Herbicide Control of Sagebrush on Seeded Foothill Ranges in Utah

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It has been shown that big sagebrush *(Artemisia tridentata)*, which is relatively unpalatable, competes seriously with forage plants. It has invaded millions of acres of deteriorated foothill range in the intermountain area to the extent that associated forage plants produce only a modicum of their potential. Sagebrush also has reinvaded many seeded foothill ranges and reduced their forage producing capacity.

The use of 2,4-D has become an accepted practice for controlling big sagebrush and eliminating competition with other plants. However, success on foothill ranges has been sporadic. Many range technicians and land operators have been disappointed by the results even though they followed recommendations as prescribed from present research knowledge.

The present study was initiated in the spring of 1958 on seeded foothill range in central Utah after four years of disappointing attempts to control sagebrush infestation with selective herbicides. The objectives of the study were to determine: (1) the rate and date of application of 2,4-D that would give most effective kill, and (2) the relationship of soil moisture and of temperature (soil and atmospheric) to the effectiveness of herbicides.

Review of Literature

The percentage kill of sagebrush with selective herbicides has shown considerable variation with respect to rate of application. Cornelius and Graham, 1958; Hull and Vaughan, 1951; and Hyder *et al.*, 1958b all reported satisfactory and economical kill of big sagebrush with butyl ester of 2,4-D at a rate as low as 1.5 pounds of acid equivalent per acre. Plummer *et al.* (1955) suggested that two pounds of 2,4-D per acre, properly applied, would kill 60 to 90 percent of a big sagebrush stand. Kills of 75 percent have been reported by Hull *et al.* (1952) when 2,4-D was applied at the rate of two pounds of acid equivalent per acre. Cornelius and Graham (1958) reported the percentage kill ranged from 81 to 100 percent when using two pounds of acid equivalent per acre. Hyder (1953) achieved an average mortality of 77, 89, and 93 percent by applications of one, two and three pounds of 2,4-D per acre, respectively.

Season of applying 2,4-D seems to be of primary importance in obtaining a successful kill. Pechanec *et al.* (1954) made the general observation that spraying should be done in the spring when sagebrush is growing actively. Robertson and Cords (1956) stated that sites in Nevada with soil and rainfall favorable for crested wheatgrass would provide satisfactory conditions for control of big sagebrush if the herbicide was applied when the sagebrush began its growth in the spring. Alley and Bohmont in Wyoming (1958) and Hyder in Oregon (1954) have emphasized that effectiveness of herbicide application drops rapidly in late spring as lack of soil moisture and high temperatures become critical to growth. Alley and Bohmont (1958) concluded that the effectiveness of a given treatment may vary markedly within a 10-day period. Cornelius and Graham (1958) reported that highest percentage kill of sagebrush in northeastern California was obtained from spraying in May and June. Hyder (1953) found that the most favorable period of application in eastern Oregon was during May, but early June precipitation could extend the period of effectiveness. A more recent study by Hyder *et al.* (1962) in Oregon suggested that greatest susceptibility of sagebrush to herbicide was during the last two weeks in May when soil temperature at a depth of 18 inches was at least 50 degrees F. and available soil moisture was 40 percent or not less than 1.7 atmospheres tension as read directly by resistance from soil-moisture blocks.

Alley and Bohmont (1958), Cornelius and Graham (1958), and Hull and Vaughan (1951) suggested that the period of most effective application of 2,4-D on big sagebrush occurs during rapid twig elongation or when

about one-half the current year's growth is attained. The growth stage of other vegetation associated with big sagebrush has been used to determine the period when herbicide application is most effective. Alley and Bohmont (1958) recommended the period of greatest effectiveness as being when Sandberg bluegrass *(Poa secunda)* is in full to post bloom, Idaho fescue *(Festuca idahoensis)* heads are starting to emerge, and common phloxes *(Phlox spp.)* are in early seed formation. The period when the first heads of Sandberg bluegrass are showing development until about one-half the green color is gone also has been stipulated as the most effective time for application (Hyder, 1954; Hyder *et al.*, 1958a; and Hyder *et al.*, 1958b).

