatment, yielding a germination of 28.6%. Debracting the fruits by removing the entire pericarp using fingernail clippers was superior and gave germinations above 70%. Leighton (1972) established that Sereno saltbush was among the lowest in germination of 6 species of *Atriplex* that he compared. Three were native to Chile (*A. atacamensis, A. coquimbana,* and *A. repanda*), two to Australia (*A. leptocarpa,* and *A. nummularia*), and one to North America (*A. canescens*). He also compared several treatments to improve germination in Sereno saltbush and obtained the highest germination, 68%, with debracted fruits. These studies have indicated a considerable impairment to germination associated with the bracts. Our studies have implicated other structures as well.

## Materials and Methods

The Sereno saltbush fruits used in this investigation were kindly provided by the University of Chile and the Corporation for Development of Production (CORFO), having been collected in the provinces of Santiago and Coquimbo in north-central Chile. The utricles were treated 6 to 8 months after collection. Only the larger fruits appearing fully developed and heavier than 6.5 mg were used as controls and in the following treatments:

- Debracted–bracts cut with a razor blade and removed from the seed.
- Partially debracted–one wing trimmed with a razor blade until the ovary locule was reached, but the seed including the testa remained uncut and in the locule.
- Testa pierced–small tangential cut through the testa with razor blade without damage to embryo after total or partial bract removed.
- Testa intact–no break observable in testa under 40-fold magnification.
- Sulfuric acid–lots of 50 utricles were immersed in 20 ml of $H_2SO_4$ sp gr 1.834 for 45 to 60 minutes or sp gr 1.625 for 60 to 80 minutes, then washed in running tap water for 30 minutes and blotted dry.
- Sodium hypochlorite–lots of 50 utricles were immersed for 9 to 15 hours in 20 ml of fresh household Clorox (5.25% NaClO), washed in running tap water for 30 minutes and blotted dry.

The germination chamber operated in darkness at 20°C for 10 hours alternating with 12°C for 14 hours. These simulate the mean temperatures during the germination season in the area of adaptation. Twenty-five seeds were equally spaced on germination blotters 20 by 25 cm in size, were then covered with a second moist blotter, and both blotters were rested on an inclined plexiglass plate. The bottom edge of the blotters contacted distilled water in a reservoir and served as a wick to supply moisture for germination. This technique is an adaptation of the slanted-substrate method described by Jones and Cobb (1963). The covering blotter was periodically sprayed with the fungicide Captan to control contamination during the germination period which extended to 56 days in some cases. In initial trials a seed was considered germinated and was removed from the blotters when the combined length of radicle and cotyledons exceeded 10 mm. Later this required length was reduced to 5 mm, since it was observed that most seedlings of this size were capable of continued growth. Upon removal from the blotters, the seedlings were placed on a steam-sterilized mixture of moist soil and sand, and nearly all became established to be used later for transplanting.

Except for the percentages in Table 3, treatment means were based on 50-seed lots (the total of two slants) replicated in 4 or 6 blocks. The data were transformed to arcsine values and analyzed by Duncan's Multiple Range test for statistical comparison.

## Results and Discussion

Germination of Sereno saltbush has been improved by sulfuric acid treatment of the utricles and by mechanical removal of the pericarp (Cristi and Gastó, 1971). In view of their results, we tried two immersion durations in each of two concentrations of sulfuric acid and manually debracted utricles with a razor blade. In addition we included several intervals of immersion in sodium hypochlorite, which is easier to handle than sulfuric acid and yet is effective with some plants (Laude, 1951), and also a treatment of debracted fruits which showed visible damage to the testa. The latter was included since we had previously observed an instance in which 30% of the debracted seeds which had not germinated in 33 days, did so within 12 additional days once the testa was intentionally ruptured. The results are presented in Table 1. Neither chemical treatment appeared to be feasible when compared to debracted seeds with the testa pierced. Three questions at least are raised by these results. Is the germination of debracted seeds attributable to a cutting of the seedcoat incidental to the debracting procedure? Must the entire pericarp be removed or will partial debracting suffice? Can debracting be

**Table 1. Germination (%) following manual or chemical treatment to weaken or remove the pericarp of mature utricles.**

| Treatment of utricle | | % germinated[1] after 24 days |
|---|---|---|
| Control (entire utricle) | | 0.0 |
| Debracted | | 32.0 |
| Debracted and testa pierced | | 93.0 |
| Sulfuric acid (immersed) | | |
| (Sp gr 1.834) | 45 min. | 0.0 |
| | 60 min. | 0.0 |
| (Sp gr 1.625) | 60 min. | 0.0 |
| | 80 min. | 1.0 |
| Sodium hypochlorite[2] (immersed) | 9 hr. | 0.0 |
| (5.25% NaClO) | 11 hr. | 1.0 |
| | 13 hr. | 4.0 |
| | 15 hr. | 17.0 |

[1] Mean of four 50-seed replications.
[2] Household Clorox.

Table 2. Influence of debracting and of piercing the testa on germination (%).[1]

| Days in germinator | Control | Testa intact[2] Partially debracted | Debracted | Testa pierced Partially debracted | Debracted |
|---|---|---|---|---|---|
| 7 | 0.0 h[3] | 0.0 h | 0.0 h | 0.0 h | 3.7 h |
| 14 | 0.0 h | 0.3 h | 0.3 h | 9.7 g | 79.3 d |
| 21 | 0.0 h | 0.3 h | 0.7 h | 24.3 f | 95.7 b |
| 24 | 0.0 h | 0.7 h | 1.0 h | 32.3 f | 96.3 ab |
| 28 | 0.0 h | 0.7 h | 1.0 h | 49.3 e | 97.7 ab |
| 35 | 0.0 h | 1.0 h | 1.0 h | 70.3 d | 98.3 ab |
| 42 | 0.0 h | 1.0 h | 1.0 h | 80.0 cd | 99.0 ab |
| 49 | 0.0 h | 1.0 h | 1.3 h | 87.0 c | 99.3 a |
| 56 | 0.0 h | 1.0 h | 1.7 h | 91.3 bc | 99.3 a |

[1] Mean of six 50-seed replications.
[2] Testa integrity verified by examination under 40-fold magnification.
[3] Factorial analysis of time and treatment effects by Duncan's Multiple Range test. Any two means not having a letter in common differ significantly at 0.01 level.

accomplished mechanically in such a way that the testa is pierced and yet a sufficient number of embryos remain undamaged?

The results presented in Table 2 pertain to the first two of these questions. Even though exacting care was exercised during the debracting process, it was necessary to ascertain whether or not the testa had been pierced. This was determined by first scrutinizing the debracted seeds under 10-fold magnification and then by examining those still of uncertain condition under 40-fold magnification. Accordingly, the "testa intact" and "testa pierced" columns of Table 2 are presented with considerable assurance of accuracy. Whether or not the fruit is partially or fully debracted, it is evident that germination is negligible and not significantly different from the control if the testa remains intact. With the testa cut through, either degree of debracting yielded over 90% germination and in the case of the fully-debracted, reached 99.3%. We would suggest that the germination reported for debracted utricles in earlier studies may reflect the amount of inadvertent testa rupturing or piercing. Indeed, before we appreciated the importance of testa condition, we obtained germination in our debracted seedlots ranging from 24 to 70%. A comparison of the partially and fully-debracted treatments, both with testa pierced, suggest a delay in germination when part of the pericarp remains with the seed. After partially debracting the fruit, the seed still is encased by bract tissue. This delay, therefore, may be attributable to mechanical impairment by the remaining bract or to some germination-inhibiting substance in the bract, or to both. We did not investigate this further.

