Economics of Spraying Big Sagebrush Communities of Eastern Oregon

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ECONOMICS OF SPRAYING BIG SAGEBRUSH COMMUNITIES OF EASTERN OREGON

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SUMMARY

The primary objective of spraying sagebrush is increased forage production at competitive costs. But other benefits such as increased forage utilization, an increase in desirable forage species vigor, and a reduction in soil erosion are often possible. Chemically spraying sagebrush should not affect soil water content because, most often, sagebrush control merely shifts moisture use from sagebrush to understory vegetation.

Degree of sagebrush kill and the nature of the understory present before spraying strongly influence the relative success of sagebrush spraying. To successfully reoccupy the area after control of sagebrush, it is critical that an adequate level of desirable forage species exist on a site before treatment. If not, increases in understory productivity, if they occur, are often of limited value. Increases in forage production also are closely linked to the degree of sagebrush kill. As kill of sagebrush increases, one can expect increased and longer lasting forage responses.

To determine the rate of return from spraying sagebrush, forage responses attributed to sagebrush control were valued and then discounted at a rate which made the sum of the values equal to the cost of spraying. The discount rate that made these two figures equal represented the rate of return generated by the initial investment in sagebrush control. Forage responses were identified by using a literature survey of appropriate sagebrush spraying research for eastern Oregon rangelands.

Although forage responses from spraying native high desert range have been reported to vary from 60 to 700 pounds per acre, an average forage response of 282 pounds per acre during the first five post treatment years and 266 pounds thereafter until the fifteenth year was evaluated. Given this response (valued at $6.67 per AUM) and a spray cost of $8 per acre, spraying generated a return on investment of about 34 percent. Even if this response were attained only during the first 10 or even five years, spraying still generated a return of about 32 and 22 percent, respectively, with a spray cost of $8 per acre.

On high desert seeded range, annual forage responses attributed to spraying sagebrush have been higher than responses obtained on native range but about equally as variable. An average forage response from spraying seeded high desert range of 321 pounds per acre during the first 15 post-treatment years was evaluated. Given this response (valued at $6.67 per AUM) and a spray cost of $8 per acre, spraying generated a return on investment of about 41 percent. Even at a spray cost of $8 per acre and forage responses only during the first 10 or even five years, spraying still generated a return of about 38 and 28 percent, respectively.

Forage responses from spraying sagebrush on native foothill range have been reported to vary from 90 to 560 pounds per acre. The response evaluated here was 275 pounds per acre during each of the first 15 post-treatment years. At a spray cost of $8 per acre, this forage response (valued at $6.67 per AUM) generated a return on investment of about 33 percent. Even if this response was attained only during the first 10 or even five years, spraying still generated a return of about 32 and 21 percent, respectively, with a spray cost of $8 per acre.

Forage responses from spraying sagebrush on seeded foothill range have been reported to range up to 1,435 pounds per acre during the five year-period after spraying. The response evaluated here was 531 pounds per acre during the first 15 post-treatment years. Valuing this forage response at $6.67 per AUM and at a spray cost of $8 per acre, spraying generated a return on investment of about 65 percent. Even at a spray cost of $8 per acre and forage responses only during the first 10 or even five years, spraying still generated a return of about 65 and 60 percent, respectively.

Of the four range types evaluated, seeded foothill range produced the greatest return to the spray investment. Next most productive were seeded high desert range and then either native foothill or High Desert range.

INTRODUCTION

Various subspecies of big sagebrush *(Artemisia tridentata)* have been successfully controlled throughout its range of occurrence with different forms of 2,4-dichlorophenoxy acetic acid (2,4-D). Although response of vegetation after spraying without seeding is documented, evaluation of costs and benefits is scarce. The purpose of this publication is to summarize results of forage responses to spraying sagebrush without artificial seeding in big sagebrush communities and to evaluate the economics of these practices.

The objective of spraying sagebrush is to increase the productivity of desirable forage species by selectively removing competitive nondesirable species. This means an adequate level of desirable species must be present in the community before spraying to substantially increase forage production within a practical amount of time. Hyder and Sneva (1956) reported 165 pounds of desirable forage per acre is necessary to attain a successful release of these species. Plummer, et. al., (1955) recommended there be at least one desirable bunchgrass to every 10 square feet for natural seeding to be practical. However, this practice may be limited by the presence of competitive nondesirable species such as Sandberg bluegrass (*Poa sandbergii*) that are not affected by the herbicide. The success of spraying sagebrush also depends on such conditions as soil moisture and air temperature at time of spraying (Cornelius and Graham, 1958; Hyder, et. al., 1962; Mohan, 1962; Cook, 1963). Season of spraying also has been reported to significantly affect results (Hyder and Sneva, 1955; Hyder, et. al., 1962; Sneva and Hyder, 1966).

Scifres (1977), after an extensive review of literature, reported proper application of herbicides applicable to range improvements provides excellent levels of brush control without undue hazard to sensitive crops, man, livestock, or wildlife.

RESPONSES TO SPRAYING SAGEBRUSH

Yield Response

High Desert Native Range

Several studies have evaluated the response of native herbage after chemical control of sagebrush on high desert range. The arid conditions of these ranges are characterized by average annual precipitation rarely exceeding 11 inches coupled with hot, dry summers.

