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ECOLOGICAL RESPONSE OF SAGEBRUSH-GRASS RANGE IN CENTRAL OREGON TO MECHANICAL AND CHEMICAL REMOVAL OF *ARTEMISIA*[1]

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Abstract. Big sagebrush was controlled by rotobeating and spraying on both fair- and poor-condition ranges. A randomized block design was used with two replications of each treatment (untreated, sprayed, and rotobeaten). Data were taken from 10 permanent sampling units within each treatment plot. Numbers and crown cover of big sagebrush on treated range in fair condition changed little in 8 years after treatment. However, on poor-condition ranges sagebrush rapidly reoccupied mechanically treated areas. Some sagebrush increase occurred on sprayed poor-condition ranges, but brush numbers are strikingly lower than on rotobeaten plots. Herbage yields corrected to median-year precipitation varied considerably on untreated and treated plots, but herbage production was at least doubled, mostly from increaser-type species, on both sprayed and mechanically treated fair-condition range. On poor-condition ranges, herbage response was primarily from annuals with a marked trend toward an increasing amount of cheatgrass on treated plots. Soil moisture contents are generally greater on treated plots until the deep-rooted herbage species increase considerably. Soil temperatures are consistently lower on poor-condition, rotobeaten plots, and this difference is attributed to the insulating effect of the persistent woody residue on the soil surface.

Stands of big sagebrush (*Artemisia tridentata* Nutt.) have been subjected to large-scale control measures since the end of World War II. Of necessity, these treatment recommendations have generally been based on results over a relatively short period of time. This study was designed to provide more complete ecological information on treated sagebrush stands over a longer time interval than has heretofore been reported. Specifically, answers were sought to three questions: (1) What ecological changes in plant cover and soil moisture occur after successful sagebrush control on ranges in both fair and poor condition? (2) Which method, rotobeating or chemical spraying, is most effective for increasing forage production on big sagebrush-bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith) range? and (3) How are trends in forage production influenced by subsequent brush reestablishment on range areas treated by rotobeating and spraying?

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Literature Review

Many studies on western ranges have been directed toward the problem of woody plant control; for example, Cassady (1952) and Darrow (1957) in the oak type; Leonard and Harvey (1956) in the California chaparral; Reynolds and Tschirley (1957) and Pond (1961) in the southwestern mesquite type; and Pechanec, Stewart, and Blaisdell (1954), Cook (1958), and Hervey (1958) in the sagebrush type. Few studies, however, have been concerned with comprehensive ecological changes following brush treatment. Sampson (1944) studied ecological changes on chaparral lands in California, and Blaisdell (1953) reported similarly on sagebrush-grass range in southern Idaho. Both of these men reported ecological data accumulated from areas where brush cover had been removed by fire.

Studies of ecological changes on sagebrush-grass range following sagebrush control or removal include those by Blaisdell and Mueggler (1956), Hyder and Sneva (1956), and Alley and Bohmont (1958). Of these, only Hyder and Sneva attempted to compare the ecological influences of mechanical (hand grubbing in their case) and chemical means of brush control. Sagebrush treatment resulted in a threefold increase in herbage production with the biggest response from increaser-type grass species. There was more rapid depletion of soil moisture on treated plots, and soil moisture-soil nitrate balance was apparently important in the competition between big sagebrush and native bunchgrasses. Hyder and Sneva concluded that sagebrush-bunchgrass range in fair condition, with deep-rooted bunchgrasses yielding about 150 lb./acre, is suited to profitable improvement by chemical control of big sagebrush.

Alley and Bohmont (1958) reported on the chemical control of big sagebrush in the Bighorn Mountains of Wyoming at 8,200 ft elevation with an average annual precipitation of 22 inches. Under these conditions, production of common native grasses such as fescues, bluegrasses, and wheatgrass was increased from 100 to 150% the first year following treatment. Percentage composition of all forbs was not measurably changed and production from native grasses increased fourfold over a 5-year period. Unsprayed areas produced 526 lb. air-dry herbage per acre versus 2,075 lb. from areas treated to control 75% or more of the big sagebrush. The Wyoming work indicated that livestock used 60% of the forage production on sprayed compared with only 25% on check areas.