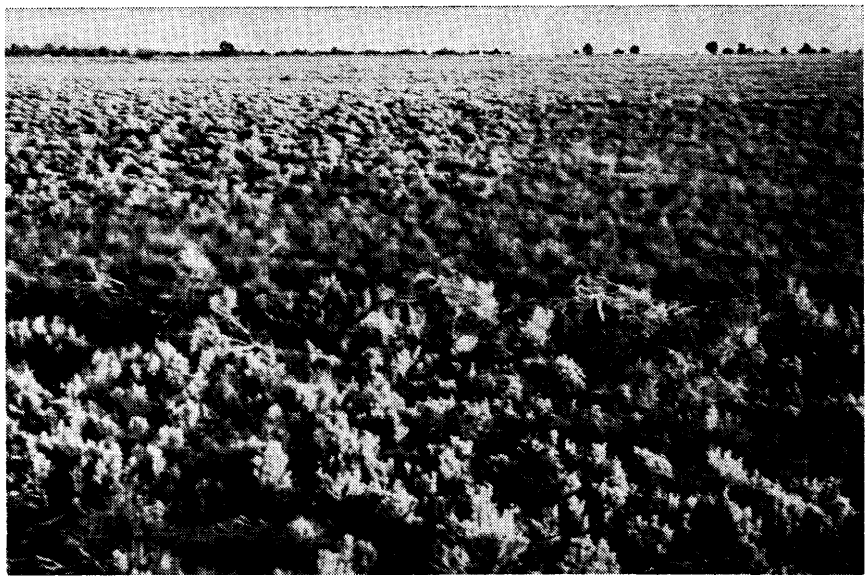

FIGURE 1. Seeded foothill range showing reinvasion of sagebrush. Area on right side was sprayed with herbicide.

Description Of The Area

The study area was on gentle, rolling ground at 5500-feet elevation, below the steeper slopes of the foothills. The texture of soil was classified as a clay loam in the first foot and a sandy clay loam in the second foot. Experimental areas were plowed in the summer of 1951 to eradicate big sagebrush and were seeded with introduced wheatgrasses by drilling in the fall of 1951. A reasonably good stand of grass was established, yet sagebrush reinvasion was rapid and extensive. By 1958, the sagebrush was uniform and dense over the area (Figure 1). A good stand of grass remained, but the competition with sagebrush had greatly reduced its productiveness. Most of the sagebrush plants ranged from one to seven years of age when the study was initiated. About 80 percent were five to seven years of age, about eight percent were under five years of age, and the remaining 12 percent were older plants that survived the initial plowing.

Light use by sheep had been permitted on the study areas in the spring of each year from 1953 to 1958. Monthly precipitation records were kept at four locations, beginning in January, 1958. Table 1 presents the monthly distribution of precipitation from 1958-1962.

Method And Procedure

The selective herbicide, esteron 76-E (2,4-D isopropyl and butyl ester) in water, was used to treat the sagebrush infested areas. This herbicide combination was superior to eight other forms of 2,4-D formulation tested in previous trials and water as a carrier was as effective as Diesel oil. The mixture was applied at five gallons per acre at three rates (1.5, 2.0, and 3.0 pounds of acid equivalent per acre) on three dates (about May 15, May 30, and June 15) for five years (1958-62) in two replications.

In other studies (1954-58) using herbicide to treat sagebrush, effectiveness of season was tested at about two-week intervals from April 1 to July 1. From these studies it was determined that dates before May 15 and after June 15 did not give as effective control of sagebrush as the mid-season dates. Therefore, only dates from May 15 to June 15 were tested in the present study. Rates of herbicide application above three pounds, in these earlier studies, had given little or no additional kill of sagebrush from April 15 to July 1, regardless of soil or weather conditions.

A jeep-mounted power sprayer employing a 15-foot boom fitted with No. 1 nozzles under a pressure of about 70 pounds was used for applying the herbicide. The herbicide was applied early in the morning to avoid drift caused by wind. In no case was a rain received within 24 hours following the application of the spray.

Data on the effectiveness of herbicide application in killing the sagebrush were collected the year following treatment except for the 1962 application in which case data were collected in the late fall of 1962. Seven transects (1 foot wide x 100 feet long) were located at 200-foot intervals in each application rate for each date. Each sagebrush plant falling within the transect was recorded as dead or alive, and if alive, the percentage of foliage reduction was estimated.

On each spraying date phenological stages of six grasses and three forbs were identified.

Soil moisture at two depths (first foot and second foot), and soil and atmospheric temperatures were determined the day

the herbicide was applied. Soil moisture was determined from 24 random locations at each date. Soil temperature was read at a two-inch depth between one and two p.m., which was considered maximum for the day. Both maximum and minimum atmospheric temperatures were determined at the experimental area the day the treatment was made. Average daily maximum and minimum temperatures were obtained from nearby weather stations for a period of six days following treatment.