Based on preliminary information obtained from spraying a 40-acre native range at the Squaw Butte Experiment Station, Hyder (1954) concluded one can expect an increase of 300 to 400 pounds of herbage per acre during the first year after the spraying year, and production to be 500 to 700 pounds above unsprayed production during the second year. These expectations were later confirmed by experimental plot work on the same site by Hyder and Sneva (1956). These researchers found that in the three years after sagebrush treatment, sprayed plots produced 882 pounds per acre more grass and 1,226 pounds per acre more total herbage than untreated plots (Table 1). The experimental range before

Table 1. Herbage yields and yield responses attributed to spraying sagebrush on Oregon high desert native range with a sagebrush crown cover of 20 to 25 percent producing about 175 pounds of herbage per acre per year before treatment (Hyder and Sneva, 1956)

Year after treatment	Herbage yields: Sprayed	Untreated	Additional production[a/]
	(air dry herbage in pounds per acre)		
0	177	119	58
1	528	173	355
2	807	220	587
3	461	177	284

a/ Based on a sagebrush kill of 83 percent.

treatment had a sagebrush crown cover of 20 to 25 percent and produced about 175 pounds of herbage per acre per year. In this experiment, spraying reduced the stand of sagebrush 83 percent and the percentage of ground covered by live sagebrush crown 91 percent. Higher production was caused, in part, to an increase in numbers of grasses and an increase in basal size. But it was caused primarily by more vigorous and higher growth resulting from a release of soil moisture and nitrogen competition. In Wyoming, Hull, et. al., (1952) also found higher levels of forage production after sagebrush spraying were primarily from increases in the spread and vigor of original plants rather than establishment of new plants from seed.

In other spray release work on Oregon high desert native range, Hedrick et. al., (1966) reported post-treatment herbage yields averaged 200 and 387 pounds per acre on untreated and sprayed plots over an eight-year period. Before treatment, this range had a 20 to 25 percent sagebrush cover and produced about 200 pounds of herbage per acre per year. Untreated and treated plot yields diverged slightly in the first four years of the trial and converged in the last four years. The researchers observed spraying stimulated a forage response similar to that obtained by fertilizing native bunchgrass range. On a less productive native range site, producing about 110 pounds of herbage per acre per year, Hedrick and his co-workers found post treatment herbage yields on untreated and sprayed plots averaged 122 and 489 pounds per acre during an eight-year period. The additional production attributed to sagebrush spraying, however, was primarily cheatgrass (*Bromus tectorum*). Herbage yields associated with sagebrush control at both sites appear in Table 2.

Spraying increased herbage production about 215 pounds per acre one year after treatment and about 140 pounds per acre in the third post-treatment year

Table 2. Herbage yields and yield responses to spraying sagebrush on two native range sites of the Oregon high desert both with a sagebrush crown cover of 20 to 25 percent. Site one produced about 200 pounds of herbage per acre per year before treatment and site two produced about 110 pounds of herbage per acre per year (Hedrick, *et. al.*, 1966)

Year after spraying	Herbage yield a/ (oven dry yields per acre adjusted for median year precipitation) Sprayed	Untreated	Yield response b/
	Site I		
1	300	240	60
2	310	155	155
3	450	200	250
4	560	270	290
5	450	200	250
6	300	110	190
7	380	175	205
8	410	210	200
	Site II		
1	425	95	330
2	350	98	252
3	625	180	445
4	925	210	715
5	590	150	440
6	290	95	195
7	325	100	225
8	450	105	345

a/ Based on a sagebrush kill of 98 percent at Site one and 85 percent at Site II.

on a bluebunch wheatgrass (*Agropyron spicatum*)-thickspike wheatgrass (*Agropyron dasystachyum*)-Idaho fescue (*Festuca idahoensis*) range near Dubois, Idaho (Mueggler and Blaisdell, 1958). Sagebrush kill, however, was only 40 percent. The study area received about 13 inches of precipitation annually, and before treatment it was occupied by a fairly homogenous, dense stand (23 plants per 100 square feet) of sagebrush two to three feet in height. Pre-treatment herbage production averaged about 250 pounds per acre per year. Approximately 88 percent of the herbage was available for utilization on the sprayed range compared to only 75 percent on the untreated site. Thus, spraying resulted in sizable increases in available forage through increased production and better access to what was produced. Also, grass production responded immediately to sagebrush control.

High Desert Seeded Range

The effect of sagebrush spraying on high desert crested wheatgrass (*Agropyron cristatum*) range has been studied by Hull and Klomp (1974) in southern Idaho. The experimental site received about nine inches of precipitation annually. Before treatment, this site had 21 sagebrush plants per 100 square feet and produced about 470 pounds of forage per acre per year. At this site, yield of crested wheatgrass increased as density of sagebrush decreased (Table 3). Complete control of sagebrush resulted in the greatest increase in grass yields.

Foothill Native Range

Studies evaluating spraying sagebrush also extend into foothill native rangelands. These rangelands include numerous plant communities and site

Table 3. Crested wheatgrass yields at Twin Falls, Idaho. The site receives about nine inches of precipitation annually. (Hull and Klomp, 1974)

Percent sagebrush kill	Yields (pounds air dry grass per acre) years after treatment 0	1	2	3	4	5
Control	498	210	415	250	452	652
50	429	201	481	312	552	857
75	510	212	637	373	582	1,017
100	473	250	714	522	873	1,227

potentials. These sites usually are found above the desert floor and below the coniferous forest. Foothill rangelands are generally inclusive of most of the juniper, mid-elevation sagebrush species and certain mountain brush sites. Bunchgrasses are the primary grasses endemic to these sites. Mean precipitation, although highly variable, is more commonly 10 inches or above. Climatic conditions generally are not as harsh as in the high desert.