Blaisdell and Mueggler (1956) studied the effect of 2,4-D on forbs and shrubs associated with big sagebrush. The response of associated species varied from no damage to severe damage; e.g., few other shrub species but many valuable forbs were adversely affected by 2,4-D spray. Hyder, Sneva, and Freed (1962) studied susceptibility of big sagebrush and green rabbitbrush(*Chrysothamnus viscidiflorus* (Hook.) Nutt.) to 2,4-D and found that big sagebrush mortality was influenced strongly by soil moisture contents at less than 12 inches, whereas green rabbitbrush was more dependent on soil moisture at depths of 12 inches or more. Furthermore, environmental conditions were most important for killing big sagebrush, whereas green rabbitbrush depended on phenological and physiological conditions as well. Mohan and Currier (1962) developed a spray-drill technique for improving sandy soils where rabbitbrushes are a problem. When these mixed stands of big sagebrush and rabbitbrush were sprayed with 2 lb. of butyl ester in 5 gal of water or 3 gal of diesel, satisfactory kills were obtained if new twig growth was at least 4 inches long and soil moisture was present within 4 inches of the surface. Under these conditions, no serious damage was inflicted on bitterbrush (*Purshia tridentata* (Pursh) DC.), a valuable browse plant.

Description of Study Area

The Squaw Butte Experiment Station, on which this experiment was carried out, is considered by Anderson (1956) to lie within the "high desert" ecological province of eastern Oregon. Physiographically, Squaw Butte is located in the extreme western edge of the Harney Basin, which, according to Piper, Robinson, and Park (1939), is typical of an extensive region in eastern Oregon and adjacent parts of Idaho, Utah, Nevada, and California. This basin contains a low central area whose landforms are relatively young and have been constructed by sedimentation and volcanism and a higher marginal area which has been eroded from a fault-block terrane.

Soils in the study area are well drained, have a sandy loam texture in the surface, clay loam in the B horizon, and are part of a gently sloping fan derived from alluvial materials of basaltic and rhyolytic origin. A cemented pan, found at depths of 30-35 inches, restricts the growth of grass roots but is penetrated by shrub roots. The pH of the profile varies from about 6.2 in the A horizon to 7.0 in the B and 7.8 in the cemented layer. Percentage moisture content of the surface soil is approximately 17 at field capacity and 8 at wilting point, as determined from moisture-tension curves.

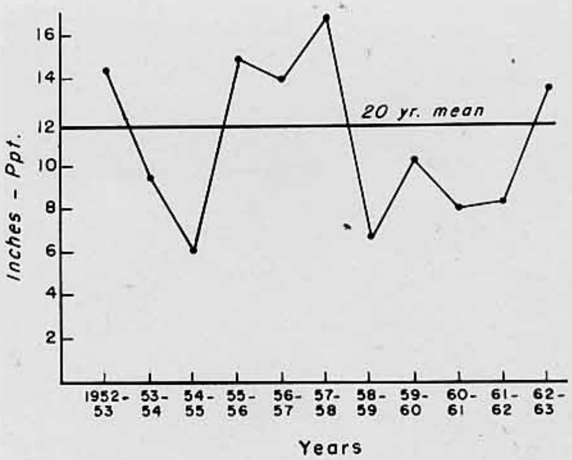

FIG. 1. Crop-year (July 1–June 30) precipitation at Squaw Butte Range, Burns, Oregon.

Average crop-year precipitation for the past 20 years in the study area was 11.8 inches with extremes ranging between 6.1 and 16.8 inches (Fig. 1). About 60% falls in a 6-month winter period, but nearly 25% occurs in May and June. Low temperatures limit growth until May and frosts may occur at any time. The 4-year drought from 1959 through 1962 was severe and a marked cumulative influence was noted in the declining vigor of the principal forage plants during and even for 1 year after the drought period.

Work by Eckert (1957) indicates that the original vegetation on the experimental area would be classified as the *Stipa thurberiana* phase of the *Artemisia tridentata/Agropyron spicatum* association. Eckert's criteria for the *Stipa* phase are that it has significantly more Thurber needlegrass (*Stipa thurberiana* Piper) with less bluebunch wheatgrass and significantly more Idaho fescue (*Festuca idahoensis* Elmer) than the typical *Artemisia tridentata/Agropyron spicatum* vegetation. Other important grass species are: squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith), Sandberg's bluegrass (*Poa secunda* Presl.), and junegrass (*Koeleria cristata* (L.) Pers.). In wet years cheatgrass (*Bromus tectorum* L.) is abundant on brush-cleared areas and several forbs are conspicuous. The dominant perennial forb is *Phlox diffusa* Benth., and *Collinsia parviflora* Dougl. ex Lindl. is the most abundant annual species. The only woody species other than big sagebrush is green rabbitbrush.