Age of the sagebrush on the experimental areas was determined by counting growth rings from a random sample on the experimental area during 1958.

Table 1. Average precipitation for the experimental area, 1958-62.

Month	1958	1959	1960	1961	1962	Average
	(Inches)					
January	1.34	.94	.52	.02	1.29	.82
February	1.30	1.58	3.74	.39	3.23	2.05
March	2.87	.83	.97	1.86	1.36	1:58
April	1.70	.81	.24	.92	.95	.92
May	.78	.88	.44	.22	2.28	.92
June	.34	1.23	.27	.47	.22	.51
July	.01	.16	.54	.39	.70	.36
August	.37	1.64	1.05	3.18	.04	1.26
September	.77	1.68	.24	1.38	.13	.84
October	.04	.57	1.72	1.60	.14	.81
November	.69	.11	1.88	1.48	.20	.81
December	.45	2.16	.11	.98	—	
Total	10.66	12.59	11.72	12.89	—	

Results And Discussion

In some cases, percent foliage reduction indicated excellent results, but the actual kill of plants below 75 percent was considered unsatisfactory. When less than 80 percent of the foliage on a plant is killed, the plant can be expected to grow back to its original size within a few years. If less than 20 percent remains alive, the plant stays in a lowered state of vigor for several years and may actually die after a time.

Herbicides were about 1.5 times more effective in controlling old sagebrush plants that survived tillage than in controlling young plants that invaded the area following seeding. The average percent kill of old surviving plants was about 65 percent for all treatments over all five years and only about 45 percent for the young invading plants. The data in Table 2 include an average of all plants regardless of age.

Period and Rate of Treatment

Phenological Stage:

In all species on the experimental area, greater differences in phenological development were found among the individual plants at any one date than could be accurately distinguished between treatment dates. Therefore, no importance was attached to phenological development because of the variation among plants on various sites within the experimental area and the inability to precisely identify distinguishable phenological stages within a 2-week period between treatments.

Date of Application:

The analysis showed that differences in plant kill and reduction of foliage between dates of application were highly significant ($P < .01$). The late date, about June 15, gave poorest results during all five years (Table 2). Averages for all five years showed little difference between May 15 and May 30. The interaction between date and year was statistically significant ($P < .01$). The first date (about May 15) gave best results during 1958 and 1959, but the second date (about May 30) gave best results during 1960 and 1962 (Table 2). This was generally true for all three rates of herbicide. During 1961 there was little difference between the first and second date when all rates of spraying were considered. The three-pound rate gave best results on the first date, however, and the 1.5- and two-pound rates gave best results on the second date.

Rate of Application:

The effect of different rates of herbicide application upon control of sagebrush was statistically significant ($P < .05$). As would be expected, increasing rate of herbicide from 1.5 to 3.0 pounds of acid per acre gave increasing foliage reduction and kill (Table 2). When conditions were favorable for growth, especially during the first and second spraying dates, all three rates (1.5, 2 and 3 pounds) gave excellent kills, but when conditions were unfavorable, none of the rates of application gave satisfactory results. When growth conditions were favorable, there was little difference in kill of brush between the two- and three-pound rates. When growing conditions were unfavorable, such as during 1959 or during the late season applications (June 15), higher rates of herbicide gave markedly better kill (Table 2). This increased kill, however, did not completely compensate for unfavorable growing conditions since the highest rate (three-pounds per acre) did not give satisfactory control at the late date during any year or at any date during 1959 (Table 2).

Soil and Atmospheric Conditions

Simple correlations were determined for all combinations of the following factors: soil moisture, soil temperature, maximum and minimum atmospheric tem-

Table 2. Big sagebrush plants killed and foliage reduction from the application of herbicide at three rates and three dates for 5 years.[1]