Yield responses attributed to chemical control of sagebrush on three mountain big sagebrush (*Artemisia tridentata* subsp., *vaseyana)* habitat types near Ironside, Oregon, have been studied by Miller, et. al., (1980). Increases in forage production on all three treated sites averaged about 220 pounds per acre in the third year after spraying and about 280 pounds in the fourth post treatment year. These results were obtained by reducing sagebrush canopy cover an average of about 91 percent. On all three habitat types, the source of increased forage production was partially an increase in newly established plants, but a substantial increase in production was a result of increased plant height and diameter. Forage responses associated with sagebrush control at each habitat type are listed in Table 4.

Table 4. Forage yields (perennial grasses) and yield responses to spraying sagebrush on three big sagebrush habitat types on foothill range near Ironside, Oregon (Miller, *et. al.*, 1980)

Year after spraying	Yields (air dry pounds per acre): Untreated	Sprayed	Additional yield response
	Big sagebrush - Idaho fescue habitat type[a/]		
3rd	180	268	88
4th	245	505	260
	Big sagebrush - bluebunch wheatgrass habitat type[b/]		
3rd	262	615	353
4th	242	576	334
	Big sagebrush - Idaho fescue - bluebunch wheatgrass habitat type[c/]		
3rd	252	445	193
4th	218	443	225

a/ Sagebrush cover before treatment was about 22 percent, and an 80 percent sagebrush kill was achieved.

b/ Sagebrush cover before treatment was about 34 percent, and a 97 percent sagebrush kill was achieved.

c/ Sagebrush cover before treatment was about 29 percent, and a 95 percent sagebrush kill was achieved.

In southwestern Idaho, near the Idaho-Oregon state line, Schumaker and Hanson (1977) measured forage responses attributed to spraying sagebrush on several mountain big sagebrush habitat types (Table 5). On a mountain big sagebrush-Idaho fescue site containing cheatgrass and Sandberg bluegrass, understory yields produced on sprayed plots were significantly higher than those on untreated plots. Although spraying increased cheatgrass production, this species represented only 39 percent of the total herbage yield of sprayed plots. The study site, receiving about 23 inches of precipitation annually, had a dense cover of sagebrush (percentage cover unspecified) and produced about 600 pounds of forage per acre per year before treatment. Sagebrush kill rate was not reported. On a drier (13 inches of annual precipitation) Wyoming big sagebrush-(*Artemisia tridentata* subsp. *Wyomingensis)* bluebunch

Table 5. Understory yields and yield responses to spraying sagebrush on two big sagebrush habitat types in southwestern Idaho (Schumaker and Hanson, 1977)

	Yields (air dry pounds per acre)		
Year after spraying	Untreated	Sprayed	Yield response
	Big sagebrush - Idaho fescue habitat type		
1	393	531	138
2	695	851	156
3	754	912	158
	Big sagebrush - bluebunch wheatgrass		
1	173	356	183
2	684	636	-48
3	396	518	122
4	354	439	85

wheatgrass site, understory yields produced on sprayed plots were not significantly different than those on untreated plots. Sagebrush kill was only 65 to 70 percent and believed responsible for the limited yield response.

Based on sagebrush control work in south central Wyoming, Sturges (1977b) found that grass production doubled on sprayed plots the year after treatment and was 2.6 times larger than on untreated plots in the third year (Table 6). These yield responses were obtained with a 100 percent sagebrush kill. The experimental site, at 7,300 feet elevation, received about 20 inches of precipitation annually and was inhabited by a mature stand of mountain big sagebrush. Understory vegetation was primarily a bunchgrass mixture comprised chiefly of Idaho fescue and bluegrasses (*Poa sp.*). Before treatment, sagebrush crown cover was 28 percent on unsprayed plots and 29 percent on plots to be sprayed, while grass yields averaged about 290 pounds per acre per year on both control plots and those to be treated.

Table 6. Grass yields on sprayed and unsprayed plots of a mountain big sagebrush-bunchgrass range in south central Wyoming (Sturges, 1977b)

Year after spraying	Yields[a/] (oven dry pounds per acre)		
	Untreated	Sprayed	Yield response
0	334	401	67
1	424	802	378
2	424	981	557
3	334	892	558

a/ Derived from Figure 4 appearing in Sturges (1977b).

b/ Based on a 100 percent sagebrush kill.

Foothill Seeded Range

The competitive effect of sagebrush on yield of seeded grasses on foothill range in central Utah was studied by Cook and Lewis (1963). Yield responses from controlling sagebrush were obtained on sites seeded to three introduced grass species -- crested, tall (*Agropyron elongatum*), and intermediate (*Agropyron intermedium*) wheatgrasses -- receiving about 15 inches of precipitation annually (Table 7). Sites were not all treated or harvested

Table 7. Grass yields on sprayed and untreated plots and the yield increase attributed to spraying sagebrush on seeded foothill ranges in Utah (Cook and Lewis, 1963)

Year after spraying	Yields[a/] (pounds air dry forage per acre)		
	Untreated	Sprayed	Yield response
		Crested wheatgrass	
1	360	974	614**
2	273	869	596**
3	314	1,012	698**
		Intermediate wheatgrass	
1	560	882	322*
2	630	782	152*
3	624	934	310**
		Tall wheatgrass	
1	260	505	245*
2	333	1,188	855**
3	325	1,065	740**

a/ Comparison of yield responses to sagebrush control among seeded species is not appropriate as the three seeded species were not all treated or harvested in the same years.

* Significant at the .05 probability.