How to debract the utricles in quantity and to pierce the testa, yet to keep embryo damage to a minimum, is still largely unresolved. Springfield (1970) has used hammermilling to dewing fruits of *A. canescens*. He reported that total germination was not increased but faster germination and greater ease in planting resulted. Our quantity of fruits was inadequate to try this method. Graves et al. (1974) used a legume-seed scarifier designed for small seedlots on *A. canescens* and *A. polycarpa*. This scarifier consisted of a brass cylinder 5.4 cm in diameter by 7.5 cm in length, lined with emery cloth over which the seeds were driven by compressed air. Although they varied the air pressure, time, and coarseness of emery cloth, this method did not benefit germination in *A. canescens* and did produce some damage to embryos in *A. polycarpa*.

We tried this same scarifier but with modification on the more indurated utricles of Sereno saltbush. The emery cloth was withdrawn, exposing the brass surface of the cylinder, and air at 40 psi was used to strike the utricles against that metal surface. This succeeded in breaking the pericarp and in freeing the seed from the locule of some fruits. We termed these seeds "peeled" to distinguish them from those debracted with a razor blade. Starting with lots of 3000 utricles in the scarifier cylinder we found that an average of 12.5% were peeled after 100 seconds of continuous operation and 23.4% were peeled after 400 seconds. Seeds peeled during this processing continued to churn within the cylinder and were subject to abrasion of the testa and breakage of the embryo. After processing, the seeds were divided into those remaining unpeeled, those peeled having visibly broken embryos, and those peeled having unbroken embryos. The latter condition was verified under 40-fold magnification, which also revealed that many peeled seeds with unbroken embryos showed abrasion of the testa. No determination was made of the proportion of these abraded testas that were actually pierced, but the germination percentages in Table 3 would indicate that about half were pierced, since they germinated from 46 to 57%. Indeed, the condition desired from treatment of the utricles is peeling together with testa piercing but without damage to the embryos. Utricles remaining unpeeled after processing germinate no better than

Table 3. Effect of processing utricles using compressed air to strike fruits against metal surface of scarifier.

| Condition after processing | % germination after 30 days | Calculated % germination for total sample |
|---|---|---|
| Sample A[1] (no processing | | 2.0 |
| 100% unpeeled) | 2.0 | |
| Sample B | | – |
| 7.4% peeled, embryo unbroken | 46.0 | |
| 4.1% peeled, embryo broken | – | |
| 88.5% unpeeled | – | |
| Sample C | | 9.3 |
| 9.9% peeled, embryo unbroken | 57.3 | |
| 12.3% peeled, embryo broken | 21.5 | |
| 77.8% unpeeled | 1.2 | |
| Sample D | | 6.2 |
| 6.8% peeled, embryo unbroken | 56.0 | |
| 24.5% peeled, embryo broken | 6.5 | |
| 68.7% unpeeled | 1.2 | |

[1] 3000 utricles per sample.

the untreated, and broken embryos reduce germination. These facts account for the low germination of the total sample.

The intensity of processing was increased progressively from sample B to C to D and this was evidenced by the proportion of each sample that was peeled (11.5%, 22.2%, and 31.3%, respectively). We considered the proportion peeled to be a better measure of treatment severity than the length of time in the scarifier, although these are related. In samples B, C, and D the proportion of the peeled seeds that showed damaged embryos was 35%, 55%, and 78%, respectively. For these samples a straight linear relationship existed between the percent of a seedlot that was peeled and the amount of damage in that portion that was peeled. This is to be expected when seeds once peeled remain in the churning mass of utricles during processing. Were the compressed air stopped periodically and the peeled seeds removed before resuming treatment on the remainder, the damage should be reduced and the yield of peeled seeds increased. This was demonstrated in each of four runs of 390 seconds duration but interrupted every 30 seconds to remove the peeled seeds by screening. Of the 3000 utricles in each run, an average of 75% were peeled using this technique.

The information in the previous two paragraphs is presented not as a fully developed procedure, but rather to be suggestive of an approach which may be applied to utricles of Sereno saltbush before sowing and possibly to other species with small but heavily indurated fruits.

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# THESIS: THE UNIVERSITY OF WYOMING

**Moisture Stress in Woody Plants of Wyoming as Influenced by Environmental Factors, by Carl L. Wambolt. PhD, Range Management. 1970.**

An investigation of moisture stress in several woody plants was conducted to evaluate the influence of certain environmental factors on stress values. These environmental factors included atmospheric, edaphic, topographic, and vegetation variables. Data were obtained in the following plant communities: *Juniperus osteosperma, Juniperus scopulorum, Atriplex nuttallii, Artemisia tridentata, Pinus ponderosa, Pseudotsuga menziesii, Pinus contorta, Pinus flexilis,* and *Picea engelmanni.*

A number of preliminary trials were conducted to develop techniques necessary for standardized field procedures. It was found that sample twigs should have a cluster of twigs at least 2½ inches in diameter and several years of secondary growth for minimum variance of stress values. Stress determinations had to be taken within 5 minutes after the sample was cut from the plant to avoid abnormally high stress values. Increased effective solar radiation resulted in higher stresses on the sunny side of plants than on the shaded side. The position of the sample twig on the plant, other than in relation to sunlight, had no influence on stress values. Different species growing in close proximity to each other often had large variations in their moisture stresses. Individuals of a species varying in size and age, at times had quite different stresses. Plants growing in deeper soils were found to have significantly lower moisture stress values than plants in shallow soils.

The environmental factors considered in this investigation varied in their importance to moisture stress. Moisture stress varied between opposite exposures, but no exposure was consistently higher than its opposite. Stress values were higher near the top of slopes than near the bottom.

Diurnal variation in moisture stress was highly correlated to changes in temperature, relative humidity, and vapor pressure deficit. The correlation coefficients approached 1.0 for most analyses. The diurnal fluctuations in stress were up to 4 times the minimum stress values for the days of observation. As the summer progressed both the maxima and minima stresses increased for the 24-hour periods. Stress values for trees sampled at intervals throughout the summer increased significantly as the season progressed and soil moisture decreased.

Correlation coefficients averaged close to 1.0 for the relationship of plant density to moisture stress when other environmental influences were held constant. This was interpreted as quantitative proof of the intraspecific competition for available moisture by plants.

Moisture stress values of 21 stands of coniferous trees, three each of seven species, were quite highly correlated ($R = 0.84$) to elevation, percent sand, temperature, relative humidity, and vapor pressure deficit. These factors were highly correlated even though the stands were found in widely divergent habitats. High cation content in the xylem sap was associated with high moisture stress for the stands from which sap was collected.

Two resource management techniques were found to influence plant moisture stress. Young lodgepole pine in a clear cut area had lower stresses than young pines in adjacent old growth timber. Utah juniper trees sprayed with an herbicide (Tordon) had lower stresses than did unsprayed individuals close by.

# TECHNICAL NOTES

# Effects of Fire and Mechanical Treatment on *Cercocarpus montanus* and *Ribes cereum*

D. LEWIS YOUNG AND JAMES A. BAILEY

**Highlight:** *Effects of fire and of clipping stems at ground level on the quantity and quality of production (current annual growth) of true mountainmahogany (*Cercocarpus montanus *Raf.) and squaw currant (*Ribes cereum *Dougl.) were studied. For both plant species, treatments applied during the dormant season, and especially fire treatments, were more effective in increasing production than were treatments during the growing season. Dormant season burning increased production by 200 to 900% for at least 2 years. As production increased due to treatment effects, the concentrations of crude protein, phosphorus, and calcium decreased slightly in current annual growth of squaw currant. Similar, but nonsignificant trends were noted for crude protein and phosphorus in current annual growth of true mountainmahogany.*

Browse constitutes an important, often critical portion of the winter diet of several wild ungulate species in the United States. Browse stands may lose their value to ungulates because (1) plant succession changes species composition, (2) stems grow out of reach of animals, or (3) plants become decadent and decline in productivity. Fire, mechanical manipulation, and herbicides are methods most used to rejuvenate browse stands. This study was designed to explore several factors affecting shrub responses to disturbance and to estimate among-plant variation in response to treatments. It was intended to serve as a basis for designing more intensive studies. Emphasis was therefore on testing many treatment combinations rather than on large sample sizes within treatments. However, since results indicate potential for managing two shrub species about which little is known, we are reporting them briefly, without review of literature which is contained in Young (1973).

