5-1974

Economic Feasibility of Controlling Big Sagebrush (Artemisia tridentata) on State and Private Rangelands in Utah

Stan D. Hinckley

ECONOMIC FEASIBILITY OF CONTROLLING BIG SAGEBRUSH (ARTEMISIA TRIDENTATA) ON STATE AND PRIVATE RANGELANDS IN UTAH

by

Stan D. Hinckley

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agricultural Economics

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1974

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to Dr. Darwin B. Nielsen, committee chairman, for his suggestions and help in reviewing this manuscript. I express my appreciation to Dr. John P. Workman and Dr. John C. Malachek, members of my advisory committee, for their time and assistance in completion of this study.

My thanks to Dr. Lowell Wood, Head of the Department of Agricultural Economics at Brigham Young University, for his encouragement to do graduate work at Utah State University.

Stan D. Hinckley

Stan D. Hinckley

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

ABSTRACT

Economic Feasibility of Controlling Big Sagebrush

(*Artemisia tridentata*) on State and Private

Rangelands in Utah

by

Stan D. Hinckley, Master of Science

Utah State University, 1974

Major Professor: Dr. Darwin B. Nielsen
Department: Agricultural Economics

Spraying with the chemical herbicide 2,4-D is the most widely used method of controlling big sagebrush. Spraying is very effective in increasing forage production and generally is not poisonous to either man or animals.

Two procedures can be used to calculate the internal rate of return to big sagebrush control: standard and modified discounting. Standard discounting assumes all nonuse costs are incurred in the year of treatment, and the annual income stream is constant throughout the effective life of treatment. Modified discounting correctly assumes the nonuse cost is incurred in the period of deferment, and the income stream does not reach its full potential until after deferment. Thus, modified discounting yields a lower internal rate of return.

Three big sagebrush control methods (spraying, burning, and chaining) offer internal rates of return which are greater than 8 percent (cost of obtaining capital for range improvement).

The most important factors in determining the internal rate of return are the site vigor index and the amount of forage present before

treatment. A larger pre-treatment forage yield will give a larger internal rate of return, assuming the vigor index is sufficiently high.

If state and private rangelands infested with big sagebrush are not improved by spraying or other big sagebrush control methods, certain benefits, called opportunity costs, will be foregone. For spraying alone, the expected annual opportunity costs would be $3,048,102.

The economic feasibility of controlling nearly 2 1/2 million acres of state and private rangelands infested with big sagebrush are excellent. The expected annual increase in carrying capacity of 1,830,000 acres of sagebrush rangeland meriting improvement by spraying is 765,855 AUMs. The remaining 623,000 acres meriting control other than by spraying could possibly increase the total number of additional AUMs to over 1 million.

(94 pages)

INTRODUCTION

The General Problem

Managers of Utah's finite rangelands are faced with the challenge to meet present and future needs of our society and the associated environment. Some uses of this multiple-use resource are recreation, wildlife habitat, urban and rural expansion, and aesthetics.

The range livestock industry makes use of rangelands for production of food and fiber that would otherwise be unusable because of low rainfall, unsuitable soils, or rough terrain. Present trends indicate that each representative user of the land is demanding consideration for his needs in future land use planning.

The world demand for red meat, especially beef, is increasing and is expected to continue to increase in years to come due to an increase in world population and the ever increasing taste and preference for beef. In 1972, U.S. beef production was 25 billion pounds. In 1985, projected beef production will be 32.5 billion pounds and by the year 2000, 35 billion pounds.*

It is hypothesized that judicious range improvement by means of brush control is an efficient way to increase red meat production without serious harm to man, animals, and the associated environment.

Nevertheless, during the years 1972 and 1973, the Utah Office of the Bureau of Land Management (BLM) didn't implement a single brush

---

*Dwyer, D. D. 1973. Professor, Range Science, Utah State University, Logan. Class notes from Range Science 340, Fall Quarter, 1973.

control project on any rangeland under their management, even though 2,469,750 acres were classified as having potential for further development by "reseeding, brush control, and other vegetative manipulations" (U.S. Department of the Interior, Bureau of Land Management, 1972, p. 24).*

Furthermore, on October 30, 1973, the Natural Resources Defense Council, Inc. (NRDC) filed suit against the BLM for mismanagement of Public Lands. The NRDC asked the courts to prohibit the issuance or reissuance of grazing permits to ranchers until the BLM prepares public environmental impact statements (Natural Resources Defense Council, Inc., 1973).**

If, through court action, the BLM is compelled to limit the number of livestock grazing permits to private ranchers, state and private rangelands may be required to produce more forage in order to help supplement the loss of BLM grazing.

Purpose of Study

In Utah, 20.2 percent (2,453,000 acres) of state and private rangelands are infested with big sagebrush (Artemisia tridentata) and merit improvement (Environmental Protection Agency, 1972).*** Of this estimated total, 1,830,000 acres are recommended to be improved by use

---

*Hereafter in all citations U.S. Department of the Interior, Bureau of Land Management will be abbreviated BLM.

**Hereafter in all citations Natural Resources Defense Council, Inc. will be abbreviated NRDC.

***Hereafter in all citations Environmental Protection Agency will be abbreviated EPA.

of chemical herbicides, namely 2,4-D. The remaining 623,000 acres are to be improved by other methods.

This study will present information showing both the adverse and the beneficial effects which may be expected when using chemical herbicide 2,4-D and other control methods.

The objectives of this study are the following:

1. to outline what the probable impacts of sagebrush spraying will have on the environment,
2. to discuss the effectiveness of the various sagebrush control methods in increasing herbage production and controlling undesirable plants,
3. to determine the costs of the various methods of sagebrush control, and
4. to determine the economic feasibility of controlling approximately 2 1/2 million acres of state and private sagebrush infested rangelands.

Methods of Procedure

In preparing this report, a thorough study was made of the various sources of literature pertaining to big sagebrush control. These literature sources contained environmental and economic data collected from experimental areas in Utah and surrounding states.

Also, personal interviews were held with various professors within the departments of Economics and Range Science at Utah State University discussing the problems that developed as the study progressed. Interviews by phone and in person were also conducted with personnel assigned to the following agencies and institutions: Utah State Land Board (SLB), Utah Soil Conservation Service (SCS), and University of Wyoming (U of W).

Throughout the summer of 1973, the author travelled extensively in Utah visiting and taking pictures of numerous areas that had controlled big sagebrush. A few ranchers were interviewed, but this practice was discontinued for lack of reliable data. (Most ranchers do not keep records of forage production before and after sagebrush control.)

Limitations of the Study

This study was limited to the economic feasibility of big sagebrush control on state and private rangelands in the state of Utah. However, the results of the study may apply to federal and other state and private rangelands either in and/or out of the state.

Considerable attention was given to the environmental impact of 2,4-D spraying. Even so, this part of the study should not be considered a formal environment impact statement, or an environmental feasibility study for 2,4-D. Its main purpose was to direct range managers' attention to the importance of environmental quality as well as increased forage production when controlling big sagebrush.

Alternative methods of controlling big sagebrush (other than spraying) were largely confined in content to the expected response of the plant community following treatment. These data, together with comparable data from spraying, were used to determine the economic feasibility of big sagebrush control.

PRESENTATION OF DATA

Introduction to Big Sagebrush Control

Sagebrush is native to Utah as it is to a vast area of the western United States. Although a number of sagebrush species are found in the state, big sagebrush is the most dominant species (U.S. Department of Agriculture, Forest Service, 1973).*

Changes in big sagebrush density and vigor can be distinguished across altitudinal gradients. Altitudinal changes are generally observed from shrub through grass to forest. In the lowest or driest areas of Utah, desert shrub vegetation dominates and limited quantities of grasses and big sagebrush are found. At higher elevations, greater rainfall produces a more desirable site for the sagebrush-grass association, and this association is often interspersed with groves of aspen (Populus tremuloides), pinyon-juniper (Pinus monofila and Juniperus sp.), and other conifers (Picea sp., Pinus sp., Aibes sp.).

Big sagebrush is a very inefficient user of water and competes heavily for moisture with the more desirable forage, i.e., grasses, forbs, and other shrubs (EPA, 1972). It produces a minimal amount of forage for wildlife during summer months, but as the more palatable species are consumed or are covered by snow, big sagebrush may provide almost the entire sustenance for these animals (USFS, 1973). Domestic livestock, especially sheep, have been known to consume large

---

*Hereafter in all citations U.S. Department of Agriculture, Forest Service will be abbreviated USFS.

quantities of big sagebrush in fall months when other forage was limited (Frischknecht and Harris, 1973).

Animals found in sagebrush and associated vegetational communities are mostly herbivores. Cattle, sheep, elk, deer, and antelope are the larger herbivores. Rabbits and rodents are the major small herbivores. The vegetation also supplies seeds, grasses, and forbs for sage grouse, songbirds, and various other birds. Other animals that frequent this environment are coyotes, foxes, and various species of lizards, snakes, and insects.

Methods of Controlling Big Sagebrush

It is believed that the herbicide 2,4-D is a highly effective method of controlling big sagebrush. Other control methods such as selective grazing, planned burning, and mechanical control and biological control have been used throughout the West and to a certain extent in Utah.

Chemical Spraying

Spraying with herbicide has been a very popular method of controlling big sagebrush on Utah rangelands.* However, before spraying is implemented, the following questions should be answered:

When to spray

It is often said the most effective time to spray is between May 15 and June 15. A more effective criteria to follow would be the

*Mason, L. 1973. Range Conservationist for the Utah Soil Conservation Service, Salt Lake City, Utah. Personal interview, August 1973.

growth stage of big sagebrush and associated species (Alley and Bohmont, 1958).

Big Sagebrush - rapid twig elongation

Sandberg bluegrass (Poa secunda) - full to past bloom

Common phloxes (Phlox sp.) - early seed formation

Idaho fescue (Festuca idahoensis) - beginning to head

A study was conducted by Hyder and Sneva (1955) to test the effectiveness of herbicides on big sagebrush in eastern Oregon. The percentage of big sagebrush killed varied between the years 1952 and 1953. The variation in plants killed was due to a longer growing season in 1953 (Table 1). Total May-June precipitation in 1952 was 2.53, and 6.03 inches in 1953. Temperature and humidity differences also were important factors. The mean monthly temperatures for May and June were 51° F. and 56° F. in 1952, and 45° F. and 52° F. in 1953. It appears that a longer growing season influences the mortality rate of big sagebrush sprayed with 2,4-D.

What to use

A number of herbicides have been used to control big sagebrush; propyleneglycol butyl ether ester 2,4-D, propyleneglycol butyl ether ester 2,4,5-T, and butyl ester 2,4-D. The latter herbicide, butyl ester 2,4-D, has been the most popular due to its effectiveness and economic appeal. Hyder and Sneva (1955) found there was no significant difference in big sagebrush mortality using the solvent carriers, water emulsion, and diesel oil with butyl ester 2,4-D (Table 2).

Table 1. Percentage of big sagebrush killed, by dates, 1952 and 1953 (Hyder and Sneva, 1955, p. 6)

Spraying Date[1]	Percentage of plants killed		
	1952	1953	Average
A	87	76	82
B	90	88	89
C	91	90	90
D	88	94	91
E	64	93	80
F	50	61	55
Average	80	85	

[1]Corresponding dates of spraying for the two years were:

	1952	1953
A	April 24	April 20
B	May 3	May 4
C	May 15	May 18
D	May 27	June 1
E	June 13	June 17
F	July 3	July 8

Table 2. Percentage of big sagebrush killed using three different solvents, 1952 and 1953 (Hyder and Sneva, 1955, p. 9)

	Percentage of plants killed		
Solvents	1952	1953	Average
Water[1] ------------------------	79	85	83
Emulsion[2] ---------------------	77	86	82
Diesel oil[3] -------------------	82	83	82

[1]Water plus Tween 20 at 0.1 percent by volume.

[2]Diesel oil emulsion with a water to oil ratio of 2:1 and emulsified with Tenlo 400 at five percent of total oil volume.

[3]Diesel oil.

In the same study, solution volume was equally as important as the amount of acid used (Table 3). For each treatment rate, an increase in solution volume was equally effective, and likewise for each solution volume, an increase in acid equivalent of herbicide was equally effective.

Small airplanes or helicopters are used to spray the herbicide over a given area. Drifting and/or evaporation of the herbicide solution can be a problem, necessitating the aircraft to fly very close to the ground (5 to 10 feet) in the early morning or early evening hours when the temperature is relatively low and the humidity is relatively high.

Table 3. Percentage of big sagebrush killed using different acid equivalent rates and solution volumes per acre (Hyder and Sneva, 1955, p. 9)

Acid Rate	Percentage of plants killed at solution volume of -		
	3 gallons	6 gallons	Average
1 pound ----------------------	72	83	78
2 pounds ---------------------	81	91	87
Average ----------------------	77	87	

<u>Where to spray</u>

Areas should not be sprayed that receive less than 10 inches average annual precipitation and/or there is an insufficient understory of grasses and forbs. Big sagebrush sites, in fair to good condition, usually can benefit from spraying.