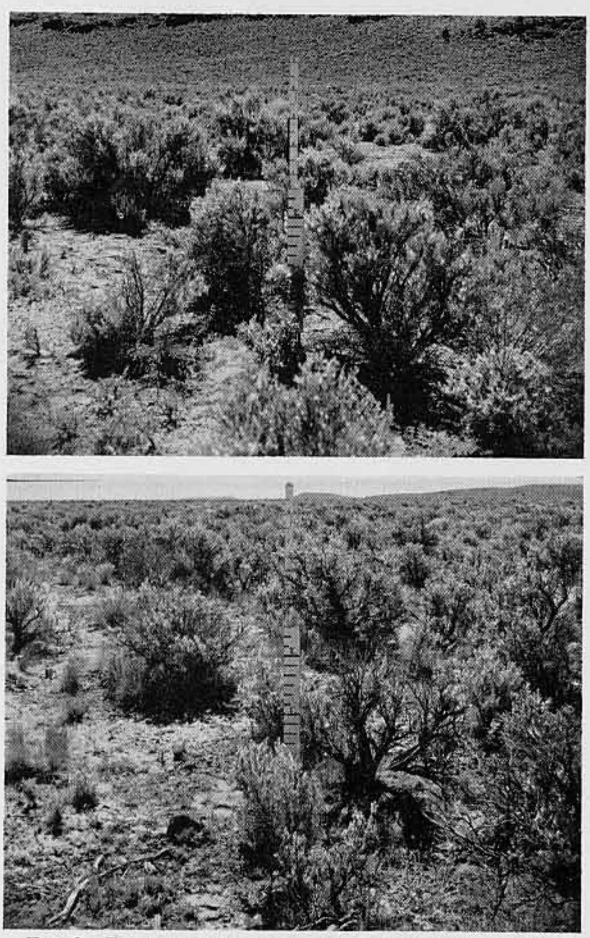

Fig. 2. Representative poor- (above) and fair- (below) condition big sagebrush-grass areas before treatment.

The poor-condition areas used in this experiment were plowed about 1920 and since then have been invaded by big sagebrush to the near exclusion of all herbaceous plants (Fig. 2). Squirreltail was the only important perennial grass at the start of the experiment. Cheatgrass plants, prior to treatment, were small and inconspicuous and failed to occupy bare areas among the sagebrush.

Methods

A randomized block design with two replications in each of two range-condition classes was used in this study. Three treatments—check, spray, and rotobeat—were established on both fair- and poor-condition units for a total of 12 plots in the overall design. All treatments were applied in May 1955. The spray treatment was 2 lb. butyl ester 2,4-D per acre in 10 gal water. The rotobeating treatment reduced sagebrush to stumps about 4 inches above the ground level. These treated areas were each 1½ acres in size, but the exclusion of a 50-ft border strip reduced the area sampled to about one-half acre with dimension of 100 by 200 ft. Ten permanent sampling units measuring 10 by 10 ft were randomly selected in each treatment plot. Both herbaceous and shrub-sample data were taken on these 10 units. Shrub density was taken within the 10-ft square and foliar intercept around the 40-ft perimeter.

Herbage yields were obtained by hand-clipping at ground level on permanent, circular, 9.6-ft^2 plots located in the center of each sampling unit. Pre-treatment yields were taken in August 1953, 1954, and 1955. Post-treatment yields were obtained in August 1956, 1957, 1959, 1961, and 1963. Each herbage sample was separated into individual species components, except in 1953, to determine species composition. Cumulative effects of clipping permanent plots were evaluated in 1963 by harvesting four temporary samples from each treatment plot. Yields from permanent and temporary plots are averaged to estimate 1963 yields because clipping had not resulted in significant yield depression on permanent plots.

