Sagebrush CONTROL on Rangelands

AGRICULTURE HANDBOOK NO. 277
UNITED STATES DEPARTMENT OF AGRICULTURE

ACKNOWLEDGMENTS

The authors gratefully express their appreciation to employees of the Bureau of Land Management, Soil Conservation Service, Bureau of Indian Affairs, Forest Service, Agricultural Research Service, State agricultural experiment stations, State fish and game departments and extension services, and to many private individuals for their cooperation in setting out demonstrations of sagebrush eradication and seeding, and for information on equipment design and procedures in sagebrush control and seeding. So many individuals have contributed material that it is impossible to make specific acknowledgment.

Washington, D.C. February 1965

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 20 cents

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Much of the material in this handbook, in an earlier form, was in Farmers' Bulletin No. 2072, Controlling Sagebrush on Range Lands, issued October 1954.

SAGEBRUSH CONTROL ON RANGELANDS

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INTRODUCTION

Sagebrush control brings about major increases in grass production on millions of acres of western range. Getting rid of competing sagebrush and restoring a good stand of forage plants through natural or artificial seeding enables ranges to supply forage for more sheep and cattle, and is helpful in improving watersheds. In effect, new range is created on large areas, making possible a superior plant cover on adjoining ranges by better grazing management.

Innumerable examples have demonstrated that sagebrush eradication can more than repay its cost on many ranges in the West; double to 25 times greater grazing capacities have been obtained.

There are approximately 96 million acres of western range in the sagebrush type. On a large part of this rangeland, sagebrush is overly dense and must be reduced before increased forage yields can be obtained. This overly dense sagebrush is largely the result of overgrazing, together with drought. Sagebrush control is recommended primarily for ranges used by livestock in the spring, fall, and summer but not for those grazed chiefly in the winter. Here sagebrush, especially black sagebrush,[2] is often a desirable forage.

Likewise, control on ranges used by big game in the winter is not advocated where sagebrush is an important source of browse. A balanced mixture of broad-leaved herbs, grasses, and shrubs is considered desirable for most wildlife of these sagebrush ranges.

In tall, dense stands sagebrush is definitely undesirable (fig. 1, *A*). It is relatively unpalatable to sheep and cattle, and it uses moisture and nutrients that should be producing good forage (figs. 1, *B;* 2).

Sagebrush prevents grazing of grasses hidden under its woody stems and crown. It hampers movement of livestock, especially sheep. The brush snags wool from fleeces. It causes lambs and calves to stray and become lost, and heavy brush makes conditions ideal for predators such as coyotes. As a result of the increasing preponderance of sagebrush over valuable herbs and grasses, western ranges now carry far fewer livestock than they should.

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[2] Scientific names of all plant species mentioned are given at the end of this handbook.