True mountainmahogany (*Cercocarpus montanus* Raf.) is an important browse species in Colorado and has been studied somewhat. Squaw currant (*Ribes cereum* Dougl.) is less utilized but is also common in Colorado. The study was conducted at two sites in the eastern foothills of the Rocky Mountains in northcentral Colorado near Fort Collins. Site 1 was at 5,400 feet elevation; site 2 was at 7,000 feet.

Authors are graduate student and assistant professor of wildlife biology, respectively, Colorado State University, Fort Collins. At present, Young is soil scientist, U.S. Department of Agriculture, Santa Fe National Forest, Santa Fe, New Mexico.

This report is from a thesis submitted to the Graduate Faculty of Colorado State University in partial fulfillment of the requirements for the degree of Master of Science. Collection of 1972 data by William Reneau, Steve Brock, and Fred Provenza is gratefully acknowledged.

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## Design and Methods

Treatments were arranged for factorial analysis with: two study sites, two plant species, two seasons of treatment (dormant–late winter or March, 1971; and growing–height of blooming stage or May and early June, 1971), three treatments (control, fire, and clipping), and two intensities of both fire and clipping treatments. Plants were treated in both seasons at one site but only in the growing season at the other. Each treatment category was replicated on five randomly selected shrubs so that 75 plants of each species were studied.

Fire treatments were applied to plants individually with a kerosene-burning flame gun. For the high-intensity treatment, the flame was applied to the plant until the bark glowed red.

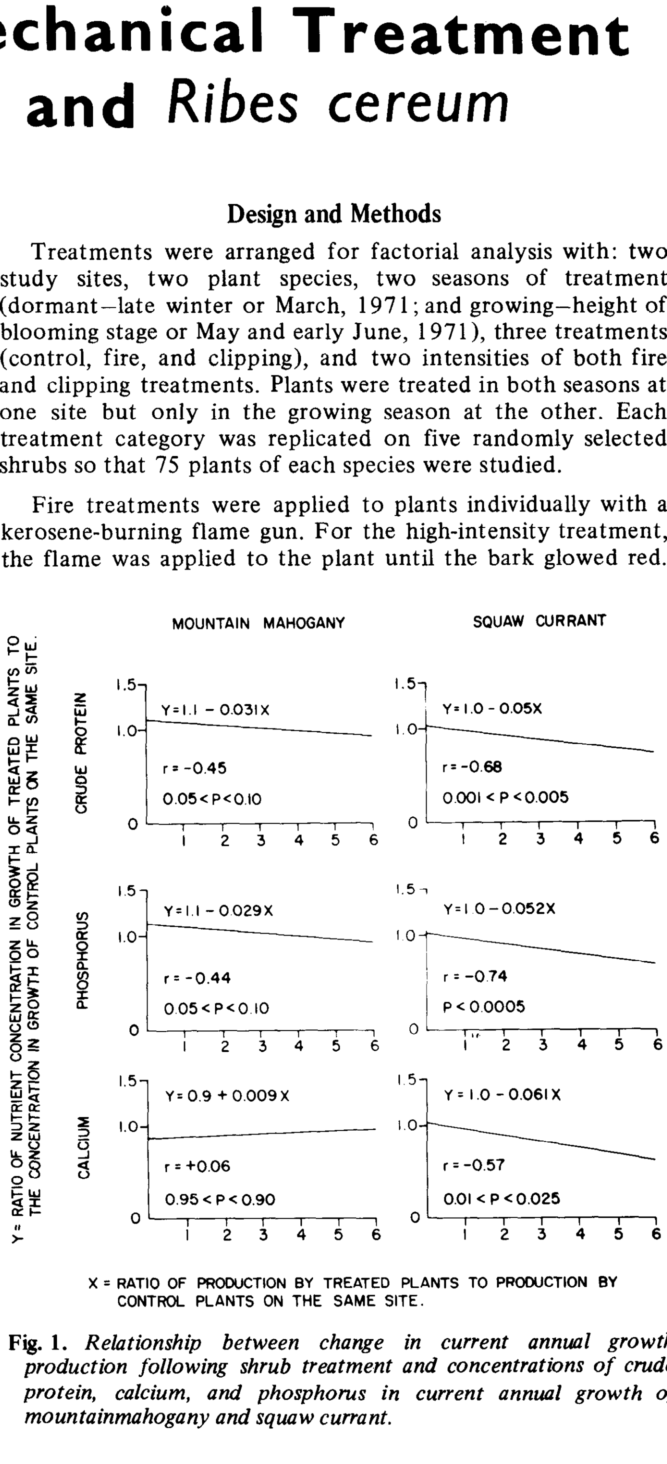


**Fig. 1.** *Relationship between change in current annual growth production following shrub treatment and concentrations of crude protein, calcium, and phosphorus in current annual growth of mountainmahogany and squaw currant.*

Table 1. Mean first year (1971) and second year (1972) production of current annual growth for five mountainmahogany plants in each treatment.

| | Site 1 | | Site 2 | | | |
|---|---|---|---|---|---|---|
| | Growing-season treatment | | Growing-season treatment | | Dormant-season treatment | |
| Treatment | 1971 | 1972 | 1971 | 1972 | 1971 | 1972 |
| Control (g/plant) | 62.9 | 37.2 | 6.1[2] | 2.5[2] | 6.1[2] | 2.5[2] |
| Fire | | | | | | |
| High-intensity (ratio)[1] | 0.6 | 1.1 | 0.6 | 1.0 | 4.8 | 4.6 |
| Low-intensity (ratio)[1] | 0.7 | 1.8 | 1.0 | 1.7 | 6.5 | 9.1 |
| Clipping | | | | | | |
| High-intensity (ratio)[1] | 1.3 | 2.0 | 0.5 | 0.4 | 1.8 | 1.8 |
| Low-intensity (ratio)[1] | 0.7 | 1.1 | 0.7 | 1.3 | 3.6 | 1.6 |

[1] Production by treated plants is expressed as a ratio to production by control plants in the same year-site class.
[2] Average of ten control plants; five from growing-season series and five from dormant-season series.

The entire plant was treated. For the low-intensity fire treatment, each part of the plant was treated for approximately 1 second. Eighty and 40% of the stems arising from the root collar of each plant were severed 5 cm above ground level for the high- and low-intensity clipping treatments, respectively.

Production by the shrubs was estimated during winters following the 1971 and 1972 growing seasons using an average twig-weight method similar to that of Schaefer (1963). Only sprouts or twigs longer than 1 cm were considered. A sprout is defined as a unit of current annual growth originating directly from the root crown of a plant or in the case of the clipping treatment originating from either the root crown or the remaining 5 cm of a severed stem. A twig is a unit of growth originating from older growth on a stem except as a sprout is defined on severed stems. From each shrub, samples of newly grown sprouts and twigs were collected, dried at 60° C for 48 hours, and weighed. Mean weights per sprout and per twig were calculated, then multiplied by the numbers of sprouts and twigs, respectively, on the shrub to obtain the estimated production.

Samples of 1971 growth, collected in February and March, 1972, were analyzed for crude protein using the micro-Kjeldahl method of the Department of Animal Science, Colorado State University. Samples were also analyzed for phosphorus and calcium using the Association of Official Analytical Chemists method (Horwitz, 1970).

Data from the 1971 growing season were analyzed by the Statistical Laboratory, Colorado State University. The 0.05 significance level was used in declaring significant differences between means.

## Results and Discussion

All plants survived the first growing season after treatment. Two plants died the second growing season, for a survival rate of 98%. Both these plants were squaw currant that had been burned during the growing season.

Treatments applied during the dormant season resulted in significantly greater production than did treatments applied during the growing season (Tables 1, 2). This was true of both plant species and was supported by second-year data.

Fire treatments applied during the dormant season were most effective in increasing production of mountainmahogany (Table 1). For dormant-season treatment of squaw currant, fire treatments showed little or no advantage over clipping treatments (Table 2).