Herbage samples were dried in a forced-air oven at 70°C before weighing. Herbage weights then were adjusted to a median-year precipitation amount, as proposed by Sneva and Hyder (1962), to reduce year-to-year fluctuations. Thus, herbage weights are reported as adjusted ovendry yields.

This sampling design provided herbaceous yield from 96 ft^2, brush density from 1,000 ft^2, and brush foliage cover from 400 ft of line intercept for each treatment plot.

Bouyoucos plaster-of-paris blocks were installed in April 1955 at depths of 6, 15, 24, and 30 inches near the odd-numbered sampling units within each treatment plot. Electrical resistance readings of soil-moisture contents were initiated in 1956, when gravimetric determinations were obtained to define field capacity and wilting point ranges in resistance readings.

Soil temperatures were obtained from thermistors (waterproofed with glyptol varnish) planted at depths of 6, 15, and 24 inches in three plots on poor-condition range. Temperature readings were begun in 1956 and discontinued in 1962.

RESULTS

Changes in big sagebrush

Rotobeating killed 84% of big sagebrush on fair-condition range and 61% on poor-condition range. Spraying killed 98% and 85%, respectively, on fair- and poor-condition ranges (Table I). Greater reductions in sagebrush crown cover than in sagebrush density show that the treatments were most effective on large shrubs Rotobeating was especially ineffective in controlling sagebrush seedlings and young plants below 12 inches in height. Except for rotobeating on poor-condition range, the treatments provided good to excellent sagebrush control, reflecting a larger proportion of small plants in the poor-condition area.

Since treatment, big sagebrush reproduction has been held in check on fair-condition range (Table I). Sagebrush density has remained nearly constant on all plots, but sagebrush cover has increased to 11% of that measured before treatment on rotobeaten plots.

Big sagebrush density has increased slightly on sprayed, poor-condition plots and greatly on the rotobeaten ones. In fact, 8 years after rotobeating, sagebrush density was 110% and cover 33% as much as before treatment. By contrast, seedling establishment was almost non-existent on the sprayed plots.

Herbage yields on fair-condition range

Since pre-treatment yields were equal among plots and differences in species composition were small, post-treatment comparisons between treated and untreated plots are valid without covariance corrections. The highest yielding herbaceous species in pre-treatment yields were squirreltail, Thurber needlegrass, and Idaho fescue. The other important components were Sandberg's bluegrass, bluebunch wheatgrass, and junegrass.

Post-treatment herbage yields on fair-condition range averaged 200, 378, and 387 lb./acre, respectively, on untreated, rotobeaten, and sprayed plots. Between untreated and treated plots the yields diverge slightly in the first 4 years and converge in the last 4 years (Fig. 3). Responses to rotobeating and spraying were essentially equal in all years.

The comparison of yields by individual species shows that sagebrush control contributed mainly to increases in junegrass and squirreltail. June-

TABLE I. 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

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

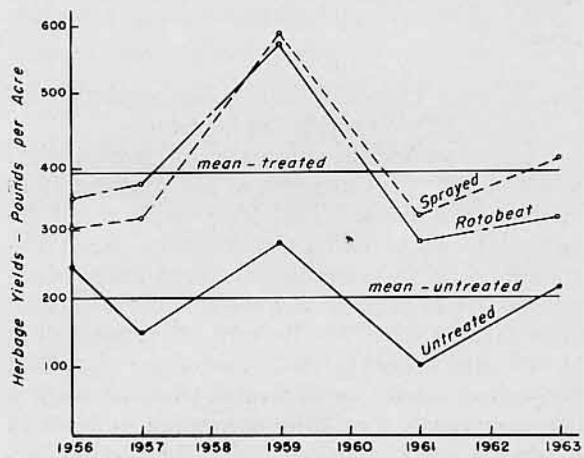

FIG. 3. Post-treatment herbage yields on fair-condition range.

grass yields on rotobeaten and sprayed plots averaged 517 and 364% more, respectively, than on untreated plots. Squirreltail yields on rotobeaten and sprayed plots averaged 242 and 247% more, respectively, than on untreated plots. These two species increased in the first 6 years after treatment and decreased in the last 2 years. Idaho fescue and Sandberg's bluegrass yields on treated plots averaged about 60% greater than on untreated plots. Cheatgrass appeared as an important component only on treated plots in the eighth year after sagebrush control. Differences between rotobeating and spraying were always small.