<u>Why spray</u>

Chemical control of big sagebrush first began in the West in the late 1940's (Hyder, 1953). Since that experimental period, research and management experience have established that big sagebrush can be economically controlled and a considerable increase in forage production can be expected if proper sites are selected.

Control of big sagebrush on rangelands is not always desirable. It may be a major winter forage for wildlife, may serve as a natural habitat for sage grouse, or the site may lack the ability to produce a desired level of forage after being sprayed due to an insufficient understory of grasses and forbs.

There are times when big sagebrush merits control.

> "The purpose of applying 2,4-D herbicide to dense stands of sagebrush...is to break up near pure stand or stands strongly dominated by these plants, caused by past disturbances and improper grazing practices, in order that a more diversified and desirable variety of plant species may again become established and productive." (USFS, 1973, p. 4)

Planning

Use of herbicides in relation to the environment has received considerable public attention. Many critics have based their criticism of using herbicides on emotionalism rather than scientific fact, thus, beneficial uses of herbicides have often been ignored (Vallentine, 1971).

There also have been times when herbicides were used in excess amounts, creating a hazard to both man and animal. Chemicals such as 2,4-D and 2,4,5-T are generally not poisonous to animals at rates commonly used in brush control and cause no problems if used at recommended levels and under the supervision of qualified personnel (Vallentine, 1971).

The following procedure should help alleviate any adverse effects of using 2,4-D: Months in advance, a rancher or group of ranchers, together with other interested parties such as the Utah State Land Board, Utah Soil Conservation District, Utah Bureau of Land Management, U.S. Forest Service, and Utah Game & Fish Department, should develop plans and procedures for the spring sagebrush control program. A program developed under the supervision of various interested groups will best serve the needs of everyone involved, whether they be ranchers, recreationists, hunters, those concerned with aesthetics, etc. This group should, upon agreement, determine the methodology, location, and number of acres to be sprayed.

Once the needed data are assembled, separate bids are let for the spray material (2,4-D butyl ester) and aerial application. Although either a fixed winged airplane or a helicopter could be used, the maneuverability of the helicopter may be desired to avoid spraying desirable vegetation interspersed throughout the sagebrush.

Follow-up management and expected benefits

Many land management agencies recommend or require one or more years of deferment from grazing in order to aid attainment of maximum forage production (Pechanec et al., 1965). This requirement may place a hardship on the ranching operation in that herds must be reduced or additional range must be acquired to replace the temporary loss of forage.

Smith (1969) found that deferment from grazing was not always necessary following chemical control of big sagebrush. Four experimental areas were evaluated in his study--Buck Creek, Grouse Creek, Antelope Butte, and Soldier Creek, all of which were located in the Big Horn National Forest, Wyoming. The sagebrush community on all sites contained a relatively dense understory of grasses and forbs before spraying. Crown cover and density of sagebrush was reduced by about 98 percent following aerial spraying with 2,4-D.

Each of the experimental areas were divided into four sections, comparing the effects of zero, one, two, and three years deferment on forage production and reinvasion of sagebrush.

At Buck Creek and Grouse Creek, length of deferment had no effect upon production of all grasses and forbs. In the Antelope Butte area, total production of grasses and forbs was not effected by length of deferment except the yield of Idaho fescue was greatest under no deferment.

Soldier Creek showed similar results in that one and two years' deferment had the same effect as three years of deferment, although the non-deferred areas produced 547 pounds per acre air-dry more forage in 1963.

Excess litter on deferred areas could possibly create a detrimental micro climate which inhibits production of some grasses and forbs.* Where excess litter is a problem, burning might be a possible alternative to spraying, since fire would consume the excess litter and enable the understory to increase in density and productivity.

Smith (1969) also established that sagebrush reinvasion was relatively the same; that is, there was no year-to-year increase in sagebrush density regardless of length of deferment. Utilization of the forage in post-treatment years was less than 43 percent.

Special consideration should be given to no deferment, especially at the higher elevations where the precipitation is greater than 15 inches and there is an abundant grass understory.

---

*Kearl, G. W. 1974. Professor, Agricultural Economics, University of Wyoming, Laramie. Personal telephone communication, March 1973.

Impact on physical environment

Soil erosion

Pechanec et al. (1965) report that soil erosion is usually not a hazard on sprayed sagebrush lands. Erosion is usually checked by dead sagebrush, litter cover, and grasses. The release of additional grasses following spraying generates more ground cover, which reduces soil erosion. Areas with an insufficient understory of grasses and forbs prior to spraying and ridges with shallow soils should not be sprayed.

Soil moisture

Soil moisture studies were conducted by Alley (1965) after big sagebrush had been chemically sprayed in two Wyoming experimental areas. One was located in the Big Horn Mountains of north central Wyoming, at an elevation of 8,200 feet and an average annual precipitation of 20 inches. The second area was in the Red Desert of south central Wyoming, where the elevation is approximately 7,000 feet and the average annual precipitation is 10 inches, most of which is in the form of snow.

In the Red Desert region, sprayed areas with big sagebrush kills of 80 to 100 percent were characterized by a significantly higher percentage of soil moisture than on unsprayed areas. From three years after spraying (1960) to the time when this study was published (1965), no appreciable difference in moisture levels existed between sprayed and unsprayed areas. It was suggested that this negligible difference existed because native grasses require three years to obtain maximum ground cover and production, thus utilizing moisture once used by the dead sagebrush.

Similar results were found on fair condition range near Burns, Oregon by Hedrick et al. (1966). During the first few years following sagebrush control, soil moisture was depleted less rapidly on sprayed than on unsprayed plots. As the grasses and forbs responded to sagebrush control, they depleted the soil moisture as rapidly as the unsprayed plots.

Ranchers in the Big Horn Mountains, having sprayed complete watersheds, reported underground water sources, such as springs, began running year round. Prior to spraying, these water sources usually dried up the first part of July (Alley, 1965).

Soil contamination

Soil contamination is not an anticipated problem where chemical control of sagebrush is exercised. Chemicals (2,4-D), once they reach the soil, may be volatilized and re-enter the atmosphere. They also may be absorbed by soil colloids and organic matter, leach through the soil, be absorbed by plants, or be degraded by chemical or biological processes. In a study by Norris (1971), 94 percent of the 2,4-D on the forest floor was degraded in 35 days after spraying.

Water

Stream or reservoir contamination is one of the most immediate expressions of contamination in the range environment. Reservoirs could contain low levels of chemical 2,4-D for extended periods of time due to drift or intentional spraying, causing injury to aquatic organisms. Special care must be taken to avoid treatment of these areas.

Air

Considerable amounts of herbicide may never come in contact with the vegetation sprayed. In a western Oregon study, Norris (1971) reported 20 to 75 percent of the aerial sprayed herbicide never reached the first intercepting surfaces. This could create a hazard to the environment, but the loss is minimized by atmosphere dilution and the avoidance of spraying large contiguous blocks of land.

Impact on biological environment

Response of big sagebrush and other shrubs

Big sagebrush is responsive to 2,4-D. If recommended procedures are followed when spraying 2,4-D, one can expect a kill of big sagebrush ranging from 67 to 100 percent (Blaisdell and Mueggler, 1956).

In the same study conducted by Blaisdell and Mueggler, of the 15 shrubs and trees present when sprayed with 2,4-D, only serviceberry (*Amelanchier alnifolia*), threetip sagebrush (*Artemisia tripartita*), and silver sagebrush (*Artemisia cana*) suffered moderate or heavy damage. The top portions of aspen, chokecherry (*Prunus virginiana*), willows (*Salix sp.*), snowberry (*Symphoricarpos oreophilus*), and rabbitbrush (*Chrysothamnus spp.*) were killed, but a large proportion of these species resprouted abundantly. Bitterbrush (*Purshia tridentata*) was only slightly damaged.

Conversely, Hyder and Sneva (1962) found that bitterbrush sprayed when plants were less than 12 inches tall was consistently killed and plants over 12 inches tall were only slightly damaged if spraying occurred at the time of leaf origin. Bitterbrush survival seems dependent upon its stage of growth and age when sprayed with 2,4-D.

Response of grasses and forbs

One of the biggest nutritional problems on our ranges is that of a forage energy shortage or lack of forage to be consumed. When forage is abundant, animals will gain more, a condition desired by both rancher and game manager alike.

In a Wyoming study, Alley and Bohmont (1958) found that at elevations higher than 7,500 feet, the average production of air-dry grass per acre was 526 pounds. In the same area where big sagebrush had received 75 percent or more control, the average production per acre over a five year period was 2,075 pounds.

Cook (1966b) applied herbicides to mixed stands of both big sagebrush and rabbitbrush at four locations in Utah where elevations ranged from 5,200 to 6,500 feet. Prior to treatment, the experimental plots were producing from 430 to 800 pounds of forage (mainly grasses) per acre with a cover of brush ranging from 20 to 40 percent. Following spraying, forage yields varied from 800 to 1500 pounds per acre of air-dry material.

A number of ranchers in Wyoming have been sold on the idea of spraying dense big sagebrush stands in order to increase forage production. Hyatt (1966) of Hyattsville, Wyoming is one of these men. An original survey made in 1956 revealed a 52 percent ground cover of sagebrush and a 28 percent ground cover of grasses. Air-dried forage production was 343 pounds per acre. Six years after spraying, sagebrush ground cover was reduced to 13 percent, most of which was dead sagebrush stalks. The ground cover of grasses had increased to 70 percent and produced 1,143 pounds per acre of air-dried forage.

Squaw Butte Experiment Station in southeastern Oregon was the site of an experiment conducted by Sneva (1972). The area is mostly high desert country with an elevation of approximately 4,500 feet. The average annual precipitation (over a 30 year period) is 11.71 inches, most of which is snow or rain in winter months. In the 17 years following spraying of big sagebrush, herbage production (air-dry) averaged 681 pounds per acre, while prior to treatment it averaged 227 pounds per acre. Days of grazing (yearling cattle) increased 1.9 times and beef gains per acre increased 2.3 times that prior to brush control.

Hedrick et al. (1966) concluded in an Oregon study that 2,4-D spraying of big sagebrush produced a substantial increase in available forage. The mean precipitation for the past 20 years was 11.8 inches, with 60 percent of the moisture falling in the six month winter period and 25 percent falling in May and June. Big sagebrush was controlled by spraying and rotobeating on both poor and fair condition ranges.

In the same study by Hedrick, et al., pre-treatment yields on fair condition range were the same on all test plots as were species compositions. Squirreltail (Sitanion hystrix), Thurber needlegrass (Stipa thurberiana), and Idaho fescue were the highest yielding species followed by Sandberg bluegrass, bluebunch wheatgrass (Agropyron spicatum), and June grass (Koeleria cristata) previous to treatment.

Post-treatment herbage yields averaged 200 pounds, 378 pounds, and 387 pounds per acre, respectively, on untreated and treated plots. Spraying and rotobeating produced essentially the same results.

Comparing yields by individual species, June grass and squirreltail responded the most following treatment. June grass, on rotobeating and sprayed plots yielded an average of 517 and 364 percent more, respectively, than on unsprayed plots. For the first six years, these two species increased, but decreased the following two years. On treated plots, Idaho fescue and Sandberg bluegrass yielded 60 percent more forage than on untreated plots. Cheatgrass (*Bromus secalinus*) became an important species on the treated plots in the eighth year following sagebrush control. No significant differences existed between spraying and rotobeating.

On poor-condition range, the pre-treatment yields (33 to 41 pounds per acre air-dry) were approximately the same. Following treatment, the yields averaged 122 pounds, 420 pounds, and 489 pounds per acre air-dry, respectively, on untreated, rotobeaten, and sprayed plots. Spraying led to greater yields than did rotobeating after 1957 because big sagebrush increased rapidly on rotobeaten plots (Table 4). On treated plots, squirreltail increased 100 times as much as found on untreated plots. Following the fourth year, squirreltail on treated plots decreased to about two times that found on untreated plots. Cheatgrass increased from a trace to approximately 200 pounds per acre air-dry and 330 pounds per acre air-dry, respectively, on rotobeaten and sprayed plots in four years.