** Significant at the .01 probability.

in the same year. Before treatment, however, sagebrush canopy cover on all sites was about 10 percent. Pre-treatment forage production averaged about 300 pounds per acre per year on the crested and tall wheatgrass sites and about 600 pounds per acre on the intermediate wheatgrass sites. Yield responses were a result of a 77 percent sagebrush kill on the tall and intermediate wheatgrass sites and a 70 percent kill on the crested wheatgrass sites. Spraying sagebrush significantly increased forage yields in all years of the study and at all three sites. The researchers concluded big sagebrush and grasses competed for moisture in the upper soil surface, thus the favorable yield response to reduced sagebrush competition. Direct competition for soil moisture between sagebrush and grass also was observed by Frischknecht (1963) in work on sagebrush control on foothill seeded range in west central Utah.

The competitive effect of sagebrush on crested wheatgrass on foothill range also was studied by Hull and Klomp (1974) in southern Idaho. The experimental site received 16 inches of precipitation annually and had a deep silt loam soil. Before treatment, this site had about 20 sagebrush plants per 100 square feet. The average yield of forage before treatment was about 650 pounds per acre, but sagebrush made an estimated 60 percent of the forage unavailable to grazing animals. At this site, yield of crested wheatgrass increased as density of sagebrush decreased (Table 8). Complete control of sagebrush resulted in the greatest forage yield increase.

In Nevada, on seeded foothill range sites receiving about eight inches of precipitation, Robertson (1969) found the yield increase of crested wheatgrass attributed to sagebrush control varied from 20 to 140 pounds per acre during the four-year period after spraying. Significant increases in yield, however,

Table 8. Crested wheatgrass yields under four levels of sagebrush density at Holbrook, Idaho. The site receives 16 inches of precipitation annually (Hull and Klomp, 1974)

Percent sagebrush kill	Yields (pounds air dry grass per acre) years after treatment 0	1	2	3	4	5
Control	627	397	555	503	400	502
50	675	403	866	722	457	668
75	687	531	1,043	887	774	910
100	570	545	1,553	1,324	1,209	1,937

were not observed until the third year after spraying. Before treatment, the site had a sagebrush canopy cover of about 12 percent and produced about 300 pounds of forage per acre per year.

Composition of the Forage Response

Although it is evident that forage quantity of native range can be increased by spraying sagebrush, the species composition of the yield response also must be considered. Several researchers have evaluated the species composition of the forage response on native high desert and foothill ranges.

Hyder and Sneva (1956), working with Oregon high desert native range, reported individual native grass species responded differently to sagebrush control. Squirreltail (*Sitanion hystrix*) and Junegrass (*Koeleria cristata*) responded more than other grasses. Yields of bluebunch wheatgrass and Idaho fescue showed a more modest response to sagebrush control, and yield of Thurber's needlegrass (*Stipa thurberiana)* actually declined (Table 9). Spraying restricted weed growth, (mostly *Lupinus caudatus)*, in the spraying year, but complete kill was not obtained for any of the weed species. In fact, in the year after spraying, yield of weeds was slightly higher on sprayed plots than on controls. Weed yields, however, appeared to be directly related to precipitation.

In other sagebrush control work on the Oregon high desert, Hedrick et. al., (1966) found the perennial grass component of sprayed range increased about 2½ times; total herbage production increased only two times. These researchers quickly point out, however, no clear trend was evident among species except that increases in types such as squirreltail and Junegrass were accounting for most of the yield increase even eight years after spraying the sagebrush. The proportion of forbs fluctuated in relation to the amount of precipitation. Cheatgrass became an important component of the forage response four years after sagebrush treatment. These results were obtained on a site annually producing about 200 pounds of forage per acre before treatment.

At another site, which produced about 120 pounds of forage per acre per year before treatment, Hedrick and co-workers found that on sprayed plots squirreltail increased about 100 times more than on untreated plots within the first four years after spraying. Within the first few years, cheatgrass production on sprayed plots also increased from essentially no yield to about 330 pounds per acre.

On native desert range in southeastern Idaho, Mueggler and Blaisdell (1958) found most native grasses responded to sagebrush control, especially subalpine needlegrass (*Stipa columbiana)*. Spraying did, however, result in reductions in Lupinus and Erigeron species.

Table 9. Herbage yields by species in four years following sagebrush control on Oregon high desert native range (Hyder and Sneva, 1956)

Treatment	Year	Bluebunch wheatgrass	Idaho fescue	Thurber's needlegrass	Squirreltail	June grass	Cheat-grass	Weeds
		(air dry herbage in pounds per acre)						
Control	1	5	3	28	6	40	-	26
	2	5	4	40	8	83	-	14
	3[a]	4	3	30	18	71	2	92
	4[b]	2	4	28	14	107	0	11
Sprayed	1	38	10	9	46	55	-	4
	2	51	21	13	137	139	-	27
	3[a]	53	10	8	137	104	122	365
	4[b]	40	9	7	117	131	64	69

a/ Very wet year with 6.6 inches of precipitation in the growing year.

b/ A very dry year with 2.74 inches of precipitation in the growing year.

Herbage production attributed to spraying native foothill range in Oregon consisted primarily of those grasses playing a dominant role before spraying (Miller et. al., 1980).

In other sagebrush control work on foothill range in Idaho, Schumaker and Hanson (1977) found that yield of bluegrass (*Poa sp.)* did not increase or decrease after spraying. Squirreltail increased slightly, while bluebunch wheatgrass increased almost 3.5 times. After spraying, cheatgrass also increased almost 2.5 times. Lupine (*Lupine sp.)* composition decreased after herbicide was applied (Table 10).