Fire treatments applied during the growing season were detrimental to production for both plant species the first year (Tables 1, 2). Decreased production was still evident in squaw currant the second year, although mountainmahogany appeared to have recovered. Of treatments applied during the growing season, only clipping treatments on squaw currant showed any promise for increasing production (Tables 1, 2).

While production by control plants was greater at Site 1 than at Site 2 (Tables 1, 2) there were no significant differences between sites in the responses of shrubs to growing-season treatments.

To aid in designing future similar experiments, it is noted that the coefficient of variation of production among plants treated alike was 85% of mean production for squaw currant and 80% of mean production for mountainmahogany.

Mean crude protein concentrations were significantly greater in current annual growth of mountainmahogany (8.0%) than in squaw currant (5.6%). Mean concentrations of phosphorus and calcium were significantly greater in current annual growth of squaw currant (P, 0.23%; Ca, 0.85%) than in mountainmahogany (P, 0.20%; Ca, 0.39%).

With squaw currant, crude protein, phosphorus, and calcium concentrations in current annual growth decreased slightly but significantly as production increased due to

Table 2. Mean first year (1971) and second year (1972) production of current annual growth for five squaw currant plants in each treatment.

| | Site 1 | | Site 2 | | | |
|---|---|---|---|---|---|---|
| | Growing-season treatment | | Growing-season treatment | | Dormant-season treatment | |
| Treatment | 1971 | 1972 | 1971 | 1972 | 1971 | 1972 |
| Control (g/plant) | 36.8 | 42.2 | 10.8[2] | 7.6[2] | 10.8[2] | 7.6[2] |
| Fire | | | | | | |
| High-intensity (ratio)[1] | 0.5 | 0.5 | 1.3 | 1.5 | 3.2 | 2.6 |
| Low-intensity (ratio)[1] | 0.5 | 0.7 | 0.4 | 0.3 | 5.2 | 2.1 |
| Clipping | | | | | | |
| High-intensity (ratio)[1] | 2.4 | 1.7 | 3.1 | 4.0 | 3.7 | 2.6 |
| Low-intensity (ratio)[1] | 2.7 | 1.3 | 2.0 | 1.4 | 2.0 | 2.0 |

[1] Production by treated plants is expressed as a ratio to production by control plants in the same year-site class.
[2] Average of ten control plants; five from growing-season series and five from dormant-season series.

treatment effects (Fig. 1). With mountainmahogany, crude protein and phosphorus concentrations also tended to decrease as production increased, whereas calcium levels appeared unrelated to changes in production.

The importance of relatively small changes in chemical composition as production varies is unknown. More important, these results show from 200 to 900% increase in browse production for at least 2 years after shrub treatment during the dormant season. This suggests great potential for management of big game winter ranges on public lands to compensate for loss of winter ranges due to expanding human activities on private and public land in the Rocky Mountain Region.

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# Effect of pH on Germination of Four Common Grass Species of Ujjain (India)

V. P. SINGH, S. L. MALL, AND S. K. BILLORE

**Highlight:** *The effect of acids and bases on the seed germination of four important grasses were evaluated at Ujjain (India). The species were* Iseilema anthephoroides, Sehima nervosum, Apluda mutica *and* Dactyoctenium aegyptium. *The seeds were treated in petri dishes by pH solutions ranging from 2.0 to 11.0 and percent of germination was recorded. No germination was observed at pH 2.0 in any species. In contrast to that of the* Apluda, *germination of* Iseilema *and* Sehima *was better in acidic medium.* Dactyloctenium *had high germination at all pH levels. The graph between pH and percent germination reveals a curvilinear relationship. Second degree quadratic equation* $Y = a+bX + cX^2$ *was fitted for each species to get the best estimate of the percent of germination for any particular pH value. Statistical analysis shows significant differences among the different pH levels and among species.*

Difficulties in obtaining good germination of grass seeds under natural condition have received considerable attention (Bruns and Rasmussen, 1958; Toole et al., 1956). The germination of seeds of grass plants has been of particular interest and has been subjected to detailed studies by Dahlberg (1916), Arny (1927), Williams (1968), and Stubbendieck (1974). It has been found that in grass seeds the germination-regulating mechanism is complicated and varies from one species to another in the same genus. One factor that has received little attention is the effect of pH. Soil pH was found to determine species distribution by affecting germination (Justice and Reele, 1954). The effect of acidity and alkalinity ($^+$H concentration) on seed germination and plant growth in nature is a rather profound one. Although a mass of data exists on the relation of soil acidity and alkalinity to plant growth, only a few studies made with water culture have attempted to examine such an effect including the germination stage.

The effects of acid and alkali upon the germination of seeds have been studied by Michaels (1910), Promsy (1911), and Plate (1913). A general conclusion from these investigations may be that a strictly acid reaction exerts an injurious effect. Furthermore, they point out that the relationship of germination to acidity varies considerably with the seeds of different plants and with the kind of acids used, organic acids being more favourable than inorganic, when used in equivalent amount.

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The authors are indebted to Prof. L. P. Mall, head, School of Studies in Botany, Vikram University, for guidance throughout the course of the study.

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## Materials and Methods

The present studies were made on four dominant grasses of Ujjain (23° 11′N, 75° 43′E) commonly occurring throughout the Madhya Pradesh State on various types of soil. These were *Sehima nervosum* (Rottl.) Stapf., *Iseilema anthephoroides* Hack., *Apluda mutica* Hack. and *Dactyloctenium aegyptium* (L.) Ritcher. Seeds were collected in October and November, the time for ripening of seeds of the four species studied. All seeds were kept 4 to 5 months in air-tight glass bottles because all have a 4- to 5-month dormant period (Singh, 1969; Mall, 1972; and Gupta, 1973).

Petri dishes with Whatman No. 1 filter papers in the bottom were used as germination containers. The range of hydrogen ion concentration was established by adding hydrochloric acid or potassium hydroxide to distilled water. The pH levels of the solutions used were 2.0 to 11.0. Ten milliliters of a solution was added to each petri dish and 100 seeds for each species were placed in it. Germinated seeds (when coleoptile was > 2 mm for *Dactyloctenium* and coleorhiza was > 2 mm for the remaining three species) were removed after counting. For each pH treatment sufficient replications were taken to have reliable experimental finding. All the data so obtained were treated for various statistical analyses.

## Results and Conclusions

Figure 1 shows that each grass species responded differently to varying pH levels during germination. No germination was recorded at pH 2.0 in any species. At pH 2.5, *Iseilema* alone is capable of germination. Seed of this grass shows better germination towards the acidic range than on the alkaline side, with maximum percentage germination at pH 5.0. Similar results have been shown by *Sehima*. These data support the view of Salter and McIlvaine (1920), who concluded that slight acid reaction is favourable for seed germination.