Year treated	Rate	Plants killed May 15	Plants killed May 30	Plants killed June 15	Plants killed Avg.	Foliage reduction May 15	Foliage reduction May 30	Foliage reduction June 15	Foliage reduction Avg.
		(Percent)							
1958	1.5	71.5	50.5	18.4	46.8	84.0	73.0	39.2	65.4
	2.0	91.7	43.1	43.3	59.4	95.0	66.7	69.1	76.9
	3.0	94.9	69.5	36.9	67.1	98.2	86.3	61.7	82.1
	Avg.	87.6	54.4	32.9	58.3	92.4	75.3	56.7	74.8
1959	1.5	13.1	6.6	1.2	6.9	34.8	28.4	21.9	28.4
	2.0	43.1	18.8	8.4	23.4	57.4	37.5	27.1	40.7
	3.0	58.9	25.4	17.3	33.9	76.3	52.5	39.6	56.2
	Avg.	38.4	16.9	9.0	21.4	56.2	39.5	29.5	41.7
1960	1.5	74.6	74.8	19.2	56.2	88.0	90.3	46.6	74.9
	2.0	94.5	91.3	35.8	73.9	98.4	97.7	66.9	87.7
	3.0	82.4	96.8	61.6	76.9	90.1	99.5	82.1	87.1
	Avg.	83.8	87.6	38.9	69.0	92.5	95.8	65.2	83.3
1961	1.5	20.6	31.1	18.1	23.3	32.2	42.2	31.9	35.4
	2.0	41.9	44.9	21.0	35.9	56.8	58.8	42.0	52.5
	3.0	66.3	52.6	24.2	47.7	78.6	64.4	44.9	62.2
	Avg.	42.9	42.9	21.1	35.6	55.9	56.1	39.6	50.5
1962	1.5	37.3	64.3	18.7	40.1	43.2	78.6	44.2	55.4
	2.0	34.6	70.0	37.2	47.3	49.8	83.8	53.1	62.3
	3.0	70.7	91.3	44.6	68.9	75.5	91.9	80.0	82.5
	Avg.	47.5	75.2	33.5	52.1	56.2	84.8	59.1	66.7
Average	1.5	43.4	45.5	15.1	34.7	57.8	62.5	36.8	52.4
	2.0	61.2	53.6	29.2	48.0	71.5	68.9	51.6	64.0
	3.0	74.6	67.1	36.9	58.9	83.7	78.9	61.7	74.1
	Avg.	59.7	55.4	27.1	47.3	71.0	70.3	50.1	63.5

[1]Dates of application of herbicide for each year varied a few days from those indicated in the heading.

peratures, and extent of sagebrush kill. Soil moisture, soil temperature, and atmospheric temperatures all were significantly correlated with one another, but none was directly correlated with percent kill or foliage reduction of sagebrush. Soil moisture decreased with advancement of season while soil and atmospheric temperatures increased. Effectiveness of sagebrush kill did not show a linear relationship with advancement of season, instead it appeared to be related to limits of soil moisture and minimum temperatures.

Soil Moisture:

Moisture in the upper foot of soil was slightly higher or about the same as the moisture in the second foot at the first date of treatment, but the second foot of soil possessed more moisture than the first foot at the last date of treatment (Table 3). During each of the first four years, soil moisture decreased gradually from the first to the last date of treatment in both the first and second foot of soil. During the last year, 1962, late spring rains had increased the soil moisture content at the second treatment date so that it exceeded that of the first treatment date. During 1959 the soil moisture content was never more than one percent above the wilting coefficient. Soil moisture was highest during 1960 and 1962. Best sagebrush kills were obtained, however, during 1960 and 1958.

Soil Temperature:

Soil temperature at a depth of two inches during mid-day on the day treatments were made did not differ materially from maximum atmospheric temperatures but were slightly higher in most cases (Table 3). During 1961 the soil temperatures were taken in the shade under the sagebrush, but during the remaining four years temperature readings were taken where the sun shone on the soil most of the day. During each year of the study, soil temperature increased as the season advanced.

Atmospheric Temperature:

As would be expected, both maximum and minimum temperatures increased with advancement of season (Table 3). Temperatures during the day that treatments were applied did not differ materially from the average temperatures during the six days following treatment. In some cases they were slightly higher, while in others they were slightly lower. Since most herbicides are absorbed rather rapidly by the plants, it was believed that the temperature the day of treatment was more important than the average temperatures following treatment.

In most cases, the maximum temperatures were above 70° F. and minimum temperatures were above 40° F. for all dates of treatment (Table 3). On the second date in 1959, and the first date in 1961, however, maximum temperatures were below 70 degrees, and on the first date in 1962, the minimum temperature was 34 degrees.