Herbage yields on poor-condition range

Pre-treatment yields were essentially equal among plots (33 to 41 lb./acre), and squirreltail was the only important species encountered. Post-treatment yields averaged 122, 420, and 489 lb./acre, respectively, on untreated, rotobeaten, and sprayed plots. The greatest response to sagebrush control was obtained 4 years after treatment (Fig. 4). Spraying induced greater yields than roto-

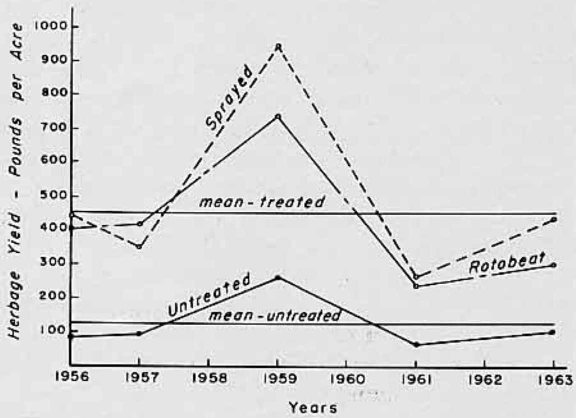

FIG. 4. Post-treatment herbage yields on poor-condition range.

beating only after 1957 when big sagebrush increased rapidly on rotobeaten plots.

Squirreltail increased equally on treated plots to about 100 times as much as on untreated ones in the first 4 years. Thereafter, squirrel tail decreased to about two times as much as on untreated plots. Cheatgrass increased from essentially no yield to about 200 lb./acre on rotobeaten plots and to about 330 lb./acre on sprayed plots in 4 years. Cheatgrass remains the dominant herbaceous species on all treated plots, although it has decreased about half on rotobeaten plots in the last 4 years. Annual forbs, *Descurainia pinnata* (Walt.) Britt. and *Gayophytum ramosissimum* Torr. and Gray, increased on treated plots

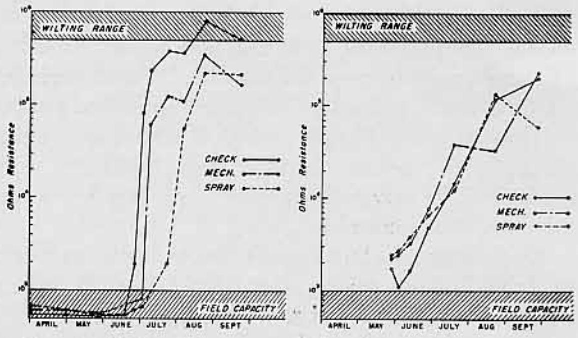

FIG. 5. Soil-moisture trends at 30-inch depth as influenced by sagebrush control treatments on fair-condition range. Left, in 1956; right, in 1963.

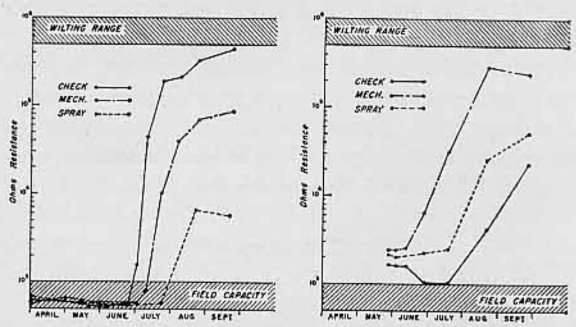

FIG. 6. Soil-moisture trends at 30-inch depth as influenced by sagebrush control treatments on poor-condition range. Left, in 1956; right, in 1963.

in the first year to about six times as much as on untreated plots. Thereafter, the annual forbs decreased as cheatgrass increased. By 1963 the annual forbs produced equal amounts on all plots.

Soil moisture and temperature

The pattern of soil-moisture depletion at the 30-inch depth on fair-condition range shows a greater similarity among all treatments in 1963 than in 1956 (Fig. 5). In the first few years after sagebrush control, soil moisture was depleted less rapidly on treated than on untreated plots. But as the herbaceous species responded to sagebrush control, their capacity to deplete the soil moisture increased to that of untreated vegetation. The soil-moisture regime on poor-condition areas (Fig. 6) shows similar trends to those on fair condition except that the rotobeaten plot was definitely drier in 1963 than either the spray or check plot.