Yield data were obtained from clippings taken from a mountain loam range site in Rich County, Utah. Prior to spraying, the pasture

Table 4. Changes in density and crown cover of big sagebrush plants on fair- and poor-condition areas before and after treatment in 1955--expressed as percentage of 1953 values (Hedrick et al., 1966, p. 435)

Range Condition	Measurement	Treatment	1953	1956	1959	1961	1963
Fair	Density	Untreated	100	87	87	69	70
		Rotobeaten	100	14	16	13	12
		Sprayed	100	2	1	1	1
	Cover	Untreated	100	70	68	70	79
		Rotobeaten	100	1	4	6	11
		Sprayed	100	0	0	0	0
Poor	Density	Untreated	100	94	79	64	71
		Rotobeaten	100	37	51	80	110
		Sprayed	100	14	10	10	17
	Cover	Untreated	100	107	88	89	93
		Rotobeaten	100	3	8	17	33
		Sprayed	100	1	5	8	12
Crop-year precipitation (inches)			14.3	14.9	6.8	8.1	13.6

produced 221 pounds per acre of air-dry forage, and three years following spraying, forage production had increased nearly four-fold, producing 842 pounds per acre air-dry basis. The annual precipitation was greater than 15 inches.*

In the Vernal, Utah area, clippings were also taken following spraying, but forage increased only two-fold. Forage production on pre-treated range was 191 pounds per acre air-dry and post-treated

*Peterson, M. 1973. Range Conservationist for the Utah Soil Conservation Service, Randolph, Utah. Personal interview, August 1973.

range produced 384 pounds per air-dry three years after spraying. The annual precipitation ranged between 10 and 13 inches.*

In 1966 and 1968, approximately 10,000 acres of big sagebrush were sprayed on Parker Mountain, west of Loa, Utah. Parker Mountain consists of 55,000 acres of state owned rangeland, which is leased by the Parker Mountain Grazing Mountain. Following spraying, the carrying capacity of the treated range increased 55 percent (Figures 1 and 2). Present plans call for an additional 2,000 acres to be sprayed in spring of 1974.**

Figure 1. Location: Parker Mountain, west of Loa, Utah

Elevation: 8,000 - 9,800 feet

Precipitation: 15 - 18 inches

Date: August 1973

---

*Brady, B. L. 1973. Range Conservationist for the Utah Soil Conservation Service, Vernal, Utah. Personal interview, August 1973.

**Crystal, M. H. 1974. Land Specialist for the Utah State Land Board, Salt Lake City, Utah. Personal interview, March 1974.

This particular area is part of the 10,000 acres of big sagebrush aerial sprayed with 2,4-D. The percent of sagebrush killed was excellent and the native understory thrives. Note that the aspen trees were avoided where the area was sprayed, a sign of good management.

Figure 2. Same area as in Figure 1. The big sagebrush remains uncontrolled. This site is part of the additional acreage that merits control.

Forbs generally are reduced when sagebrush is treated with 2,4-D. Blaisdell and Mueggler (1956) reported that of 38 forb species studied in eastern Idaho, 13 were moderately or severely damaged. Among these were important forage species such as arrowleaf balsamroot (Balsamorhiza macrophylla), milkvetch (Astragalus eurekensis), oneflower sunflower (Helianthus muttallii), lupines (Lupinus spp.), and bluebell (Campanula rotundifolia). Important forage plants that were unharmed or only slightly damaged were hawksbeard (Crepis spp.), geranium (Erodium spp.), penstemon (Penstemon spp.), and groundsel (Senecio integerrimus).

Alley and Bohmont (1958) on the other hand, found the percentage composition of all forbs did not change measurably on a given range site sprayed with 2,4-D. Decreases in some forb species were countered by increases in other forb species.

Longevity of controlled vegetation

There has been varied success in controlling the reinvasion of big sagebrush following treatment. Hedrick et al. (1966) reported sagebrush density, eight years after spraying, remaining nearly constant on all fair-condition range plots and increasing slightly on poor-condition plots (Table 4).

Johnson (1969) conducted a study 36 miles southeast of Lander, Wyoming at an elevation of 6,800 feet with an annual precipitation of between seven to nine inches. The benefits of sagebrush spraying on range grazed by livestock began to decrease five years after spraying and within 14 years, they were negligible. Seventeen years after spraying, the density of sagebrush was greater than before spraying. Johnson cautioned range managers against spraying low-altitude, semi-arid sagebrush ranges when annual precipitation is minimal.

Sneva (1972) reported an average of 15.4 pounds gained per animal on range sprayed with 2,4-D 17 years earlier, compared with 6.7 pounds gained per animal on pre-sprayed range.

Response of wildlife habitat

Moose. Studies conducted by the USFS (1973) indicate moose inhabit spruce-fir forests. They will eat most browse species but prefer the willow (Salix sp.) when it is available. Moose often wander over sagebrush areas and utilize the forage found there. However, big sagebrush is not considered an important forage species for moose.

Elk. In a study to determine the food habits of Rocky Mountain elk in the western U.S. and Canada, Kufeld (1973) found big sagebrush to be a valuable shrub species in fall and winter months. During spring and summer months, the diet of Rocky Mountain elk consisted mainly of grasses and forbs. Although big sagebrush is not considered a preferred browse species, it does make a significant contribution to the diets of elk during food shortages (USFS, 1973).

Bighorn Sheep. Big sagebrush is rarely eaten by bighorn sheep (USFS, 1973). Their diet contains mixtures of palatable browse, forb and grass species. The critical winter ranges of bighorn sheep are located at elevations where rocky cliffs allow them to escape when danger arises.

Deer. Deer populations often are limited by the quality and quantity of their winter range (USFS, 1973). Ranges containing a wide variety of shrubs, forbs, and grasses are preferred to those dominated by big sagebrush. Big sagebrush is utilized heavily during the late winter months by mule deer in the Rocky Mountain region (Nagy et al., 1964). Similar food habit studies in Idaho showed mule deer's diet in winter consisted of about 40 to 45 percent sagebrush. When more palatable species of shrubs were available, the percentage of sagebrush decreased in their diet (Humbird, 1971).

Antelope. Antelope's dependency on sagebrush seems to vary with the variety of plants available for consumption (Figure 3). When sagebrush dominates a given area, they depend heavily on sagebrush, especially during a dry summer or winter when snow covers other forage.* During the growing season, antelope increase their consumption of grasses and forbs, especially forbs (Figure 3).

Sage grouse. Sage grouse are not only dependent upon the existence of the grass-forb association, but the restoration and preservation of some sagebrush (Wallestad, 1971). The following sections explain this sagebrush dependency.

During the winter, sage grouse are almost, if not completely, dependent upon sagebrush for food. During this season, they can be found at most elevations depending on snow depth.*

In spring and summer, while participating in the strutting and breeding activities, both hens and cocks occupy open areas surrounded by sagebrush. During this time, a large percent of their diet consists of sagebrush, but as spring advances, they consume more and more grasses and forbs (USFS, 1973).

The nesting areas are usually found near the strutting grounds. Hens, when nesting, seem to prefer sagebrush ranging from 7 to 28 inches in height and a sagebrush canopy cover between 25 and 29 percent (USFS, 1973).

Klebenow (1970) stated chicks are highly dependent on insects for food when first hatched. As they advance in age (during the summer months), a habitat consisting of sagebrush, forbs, and grass is used extensively for both cover and food. Wallestad (1971), in a Montana study, found summer broods preferred a sagebrush canopy cover of less than 25 percent and an average of 14 percent during the summer months.

---

*Urness, P. 1973. Professor, Range Science, Utah State University, Logan. Class notes from Range Science 567, Fall Quarter, 1973.

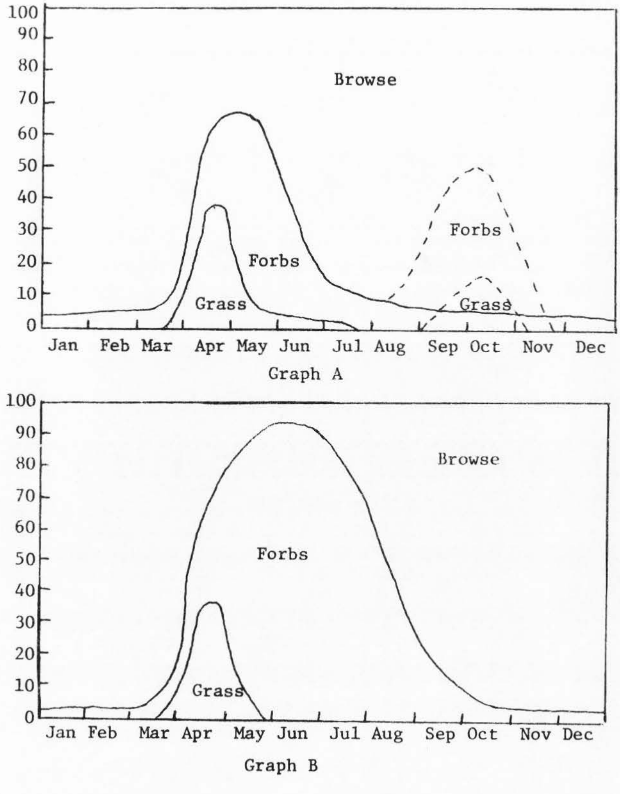

Figure 3. Diet of antelope in southwestern Utah under different moisture regimes. A. Dry season. Dotted lines indicate change in diet in late summer when summer rains occur. B. Wet season. Diets under high precipitation during spring and summer. (Beale and Smith, 1970, p. 573)

As fall approaches, grasses and forbs become less succulent and abundant, necessitating both young and mature sage grouse to depend more upon sagebrush for food. In the fall, the broods are able to fly to distant feeding grounds in search of remaining grasses and forbs (USFS, 1973).

Songbirds. Songbirds are usually abundant in a sagebrush environment. Best (1972) found when large tracts of sagebrush were sprayed with herbicides, breeding pairs of Brewers sparrows declined 54 percent. No change occurred in pairs of vespers sparrows. Strip spraying of sagebrush had no notable effects on vesper and Brewers sparrows the first year after spraying. Other nongame birds that usually are found in a sagebrush-grass habitat, but in limited numbers are the western meadowlark, horned lark, lark bunting, mourning dove, and sage thasher (USFS, 1973).

Predatory birds. Johnson and Hansen (1969) did not think sagebrush spraying had any noticeable effects on numbers of predatory birds. Total number of prey species remained about the same over a given sprayed area, although specific prey species may have increased or decreased.

Aesthetics as effected by spraying

Within four or five months after spraying, it becomes quite apparent an area has been sprayed. By fall, most of the sagebrush has defoliated and by the following spring, dead sagebrush stalks dominate the area. Gradually, the weather and animals break down the dead stalks and other vegetation dominate the area (USFS, 1973).

Although we have limited control in obscuring the view of dead sagebrush stalks, there are some guidelines to follow in retaining the natural beauty of an area being sprayed with 2,4-D herbicide. Large continuous areas, ridge tops, groves of trees, and thickets should be avoided, as should areas adjacent to main roads, streams, and other water sources. Spraying should follow the topography, avoiding straight lines. This not only is more pleasing to the eye, but benefits the wildlife habitat.

Grazing

Grazing as a management tool

Livestock usually graze big sagebrush very lightly under normal grazing conditions, therefore, associated palatable grasses and forbs are often unable to gain a competitive advantage over big sagebrush. Lommasson (1948, p.19) presented detailed scientific data to show that sagebrush "on high grasslands of the Gravelly Range of the Beaverhead National Forest in southwestern Montana apparently will maintain itself indefinitely under natural conditions". This conclusion resulted from a 31 year-old study to test the possibility of sagebrush giving way to grass under good rangeland management.

However, Frischknecht and Harris (1973) in an experiment conducted at the Benmore Experimental Range in Tooele County, Utah determined that big sagebrush on seeded cattle range can be controlled when grazed by sheep in late fall. The size and reproduction of big sagebrush were reduced considerably when this practice was initiated before big sagebrush plants became too numerous.

Similar results were found by Laycock (1967) at the U.S. Sheep Experiment Station near Dubois, Idaho. Spring deferment followed by late fall grazing of sheep improved deteriorated sagebrush-grass ranges by reducing sagebrush and increasing the production of grasses and forbs. Although the sagebrush controlled was threetip sagebrush, comparable results could be expected with big sagebrush (Frischnecht and Harris, 1973).

Big sagebrush also can be controlled on range sites where precipitation is abundant and the native understory has the potential of reaching or approaching climax conditions. The process involves many years of light to moderate grazing and proper rotation of livestock.

Such a phenomena was reported in an aspen-sagebrush-grass type association east of Price, Utah. The elevation is approximately 9,100 feet and the average annual precipitation is 18 inches.*

Thirty years ago, the ranch was seriously overgrazed by livestock and big sagebrush had increased tremendously. From that time forward, various grazing methods have been used to improve the range. Recently, Mr. Wilcox has implemented rest-rotation grazing management. The range has been divided into six pastures whereby according to Hormay (1970, p. 16) "...each pasture is systematically grazed and rested so as to provide for the production of livestock and other resource values and at the same time, improve and maintain the vegetation and soil fertility". Although big sagebrush still is found on

---

*Wilcox, D. 1973. Rancher near Price, Utah. Personal interview, August 1973.

the range in abundance, carrying capacity has increased 75 percent over that of 30 years ago (see Wilcox, p. 29, footnote).

The most phenomenal change in vegetation has occurred in a horse pasture which has been lightly grazed or not grazed at all for the past 30 years. For certain areas of the pasture, the big sagebrush has been virtually replaced with a lush understory of grasses and forbs (Figures 4 and 5).