Contrary to the germination results of foregoing two species, *Apluda* had best germination at alkaline pH values from 8.0 to 9.5. It seems that acidic medium does not favour the synthesis or action of an enzyme necessary for

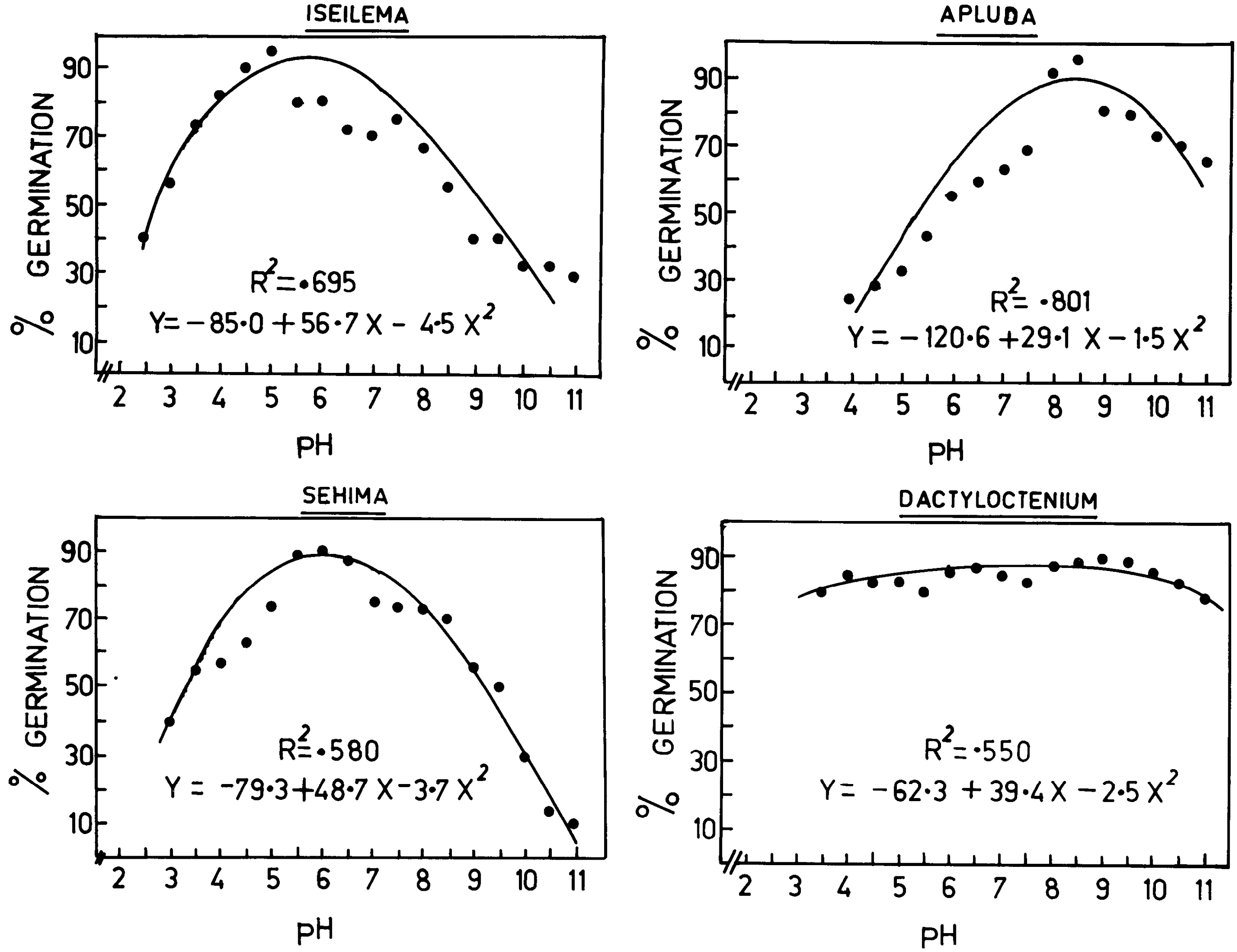


**Fig. 1.** *Graph showing relationship between pH and % germination for the four species.*

germination. Thus the effects of acids or bases on germination may be a result of their favourable or unfavourable influence on the enzymic processes concerned. For *Dactyloctenium,* germination was comparatively higher at all levels (Fig. 1). An analysis of variance of the data reveals that statistical significant differences at 5% level occur between the species for percentage germination (F = 3.993, df 3 and 54) and for different pH levels (F = 4.879, df 18 and 54).

The relationship between pH versus percentage germination reveals a curvilinear nature (convex hyperbola) in the graph (Fig. 1). To obtain a good estimate of the dependent variable (% germination) for any particular value of the independent variable (pH), a quadratic second degree regression of orthogonal polynomial type was fitted to the data for each species:

$$\mathbf{Y = a + bX + cX^2}$$

where **Y** and **X** represent the percentage germination and pH, respectively. This equation along with the correlation coefficient ($R^2$) for each species were found to be significant at 5% level.

No germination was noted at pH 2.0.

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# An Inventory of Rangeland Brush Control Projects from ERTS-1 Space Imagery

KIRK McDANIEL, DILLARD H. GATES, ROGER FINDLEY, AND GLEN MILLER

**Highlight:** *Shrub-brush manipulation projects have had major ecological and economic impacts upon the 9,136 square miles of public and private rangeland in Malheur County, Oregon. Analysis of imagery from the Earth Resources Technology Satellite (ERTS-1) indicated that space-acquired data used in conjunction with field data, holds a potential for identifying, classifying, inventorying, and monitoring these changes occurring on rangeland areas.*

An estimated 160,000 acres of private rangeland in Malheur County, Ore., have been altered by brush control projects since 1967.[1] Many of these projects have been cooperative cost-share arrangements between private land owners and the Agricultural Stabilization and Conservation Service. Field records kept by the Bureau of Land Management, Vale District, estimate 536,000 acres of federal rangeland in Malheur County have been affected by brush control projects since 1957.[2] Approximately 313,152 acres of this public land was treated from 1962 to 1969 when the BLM was allocated nearly $13,615,000 for rehabilitation and improvement of rangeland within the Vale District (Godfrey, 1971).

Control of undesirable brush on both private and public lands in Malheur County has been achieved primarily by mechanical techniques (plowing) and chemical means (aerial application of herbicides). Fire, either started accidentally or under a controlled management plan has also been effective for control of sagebrush. The objective of this study was to use space-acquired imagery from the Earth Resources Technology Satellite (ERTS-1) to identify the type and location of these brush control projects and to inventory the treated acreage.

## Procedure

Five overlapping 9" x 9" ERTS–1 photo frames (scale 1:1,000,000) cover Malheur County. For purposes of mapping, black and white transparencies, both positives and negatives, including spectral bands 4, 5, 6, and 7 were used. These spectral bands, recorded by a multispectral scanner aboard ERTS-1, refer to electromagnetic energy detected in four visible spectral bands from 0.5 to 1.1 micrometers. Each of these spectral bands provides unique information about various land areas. For example, contrast in natural vegetation appears most distinctive on band 5 imagery, while areas treated by cultural improvement practices are generally easiest to detect from band 7 imagery. In addition, color reconstituted photo images were produced using a composite of spectral bands 4, 5, and 7. All imagery interpreted was taken between the months of July to October, 1972.

Land units where brush control projects were interpreted as being implemented were outlined on separate acetate overlays placed over the ERTS-1 photo frames. The units delineated were examined for a unique image characteristic or signature and then classified according to one of the following brush control improvement classes:

a) *Mechanical control* – straight edges, sharp squared corners, nearly level topography (smooth, uniform texture in and around the treated area).

b) *Chemical control*– straight outer margins with some irregular edges, squared to rounded corners, generally hilly topography resulting in rougher photo texture, often darker contrast than mechanical and fire treatments because of less total vegetation removal (Fig. 1).

c) *Fire control* – irregular margin pattern, few straight edges, very dark color first year after burn, usually much lighter color in succeeding years (Fig. 1).

To verify the accuracy in mapping and classifying delineated land units, a ground truth field check was made along a preselected route through parts of Malheur County. Records were kept on the accuracy in mapping and identifying treatments which could be seen along this route.

With knowledge gained from the ground truth field trip, some earlier interpretations were revised and final interpretations completed. Then by using a dot-grid count (1,156 dots/square inch or 138 acres/dot), an inventory was made to measure the acreage altered by each of the brush control projects.