Soil temperatures for the 15-inch depths on the poor-condition range are presented in Fig. 7. The differential temperature (an average of about 5°F (2.8°C) higher for sprayed and untreated than for rotobeaten) can probably be explained by the woody residue from rotobeating which still persists on the mechanically treated area.

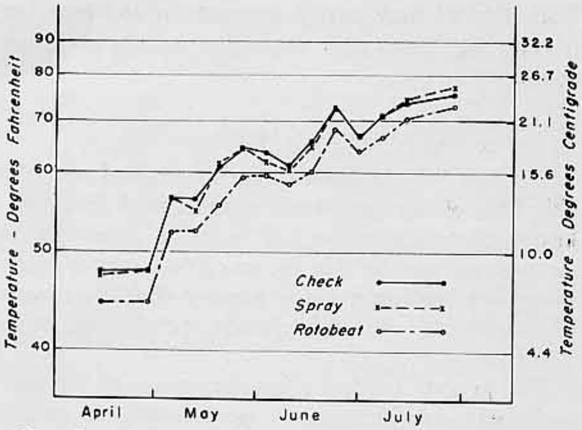

FIG. 7. Soil temperatures by treatments at 15-inch depth on poor-condition range in 1958.

Discussion

Changes in big sagebrush

Definite trends in the reestablishment of big sagebrush are evident 8 years after treatment. The rate of reestablishment is related both to the condition of the range and the method of control used. Sagebrush rapidly reoccupied mechanically treated, poor-condition ranges; after 6 years rotobeaten plots contained more sagebrush than check plots. In contrast, sprayed plots have been reoccupied rather slowly even on poor-condition areas. This observation agrees with conclusions of Weldon, Bohmont, and Alley (1958) who found that range land on which 75% or more of the sagebrush had been killed remained relatively free from sagebrush seedlings for at least 4 years after chemical treatment.

Herbage yields

Trends in herbage production are not as clear-cut as those in density and crown cover of big sagebrush. Total herbage production on treated fair-condition range increased two times over untreated, but the perennial grass component increased about 2½ times. However, no clear trend is evident among the species except that increaser-types, such as squirreltail and junegrass, were still accounting for most of the increase even 8 years after treatment.

The proportion of forbs fluctuated in relation to the amount of precipitation received. Four years after treatment cheatgrass became important on treated plots. If the same pattern is repeated here as on an adjacent 40-acre unit sprayed in 1952, cheatgrass will become more abundant in the future. This tendency for annual grasses to replace forbs and perennial grasses in the composition of treated sagebrush-bunchgrass range may be explained by the increase in nitrogen made available to grasses by the control of sagebrush, and by the late-season grazing or clipping of these areas. Treatment of fair-condition ranges may simulate a response obtained by fertilizing native bunchgrass range. Increases in cheatgrass have been observed on both native bunchgrass ranges and crested wheatgrass seedings fertilized with nitrogen (Patterson and Youngman 1960, Sneva 1963, Mohan 1964). The control of sagebrush on poor-condition ranges where perennial forages are unable to make use of increased moisture and nitrogen appears to give an ecological response similar to adding nitrogen.

Piemeisel (1938) studied changes in weedy plant cover on cleared sagebrush land in southern Idaho and found that under favorable conditions it progressed through two stages before being dominated by cheatgrass. The first 2 years were characterized by Russian thistle (*Salsola kali* var. *tenuifolia* Tausch) and the next 2 by mustards. In the fifth year, cheatgrass predominated. At Squaw Butte squirreltail was present along with annual forbs at the time of treatment, but 4 years elapsed before cheatgrass became abundant.

On poor-condition ranges, greater differences have been obtained in total herbage, ranging from three or four to one, but most of this has been either annual forbs or cheatgrass since perennial grass production has only doubled on treatments compared with check plots. Greater yearly variation has occurred on both check and treated areas in poor condition.

Soil moisture and temperature

Hyder and Sneva (1956) reported that treated sagebrush areas dried earlier in the season than untreated areas. The same tendency was noted in this study at shallower depths in the first few years after treatment and after 8 years at the 30-inch level. Although root studies were not included in this trial, it is likely that roots of perennial grasses are now making greater use of soil moisture in the deeper layers. On untreated plots, sagebrush roots are probably still the principal water users at this depth.