In south central Wyoming, Sturges (1977b) reported that on a mountain, big sagebrush site, herbaceous species responded typically to control with 2,4-D. Forb production was cut in half the year of treatment and was still suppressed the third year after spraying. Grass production doubled on sprayed plots the year after treatment and was 2.6 times larger than on untreated plots three years later.

Table 10. Yield by species on sprayed and untreated big sagebrush-bluebunch wheatgrass foothill range plots in Idaho (Schumaker and Hanson, 1977).

	Sprayed	Untreated
	(pounds per acre)	
Bluebunch wheatgrass	108	30
Cheatgrass	218	88
Idaho fescue	79	62
Sandberg bluegrass	38	20
Bottlebrush squirreltail	30	26
Needle and thread	--	1
Arrowleaf balsamroot	6	44
Lupine	--	14
Other forbs	182	268

Sagebrush-Understory Interrelationship

Yield response data cited earlier indicate there is a direct relationship between understory production and sagebrush density. Several scientists have studied this interrelationship in some detail. In central Wyoming, Hull et. al. (1952) reported a sagebrush kill of 60 percent increased forage production in the third post-treatment year by 268 pounds per acre compared to yield increases of 337 and 423 pounds per acre with kills of 80 and 95 percent. Also, in central Wyoming, Kissinger and Hurd (1953) found increases in perennial grass production were nearly in direct proportion to sagebrush kills. Grass yields on unsprayed plots averaged 220 pounds per acre and 460, 540 and 590 pounds per acre where sagebrush was reduced by 60, 80, and 95 percent, respectively. On a site in the Big Horn Mountains, Alley (1956) reported forage production ranged from 480, 769, 1,013, and 1,347 pounds per acre on plots with no control, 50 to 75 percent kill, 76 to 95 percent kill, and 96 to 100 percent sagebrush kill, respectively. In Idaho, Hull and Klomp (1974) also reported a similar type of response for crested wheatgrass as the density of sagebrush decreased. Hyder and Sneva (1956) concluded the balance in soil moisture and nitrogen may be the primary factor determining the competitive advantage between grasses and sagebrush with sagebrush holding the upper hand as it is a stronger competitor for soil nitrogen.

Rittenhouse and Sneva (1976), using regression techniques to express the competitive relationship between Wyoming big sagebrush and crested wheatgrass, determined each one percent increase in sagebrush cover reduced crested wheatgrass production about 42 pounds per acre. Approximately 73 percent of the total variation in crested wheatgrass yield was accounted for by percentage of crown cover of Wyoming big sagebrush. Their estimating equation was based on sagebrush control work at the Squaw Butte Experimental Range in Eastern Oregon. In this study, sagebrush crown cover ranged from 0 to 14 percent in 1970 and 1971. The 1963 data ranged from 5 to 22 percent crown cover. The average potential production of the study location was 1,031 pounds per acre at zero crown cover of big sagebrush.

Sagebrush-Hydrologic Interrelationship

Sagebrush control also affects hydrologic changes as well. Such changes as snow accumulation and melt, surface runoff, and soil moisture are discussed here.

At a big sagebrush site (elevation 2,450 feet) in south central Wyoming, Sturges (1977a) reported a small but significant reduction in snow accumulation was detected on sprayed plots before vegetation was fully covered by snow. Once snow depth exceeded vegetation height, however, snow accumulation was controlled by topographic factors. Sagebrush control had no effect on maximum depth of snow accumulation or snowmelt rates.

At higher elevation sites (9,500 feet) in Wyoming, Hutchison (1965) reported significantly more snow accumulated on sagebrush-covered areas than in comparable grass-covered areas because of the efficiency of sagebrush crowns in inducing deposition of drifting snow. Study plots were on level ground to minimize snow trapping from topography. During the snow melt period, a continuous sheet of ice was only observed overlying the soil surface of grass covered plots. This phenomenon and the observation that less snow accurulates on grass cover led Hutchison to conclude the conversion of high elevation sagebrush areas to grass may have profound effects upon the hydrology of these areas.

In the Red Desert and Big Horn Mountain areas of Wyoming, at elevations of 7,000 and 8,200 feet, respectively, Sonder and Alley (1961) found sagebrush control (80 to 100 percent kill) had no effect on the snow-holding capacity on sites where drifting usually occurred. At higher elevations, areas where sagebrush was controlled retained snow longer in the spring than did areas where sagebrush was not controlled.

Sagebrush cover also influences the amount of rainfall reaching the soil surface. West and Gifford (1976) using a rainfall simulator estimated that sagebrush with an aerial cover of about 19 percent intercepts about four percent of the average annual rainfall occurring at Snownville, Utah.

In southern Idaho, Hull and Klomp (1974) reported sagebrush plants intercepted both rain and snow (Table 11). After interception, water evaporated from the plant surfaces with little water getting into the soil. As intensity and duration of precipitation decreased, the percentage of interception increased. In comparison to brush-free sites, heavy brush cover intercepted about 30 percent of the rain and about 37 percent of the snowfall.