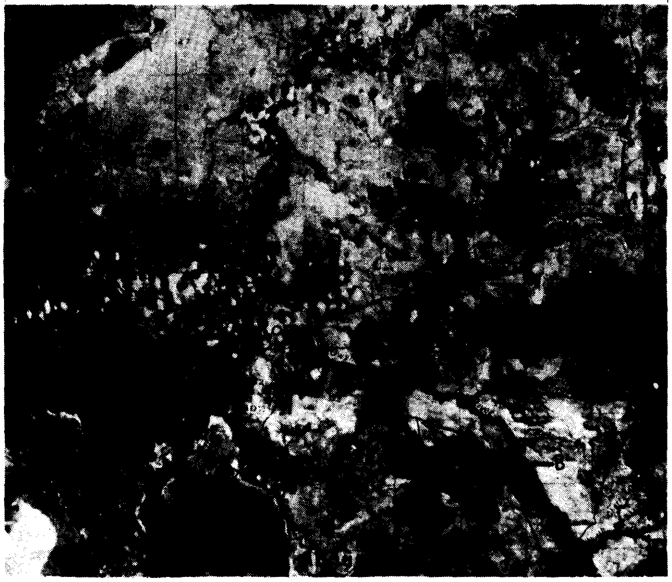

**Fig. 1.** *ERTS-1 photo taken over a portion of Malheur County, Oregon. Arrow A points to an area treated by aerial spraying. Arrow B points to a burned area.*

Authors are research associate, Department of Range Science, Texas A&M University, College Station; range specialist, US-AID, Washington, D.C.; rancher, Ontario, Oregon; and graduate research assistant, Department of Forest Management, Oregon State University, Corvallis. At the time of the research, McDaniel and Findley were graduate research assistants, Rangeland Resources Program, Oregon State University, Corvallis, and Gates was director of the Rangeland Resources Program there.

The paper was submitted as Technical Article No. 3931, Oregon Agricultural Experiment Station.

Manuscript received January 31, 1975.

[1] Personal communication with George Bain, Malheur County Extension Agent, and Jim Christian, Manager of Agricultural Stabilization and Conservation Service, Ontario office.

[2] Personal communication with Robert Sherve, Northern Area manager, Vale District of Bureau of Land Management.

**Table 1. Brush control treatments (sites) as interpreted from ERTS-1 photo compared with correct identifications based on ground truth field checks.**

| Treatment method interpreted from ERTS-1 photo | Treatment method determined by field check: Mechanical | Chemical | Fire | Other | Total sites observed | Correctly identified from ERTS-1 photo (%) |
|---|---|---|---|---|---|---|
| Mechanical | 7 | 1 | 1 | | 9 | 74 |
| Chemicl | 1 | 3 | | 3 | 7 | 43 |
| Fire | | | 2 | | 2 | 100 |

## Results and Discussion

A total of 56 different areas thought to be treated land units were interpreted on the images. Field records provided by the BLM and the Malheur County Extension Service showed that over the past 15 years about 150 different brush control projects have been conducted. Discrepancies between data collected from ERTS-1 imagery and field records can generally be attributed to three causes: (1) some treated land units were too small to detect on the imagery (generally less than 150 to 350 acres in size); (2) several brush control projects were conducted in close proximity to each other, giving the appearance on the images of being a single treated land unit; and (3) some areas which should have been detected were simply overlooked due to low contrast between treated areas and adjacent untreated areas.

During the ground truth field check, three areas were noted which were improved but had not been previously identified from the photos. Two of these areas were treated after the summer 1972 ERTS-1 flight data and thus would not have been detected. The third area noted was a spray-release project which was later recognized on the imagery. From a total of 18 mapped areas checked, 15 (83%) were examples of some form of cultural improvement (Table 1). Two wild hay meadows and a sparsely vegetated silver sagebrush (*Artemisia cana*) flat were erroneously classified as treated areas. Considering errors made while classifying all delineated units, the accuracy of interpretation was 67%.

A total of 457,996 acres was estimated to occur within photo mapped areas by the dot-grid count. Field records kept by the BLM and the Malheur County Extension Service estimate 470,152 to 662,546 acres of private and public land have been treated in Malheur County since 1962. The lower estimate from the photos can largely be atrributed to two factors: first, the inability to identify smaller brush control projects; and secondly, areas treated by chemical methods, particularly using spray-release treatment, could not be identified satisfactorily as the treatments became older (approximately 7 years). Some exceptions were found, particularly if the area treated was large or vegetation reestablishment was retarded.

## Conclusions

The results from this study indicated that ERTS-1 imagery used in conjunction with field data can be a useful tool for identifying and inventorying range brush control projects. The primary advantage of small scale space imagery is that it provides a comprehensive view of large land areas. As such, it holds a significant potential for gaining a greater perspective of land in and around such improvements. It seems possible that space-acquired imagery could assist land resource managers in the future for monitoring when and where such practices occur on lands under their jurisdiction.

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# A Technical Information System for Range Mangement

STAN TIXIER

How many times have you as a practicing range manager (whether a researcher, public land administrator, range technician, or stockman) pondered the question, "How can I get my hands on published research findings to help me solve a specific problem?" Sure, you have a stack of *Journal of Range Management,* a bookcase full of various publications, and maybe a pretty good card file, and the answer you're looking for may well be there. Maybe you're better organized for this task than most, but still, finding all of the pertinent material can be a frustrating, time-consuming experience. There has to be a better, quicker, more efficient way. There is! Or at least there soon will be. It is within reach in the state of the art, and being developed by the Society for Range Management, three cooperating Federal agencies, and Colorado State University.

Under an agreement recently signed by the Forest Service (in cooperation with the Soil Conservation Service and Bureau of Land Management) and Colorado State University, the first phase of input into a technical information system for range management is underway. Phase One includes all of the articles that have appeared in the *Journal of Range Management* since it was first published in 1948. These articles are being cataloged, and pertinent information fed into an Energy Research and Development computer in Oak Ridge, Tennessee. In later phases, range articles in other publications will be added. These will include other journals, periodicals, publications, technical papers, and dissertations—the full scope of published scientific information on the subject of range management.

The system is designed to be kept current. Future articles of the *Journal* will be included automatically. Provisions will be made to add other scientific range information as it becomes available.

Once the computer based file is constructed, it will be made available to interested users through an information brokerage service. That may sound complicated, but what it means to you and me is this: If we want to know what has been published on a given subject, we simply define that subject as precisely as possible by using appropriate key words and standard range terminology (as appears in the new glossary for range terms). Then we call or write the information broker and request a printout of the pertinent information on that subject. We will pay a nominal fee for the service provided. If we have access to a subscribing terminal, we can get the information back in a matter of minutes; otherwise, it will require regular mail service time.

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A future refinement of this system will be availability of information digests or detailed abstracts of more recent or pertinent material. With this service, a great deal of information on a given subject can be obtained quickly and efficiently.

Such systems are currently available for a few other disciplines and being developed for several others. The range technical information system promises to be a tremendous assist to range managers in rapidly locating the material they need. Research on the shelf and gathering dust does little good. This system is designed to make a wide range of research findings readily available to those who can best put it to work with a minimum of time, effort, and expense. It should be a significant step forward in range management.

# VIEWPOINT

# Industry's Role in Rangeland Restoration

MICHAEL J. CWIK

Will government determine the future of our rangelands? It is currently confronted by overlapping rangeland-oriented demands from ecologists, stockmen, and industry. Polycentric organizations, motivated by ecological interest groups such as the Sierra Club, Audubon Society, and the Izaak Walton League, demand that government give increasing emphasis to environmental considerations in industrial development. Government is also faced with demands from livestock interests trying to maintain themselves in the crossfire of a tight economy, increased demand for meat protein, and an awareness toward energy efficiency in agriculture. Finally, government is faced with demands from industry to be reasonable in establishing environmental guidelines which have to be met as a prerequisite for continued construction or operation of new facilities.

Government has failed in many instances to adequately cope with ecological and livestock interests in its philosophy on environmental impact assessments. Rather, it assumes an industry-oriented policy posture which encourages industrial development regardless of environmental consequence. At the Western Governors' Conference held in Albuquerque, New Mexico, last August the Phoenix Gazette quoted Governor John Vanderhoof of Colorado as saying,

> We're not going to be run roughshod over by bureaucrats and people from high levels in Washington in the development of these resources unless the tradeoffs and the accommodations of our people are properly made.

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Among tradeoffs listed at the conference as necessary for western industrial expansion to proceed are:

1) Federal loans and grants to pay for water and sewer projects, schools, and other facilities that will be needed to handle an influx of population.