Figure 4. Location: Roan Plateau east of Price, Utah
Elevation: 9,100 feet
Precipitation: 18 inches
Date: August 1973

As can be seen in Figure 4, the scene is dotted with both living and dead big sagebrush stalks. Over a period of 30 years, the native understory assisted with abundant precipitation has nearly eliminated the big sagebrush.

Figure 5. Same pasture as in Figure 4

Figure 5 is an even better example of a decrease in big sagebrush density. The upper portion of Figure 5 is still dominated by big sagebrush; whereas, the lower portion is sagebrush free and has been revegetated naturally with grasses and forbs.

Intensive livestock management will be the prevalent practice to maintain the range environment in a desirable condition or to rehabilitate deteriorated ranges. This practice is continuous and many years may pass before a significant improvement is noticeable.

Planned Burning

Burning as a management tool

Burning has been used as a management tool to control sagebrush for many years. It is relatively inexpensive and widely adaptable, although it should only be used under direction of qualified personnel. The range to be burned must be carefully selected, time of burning is important, and precautions must be taken to control the fire within prescribed boundaries or range deterioration may occur (Pechanec et al., 1954, revised).

Effects on forage production of controlled vegetation

When sagebrush-grass type rangeland has been burned, grazing capacity of sheep and cattle has increased an average of 70 percent on several ranges without reseeding (Pechanec et al., 1954, revised). From the same study, it was determined that on ranges needing reseeding, the carrying capacity has been increased 5 to 12 fold.

Sagebrush burning experiments were conducted by Pechanec et al. (1954, revised) in Clark and Fremont Counties of southeastern Idaho for a number of years beginning in 1932. Two different big sagebrush areas were burned in 1933 and 1936, each area having a good understory of perennial grasses and weeds before burning. Fires were set in late summer and grazing of livestock was deferred from the burned areas for a full year; thereafter, grazing was only of moderate intensity and well regulated.

Within four years after burning, the grazing capacity had increased about 85 percent; and after 15 years, the grazing capacity was still 60 percent higher than on unburned range.

Effects on longevity

In the same study by Pechanec et al. (1954, revised), perennial grasses and weeds increased approximately 90 percent within four years following burning of big sagebrush. After 15 years, the burned areas were still producing 33 percent more grasses and weeds than the unburned areas. There had been almost a complete kill of big sagebrush by burning and after 15 years, the area was producing at 25 percent of its original yield. Other sprouting shrubs were able to return to pre-burn production levels.

Effects on nutrient level

Increased forage production is not the only reason for burning. Leege (1966) credited prescribed spring burning on the elk ranges in northern Idaho as contributing to increased nutrient level of new growth plants (browse). Protein was consistently higher in forage on burned areas and phosphorus content of forage was higher two years after the area had been burned depending on the species of browse. The changes in nutrient quantities were the same as other burned areas which had only one growing season following burning. This leads one to assume nutrient changes would last for at least two growing seasons. A study conducted by Lay (1957) in Texas, concluded that burning in any season increased the protein and phosphorus content of browse, but most of the benefits would disappear within a year or two. Although neither the study by Leege nor Lay involved big sagebrush, one could expect comparable results from planned burning on a sagebrush-grass type range.

Effects on palatability

Leege (1966) also determined that browse palatability increased due to prescribed burning. All species of browse, native to conifer forests in northern Idaho, were browsed heavier on burned areas. Even previously, unpalatable species were eaten more readily than before. No measurable improvement in browse palatability existed on the burned area two years later.

Effects on species density

Another benefit of prescribed burning is a substantial increase in the number of plant species, assuming they are desirable species. Lyon (1971) reported in a USFS study conducted near Ketchum, Idaho, that the number of species in the herbaceous component almost doubled the first seven years following burning. The number of tree and shrub species did not show a substantial change in numbers.

Plowing and Seeding

Plowing and seeding as a management tool

Plowing followed by seeding is usually employed when other treatment methods are not adequate to meet land management objectives. This action occurs when sagebrush becomes the dominant plant species and the understory of grasses and forbs is lacking in vigor and density to make a significant recovery.

Several million acres of sagebrush have been plowed and seeded in the western United States in an effort to increase forage, reduce erosion, and control undesirable plants. As of June 30, 1972, 513,591 acres of private and state rangeland in Utah had been plowed and seeded with exotic grass species, crested wheatgrass (Agropyron desertorum) being the most popular (see Mason, p. 6, footnote).

Effects on forage production

A number of wheatgrasses have proven to be well adapted on most sagebrush sites in Utah. Cook (1966a), in conjunction with the Utah Agricultural Experiment Station, studied methods of developing spring-use of foothill ranges on experimental areas located at Benmore and Eureka, Utah.

Both areas had a native vegetation consisting primarily of big sagebrush and various grasses. The experimental areas were characterized by limited precipitation, the mean annual precipitation between 1956 and 1964 being 12.64 at Eureka and 11.36 inches at Benmore. About 30 percent of the precipitation came as snow during December through February. Soils at Eureka are silt loam and at Benmore they are clay loams.

All pastures at Benmore and Eureka were seeded in 1950. A number of wheatgrasses were used and proven successful (Tables 5 and 6). Average forage productions at Benmore between 1956 and 1964 were 1148 and 788 pounds per acre air-dry for crested and pubescent (Agropyron trichophorum) wheatgrass, respectively, and 771 and 882 pounds per acre air-dry for tall (Agropyron elongatum) and intermediate (Agropyron intermedium) wheatgrass. Pre-treatment production was only 190 pounds per acre air-dry on adjacent sagebrush-grass (Table 5). Similar results were observed at Eureka (Table 6).

Table 5. Average production, utilization, and composition of pasture at Benmore from 1956 to 1964 (Cook, 1966a, p. 17)

Species	Number of plants per plot	Production in pounds per acre	Percent utili- zation	Percent com- position	Production range High	Production range Low
Crested wheatgrass	4.5	1148	39.6	100	2043	702
Intermediate wheatgrass	---	882	40.0	100	1528	553
Tall wheatgrass	3.5	771	50.7	100	1350	455
Pubescent wheatgrass	---	788	42.5	100	1518	351
Mixture						
crested	1.9	315	34.5	45		
intermediate	0.9	101	54.3	14		
tall	0.3	44	57.8	6		
pubescent	1.1	240	31.0	35		
Total or Average	4.2	700	37.7	100	1382	351
Control						
sagebrush-grass		190	31.2	---	240	160

Table 6. Average production and utilization of the experimental pastures at Eureka from 1956 to 1964 (Cook, 1966a, p. 18)

Species	Number of plants per plot	Production in pounds per acre	Percent utili- zation	Percent com- position	Production range High	Production range Low
Crested wheatgrass	6.4	965	38.5	100	1570	566
Intermediate wheatgrass	---	935	36.1	100	1703	647
Tall wheatgrass	4.7	1027	28.5	100	1616	559
Mixture						
crested	5.1	707	33.6	51		
intermediate	2.5	382	39.7	28		
tall	1.6	295	19.4	21		
Total or Average	9.2	1384	32.3	100	2275	761
Controls						
sagebrush-grass		199	30.6	---	318	84

Hull and Klomp (1966) conducted similar experiments in southern Idaho using a variety of wheatgrasses and Russian wildrye (Elymus junceus). The U.S. Sheep Experimental Station located near Dubois and an experimental area near Raft River have average annual precipitations of 11 and 10 inches. The soils at both areas are of silt loam type. Although crested wheatgrass proved to be the best yielding, all grasses produced relatively well (Tables 7 and 8).

Effects on longevity of controlled vegetation

Sagebrush reinvasion can be expected when crested wheatgrass or other adapted species are seeded in sagebrush-grass type rangeland. Sagebrush seeds are available at the time grasses are seeded and when sprouted and established can suppress young grasses if proper grazing methods are not followed.

Johnson and Payne (1968) also found the most important factor relating to sagebrush reinvasion was the amount of sagebrush surviving treatments which act as seed sources. This principle could apply to any method of big sagebrush control. Sagebrush from areas adjacent to treated areas were of no practical importance relative to sagebrush reinvasion.

Crested wheatgrass has an excellent record of longevity. Hull and Klomp (1966) found from a study by Westover and Rogler, crested wheatgrass at Mandan, North Dakota growing vigorously at the end of 50 years. In their own study, Hull and Klomp (1966) reported an excellent stand of crested wheatgrass after 30 years.

Table 7. Yield of seven species (air-dry herbage lb. per acre) at Raft River, seeded in 1944 (Hull and Klomp, 1966, p. 9)

Year	Crested wheatgr.	Fairway wheatgr.	Siberian wheatgr.	Pubescent wheatgr.	Beardless wheatgr.	Russian wildrye	Average
1946	785	---	---	---	---	---	785
1947	1298	1002	---	---	---	---	1150
1948	936	402	---	296	251	172	411
1949	818	734	---	560	882	856	770
1955	592	546	610	549	---	673	594
1956	504	402	427	502	920	709	577
1957	1180	930	1280	825	1310	1000	1087
1958	1787	1075	1472	865	1430	1252	1313
1959	1120	840	1240	630	1200	1135	1027
1960	450	375	550	455	570	535	489
1961	650	445	580	435	760	717	596
1962	1740	1666	1952	1326	1538	1721	1657
1963	2265	1905	1650	1560	1150	1055	1598
1964	1405	1222	1098	1478	1254	1219	1280
Average	1109	888	1086	790	1024	920	

Table 8. Yield of six species (air-dry herbage lb. per acre) at the U.S. Sheep Experiment Station, seeded in 1946 (Hull and Klomp, 1966, p. 8)

Species	1950	1952	1953	1954	1955	1962	1963	Avg.
Crested wheatgrass	672	718	1318	975	1056	1299	2238	1268
Fairway wheatgrass	579	708	1194	952	942	1060	1738	1099
Siberian wheatgrass	579	692	1232	913	1009	1096	1513	1076
Intermediate wheatgrass	586	790	1314	919	898	1198	2037	1192
Pubescent wheatgrass	493	796	1378	1160	869	1289	2038	1254
Russian wildrye	542	578	902	574	705	668	1794	870
Average	575	714	1223	915	913	934	1893	

Also, Cook (1966a) established that seeded wheatgrasses had a longevity of at least 20 years. During the fall of 1943 and 1944, four wheatgrasses, crested, intermediate, tall, and pubescent, were seeded at Benmore, Utah. In the autumns of 1947, 1949, 1958, and 1964, stand densities were evaluated and clippings were taken to determine yields. Throughout these 20 years, the area was ungrazed. In areas that were grazed, brush invaded more rapidly than it did in protected areas. Grazing assisted by drought was conducive to more rapid brush reinvasion.

Limited precipitation decreases both forage production and the effective life of a seeding. Any time the annual precipitation averages from 10 to 11 inches, plowing and seeding big sagebrush ranges is a questionable method of improvement.*

Some excellent stands of wheatgrasses have been established throughout Utah in areas of limited precipitation. This has already been alluded to in Cook's (1966a) research. One such area is located north of Fort Duchesne at Lapoint, Utah.

In 1963, this range site was plowed and seeded to crested wheatgrass. Sagebrush has yet to noticeably reinvade the area. Note the dense stand of sagebrush in the left portion of Figure 6. This range is grazed in spring and late summer.

---

*McKell, C. M. 1974. Professor, Range Science, Utah State University, Logan. Class notes from Range Science 561, Spring Quarter, 1974.

Figure 6. Location: North of Lapoint (Ft. Duchesne), Utah

Elevation: 5,600 feet

Precipitation: 11 to 12 inches

Date: August 1973

Treatment: 1963

Figure 7. Same site as in Figure 6.

Litter and debris scattered on the ground helps control soil and wind erosion. The crested wheatgrass is well established on this particular site (Figure 7).

Rotobeating

Rotobeating as a management tool

An alternate practice of big sagebrush control is rotobeating, also called brush beating, or brush chopping. A rotobeater knocks down and slices brush and weeds by means of flairs attached to a horizontal shaft which revolves at high speed. It is quite effective in controlling large woody sagebrush plants, but is ineffective in controlling small sagebrush plants.

Use of rotobeaters in controlling big sagebrush is limited on Utah rangelands. Two areas visited this past summer (in August 1973) have used rotobeaters, Coalville and Price.

In both Figures 8 and 9, deferred grazing was not practiced following big sagebrush control. The native understory of grasses and forbs, considered to be in fair condition before treatment, was unable to gain an advantage over the increaser, rabbitbrush. The rabbitbrush is well on its way to dominating the entire right portion of Figure 9. The area to the left in Figure 9 is untreated.

Figure 8. Location: Chalk Creek area, east of Coalville

Elevation: 6,000 feet

Precipitation: 13 inches

Date: August 1973

Treatment: Fall 1972

Figure 9. Same area as in Figure 8. Treated Fall of 1971.

Contrasting the Coalville example, this range site east of Price responded well to rotobeating. The area left of the fence was rotobeaten six years ago, followed by two years of deferred grazing. At the time this area was visited (in August 1973), the range was in very good condition and only a few sagebrush plants were reinvading the site (Figure 10).