Conclusions

Poor sagebrush kill during the five years of treatment appeared to be a result of limited soil moisture or low atmospheric temperatures. When average soil moisture in the upper two feet of soil was below 12 percent, or when maximum and minimum atmospheric temperatures were below 70 and 40 degrees, respectively, on the day of treatment, satisfactory kills of sagebrush

were not obtained. The only exception to this was during the late date (June 16) in 1962 (Table 3) when average soil moisture was 13.9 percent and maximum and minimum temperatures were 84 and 56 degrees, respectively. This late date might feasibly be beyond the date of rapid growth of sagebrush regardless of soil and atmospheric conditions, and therefore, the plants were not susceptible to herbicide treatment. In general, soil moisture was most favorable the first date and atmospheric temperatures were more favorable the second and third dates. Thus the most favorable period for sagebrush control would appear to be about the third week in May. If soil moisture does not decrease too rapidly, the last week in May might be better because atmospheric temperatures normally would be more favorable.

The total soil moisture percentage as an index could be used only on soils of similar texture because available soil moisture varies markedly between light and heavy soils. In the present study it appears that about 2.5 percent moisture above the wilting coefficient would be necessary for satisfactory control of sagebrush on foothill areas. Thus, if we assume that the wilting coefficients for clay, loam, clay loam, silt loam, and sandy loam are approximately thirteen, eleven, ten, eight and three percent, respectively, the soil moisture content for satisfactory results should be about 15.5, 13.5, 12.5, 10.5, and 5.5 percent for each texture, respectively.

Summary

During a 5-year period from 1958 to 1962 a study was conducted in central Utah to determine the desirable rate and date of application of herbicide to control sagebrush invasion on seeded foothill range.

A selective herbicide composed of equal parts of isopropyl and butyl esters was applied in water at 5 gallons per acre at three rates (1.5, 2.0, and 3.0 pounds of acid equivalent per acre) on three dates (May 15, May 30, and June 15) for five years.

The early date (May 15) and the middle date (May 30) each gave best results two years out of the five. During some years none of the treatment dates gave satisfactory results. However, May 15 and May 30 were considered more reliable dates than June 15. Increased rate of herbicide gave increased effectiveness in control of sagebrush. When growing conditions were favorable, all three rates gave satisfactory results; when growing conditions were unfavorable, none of the rates gave satisfactory control.

The study suggested that soil moisture and atmospheric temperatures were limiting factors in the control of sagebrush on foothill ranges. When average percent soil moisture in the upper two feet was below 12 percent or when maximum and minimum atmospheric temperatures were below 70 degrees and 40 degrees, respectively, on the day of treatment, satisfactory kills were not obtained.

Optimum soil moisture percentages for herbicide control of sagebrush on clay loam, silt loam, and sandy loam would be about 12.5, 10.5, and 5.5, respectively.

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Table 3. Soil moisture, soil temperature, and atmospheric temperature for three dates during 5 years when herbicide treatments were applied.

Year and date	Soil moisture 0-12 inches	Soil moisture 13-24 inches	Soil moisture Average	Available soil moisture[1]	Soil temperature mid-day	Temperature day of treatment Max.	Temperature day of treatment Min.	Temperature for 6-day period after treatment Max.	Temperature for 6-day period after treatment Min.
1958									
May 10	12.4	12.7	12.6	2.6	87	83	43	83	51
May 24	10.1	10.4	10.2	1.3	89	89	53	90	54
June 7	8.6	8.9	8.8	1.9	92	88	53	83	51
1959									
May 16	10.4	8.9	9.7	0.0	77	72	46	65	39
May 30	10.2	9.1	9.7	0.8	70	69	43	70	48
June 15	9.5	9.4	9.5	0.4	83	92	55	92	59
1960									
May 14	17.4	17.3	17.4	7.4	76	70	44	69	40
May 28	15.2	14.0	14.6	5.7	84	78	43	85	50
June 14	10.9	12.3	10.2	6.5	97	92	55	90	59
1961									
May 13	12.7	11.8	12.2	2.2	48	65	41	72	41
May 24	10.0	10.9	10.4	1.5	74	86	50	83	53
June 9	9.0	9.6	9.3	1.8	82	90	57	87	53
1962									
May 19	11.6	16.2	13.9	3.9	86	75	37	66	38
June 2	17.5	17.8	17.7	10.8	89	78	40	72	41
June 16	12.3	15.5	13.9	7.3	93	84	56	82	49
Average									
May 15	12.9	13.4	13.2	3.2	75	73	42	71	42
May 30	12.6	12.5	12.6	3.7	81	80	46	80	49
June 15	10.1	11.1	10.6	3.4	89	89	55	87	54

[1]The wilting coefficient (15 atmospheres pressure) is 10.0 and 8.9 percent for the 1st and 2nd foot of soil respectively.

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