2) Doubling of the state's share of royalties paid to private firms for the extraction of resources under federal lease, from the current 37.5% to 66-2/3%.

3) Relative independence from federal rules and regulations in planning orderly development of the coal and shale fields.

This philosophy of trading environmental protection for economic expediency is primarily what environmentally aware citizens face in trying to implement environmentally sound land use policies.

### Industrial Interests

Industry's interest in rangelands results from a historical chain of events culminating in what has popularly been termed the energy shortage. Energy consumed in the U.S. has grown steadily and has increased approximately 18-fold in the last century. Today, with 6% of the world population, the U.S. accounts for over 35% of the world energy consumption. Annual energy consumption for the U.S. in 1972 was $71.5 \times 10^{15}$ British thermal units (Btu). Oil, natural gas, and coal comprised the bulk of our consumption of primary energy fuels (Table 1). Domestic sources contribute approximately 84% of the resource base from which our primary energy comes. By 1985 the National Petroleum Council projects an increase in our total energy consumption rate of 43% to $125 \times 10^{15}$ Btu's.

At present, use of electricity is emphasized as a principal energy source in the United States, particularly in light of declining supplies of petroleum and natural gas. Electrical energy supply can fall short of demand if facilities to convert primary energy, mainly coal and nuclear materials, to electricity are not available in sufficient quantity. Consequently, emphasis is being placed on development of facilities for generating electricity from coal or nuclear materials. In the case of nuclear power plants, it has been projected that between 1980 and 1990, sites for 17 new 1000 Mw nuclear units will be needed each year along with an annual requirement of 10,000 miles of accompanying transmission lines. Much of this expansion is materializing in the western states, as a result of demands from burgeoning metropolitan areas. Site investigations for power plants in our western states often point to rangelands as

**Table 1. Sources of energy fuels consumed in the U.S. in 1972.***

| Fuel | |
|---|---|
| Oil | 44.4% |
| Natural gas | 31.8% |
| Coal | 18.6% |
| Hydro | 4.1% |
| Nuclear | 1.0% |
| Electricity | generated from the above, consuming 25% of this total energy. |

*British Petroleum Co., 1972, Statistical review of the world oil industry.

offering preferable inland areas for localized and linear industrial development. Rangelands are also important to industry because many are underlain by extensive tracts of coal reserves, one of the major primary energy fuels. Northeastern Arizona and New Mexico, northern Colorado, Wyoming, and southeastern Montana all have extensive proven coal reserves.

Industry's record regarding the rangeland environment has not generally been compatible with the interests of environmentalists and stockmen. Evidence points to the seeming disinterest by industry to take a holistic approach in its industrial expansion process. One needs only to point out the paucity of water resources which will be overcommitted in our western states if all proposed coal mining, oil shale development, and energy conversion facilities become a reality. Further, possible socio-economic repercussions to land use in natural areas have historically been given low priority when plans are proposed for large industrial facilities located in rural areas. The disregard for the major role of unquantified or unquantifiable factors in sight-selection processes have exemplified industry's inability to consider the long-term cumulative environmental impact on industrial expansion into relatively undeveloped areas. Industry's interest in rangeland per se is practically nonexistent. Rather, industry looks with interest at the land surface and subsurface on which rangelands exist.

### Opportunity to Benefit

Can rangelands benefit from industrial development? The legislative process is now open for ecological, livestock, and industrial groups, to seek ways by which their particular interests can be protected.

#### Environmental Legislation

Certain ideas involving environmental issues which can affect the future of rangelands are being advanced. These ideas result from a plethora of court cases involving environmental issues and recent federal, state, and local legislation and recommendations.

On the federal level, the Council on Environmental Quality (CEQ), in their recently revised *Guidelines for Environmental Reports,* is initiating several new approaches in preparation of environmental impact statements. Section 1500.2 in the Code of Federal Regulation reads in part,

> as early as possible and in all cases prior to agency decisions concerning recommendations or favorable reports on proposals . . . federal agencies will, in consultation with other appropriate federal, state, and local agencies of the public, assess in detail the potential environmental impact.

Section 1500.8 goes on to say, in part that,

> the interrelationships and cumulative environmental impacts of the proposed actions . . . shall be presented in the statement.

Further on, Section 1500.8 states,

> Agencies should also take care to . . . determine secondary population and growth impacts resulting from the proposed actions and its alternatives . . . .

Part (2) of Section 1500.8 in the revised CEQ guidelines goes on to say in part that, among the points to be covered in environmental statements, is,

> the relationship of the proposed action to land use plans, policies and controls for the affected area. This requires a discussion of how the proposed action may conform or conflict with the objectives and specific terms of approved or proposed federal, state, and local land use plans, policies and controls, . . . .

These guidelines clearly indicate the federal government's philosophy in assessing potential environmental impact. Emphasis on estimating cumulative impact, estimating indirect impact from increased population pressures, and relating these impacts to any land use patterns in the area prior to any decisions for industrial development in an area, is a fresh approach in the environmental impact assessment process.

Associated with the revised CEQ guidelines are federal, state, and local environmental-oriented actions. On the national level, the Bureau of Reclamation has publicly taken a stand opposing the White House energy plans in western states. The Bureau believes that the possibility of augmenting energy production is severely restricted by a crisis resulting from impending water shortages. Environmental legislation and regulations from Washington have recently occurred. The U.S. Surface Mine Reclamation Act of 1973 requires that all mine areas be revegetated within 2 years of abandonment. Although this act is unrealistic in its time schedule for revegetation, it is a start in the right direction. The House and Senate have recently agreed to finance a land reclamation fund with a 35 cents/ton fee on all coal mined in the U.S. Most of the revenue from this plan would go to restoring land scarred by abandoned strip mines.

#### Industry's Responsibility

This author urges that industry play a significant role in improving conditions of western rangelands which are directly or indirectly involved in proposed industrial development. Industry, due to either voluntary or involuntary ignorance, will not take the initiative in improving these rangelands. It must be guided by legislation developed from objective scientific evaluation. Why should industry not restore indirectly impacted rangelands to their highest biological potential?

At the site of Fermi National Accelerator Laboratory near Batavia, Illinois, plans are under way to restore the lush tall grass prairie in a 900-acre area surrounding the industrial site. This would, when completed, be the nation's largest reconstructed prairie. If maintained with proper grazing and management, beef production would be increased while an example of a major grassland ecosystem would be available for study by ecological interests.

Ecological interests, livestock interests, industrial interests and especially government, should all take notice of this action. Industry has benefited. By showing a positive, action-impelling environmental awareness of the importance of our nation's rangelands, it has won support from some of those interests it spends precious time and money on in arbitration procedures. Industrial environmental awareness such as this, motivated by careful legislation and implemented for all industrial activity on rangelands, can restore at least a small portion of the rangeland environment in our country at a time when ecological and livestock interests justifiably point to its degradation, and agronomists emphasize its future importance for finishing livestock. Certainly, in our day and age, when several hundred million dollars are commonly budgeted for major industrial developments such as electric generating facilities and accompanying equipment for preventing air and water contamination, a small fraction of 1% of this budget can be dedicated to improvement of biological systems, such as rangelands, which lie immediate to these facilities.

In summary, legislation has finally provided some opportunities whereby rangelands can benefit from industrial development. Ecological, livestock, and industrial interests, aided by sound scientific consultation, should seize these opportunities and insist that sound mitigating measures be employed and supervised to restore impacted rangelands to their full biological potential.

# BOOK REVIEWS

**Poisonous Plants of Australia.** By Selwyn L. Everist. Angus & Robertson Publishers, P.O. Box 177, Cremorne Junction, N.S.W. 2090, Australia. 1974. 684 p. $45.00.