Figure 10. Location: Roan Plateau east of Price, Utah

Elevation: 9,100 feet

Precipitation: 18 inches

Date: August 1973

Treatment: Fall 1967

Some of the main determinants of success or failure in rotobeating can be shown by contrasting the environmental conditions that existed when the areas were treated and the range management principles adhered to in follow-up management.

		Price	Coalville
1.	Annual precipitation	18 inches	13 inches
2.	Condition of pre-treated range	good	fair
3.	Presence of rabbitbrush	little or none	abundant
4.	Deferred grazing	2 years	none

Disregard of one, a combination, or all of the above factors could result in a waste of time and money not to mention the quality of range forage produced. (Note: The abundance of rabbitbrush could have more effect upon the success of rotobeating than could deferment.)

Effects on forage production

Mueggler and Blaisdell (1958) found grasses and forbs increased from 250 and 43 pounds per acre air-dry to 490 and 150 pounds per acre air-dry, respectively, three years after rotobeating. Big sagebrush decreased from 368 to 100 pounds per acre air-dry.

Kearl and Brannan (1967) observed the results of rotobeating on 120 sample plots in Wyoming. Untreated sites averaged 202 pounds per acre air-dry and treated sites produced an average of 471 pounds per acre air-dry.

Hedrick et al. (1966) also reported increases in forage production following rotobeating of big sagebrush. These increases are found on page 20.

Effects on big sagebrush

In past years, it was permissible to rotobeat big sagebrush any time of the year providing the weather was permissive. Factors such as moisture and carbohydrate level in the plant were considered of little importance.

In more recent studies, Wright (1970) found that on 80 percent clipping treatments of big sagebrush, yields were reduced most when applied during July, moderately when applied during the spring, and least when applied during late summer and into the winter months. July, the most detrimental time of clipping big sagebrush, also correlates with the termination of the flower stalk and accelerated growth. This stage of phenology may be directly related to a low level of carbohydrates. Big sagebrush increases its tolerance to clipping by mid-August due to the translocation of carbohydrates to the roots and older stems.

Effects on longevity of controlled vegetation

One of the most serious problems in rotobeating is reinvasion of big sagebrush over a relatively short period of time. Cook (1966a) obtained excellent stands of crested, intermediate, and tall wheatgrasses seeded in the fall on areas which had been rotobeaten the previous July. At the end of the third growing season, the stands of grass were well established; however, five years later unkilled sagebrush plants had increased to the extent that the wheatgrasses were producing 50 percent less forage than they were at the end of the third year. Herbicide (2,4-D) was then used to control the big sagebrush reinvasion and within two years the wheatgrasses had doubled their yield previous to spraying.

Hedrick et al. (1966), comparing the rates of big sagebrush reinvasion following treatments of 2,4-D and rotobeating, found sagebrush density eight years after rotobeating remaining nearly constant on all fair condition range plots and having increased three-fold on poor condition range plots (Table 4).

Chaining

Chaining as a management tool

Chaining has virtually replaced railing except for a few isolated cases in Utah. Most of the chaining is for the purpose of removing juniper and pinyon pine, although it is quite effective on large big sagebrush. The chain links weigh from 25 to 90 pounds each, and the chain itself varies from 200 to 500 feet in length. Chaining is accomplished by two crawler tractors dragging heavy anchor chains in a U-shape, half circle, or J-shape (Vallentine, 1971).

Chaining is useful in releasing desirable forage from sagebrush competition. Usually, chains with links heavier than 70 pounds are used to eliminate big sagebrush. The area chained is gone over twice in opposite directions. After the first chaining, seed can be broadcast if needed, followed by a second chaining which not only removes additional brush, but covers the broadcast seed.

Kills up to 90 percent have been obtained from once-over treatments, but 50 to 70 percent is more common. If plants are young and flexible, it may require a third time over to get even a 50 percent kill (Pechanec et al., 1965).

Effects on forage production

The USFS (1973) estimates annual net usuable forage gained from chaining at .30 AUMs per acre. Additional forage production data are unavailable.

Effects on longevity

Longevity estimates are not available. It is thought the effective life would be less than for spraying simply because fewer sagebrush plants are killed using an anchor chain.

Biological

Biological control as a management tool

Biological control of big sagebrush has received very little attention from research institutions, probably because they lack the needed financial support. There does apparently exist some possibility with the insect (*Aroga websteri*) and the vole (*Microtus montanus*).

Approximately 10 to 15 thousand acres of sagebrush were killed by Aroga in Malheur County, Oregon in 1962 (Gates, 1964). Sagebrush species affected were big sagebrush, low sage (*A. arbuscula*), black sage (*A. nova*), and silver sage. There also has been some reports of Aroga on bitterbrush and other valuable browse species.

Where a sufficient understory of grasses and forbs exists, the defoliating action of Aroga on sagebrush could be considered as a management tool to increase the quality of the rangelands. Conversely, if the understory is insufficient, removal of sagebrush could cause serious range deterioration.

Voles also have been known to kill big sagebrush. Mueggler (1967) reported an outbreak of voles in southwestern Montana in 1962-64 that killed hundreds of acres of sagebrush by bark stripping. Other shrubs affected were silver sagebrush, skunkbush sumac (*Rhus trilobata*), antelope bitterbrush, curlleaf mountain mahogany (*Cerocarpus ledifolius*), Saskatoon serviceberry (*Amelanchier alnifolia*), and common chokecherry, of which the latter four are considered important browse species for deer and livestock.

If one could limit the herbacious matter eaten by either insects or voles to big sagebrush and other designated undesirable species, biological plant control could possibly see a future in range management. As it is, they are relatively non-selective in their eating habits, a practice which could leave a range in an even worse post-treatment condition.

ECONOMIC ANALYSIS OF DATA

Introduction

Sagebrush control costs vary depending on type of equipment, difficulty of job, whether the equipment is owned by the rancher (or an agency), or if the job is contracted. If the rancher owns the equipment and uses it for other ranch projects, fixed costs charged against range improvement are relatively low. In a case where the job is done completely on a custom basis, costs are variable (Kearl and Brannan, 1967). When a manager constructs new fences and/or reservoirs, his variable costs will increase considerably, but again this depends on size of the area being treated, type and extent of fencing, and size, type and number of reservoirs.

The main concern of a rancher is to recover the full costs of range improvement. Total costs incurred for sagebrush control can be recovered in one, a combination, or all of the following areas: (1) revenue received from increased red meat production, (2) increased sale or leasing value of rangeland by improving the watershed and increasing the forage production, and (3) revenue from selling recreational privileges. If ranchers cannot recover total costs through the areas listed above, it would be better for them to invest their money where total costs would be recovered.

Benefits from range improvement in terms of additional animal-unit-months (AUMs) available for grazing vary depending on management decisions of the rancher. One ranch manager may adopt a conservative attitude in rangeland stocking, even though his range is more than capable of increasing in carrying capacity. Another may increase the size of his operation and realize an economy of size. And there is the manager who is now able to maintain his present operation size, whereas a size reduction would have been necessary without range improvement (Kearl and Brannan, 1967).

It would be impossible to account for all the variations and combinations of variables that are involved in range improvements. However, if certain variables are held constant, then it can be determined if future range improvements are economically feasible.

Economic Evaluation Determinants of Sagebrush Control Methods

Economic evaluation of sagebrush control methods is determined by (1) cost of control method, (2) original forage production, (3) increase in forage production, (4) value of increased forage production per AUM, (5) effective life of control, and (6) market or opportunity interest rate. All these factors are used to determine the economic feasibility of sagebrush control using the internal rate of return technique.

Cost of control method

The cost of sagebrush control is somewhat flexible depending on method used and size and condition of area being treated. Other costs vary in relation to total activity and management decisions, examples of which include seeding, nonuse, construction of fences and reservoirs and miscellaneous annual costs.

Original forage production

Only 50 percent of the forage produced as a result of sagebrush control can be considered in an economic evaluation. For example, if the range forage production is 400 pounds per acre air-dry, we would assume 50 percent (200 pounds) available for animal consumption and 50 percent (200 pounds) remaining on the ground. Grazing at this intensity will allow the plants and soil to stay in a condition which will allow for a sustained yield at the estimated carrying capacity.

Also, the original forage production on a given range must be known in order to calculate the cost of nonuse.

Nonuse cost = yield before treatment in AUMs x value per AUM or the cost of replacing this number of AUMs.

Increase in forage production

The same principle applies for an increase in forage production as it did for original forage production, in that only 50 percent of the increase can be used in our economic evaluation. If forage production increased by 900 pounds per acre air-dry only 450 pounds per acre air-dry are considered available for the economic analysis.

Value of increased forage production per AUM

The market value of one AUM is $3.98 (USFS, 1973). The annual economic returns of 450 pounds forage in terms of an AUM is calculated as follows:

900 pounds (total forage increase per acre) x .50 percent = 450 pounds
450 pounds/800 pounds (forage required for an AUM) = .56 AUMs per acre.*

By multiplying .56 AUMs per acre increase x $3.98, the calculated annual economic return from useable forage is $2.23 per acre.

Effective life of control

The effective life of sagebrush control depends on method used, management practices, and percent kill of sagebrush. There is a period toward the end of a cycle when production may taper off, although forage production may never drop to the level it was before treatment. For practical purposes, once reinvading sagebrush reaches a certain density, the productive life of a treatment is considered over.

Market or opportunity interest rate

This is the rate at which a rancher can borrow money or what his next best alternative use of capital will return. The market rate of interest for range improvement is currently 8 percent.**

Internal rate of return

The internal rate of return is the discount rate which makes the discounted returns equal to the cost of obtaining the income stream (Nielsen, 1967). The internal rate of return must be greater than the market rate of interest (cost of obtaining income stream).

Various methods can be used to determine internal rates of return on a given investment depending on the nature of the income stream. If

*Workman, J. P. 1974. Professor, Range Science, Utah State University, Logan. Personal communication, March 1974.

**Nyman, R. S. 1974. Representative of Federal Land Bank, Logan, Utah. Personal telephone conversation, March 1974.

the income stream begins in year 1 and remains constant over the life of the project, the following formula can be used (Nielsen, 1967):

$$I = R\left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

where: I = Initial investment per acre
R = Net additional annual returns per acre
n = Effective life of improvement (years)

In this equation we are solving for i, which also is the internal rate of return. To find i, a hypothetical example of range improvement costs is used.

I = \$8.50 per acre
R = \$2.00 per acre
n = 15 years

$$8.50 = 2.00\left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

Divide both sides by 2.00.

$$\frac{8.50}{2.00} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$4.25 = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

The internal rate of return can be found by using present value tables (the present value of \$1 received annually for n years). The closest numbers to 4.25 in the 15 year row are 4.3152 at 22 percent, and 4.1529 at 23 percent. Therefore, the internal rate of return (i) is between 22 and 23 percent or more exactly by interpolation 22.4 percent. The value of i (22.4 percent) can vary considerably depending on whether the range is deferred from grazing following treatment, assuming all other variables are held constant.

In the above discounting method (hereafter known as the standard discounting method), the formula assumes a constant income stream throughout the effective life of the project, beginning in year 1 (year following treatment) and extending to year n. Also, all nonuse costs are assumed to be incurred in year 0 (year of treatment), regardless of the year in which the nonuse cost actually occurred.

Although the standard discounting method is a relatively easy way to calculate the internal rate of return, it is not as accurate as one may desire. For example, a sprayed range is deferred from grazing for two years. The first year of deferred grazing occurs the year the land is sprayed (year 0). This nonuse is added to the cost of spraying. Also, the income stream in year 1 would be less than in the following years (year 2 through n), because the nonuse cost in year 1 would be subtracted from the annual income stream of year 1.

Since the standard method does not properly reflect the income stream and the nonuse costs, a modified discounting procedure will be used. Under this method, each year's net income will be discounted separately and summed to arrive at the current value of the net income stream. Thus, one is able to properly account for the nonuse costs in years 0 and 1. Given the above assumptions made about nonuse, this procedure will have a lower net income stream than the income stream assumed in the standard method, where all nonuse costs are taken in year 0. Because of this difference, the internal rate of return will be smaller when one uses the modified discounting method.

To demonstrate the disparity in results obtained by the standard and modified discounting methods, internal rates of return will be calculated by both methods for actual spraying response data using three deferment schedules. Thereafter, the modified discounting method will be used unless deferment is not required.

The following assumption will hold for all control methods unless otherwise indicated:

(1) Fences and reservoirs are sufficient for proper range management following treatment.
(2) Seeding is not necessary except when plowing is done.
(3) All treatments are done on contract.

Spraying

Results of sagebrush spraying projects were gathered from sources representing Utah and various surrounding states. Following treatment, forage production increased one to three fold and AUMs per acre increased from .1 to .9. The data have been summarized in Table 9.