Table 11. Cumulative five year average of precipitation, April 1 to October 30, near ground level at Holbrook and Twin Falls, Idaho, and maximum snow depth and water content at Holbrook under 0, 5, 10, and 20 sagebrush plants per 100 square feet (Hull and Klomp, 1974)

Sagebrush plants per 100 square feet	Summer precipitation		Snowfall	
	Holbrook	Twin Falls	Depth	Water content
	inches	inches	inches	inches
0	7.2	4.7	12.6	3.8
5	5.7	3.9	10.2	3.0
10	5.4	3.6	9.2	2.7
20	5.0	3.3	8.0	2.3

Sturges (1977a) reported spraying decreased soil moisture withdrawal by sagebrush, but soil moisture content increased only if soils were significantly deep where the majority of roots from replacement vegetation were above soil formerly occupied by sagebrush roots. Precipitation also must be sufficient to recharge soil water beyond the rooting zone of replacement vegetation. On shallow soils at this south-central Wyoming site, sagebrush control did not have any appreciable effect on the soil water regime. Sturges concluded sagebrush control on these sites merely shifts moisture needs from sagebrush to replacement species. In earlier work, Sturges (1973) found spraying reduced soil moisture loss about 24 percent between June 24, the treatment date, and September 30. About 83 percent of the reduction took place within two to six inches of the soil surface. The study site in south-central Wyoming had a dense (19,000 plants per acre) stand of sagebrush. In the Red Desert area of Wyoming, Sonder and Alley (1961) found sprayed sites (80 to 100 percent kill) retained a significantly higher percent of soil moisture one year after chemical control than check plots.

Sagebrush Reestablishment

Not only is increased forage production an important consideration when evaluating the success of a sagebrush spraying program, but the life of the stand also must be considered. The time period in which a treated stand will continue to produce more forage than if not treated, primarily depends upon initial kill of sagebrush, level of established desirable species at the time of treatment, site characterstics, and follow-up management.

Sneva (1972) found numbers and the distribution of sagebrush increased slowly for the first 10 years after spraying on the Oregon high desert. But 15 years after treatment, the number of sagebrush on treated plots six inches or less in height approached the number of mature sagebrush present on untreated plots. Sneva observed young plants were well distributed and occupied about 70 percent of the plots sampled. He concluded these young plants apparently were the progeny of plants that survived spraying. During this trial, stocking rate and grazing (only after forage had matured) were controlled to favor development of grasses. Also, on the Oregon high desert, Hedrick, et. al., (1966) observed sagebrush reestablishment, after an initial kill of about 95 percent, was held in check during the first 10 years after spraying. Findley (1974) found that on Wyoming big sagebrush-Thurber needlegrass range of the Oregon high desert, sagebrush density on treated and untreated plots was about equal seven to eight years after treatment. Findley concluded the reinvasion rate of sagebrush was dictated by seedling establishment and plants surviving spray treatment. As a result of later work in eastern Oregon, Bartolome and Heady (1978) reported the primary source of reestablished sagebrush was from unkilled plants and seedlings established in the first few years.

In Utah, Cook (1963) reported a complete kill of sagebrush on foothill range delayed the necessity of controlling reestablished sagebrush. Sites with 20 to 40 percent sagebrush survival required a second spraying seven to eight years later.

Schumaker and Hanson (1977), working independently in Idaho, confirmed earlier research on sagebrush reestablishment in Oregon and Utah. They found when a good sagebrush kill was achieved, reestablishment of sagebrush was minimal.

In Southwestern Montana, on a three-tip sagebrush (*Artemisia tripartita)* bluebunch wheatgrass site, Johnson and Payne (1968) concluded sagebrush surviving treatment was the most important factor related to sagebrush reestablishment. Non-sagebrush vegetation, slope, erosion, soil texture, precipitation, and sagebrush adjacent to treated areas were seldom related to sagebrush reestablishment.

In Wyoming, Johnson (1958) and Weldon, et. al., (1958) both observed sagebrush reinvasion after spraying was not a rapid process when there were high initial kills. Johnson's observations were made on a Wyoming big sagebrush-thickspike wheatgrass range at an elevation of about 6,800 feet. Average annual precipitation was 12 to 14 inches. Weldon and his co-workers, on the other hand, used a higher elevation and more moist site. In both these studies, the effect of grazing on sagebrush reestablishment was examined. According to Johnson, a significant difference in sagebrush reestablishment was observed between grazed and ungrazed parts of sprayed plots with a greater reestablishment occurring on grazed areas. In a later report, Johnson (1969) stated that on grazed range the density of young and mature sagebrush began to increase within five years after spraying and within 14 years there were more sagebrush plants than on adjoining unsprayed areas. On ungrazed parts of sprayed range, on the other hand, the number of mature and young sagebrush plants was about the same as on adjoining unsprayed range 17 years after spraying. Weldon et. al., (1958) in their study looked at sagebrush reestablishment as affected by cattle grazing alone and by both cattle and sheep grazing. They found no differences in sagebrush numbers between areas experiencing either grazing treatment. In a later report, Weldon, et. al., (1959) concluded overgrazing promotes sagebrush reestablishment. Over-grazed range relinquishes both soil moisture and sunlight to sagebrush seeds. Greater sunlight intensity results in higher soil temperatures and a more suitable microclimate for sagebrush establishment.

According to Smith (1969), deferment of grazing after spraying has no effect on sagebrush reestablishment (Table 12). His study evaluated length of deferment as it affected herbage production on subalpine range in the Big Horn Mountains in Wyoming.

Table 12. Average herbage production as affected by length of deferment on four subalpine range sites in the Big Horn Mountains of Wyoming: 1959-65 (Smith, 1969)

Species	Years of deferment				
	0	1	2	3	LSD[a/]
	- - - pounds air dry forage per acre - - -				
Total grasses	583	460	458	376	NS[b/]
Idaho fescue	331	237	165	163	31
Columbia needlegrass	57	37	79	50	NS
Raynold's sedge	82	141	198	132	NS
Total forbs	451	437	505	513	NS
Lupine	119	107	123	89	NS

a/ Least significant difference among treatment means at the five percent level of probability.

b/ Non-significant difference among means.