Those familiar with Kingsbury's 1964 book on North American poisonous plants will find this new book by Everist a very handsome and useful supplement. It is similar in format to the former with due credit given, but is unique in other ways. The book is divided into two sections. The first section encompasses a group of six chapters introducing the subject of poisonous plants and then describing what constitutes acceptable evidence of toxicity, what factors influence toxicity, how to investigate poisonous plant problems, what classes of compounds toxins are, and what kinds of prevention and treatment are available and successful. The second section includes three chapters and three appendices. The three chapters (almost the entire bulk of the book) are devoted to detailed coverage of the various poisonous plants grouped in three main categories: seed bearing plants; ferns and fern-like plants; and fungi, lichens, and algae. The three appendices cover poisonous plant distribution in Australia, poisonous plants grouped by symptoms they produce, and a grouping of plants by toxic principle.

People in range management and in animal disease-related fields will find the first five chapters particularly interesting. Everist has "told it like it is." He describes the limitations in determining whether a plant is poisonous by showing why field observations of death losses of animals, why feeding trials with poisonous plants, and why chemical testing for toxins are seldom adequate individually in establishing the hazard of a particular plant. He reminds us that there are a variety of factors related to plants, animals, and environment that influence the toxicity of poisonous plants. He points out that few genuine treatments exist for animals already poisoned and that the best policy is for one to have a thorough knowledge of poisonous plants and then to keep animals away from them when they are a hazard.

The detailed coverage of individual poisonous plants varies in completeness—possibly a reflection of available literature. Generally, information is given on plant description, distribution and habitat, conditions of poisoning, poisonous principles, toxicity symptoms, lesions, and prevention and treatment. North Americans will find covered many plants identical to or related to North American plants such as *Lupinus, Swainsona* (the Australian locoweeds), *Solanum, Crotalaria, Datura, Senecio,* and others.

Appendix two will be particularly helpful to all who are faced with the need for speedy diagnosis of plant poisonings since plants are listed in column form adjacent to symptoms they produce. Clearly, Everist has written the book as he says, for "grazers and farmers as well as students and professional men." The book has 64 beautiful color photographs, 42 very adequate drawings, and 64 black and white photographs nearly all by the author himself and nearly all of plants. There are also a few shots of poisoned animals.

The principal disappointments of the book are that there is no comprehensive alphabetized bibliography, that in many cases coverage of more recent original references is limited, and that the photographs are not arranged with corresponding text material.

But all in all, Everist's book makes a very favorable impression and will be highly valued by all who deal with any phase of poisonous plant work.—*R. F. Keeler,* Logan, Utah.

**Wildlfowers of the Southeastern United States.** By W. H. Duncan and L. E. Foote. University of Georgia Press, Athens, Georgia 30602. 1975. 296 p. $12.00.

This attractive 6- by 9-inch hardback is the latest in the recent profusion of color-illustrated plant handbooks to appear in the southeastern United States. The youthful granddaddy of them all is Rickett's giant two-part southeastern volume of *Wildflowers of the United States* (1968), followed by Justice and Bell's *Wildflowers of North Carolina* (1968), Wharton and Barbour's *The Wildflowers and Ferns of Kentucky* (1971) and Brown's *Wildflowers of Louisiana and Adjoining States* (1972), and Dean et al., *Wildflowers of Alabama and Adjoining States* (1973). Although many plants are repeated in all six works, each book contributes uniquely to the understanding and enjoyment of our southeastern wildflowers.

Dr. Duncan, professor of botany at the University of Georgia, and Mr. Foote, the southeastern field representative for the Wildlife Management Institute and chairman of the Georgia Board of Natural Resources, took most of the 485 color photographs. Three or four illustrations on the right-hand pages with Latin names and relative scales are easily matched with descriptions on the left. Photographs were made on site, with fill-in flash when necessary. Careful choice of background, professional use of natural light, and obviously excellent camera equipment and know-how produced delightful as well as technically definitive illustrations.

Plant descriptions are arranged by families, beginning with the dicots and the lizards-tail family, *Saururaceae.* Monocots follow the composite family, *Asteraceae,* at the end of the book. This departure from the traditional Englerian arrangement followed in most plant manuals may not surprise Dr. Duncan's colleagues and former students. Each description has a common name—sometimes two—and the Latin name with author citation. Evidently the latter, usually a source of typographical errors, were meticulously prepared and proofread. Texts of the descriptions are narrative and interesting. Although metric measurements and technical botanical terms may slow some readers, an introductory glossary is included, as well as illustrated discussions of the distinguishing characteristics of leaves, flowers, and fruits. Simple keys to unusual family characteristics and floral features of species groups are also in the introduction. Relative abundance, geographic range, typical habitat or site, and flowering dates are indicated as well as interesting histories, medicinal, poisonous, or other special features where appropriate. Other species that may not be as widespread or representative as the illustrated plants are named and described in the appropriate description. Thus, according to the authors, about 1,000 plants can be identified by use of the photos and descriptions.

The book serves Louisiana well at the southwestern limit of its range and should be useful anywhere in the eastern half of the United States.—*Harold E. Grelen,* Pineville, Louisiana.

**Agriculture: Food and Man. Study guide.** By Robert L. Park, Laren R. Robison, G. Alvin Carpenter, Leon E. Orme, Max V. Wallentine, and Lamont W. Smith. Brigham Young University Press, Provo, Utah 84602. 1975. 157 p. $2.95 (paper).

This book was published to help alleviate an information gap. It is designed to provide interested laymen with a study guide on agriculture. Thirty-eight articles, on topics ranging from the history of agriculture to present-day crop production and livestock management, help the reader to gain an overall view of food production, processing, and distribution. Important consumer topics such as meat grading and the factors determining food prices are also covered in detail in the book.

This study guide has been prepared to enable the nonfarmer to more fully understand the basic biologic and economic principles fundamental to the production, processing, and distribution of food. The lectures are designed to guide students through a study of agriculture and to stress that the nation with the firmest agricultural base is also the nation most likely to be strongest politically in the future.

In the selection of topics, the authors have attempted to cover the entire field of agriculture—from producer to processor to distributor to consumer, in varying depths. It is by taking a look at the many faceted field of agriculture, with deeper study in the more relevant topics, that students can gain a truer picture of the importance of a viable and dynamic agriculture in their lives.

The major concept sets the theme and the lecture statement gives the student a preview or synopsis of the main ideas which will be developed. The objectives and questions are guides for independent study from the key references listed at the end of each topic.—*Ralph J. Kotich,* Fort Collins, Colorado

## THESIS: MONTANA STATE UNIVERSITY

**The Effect of Spring Burning of Big Sagebrush-Grassland (*Artemisia tridentata* Nutt.-Grassland) on Soil and Vegetation**, by Mutasim Bashir Nimir. MS, Range Management. 1974.

The study was planned to find the effect of spring burning of big sagebrush-grassland (*Artemisia tridentata* Nutt.-grassland) on the soils and vegetation of a part of Taylor Fork cattle and horse allotment, Gallatin National Forest, Montana.

The study area was burned on May 30, 1973. The burn was not thorough because of unfavorable weather conditions and considerable green growth.

Procedures used to obtain information on the effect of burning on the soil physical properties were: measurement of soil temperature during the burn, weekly measurements of the soil temperature following the burn, biweekly measurements of the soil penetration indices, measurements of the infiltration rates, and measurements of the soil moisture contents.

Samples of soil were collected before and after burning for chemical analyses.

Procedures used to obtain information on the effect of burning on vegetation were: weekly measurements of the basal cover, weekly measurements of the vegetational development, measurement of the production, and estimation of the big sagebrush killed by the burn.

This study produced the following results: The soil physical properties did not show major changes induced by the burn. The slight changes of the soil physical properties reported are not expected to trigger immediate changes in the vegetation. The soil chemical analyses reflected that the changes due to biological reasons were greater than the changes due to burning effect and that the change in soil nutrients was not very important. Burning resulted in a considerable temporary reduction of the basal cover of most of the vegetation as a result of direct damage caused by the fire. The damage did not last for more than 3 or 4 weeks for most of the species. Differences in vegetation and soil characteristics were more related to the time of measurement than to burning.

*Festuca idahoensis* was more susceptible to damage by the burn while *Agropyron trachycaulum* was favored by the burn.

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