The average annual AUMs per acre before treatment and the average annual increase in AUMs per acre after treatment were .2444 and .4185, respectively. These results are consistent with studies conducted by Kearl and Brannan (1967) where AUMs per acre on pre-treated and treated range were .2 and .5, respectively. The USFS (1973) estimated from 17 five-seven year old projects in the Intermountain Region, forage gained as a result of chemical treatment was .37 AUMs per acre, although the utilization rate was only 40 percent. At a utilization rate of 50 percent, forage gained would have been approximately .47 AUMs per acre. Thus, the increase in forage production used in this study (.4185 AUMs) is considered to be a conservative estimate.

It is rather difficult to determine the effective life of spraying rangeland. Kearl and Brannan (1967) projected a longevity of 15 years

Table 9. Sources of data, annual yields, and AUMs of forage before spraying, annual increase in yields and AUMs of forage after spraying, and number of years range improvement was observed

Source	Annual yield before improvement (pounds)	Annual AUMs per acre before improvement (50% utilization)	Annual increase in yield after improvements (pounds)	Annual increase in AUMs per acre after improvement (50% utilization)	Number of years observed
Alley & Bohmont (1958)	526	.3287	1549	.9681	5
Cook (1966)	430	.2687	370	.2312	3
Cook (1966)	800	.50	700	.4375	3
Hyatt (1966)	343	.2143	800	.50	6
Sneva (1972)	227	.1418	454	.2837	17
Peterson (1973)	221	.1381	621	.3881	3
Brady (1973)	191	.1193	193	.1206	3
Average	391.14	.2444	669.57	.4185	5.7

and the USFS (1973) estimated an average of more than 20 years. From data collected in this study, it seems that 15 years is a rather realistic number, although only 12 years effective life following spraying is assumed in this study. The forage production data were averaged over a period of 5.7 years (Table 9), thus, it was thought a more conservative effective life of 12 years would best represent the existing data.

Standard discounting method

The first analysis will utilize the formula $I = R\left[\frac{1-(1+i)^{-n}}{i}\right]$, with deferred grazing (type of nonuse) being the only variable. Data used is found in Table 9.

Case 1

The sprayed rangeland is deferred for two full grazing seasons.

$5.82 = Cost of chemical treatment per acre (USFS, 1973).
$3.98 = Market value per AUM.
.2444 = Annual AUMs per acre prior to treatment.
.4185 = Annual increase in AUMs per acre after treatment.
$1.95 = Cost per acre for two years of nonuse.
(.2444 x $3.98 = $.97, value of nonuse per acre x two years).
$1.67 = Value of AUM in annual returns (.4185 x $3.98)

$$I = R\left[\frac{1-(1+i)^{-n}}{i}\right]$$

I = $5.82, cost of chemical treatment per acre (USFS, 1973), + $1.95, cost per acre for nonuse during year 0 = $7.77.

R = $1.67, value of AUM in annual returns per acre in year 1 through year 12.

n = 12 years.

$$7.77 = 1.67\left[\frac{1-(1+i)^{-n}}{i}\right]$$

$$\frac{7.77}{1.67} = \left[\frac{1-(1+i)^{-n}}{i}\right]$$

$$4.67 = \left[\frac{1-(1+i)^{-n}}{i}\right]$$

By using the present value tables, 4.67 represents an internal rate of return between 18 and 19 percent. The value of i calculated by interpolation is 18.8 percent.

Case 2

The sprayed rangeland is deferred for half a year for two years. It is grazed after grass seeds are set, but at only half the potential stocking rate. Thereby, new seedlings can become established and nonuse costs are half that of full deferment.

I = \$5.82, cost of chemical treatment per acre (USFS, 1973), + \$.98, cost per acre for two years nonuse (\$1.95/2) = \$6.80.

R = \$1.67, value of AUM in annual returns per acre in year 1 through year 12.

n = 12 years.

$$\frac{6.80}{1.67} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$4.07 = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

The internal rate of return is between 22 and 23 percent. Interpolation: 22.35 percent.

Case 3

No deferment is used following spraying.

I = \$5.82, cost of chemical treatment per acre (USFS, 1973).

R = \$1.67, value of AUM in annual returns per acre in year 1 through year 12.

n = 12 years

$$\frac{5.82}{1.67} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$3.49 = \left[\frac{1 - (1 - i)^{-n}}{i}\right]$$

The internal rate of return is between 27 and 28 percent. Interpolation: 27.05 percent.

Modified discounting method

Calculating the internal rate of return using modified discounting is a rather involved process of trial and error. The methodology can best be understood if it is set out in algebraic form. The data used are the same as in the standard discounting method.

Case 1

Treated range is deferred for two full years. No grazing is allowed the year of treatment (year 0). The range is also rested from grazing the year after treatment (year 1). Grazing at full capacity begins in year 2 and continues through life of project (Table 10).

I = \$5.82, cost of chemical treatment per acre (USFS, 1973), + \$.97, cost per acre for nonuse during year 0 = \$6.79.

R = \$1.67, value of AUM in annual returns per acre in year 2 through year 13.*
= -\$.97 during year 1 (nonuse cost).

Since the income stream is not constant over the 13 years, the following modified discounting formula must be used:

$$I = \sum_{n=1}^{13} R\,(1 + i)^{-n}$$

or

$$\$6.79 = R \cdot \text{Present Value factor (PV factor)}$$

Therefore, when I (\$6.79) is equal to the sum of the annual returns

*See footnote * at bottom of Table 10.

Table 10. Nonuse costs and annual returns per acre, discounting factors, discounted costs and returns per year when sprayed range is deferred from grazing for two full grazing seasons

Year (n)	Nonuse costs and annual returns per acre (dollars)	Discounting factors		Discounted annual costs and returns (dollars)	
		(percent)		(percent)	
		15	16	15	16
0					
1	- .97	.869565	.862068	-.8434	-.8362
2	1.67	.756143	.743162	1.2627	1.2410
3	1.67	.657516	.640567	1.0980	1.0698
4	1.67	.571753	.552291	.9548	.9223
5	1.67	.497176	.476113	.8302	.7951
6	1.67	.432437	.410442	.7219	.6854
7	1.67	.375937	.353829	.6278	.5908
8	1.67	.326901	.305025	.5459	.5093
9	1.67	.284262	.262952	.4747	.4391
10	1.67	.247184	.226683	.4127	.3785
11	1.67	.214943	.195416	.3589	.3263
12	1.67	.186907	.168462	.3121	.2813
13*	1.67	.162529	.145226	.2714	.2425
		Total		7.0277	6.6452

*Discounting is carried into year 13 because two full years of grazing was lost to nonuse.

from year 1 through year 13, discounted at an interest rate of i, i is the internal rate of return.

To shorten the trial and error process of solving for i, one can first estimate the expected internal rate of return. Having already calculated i using the standard discounting method, it is known the internal rate of return will be lower than 18.8 percent. Using 15 percent, the sum of the discounted annual returns ($7.03) is greater than the cost incurred in year 0 ($6.79), therefore, the internal rate of return has been under-estimated (Table 10). A higher rate is selected, for example 16 percent, which results in the internal rate of return being overestimated, because the sum of the discounted annual returns ($6.65) is less than I ($6.79).

This iterative process is continued until the sum of the discounted returns converges on the costs incurred in year 0. By this process and using interpolation, the internal rate of return (i) is about 15.62 percent. Therefore, at a discount rate of 15.62 percent, I ($6.79) is equal to the sum of the annual discounted returns ($6.79).

Case 2

Treated range will be deferred for half of the grazing season and at half the potential stocking rate for two years. Grazing will begin after seeds are set in years 0 and 1 (Table 11).

I = $5.82, cost of chemical treatment per acre (USFS, 1973),
+ $.49, cost per acre for nonuse during year 0 = $6.31.

R = $1.67, value of AUM in annual returns per acre in year 2 through year 12,
= $.35 during year 1.*

---

*See footnote * at bottom of Table 11.

Table 11. Nonuse costs and returns per acre, discounting factors, discounted costs and returns per year when sprayed range is deferred from grazing for half of the grazing season for two years

Year (n)	Nonuse costs and annual returns per acre (dollars)	Discounting factors	Discounted costs and returns (dollars)
		(percent) 20	(percent) 20
0			
1	.35*	.833333	.2917
2	1.67	.694444	1.1596
3	1.67	.578704	.9664
4	1.67	.482253	.8053
5	1.67	.401878	.6710
6	1.67	.334898	.5591
7	1.67	.279082	.4659
8	1.67	.232568	.3883
9	1.67	.193807	.3236
10	1.67	.161506	.2697
11	1.67	.134588	.2246
12	1.67	.112167	.1872
		Total	6.3124

*Income stream for year 1 ($.84 value of AUM for half of year 1 minus $.49 nonuse cost for half of year 1).

n = 12 years.

$$I = \sum_{n=1}^{12} R\,(1 + i)^{-n}$$

$$\$6.31 = \sum_{n=1}^{12} R \cdot \text{PV factor}$$

The same iterative process is repeated as in Case 1. The internal rate of return is 20.0 percent.

Case 3

Treated range will not be deferred from grazing. The internal rate of return (i), using modified discounting, is the same as when using standard discounting, i.e., 27.05 percent.

In Cases 1 and 2 the modified discounting method yields a lesser internal rate of return than when using the standard discounting method. However, in this instance (Case 3), when we compare the two discounting methods, there is no difference in the internal rate of return (Table 12). A difference does exist in the internal rate of return in Case 2 (2.35) and an even greater difference in Case 1 (3.18).

Table 12. Type of nonuse, internal rates of return using two calculating methods when controlling big sagebrush with 2,4-D

Case (type of nonuse)		Standard (percent)	Modified (percent)	Differences in the internal rate of return per case (percent)
Case 1.	two years	18.80	15.62	3.18
Case 2.	half a year for two years	22.35	20.00	2.35
Case 3.	none	27.05	27.05	.0

Planned Burning

Planned burning was once used extensively to control big sagebrush, but in recent years its use as a management tool has been limited. It can be an excellent method of big sagebrush control, assuming a sufficient understory is present to carry the fire and proper follow-up management is used.

The USFS (1973) estimated forage production gained by planned burning the same as for chemical spraying, .37 AUMs per acre. Of course, the estimate would be somewhat higher than .37 because only a 40 percent utilization of increased forage was used.

There are some apparent differences in the estimates of increased AUMs attributed to planned burning. Pechanec et al. (1954, revised) show an increase in AUMs of .225; (740 pounds on post-burn, minus 380 pounds on pre-burn = 360 pounds .50 forage utilization = 180 pounds/800 pounds per AUM = .225). This is considerably less than the USFS estimate. However, Pechanec's estimate is the result of one study region whereas the USFS based their estimate on studies throughout the Intermountain States.

In determining the internal rate of return, the data in Table 9 will be used for planned burning. This seems justifiable because of: (1) insufficient availability of forage yield data for planned burning and (2) comparable forage yield estimates made by the USFS.

The effective life of a planned burn has been reported to have lasted for at least 15 years (Pechanec et al., 1954, revised). Whiteworth (1963), a rancher in Beaverhead County, Montana, received 12 years of unrestricted grazing following planned burning.

An effective life of 12 years will be used in the following economic evaluations. This expected longevity correlates with the forage data used from big sagebrush control using 2,4-D. It must be remembered a major determinant of big sagebrush reinvasion is the number of plants surviving treatment (Johnson and Payne, 1968). It is assumed the same percentage of big sagebrush plants killed using 2,4-D will also be killed using planned burning.

Treated range will be deferred from grazing in year 0 and will not begin until the fall of year 1, but will be only one-fourth of the potential stocking rate (Pechanec et al., 1954, revised). It is assumed not more than one-fourth year of grazing can be realized in year 1.

Economic analysis

$4.00 = Cost of planned burning per acre (USFS, 1973)
$3.98 = Market value per AUM
.2444 = Annual AUMs per acre prior to treatment
.4185 = Annual increase in AUMs per acre after treatment

$ .97 = Cost per acre for each year of nonuse
$1.67 = Value of AUM in annual returns per acre

I = $4.00, cost of burning per acre (USFS, 1973), +
$.97, cost per acre for nonuse during year 0 = $4.97.

R = $1.67, value of AUM in annual returns per acre in year 2 through year 13.

= -$.31, in year 1 (-$.73, nonuse cost for three-fourths of year 1 minus $.42, value of an AUM for one-fourth year in year 1).

n = 13 years (year 13 is added to help compensate for one and three-fourths years lost in grazing in year 0 and 1).

$$I = \sum_{n=1}^{13} R\,(1 + i)^{-n}$$

$$\$4.97 = \sum_{n=1}^{13} R \cdot \text{PV factor}$$

The internal rate of return (i) is 23.85 percent.

Plowing and Seeding

From the data collected in this study, forage production increased from four to six fold following plowing and seeding. The average annual AUMs per acre before treatment and the average annual increase in AUMs per acre after treatment were, respectively, .1216 and .5399 (Table 13).

The longevity of most exotic grasses following plowing is at least 20 years (Cook, 1966 and Hull and Klomp, 1966). Kearl and Brannan (1967) in their economic analysis projected a useful life exceeding 20 years. In this study, the longevity of plowing followed by seeding of one or various exotic grasses is estimated at 25 years, which is believed to be a rather conservative estimate.