Changes in the soil-moisture regime on poor-condition plots took place more slowly and the rotobeaten plots were definitely drier in 1963 than either the sprayed or untreated ones. This more rapid depletion may be the result of the large number of young sagebrush, which are apparently heavier users of moisture than the old plants on the check plot. The intermediate position of the sprayed plots indicates that root activity from both perennial and annual (cheatgrass) plants must be increasing at the 30-inch depth.

Sander and Alley (1961) reported on the snow-holding capacity and soil-moisture retention following chemical control of big sagebrush in Wyoming. They found that 6 years after 100% control in the Bighorn Mountains a significantly higher percentage of soil moisture was retained on treated than on untreated areas when compared in late July. However, sagebrush control by spraying had no effect upon the snow-holding capacity in the Red Desert area in south-central Wyoming where drifting snow usually occurs. The Squaw Butte area is, in this respect, apparently more like the Bighorn Mountains of Wyoming rather than the Red Desert since Hyder and Sneva (1956) have attributed the better moisture relationships on big sagebrush treated areas in central Oregon to better retention of precipitation on sprayed plots.

Soil-moisture data support the contention that big sagebrush control increases the availability of water for herbage production. A well-distributed population of desirable perennial forage grasses will make the most efficient use of this additional moisture within the first few years after the control of big sagebrush. On poor-condition ranges most of the available moisture is used by annual plants or new sagebrush.

The increased production of cheatgrass on the sprayed compared with the rotobeaten areas can be partially explained by soil-temperature differences observed for these treatments. The consistently warmer soil temperatures on the sprayed plots, together with the additional nitrogen and moisture available after sagebrush control, may account for the differential production of cheatgrass on treated poor-condition areas.

Soil temperatures, after rotobeating and spraying, appear to vary depending upon the amount of residue left on the surface. The litter left by rotobeating was effective in lowering the soil temperature to a depth of 15 inches, thereby favoring perennial grasses in comparison with annuals which are benefited more by spraying. In addition to a temperature influence, rotobeating may also interfere with the availability of nitrogen from microorganism activity or cause tie-up of nitrogen in the decomposition of woody material. There may also be greater inhibitory effects from mechanically reduced than from chemically treated sagebrush. The relative absence of herbaceous growth under dense sagebrush has been attributed by some workers to chemical inhibition from the leachate which would be more pronounced on rotobeaten than sprayed plots. Both factors may partly account for the increase of big sagebrush on rotobeaten ranges in poor condition.

Management Implications

Because fair-condition ranges remained remarkably free of big sagebrush after control and rotobeaten plots had about ten times as many plants as sprayed ones (Table I), on critical winter game range rotobeating may be a more effective means of improving desirable forage production than spraying.

The general tendency for cheatgrass to increase and forbs to decrease on poor-condition ranges where sagebrush is controlled raises a serious question about the advisability of using either mechanical or spray treatments on these ranges. In general, sagebrush control has been limited to ranges in fair condition, and if poor-condition ranges are sprayed, seeding with a rangeland drill is recommended (Mohan and Currier 1962).

Piemeisel (1951) points out that there is no known instance where such aliens as cheatgrass and participants in the earlier stages of succession supersede any native perennials except by man's direct or indirect interference. Since range-improvement activities create both direct and indirect disturbances in the natural ecology of sagebrush-grass ranges, one can expect that improvement or management practices could adversely change the proportion of annuals and perennials on treated ranges.

The fact that cheatgrass is becoming a more important component on both poor- and fair-condition ranges treated for big sagebrush control points up the need for grazing research on treated areas to clarify how livestock use may be helpful in suppressing annual grasses while encouraging the increase of perennial species.

Based on results from the soil-moisture studies, one would recommend big sagebrush treatment for ranges with a well-distributed stand of perennial forage species. Ranges in poor condition could more effectively be plowed and seeded or sprayed and seeded. The choice of method would probably depend upon local conditions and the urgency of need for more forage. Results on one large, spray-drill seeding (Moser and Hedrick 1963) indicate that production is much lower in the first 2 years than on comparable plowed and seeded areas.

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