CONCLUSIONS

Spraying sagebrush ranges of Eastern Oregon can significantly increase understory production over several years. In part, increased production comes from some new plants, but the major increase in productivity is from an increase in vigor and size of already established vegetation. On native range of the Oregon high desert, annual increases in forage production have been reported to vary from about 60 to 700 pounds per acre. In one native range trial, increased herbage yields average 187 pounds per acre over an eight-year period. In this trial, the yield response increased during the first four years and declined during the last four years. At Squaw Butte, researchers found that in the three years after sagebrush treatment, sprayed plots produced 882 pounds more grass and 1,226 pounds more total herbage per acre than untreated plots. On native foothill range, forage responses varied from about 90 to 560 pounds per acre. Responses on seeded range, although generally more substantial, appeared to be as equally variable. On crested wheatgrass foothill range in Utah, yield increases attributed to spraying averaged 636 pounds per acre per year during the three-year period after treatment. Yield responses on high desert crested wheatgrass ranges have been reported to range up to 1,435 pounds per acre during the five-year period after treatment.

Although temperature and precipitation play a major role in influencing forage response, effectiveness of the spray treatment, understory present before spraying, and follow-up management determine the economics of spraying sagebrush. It is critical that the site have an adequate level of desirable forage species before treatment to successfully reoccupy the area after undesirable species have been removed. If desirable forage species persist at a low level in the understory, these species will account for only a small amount of the increased production. Increases in understory productivity on sites in poor condition frequently are caused by such species as cheatgrass. It is also important to achieve a good sagebrush kill because forage response is closely related to effectiveness of the spray treatment. Surviving sagebrush proportionately will suppress grass production. In one research trial, typical of most others, an average yield response of 135 pounds per acre was associated with a 50 percent sagebrush kill compared to an average response of about 308 pounds per acre at a 75 percent sagebrush kill. Effectiveness of the spray treatment also influences the effective life of the treatment since surviving sagebrush plants are also a seed source of reinvading sagebrush. On the Oregon high desert, sagebrush reestablishment after an initial kill of about 95 percent was held in check the first 10 years after treatment. The reviewers expect this treatment effect to last approximately 15 years. Some researchers have tried to evaluate the impact of grazing on the life of a stand with variable results. As long as proper management is implemented to maintain a vigorous understory, the reviewers contend that grazing should have little effect on rates of reinvasion.

On most eastern Oregon range sites, sagebrush spraying probably will not have any appreciable effect on the soil water regime. Often, sagebrush control merely shifts moisture use from sagebrush to replacement species.

RATE OF RETURN FROM SPRAYING SAGEBRUSH

Economic evaluation of sagebrush spraying involves dealing with costs and returns in different time periods. A return of $5 two years hence will not justify a $5 expenditure today. Consideration must be given to the time expense is incurred and the time return is forthcoming. Discounting adjusts for this situation. Discounting is nothing more than adjusting future incomes to a present value directly comparable to the present cost of spraying sagebrush. Discounting of a future income or income stream to a present value is necessary because of time preferences for income.

In this study, a discount rate is computed which makes the annual income stream attributed to spraying sagebrush equal to the cost of spraying. The discount rate which makes these two figures equal is known as the internal rate of return. This rate represents the rate of return generated by the initial investment in sagebrush spraying. The decision to spray or not to spray is based on the magnitude of the internal rate of return relative to the expected rate of return from other investment alternatives. It is important to consider the return generated by money invested in spraying sagebrush or other resources, because the investor is giving up the opportunity of investing it elsewhere.

Information used to discount and compute the rate of return generated from spraying sagebrush on native and seeded high desert and foothill ranges of eastern Oregon is presented in Table 13. Spray costs represent typical charges for chemical spray materials and their aerial application in eastern Oregon in 1980. Forage responses associated with spraying represent the average response from selected research trials cited earlier in this report. It is assumed that with an effective sagebrush treatment, these forage responses should be evident for at least 15 years post treatment. Furthermore, yield responses are assumed

Table 13. Information used to compute the rate of return generated from spraying sagebrush on native and seeded high desert and foothill ranges of eastern Oregon

Spraying Costs

Total spraying costs	$8.00 per acre[a/]

Forage Responses

	High Desert range		Foothill Range	
Year	Native[b/]	Seeded[c/]	Native[d/]	Seeded[e/]
	(additional production:		pounds per acre)	
1	282	321	275	531
2	282	321	275	531
3	282	321	275	531
4	282	321	275	531
5	282	321	275	531
6	266	321	275	531
7	266	321	275	531
8	266	321	275	531
9	266	321	275	531
10	266	321	275	531
11	266	321	275	531
12	266	321	275	531
13	266	321	275	531
14	266	321	275	531
15	266	321	275	531

Forage Value

Value	$0.01 per pound

a/ Includes 2,4-D at 2 pounds acid equivalent, a surfactant, and custom aerial application.

b/ Based on research by Hyder and Sneva, 1956; Hedrick et. al., 1966 and Schumaker and Hanson, 1977.

c/ Based on research by Hull and Klomp, 1974.

d/ Based on research by Miller et. al., 1980; Schumaker and Hanson, 1977, and Sturges, 1977b.

e/ Based on research by Hull and Klomp 1974, and Cook and Lewis, 1963.

available for 100 percent utilization. Value of the yield response is specified at $0.01 per pound. This value equals a charge of about $6.67 per AUM (animal unit month) and approximates the expected price of much of the privately owned leased grazing in eastern Oregon during 1980.