Treated rangeland will be deferred from grazing for two full years. This nonuse period will enable young seedlings to become established

Table 13. Sources of data, annual yields, and AUMs before plowing, annual increase in yields and AUMs after plowing and seeding, and number of years range improvement was observed

Source	Annual yield before improvement (pounds)	Annual AUMs per acre before improvement (50% utilization)	Annual increases in yield after improvement (pounds)	Annual increase in AUMs per acre after improvement (50% utilization)	Number of years observed
Cook (1966)	190	.1187	668	.4175	9
Cook (1966)	199	.1243	868	.5425	9
Hull and Klomp (1966)	195*	.1218	775	.4843	14
Hull and Klomp (1966)	195*	.1218	932	.5825	14
Hull and Klomp (1966)	195*	.1218	1077	.6731	10
Average	195	.1216	864	.5399	11.2

*Yields before treatment were not available for Hull and Klomp; therefore, Cook's yields before treatment were averaged to arrive at 195 pounds per acre air-dry.

and lessen the hazard of wind and water erosion.

Economic analysis

$21.00 = Cost of plowing and seeding per acre (USFS, 1973)
$ 3.98 = Market value per AUM
.1218 = Annual AUMs per acre prior to treatment
.5399 = Annual increase in AUMs per acre after treatment
$ .49 = Cost per acre for each year of nonuse (.1218 x $3.98)
$ 2.15 = Value of AUM in annual returns (.5399 x $3.98)

I = $21.00, cost of treatment per acre (USFS, 1973), + $.49, cost per acre for nonuse during year 0 = $21.49

R = $2.15, value of AUM in annual returns per acre in year 2 through year 26
= -$.49, in year 1 (nonuse cost)

n = 26 years (year 26 was added to help compensate for two full years lost in grazing in year 0 and 1)

The internal rate of return is 7.5 percent, which is less than the market rate of interest. Any time the internal rate of return is less than the market rate of interest, it would be best to seek an alternative investment, if available.

If a range manager believed such factors as yields and/or longevities could be increased, plowing and seeding may be a worthwhile investment. Also, many ranchers may be able to decrease the cost of $21.00 per acre considerably if they used their own equipment and labor.

Rotobeating

The use of rotobeaters to control big sagebrush is very limited. Therefore, yield data before and after treatment are restricted. Data from three representative areas are listed in Table 14.

Table 14. Sources of data, annual yields and AUMs before rotobeating, annual increase in yields and AUMs after rotobeating, and number of years range improvement was observed

Source	Annual yield before improvement (pounds)	Annual AUMs per acre before improvement (50% utilization)	Annual increase in yield after improvement (pounds)	Annual increase in AUMs per acre after improvement (50% utilization)	Number of years observed
Mueggler and Blaisdell (1958)	293	.1831	347	.2168	8
Hedrick et al., (1966)	200	.1250	178	.1112	8
Kearl and Brannan (1967)	202	.1262	269	.1681	-
Average	231.6	.1447	246.6	.1653	8

By inspection, it can be seen that the average pre-treatment AUMs (.1447) and post-treatment increase in AUMs (.1653) are relatively low. This low productivity could be partially attributed to the short effective life of rotobeating (Cook, 1966 and Hedrick et al., 1966). Kearl and Brannan (1967) projected a 12 year effect life for rotobeating. Other data (Table 4) shows the longevity of rotobeating less than for chemical treatment. Therefore, an effective life of 10 years will be used in the economic evaluation.

It is assumed the range will be deferred from grazing for one full year to facilitate seedling vigor (see Workman, page 52, footnote). If a sufficient understory of grasses and forbs are present, it may be possible to not defer the treated range from grazing.

The cost of rotobeating is highly variable. Vallentine (1971) believes it can vary from $5 to $50 per acre depending on the density and age of sagebrush. Kearl and Brannan (1967) reported an average cost of $4.76 per acre, which cost would be considerably higher in 1974. For plowing and seeding, the USFS (1973) quoted a cost of $21.00 per acre and Kearl and Brannan (1967) quoted a cost of $13.61 per acre. The 1973 cost is approximately 55 percent higher than the 1967 cost. Assuming the cost of rotobeating rose proportionally to plowing and seeding, the approximate cost today would be $7.37 per acre.

Economic analysis

$7.37 = Cost of rotobeating per acre
$3.98 = Market value per AUM
.1447 = Annual AUMs per acre prior to treatment
.1653 = Annual increase in AUMs per acre after treatment
$ .58 = Nonuse cost for one year (.1447 x $3.98)
$ .66 = Value of AUM in annual returns (.1653 x $3.98)

I = \$7.37, cost of rotobeating per acre, + \$ .58, cost per acre for nonuse during year 0 = \$7.95

R = \$ .66, value of AUM in annual returns in year 1 through year 12

n = 12 years

$$\frac{7.95}{.66} = \left[\frac{1 - (1 + i)^{-n}}{i} \right]$$

$$12.06 = \left[\frac{1 - (1 + i)^{-n}}{i} \right]$$

When using the standard discounting method, the internal rate of return is less than zero (see present value tables). Therefore, it is obvious it will be less than zero using the modified method. Rotobeating is not considered an economically feasible method of controlling big sagebrush. High costs, short longevity, and limited increases in forage undoubtedly contribute to the lack of interest in rotobeating.

Chaining

The data available on chaining big sagebrush are very limited. Increases in forage production after chaining is estimated by the USFS (1973) to be .30 AUMs per acre, assuming a 40 percent forage utilization rate. With a 50 percent forage utilization rate, the increase in forage production would be .3750 AUMs per acre. Cost of chaining per acre is listed at \$8.50 (USFS, 1973).

Chaining is believed to have a shorter effective life than spraying because of fewer sagebrush plants killed. It is assumed the longevity of chaining would be very similar to rotobeating, therefore, an effective life of 10 years will be used.

Deferred grazing is not recommended following chaining if seeding is not employed (USFS, 1973). Thus, in the following economic analysis, no deferment will be used.

Economic analysis

$8.50 = Cost of chaining per acre (USFS, 1973)
$3.98 = Market value per AUM
.3750 = Annual increase in AUMs per acre after chaining
$1.49 = Value of AUM in annual returns ($3.98 x .3750)

I = $8.50, cost of chaining per acre (USFS, 1973)

R = $1.49, value of AUM in annual returns per acre in year 1 through year 12

n = 10 years

The internal rate of return (i) is 11.83 percent. Chaining is an economically feasible method of controlling big sagebrush, although the returns are considerably lower than either burning or spraying.

The internal rates of return for the different big sagebrush control methods using modified discounting are summarized in Table 15.

Further considerations of deferment

The greatest divergence between internal rates of return lies in the method of control and the type of deferment. A rancher usually will choose the control method which will best meet his economic commitments and hopefully be compatible to the associated environment. The same type of decision would be expected for deferment, except deferment is not always desired by the ranch manager and it is questionable as to whether deferment is necessary environmentally, following spraying. It is apparent deferment is needed on plowed-seeded and burned ranges.

Table 15. Internal rate of return using modified discounting for different big sagebrush control methods and types for nonuse

Control method and types of nonuse	Internal rates of return using the modified discounting method
	(percent)
Chemical spraying	
nonuse - two years	15.62
nonuse - half year for two years	20.0
nonuse - none	27.05
Planned burning	
nonuse - one and three-fourths years	23.85
Plowing and seeding	
nonuse - two years	7.5
Rotobeating	
nonuse - one year	0.0
Chaining	
nonuse - none	11.83

For instance, the Utah Agricultural Stabilization and Conservation Service (ASC) required ranchers, participating in the cost-share program, to defer their range following sagebrush control. Deferment at times placed a temporary hardship on the rancher and to compensate for the loss of forage, herds were reduced or additional range was acquired. Also, deferment often required additional fencing, which greatly increased the cost of the spraying program.

The recommendations that ranges be deferred appear to be based on the general range management principles that deferment is necessary for seedling establishment and will aid vegetation growth (Pechanec et al., 1954, p. 34). They state that, "where the natural increase of native grasses is being relied upon, it is advisable to delay grazing for at least a full year". At the time that statement was written (1954), knowledge of spraying sagebrush was very limited. Also, Pechanec talked about the value of deferment but failed to reference any experimental data which substantiates his statements (Kearl, 1966).

Hyder (1954) also made some recommendations on treatment after spraying. He said:

> You will not need to prevent grazing on the sprayed field, but you should graze lightly while the grass is green for two or three years. Because of the greater amount of forage produced, continuation of the pre-spraying rate of stocking will often result in light grazing after spraying (Hyder, 1954, p. 11-12).

Hyder goes on to recommend that the sprayed range be grazed moderately during spring and early summer to help prevent sagebrush reinvasion. Again, Hyder fails to cite any experimental evidence and it appears his judgment is based upon range management experience.

The only experimental data found on this subject is by Smith (1969) and Kearl (1966). Smith's work was discussed previously on page 13. Briefly, the experiments covered a range of elevations from 7,500 to 9,500 feet. The treatments were deferment for zero, one, two, and three years. After six years of study, Smith did not detect any significant differences between treatments.

Kearl (1966) cited some experimental unpublished work done by Walley Johnson of the Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming. The area is away from the mountains in the Beaver Rim area near Lander. It is at an elevation of approximately 6,000 feet and the annual precipitation is 12 inches or less. Although the experiment was primarily intended to determine the best time and rates of 2,4-D, some of the plots were fenced to exclude grazing and others were left open to grazing. Years later, no significant differences existed between the fenced and unfenced areas in extent of brush reinvasion, plant species composition, or forage production.

The need for deferment following spraying was researched by Kearl (1973) using mail and personal interview surveys. Information was obtained from 78 percent of the ranch operators that had sprayed 200,000 acres of sagebrush in Wyoming prior to 1963. Of the respondents, 61 percent applied no deferment. Moderate stocking or deferment of one to three months resulted in 13 percent of the cases and deferment of four to six months on an additional 13 percent of the cases. Deferment from 7 to 12 months was applied on 8 percent of the cases and deferment of 13 to 14 months on 5 percent. Through 1966, between 553,000 and 617,000 acres of private land was sprayed without adherence to deferment recommendations.

Most of the sagebrush sprayed in the early years of the cost-share program did not need respraying in the years 1967 and 1968. Also, ranch operators didn't predict the future need for respraying.

Much of the spraying in Wyoming was done at elevations from 4,000 to 9,100 feet with precipitation ranging from 10 to 20 inches. Under these conditions, it is doubtful deferment is needed. If it is not needed, it could mean as much as 11.43 percent (27.05 percent minus 15.62 percent, Table 15) greater internal rate of return.

In areas of less than 10 inches of annual precipitation, it is questionable if spraying should be done at all. Additional research needs to be done before further conclusions are drawn.

Other factors affecting
the internal rate of return

From the above discussion, it is apparent the type of deferment and the type of dicounting method chosen can alter the value of the internal rate of return. However, the most important variables in determining the internal rate of return on a given big sagebrush control project are the vigor index and pre-treatment forage production.

The vigor index of a range site is determined by such factors as soil and air temperature, light, soil nutrients, and annual precipitation; the latter two being the most important (see Dwyer, footnote, p. 1). Each of these factors must be in sufficient abundance or forage will not respond significantly to sagebrush control. The vigor index is often called the sagebrush vigor index, in that where big sagebrush grows vigorously, so should grasses and other desirable forage. Of course, as with any rule of thumb, there will be exceptions to the rule.

Secondly, there exists a direct relationship between pre-treatment yields and post-treatment forage yields. If a range site is only producing 150 pounds per acre air-dry forage prior to treatment, even with a three-fold increase, post-treatment forage yields would only be 450 pounds per acre air-dry. Contrasting this example, a pre-treatment yield of 300 pounds per acre air-dry with a three-fold increase will increase post-treatment forage yields to 900 pounds per acre air-dry. Although both increased three-fold, the second will realize a higher internal rate of return.

Opportunity Cost of Not Spraying Big Sagebrush

There exists the possibility that chemical herbicides such as 2,4-D will be banned from future use to control undesirable shrubs, in particular big sagebrush. Pesticides have been under fire for many years, but it wasn't until Rachael Carson published her book, Silent Spring, in 1962, that the early alarm was sounded. Since then, there have been innumerable books, articles, and speeches published in order to influence our decision makers to restrict or ban the use of certain pesticides.

Also, according to the NRDC, speaking of the BLM's actions, said:

> Moreover, the projects designed to increase livestock forage by chemical or mechanical means have destroyed thousands of acres of wildlife habitat, and the construction of fences to contain livestock has interfered with the migration routes of big game animals, often causing death or injury to such animals (NRDC, 1973, p. 15).

If 2,4-D is banned from our rangelands, certain benefits will be foregone. For example, the increased cost of alternative brush control methods and the foregone additional AUMs which would have been produced had 2,4-D been used are the opportunity costs of not using 2,4-D.

Of the 2,453,000 acres of sagebrush acreage meriting control (EPA, 1972), 1,830,000 acres are recommended to be controlled by 2,4-D. By multiplying .4185 (annual increase in AUMs per acre after spraying) times 1,830,000 acres, the expected increase in AUMs would be 765,855. The expected annual forage value of the total AUMs or opportunity cost would be $3,048,102 (765,855 x $3.98).

In arriving at an opportunity cost of $3,048,102, it was assumed 2,4-D was the only feasible method of sagebrush control on the designated

1,830,000 acres. This may not be the case. Undoubtedly, there is a certain percentage of this acreage which could be improved by burning and chaining, if necessary. Therefore, the opportunity cost would be somewhat lower. Rotobeating is not considered as an alternative because of its prohibitive cost (Table 15). Also, plowing and seeding are not considered as alternatives since a sufficient understory is assumed to be present for other less expensive methods to be used.

It is not known that 2,4-D will be restricted from our rangelands. What is apparent, there exists a need for our policy makers to realize the economic value of sagebrush control.

The same principle of opportunity cost also applies to ranchers and other range managers who neglect range improvement. For instance, if the 2,453,000 acres of private and state rangelands are not improved, it would have the same effect as if all sagebrush control methods were banned. Furthermore, the opportunity cost would be even greater because of the additional AUMs lost through not improving the 623,000 acres defined as meriting improvement other than by spraying.

Economic Feasibility of Controlling Big Sagebrush on State and Private Rangelands

This study has shown that at least three big sagebrush control methods offer internal rates of return which may be considered as acceptable returns on a capital investment--spraying, burning, and chaining (Table 15). (Each control method yields an internal rate of return greater than the present market rate of interest of 8 percent.)

Furthermore, in the introduction of this study (page 2), concern was voiced as to the ability of state and private rangelands to increase the number of AUMs if federal (BLM) AUMs were lost through court action. The results of the study are rather conclusive that state and private rangelands can meet the challenge of increased forage production (AUMs), in fact, if need be, possibly increase the number of AUMs to equal the present number of AUMs supplied by the BLM for livestock grazing.

For example, the total number of AUMs supplied by the BLM for livestock grazing were 1,016,293 in 1971 (BLM, 1972). The expected annual increase in AUMs of 1,830,000 acres of big sagebrush sprayed with 2,4-D would be 765,855 (page 77). Of the remaining 623,000 acres meriting control, it is very possible an additional number of AUMs could be increased to equal the total AUMs supplied by the BLM.

This latter statement is somewhat speculative and deserves further research. The EPA (1972) did not specify the control method(s) which would be applicable to the 623,000 acres. It is thought a number of these acres lack a sufficient understory to be improved without seeding; therefore, plowing followed by seeding may be an applicable method, assuming the internal rate of return is above 8 percent. Burning and chaining with or without seeding may also be considered as alternative methods.

SUMMARY AND CONCLUSIONS

This report employed a literature survey and personal interviews to determine the forage production and economic effects of controlling big sagebrush by various means.

Spraying with the chemical herbicide 2,4-D is the most widely used method of controlling big sagebrush. When recommended procedures are used, one can expect a kill of big sagebrush from 67 to 100 percent. Spraying is very effective in increasing forage production and generally is not poisonous to either man or animals.

Other big sagebrush control methods studied were selective grazing, burning, plowing and seeding, rotobeating, chaining, and biological control (insects and voles).

Economic evaluation of the various big sagebrush control methods is determined by (1) cost of the control method, (2) original forage production, (3) increase in forage production, (4) value of increased forage production per AUM, (5) effective life of control, and (6) market or opportunity interest rate. All these factors were used to determine the economic feasibility of sagebrush control using the internal rate of return technique.

Two procedures can be used to calculate the internal rate of return: standard and modified discounting. Standard discounting assumes all non-use costs are incurred in year 0 (year of treatment) and the annual income stream is constant from year 1 (year following treatment) through year n (end of effective life). Modified discounting correctly assumes the nonuse cost is incurred during the year of deferment. This also causes the annual income stream to be less in the years in which deferred grazing is implemented because the nonuse cost would be subtracted from the annual income stream. Therefore, modified discounting yields a lower internal rate of return than does standard discounting.

The highest internal rate of return was obtained with planned burning. Treated range, deferred for one and three-fourths years, realized an internal rate of return of 23.85 percent.

The returns to chemical spraying with the associated types of deferment (zero, one, and two years) were 15.62 percent, 20.0 percent, and 27.05 percent, respectively.

Plowed and seeded range deferred for two years yielded an internal rate of return of 7.5 percent which does not compare favorably with the current market rate of interest on capital borrowed for range improvement of 8 percent.

The return to rotobeating with one year of deferment was negative.

Return to chaining with no deferment was 11.83 percent. Although this return is considerably lower than either burning or spraying, it does indicate that chaining is an economically feasible method of controlling big sagebrush.

The most important factors in determining the internal rate of return are the site vigor index and the amount of forage present before treatment. The site vigor index is mainly dependent upon soil nutrients and precipitation. There is a direct relationship between pre-treatment forage yields and post-treatment yields. A larger pre-treatment forage yield will give a larger internal rate of return, assuming the vigor index is sufficiently high.

If rangelands infested with big sagebrush are not improved by spraying or other big sagebrush control methods, certain benefits, called opportunity costs, will be foregone. For spraying alone, the expected annual opportunity cost would be $3,048,102.

The economic feasibility of controlling nearly 2 1/2 million acres of state and private rangelands infected with big sagebrush are excellent. The expected annual increase in carrying capacity of 1,830,000 acres of sagebrush rangeland meriting improvement by spraying is 765,855 AUMs. The remaining 623,000 acres meriting control other than by spraying could very possibly increase the total number of additional AUMs to over 1 million.

LITERATURE CITED

Alley, H. P. 1965. Chemical control of sagebrush for range improvement. Journal of Soil and Water Conservation 20:256-258.

Alley, H. P., and D. W. Bohmont. 1958. Big sagebrush control. Wyoming Agricultural Experiment Station Bulletin 354. 8 p.

Beale, D. M., and A. D. Smith. 1970. Forage use, water consumption, and productivity of pronghorn antelope in western Utah. Journal of Wildlife Management 34:573.

Best, L. B. 1972. First year effects of sagebrush control on two sparrows. Journal of Wildlife Management 36:334-344.

Blaisdell, J. P., and W. F. Mueggler. 1956. Effects of 2,4-D on forbs and shrubs associated with big sagebrush. Journal of Range Management 9:38-40.

Cook, W. C. 1966a. Development and use of foothill ranges in Utah. Utah Agricultural Experiment Station Bulletin 461. 47 p.

Cook, W. C. 1966b. Herbicide mixtures control range brush. Crops and Soils. 18(7):28.

Environmental Protection Agency. 1972. Office of Water Programs. Pesticides study series - 3, the use and effects of pesticides for rangeland sagebrush control. 179 p.

Frischknecht, N. C., and L. E. Harris. 1973. Sheep can control sagebrush on seeded ranges if ---. Utah Science 34(1):27-30.

Gates, D. H. 1964. Sagebrush infected by leaf defoliating moth. Journal of Range Management 17:209-210.

Hedrick, D. W., D. N. Hyder, F. A. Sneva, and C. E. Poulton. 1966. Ecological response of sagebrush-grass range in central Oregon to mechanical and chemical removal of Artemisia. Ecology 47: 432-439.

Hormay, A. L. 1970. Principles of rest-rotation grazing and multiple-use land management. USDA Forest Service Training Text 4(2200). 26 p.

Hull, A. C., and G. J. Klomp. 1966. Longevity of crested wheatgrass in the sagebrush-grass type in southern Idaho. Journal of Range Management 19:5-11.

Humbird, J. 1967. All around Idaho - Idaho Fish and Game Department News. Idaho Wildlife Review 24(3):16.

Hyatt, W. S. 1966. Sagebrush control-costs, results, and benefits to the rancher. Journal of Range Management 19:42.

Hyder, D. N. 1953. Controlling big sagebrush with growth regulation. Journal of Range Management 16:109-116.

Hyder, D. N. 1954. Spray to control big sagebrush. Oregon Agricultural Experiment Station Bulletin 538. 12 p.

Hyder, D. N., and F. A. Sneva. 1955. Effect of form and rate of active ingredient, spraying season, solution volume, and type of solvent on mortality of big sagebrush. Oregon Agricultural Experiment Station Technical Bulletin 35. 16 p.

Hyder, D. N., and F. A. Sneva. 1962. Selective control of big sagebrush with associated bitterbrush. Journal of Range Management 15:211-215.

Johnson, D. R., and R. M. Hansen. 1969. Effects of range treatment with 2,4-D on rodent populations. Journal of Wildlife Management 33:125-132.

Johnson, J. R., and G. F. Payne. 1968. Sagebrush reinvasion as affected by some environmental influences. Journal of Range Management 21:209-215.

Johnson, W. M. 1969. Life expectancy of a sagebrush control in central Wyoming. Journal of Range Management 22:177-182.

Kearl, W. G. 1966. Excerpt from letter from W. Gordon Kearl to Glen Fulcher. Mimeograph copy, 1966.

Kearl, W. G. 1973. Joint U.S./Australia panel on range science, program for third seminar/workshop, Tucson, Arizona. March 26-April 6, 1973. Division of Agricultural Economics, University of Wyoming. AE 73-07. p. 16-32.

Kearl, W. G., and M. Brannan. 1967. Economics of mechanical control of sagebrush in Wyoming. Wyoming Agricultural Experiment Science Monograph 5. 35 p.

Klebenow, D. A. 1970. Sage grouse versus sagebrush control in Idaho. Journal of Range Management 35:129-136.

Kufeld, R. C. 1973. Foods eaten by the Rocky Mountain Elk. Journal of Range Management 26:106-112.

Lay, G. W. 1957. Browse quality and effects of prescribed burning in southern pine forests. Journal of Forestry 55:342-347.

Laycock, W. A. 1967. How heavy grazing and protection affect sagebrush-grass ranges. Journal of Range Management 20:206-213.

Leege, T. A. 1966. Burning several brush ranges for big game in northern Idaho. Thirty-Fourth American Wildlife and Natural Resources Conference. p. 429-437.

Lommasson, T. 1948. Succession in sagebrush. Journal of Range Management 1:19-21.

Lyon, J. L. 1971. Vegetal development following prescribed burning of Douglas fir in south-central Idaho. USDA Forest Service Research Paper InT-105. Intermountain Forest and Range Experiment Station. 30 p.

Mueggler, W. F. 1967. Voles damage big sagebrush in southwestern Montana. Journal of Range Management 20:88-90.

Mueggler, W. F., and J. P. Blaisdell. 1958. Effects on associated species of burning, rotobeating, spraying, and railing sagebrush. Journal of Range Management 11:61-66.

Nagy, J. G., H. W. Steinhoff, and G. M. Ward. 1964. Effects of essential oils of sagebrush on deer rumen microbial function. Journal of Wildlife Management 28:785-790.

Natural Resources Defense Council, Inc. 1973. Mimeograph copy of lawsuit, No. 1983-73 from the United States District Court for the District of Columbia, October 30, 1973. 23 p.

Nielsen, D. B. 1967. Economics of range improvement. Utah Agricultural Experiment Station Bulletin 466. 48 p.

Norris, L. A. 1971. Chemical brush control: assessing the hazard. Journal of Forestry 69:715-720.

Pechanec, J. F., H. P. Plummer, J. H. Robertson, and A. C. Hull, Jr. 1965. Sagebrush control on rangelands. USDA Agricultural Handbook 227. 40 p.

Pechanec, J. F., G. Stewart, and J. P. Blaisdell. 1954. Revised. Sagebrush burning--good and bad. USDA Farmers' Bulletin 1948. 34 p.

Pechanec, J. F., G. Stewart, H. P. Plummer, J. H. Robertson, and A. C. Hull. 1954. Controlling sagebrush on rangelands. USDA Farmers' Bulletin 2072. 36 p.

Smith, D. R. 1969. Is deferment always needed after chemical control of sagebrush? Journal of Range Management 25:174-178.

Sneva, F. A. 1972. Grazing return following sagebrush control in eastern Oregon. Journal of Range Management 25:174-178

U.S. Department of the Interior, Bureau of Land Management. 1972. BLM Facts and Figures for Utah, 1972. p. 23-24.

U.S. Forest Service Environment Statement. 1973. Herbicide control of sagebrush and wyethia. Final statement. 73 p.

Vallentine, J. F. 1971. Range development and improvements. Brigham Young University Press, Provo, Utah. p. 85-146.

Wallestad, R. D. 1971. Summer improvements and habitat used by sage grouse broods in central Montana. Journal of Wildlife Management 35:129-136.

Whitworth, S. E. 1963. Sagebrush control in Beaverhead County, Montana. The National Wool Grower 43(11):18-19.

Wright, H. A. 1970. Response of big sagebrush and three-tip sagebrush to season of clipping. Journal of Range Management 23:20-22.