High Desert Native Range

On high desert native range, annual forage responses attributed to spraying sagebrush have been reported to vary from 60 to 700 pounds per acre. The effective life of the spray treatment should exceed 15 years if a 90 to 95 percent sagebrush kill is achieved.

In this analysis, an average forage response of 282 pounds per acre during the first five post treatment years and 266 pounds per acre thereafter until the fifteenth post treatment is evaluated. This type of response to spraying sagebrush could be attained on sites producing about 200 to 225 pounds of forage per acre per year before treatment with an initial sagebrush crown cover of about 20 to 25 percent. A sagebrush kill of 90 to 95 percent, however, would have to be achieved. With this response (with forage valued at $6.67 per AUM and a spray charge of $8 per acre), spraying sagebrush generates a return on the $8 per acre investment of about 34 percent. If the spray charge is only $7 per acre, the investment generates a return of about 39 percent. Conversely, the investment generates a return of 30 percent if the spray cost is $9 per acre.

High Desert Seeded Range

On high desert seeded range, annual forage responses attributed to spraying sagebrush have been higher than responses obtained on native range but about equally as variable. With an effective sagebrush kill, the expected life of the treatment should exceed 15 years.

An average forage response of 321 pounds per acre during the first 15 post-treatment years is evaluated here. This type of response could be achieved on sites producing about 400 pounds of forage per acre per year before treatment. A sagebrush kill of 90 to 95 percent, however, would have to be achieved. With this forage response (valued at $6.67 per AUM and a spray cost of $8 per acre), spraying generates a return on investment of about 41 percent. At a spray charge of $7 per acre, the investment generates a return of about 45 percent. On the other hand, at a spray cost of $9 per acre, the investment generates a return of about 35 percent.

Foothill Native Range

Forage responses from spraying sagebrush on native foothill range have been reported to vary from 90 to 560 pounds per acre. Effective spray treatment can be expected to increase forage production beyond 15 post treatment years.

Evaluated here is an average forage response of 275 pounds per acre during each of the first 15 post treatment years. This type of response could be attained on sites producing about 325 to 350 pounds of forage per acre per year before treatment. A 90 to 95 percent sagebrush kill, however, would be needed. At a spray cost of $8 per acre, this forage response generates a return to investment of about 33 percent with forage valued at $6.67 per AUM. At a spray cost of $7 per acre, the investment generates a return of about 38 percent. Conversely, at a spray cost of $9 per acre, the investment generates a return of about 30 percent.

Foothill Seeded Range

Forage responses from spraying sagebrush on seeded foothill range, although generally more substantial than responses on native foothill range, appear to be equally variable. Yield responses have been reported to range up to 1,435 pounds per acre during the five-year period after spraying.

An average forage response of 531 pounds per acre during the first 15 post-treatment years is evaluated here. This type of response could be achieved on sites producing about 450 pounds of forage per acre per year before treatment with an initial sagebrush crown cover of about 15 to 20 percent. A sagebrush kill of 90 percent or better, however, would have to be achieved. With this forage response valued at $6.67 per AUM and a spray cost of $8 per acre, spraying generates a return on investment of about 65 percent. A rate of return of about 76 percent is generated if the spray charge is only $8 per acre. Conversely, a rate of return of about 59 percent is generated if the spray charge is $9 per acre.

CONCLUSIONS

Spraying sagebrush can generate returns in excess of spray costs on many of the high desert and foothill ranges in Eastern Oregon. Of the range types evaluated (Table 14), seeded foothill range produced the greatest return to the investment. Next most productive were seeded high desert range, and then either native foothill or high desert ranges. These results were based on average yield responses expected during the first 15 post-treatment years. Even if these responses were attained only during the first 10 post-treatment years, the return on investment for each range type is only about one to two percent less than that presented in Table 14. If forage responses were obtained only during the first five post-treatment years, rates of return at a spray charge of $8 per acre are: 22 percent for native high desert, 28 percent for seeded high desert, 21 percent for native foothill and 60 percent for seeded foothill range. Responses evaluated in this study or even larger ones should

Table 14. Rate of return generated by spraying sagebrush on native and seeded high desert and foothill range sites in eastern Oregon at alternative spray costs

Range type	Spray costs ($ per acre)			
	$6.00	$7.00	$8.00	$9.00
	rate of return[a]			
Native high desert	46%	39%	34%	30%
Seeded high desert	54%	45%	41%	35%
Native foothill	45%	38%	33%	30%
Seeded foothill	88%	76%	65%	59%

[a] Based on forage responses, spray costs, and forage values appearing in Table 13.

be obtainable on sites where there is an adequate level of desirable forage species present before treatment and where a 90 percent or better sagebrush kill is achieved.

Rangelands of Eastern Oregon and those common to it showed considerable variation in yield response from one site location to another and from one production year to the next. In light of this and the fact that spray costs are incurred well in advance of the income stream generated by spraying, decisions regarding spraying rangelands should be carefully evaluated in light of spraying costs, business cash flows, yield responses and their value, and opportunity costs. Good yield responses to spray treatment can be expected on sites where there is a sufficient understory of desirable forage species whose yield response is suppressed by sagebrush overstory. Also, good yield responses can be expected in years of above normal precipitation. Sagebrush spraying also might increase forage utilization on the treated site and possibly reduce soil erosion.

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