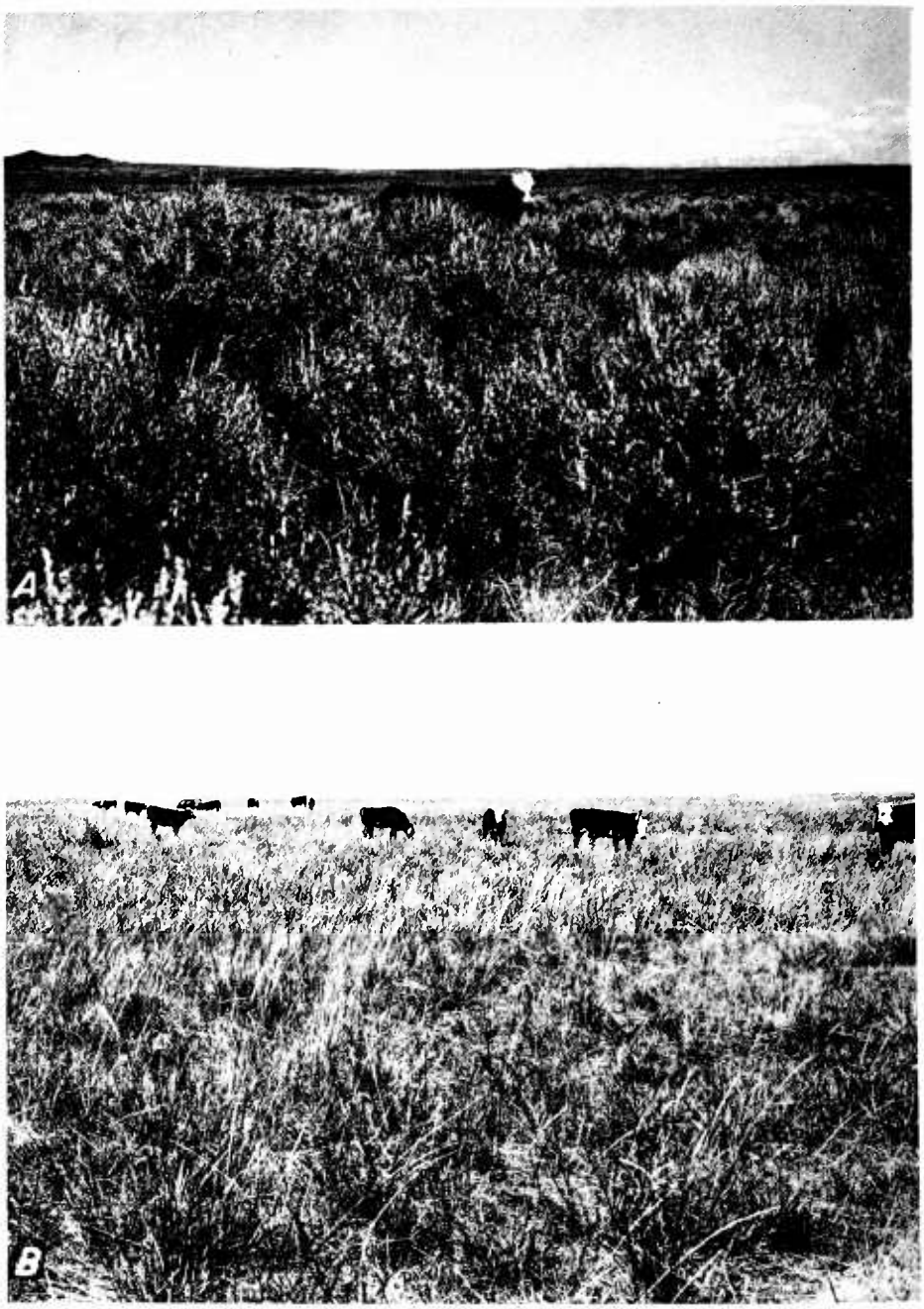

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FIGURE 1.—Dense stands of big sagebrush must be reduced before a range can be improved. *A*, Heavy stands of sagebrush such as this cover up the grass, hinder livestock movement, cause wool pulling and lamb straying, and use moisture needed to produce good grasses. *B*, Where dense stands of sagebrush have a fair understory of good native grasses, killing the sagebrush by burning, spraying with herbicides, or using some mechanical method will release the grasses from competition for moisture. With good grazing management, the grass can then increase and produce a good stand. Planned burning 3 years before this photo was taken has doubled the grazing capacity.

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FIGURE 2.—Where there is only a scattered understory of grass, the range must be seeded following sagebrush removal. This area supported a dense stand of sagebrush, like that shown in figure 1, but had no grass understory. The sagebrush was burned and the area drilled to crested wheatgrass. Three years later it could carry 15 times as many cattle as it could before treatment.

Without removal of sagebrush only slight improvement in forage yield can be expected on many ranges even after good grazing management has been practiced for 15 to 30 years. Where there is little or no understory of herbs and grasses, it may take much longer. Seeding should not be attempted until most of the sagebrush has been eliminated. Young grass seedlings cannot compete successfully for soil moisture with established sagebrush plants.

There are many shrubby species of sagebrush, all of which are often called just "sagebrush." Big sagebrush is by far the most common. Associated species are silver sagebrush, threetip sagebrush, low sagebrush, and black sagebrush. Black sagebrush is an excellent browse on winter range, but on spring-fall and summer ranges it may not be considered valuable. These associated species may be locally more abundant than big sagebrush, and methods of control may need to be altered to fit them. This publicatiton includes the best available information on methods that could be used for these species, where the methods differ from those recommended for big sagebrush. Methods for the control of sand sagebrush, a Southern Great Plains shrub, are described in other U.S. Department of Agriculture publications, which may be obtained by writing to the Southern Great Plains Field Station, Woodward, Okla.

In the past 30 years sagebrush has been controlled successfully on 5 to 6 million acres. More than half this acreage has been treated during the past 5 years. It is evident that the practice is gaining momen-

tum and will be applied to many more millions of acres in the West.

Most of the completed control work has been strikingly successful; some has not. Research and experience through these successes and failures throughout the West have shown that in planning for sagebrush control, the following items should be considered: (1) Where, (2) when, (3) how, (4) grazing management afterward, and (5) the need for regrassing afterward. The purpose of this bulletin is to make information on these items available for use by ranchers, public land administrators, and other land managers. By applying this information, they can eradicate sagebrush on large tracts more quickly and efficiently.

WHERE TO CONTROL SAGEBRUSH

Two conditions of sagebrush range may warrant control work. In the first, a dense stand of sagebrush suppresses the understory of desirable forage plants and interferes with grazing by livestock (fig. 3, *A*). In the second condition, desirable understory is lacking or is so sparse that seeding will be necessary following eradication of sagebrush (fig. 3, *B*).

On sagebrush ranges in either condition the probable returns in the form of increased forage and meat production, improved livestock management, and reduced danger of erosion determine the areas where sagebrush should be removed. Certainly it is not desirable or necessary to remove sagebrush on all of the 96 million acres of the sagebrush type. The following guides will help to determine where sagebrush control should be undertaken:

1. *Where sagebrush stands are dense and tall.*—Such stands of sagebrush (fig. 4, *A*) usually indicate fertile, productive soils and favorable soil moisture. High yields of grass can be expected; costs of sagebrush control will be quickly repaid. On the other hand, ranges with short or scattered sagebrush (fig. 4, *B*) generally do not warrant the expense unless they fill an important place in the seasonal livestock operation or unless livestock management may be simplified. Scattered tall sagebrush likewise is reason for caution. Widely spaced or short mature sagebrush often indicates poor soil or low precipitation. Hence, it pays to make sure precipitation and soil fertility are adequate for good forage production before control is undertaken.

2. *Where sagebrush makes up more than one-half of the plant cover.*—Such sagebrush stands definitely reduce forage production and hinder livestock movement, and should be controlled. Since the increase in grazing capacity will be related to the amount of sagebrush removed, investments in control work will bring best returns where sagebrush is thickest.

3. *Where other undesirable plants are not important parts of the plant cover, or will be controlled.*—Other undesirable plants such as rabbitbrush, horsebrush, cheatgrass, or halogeton often make up more than one-tenth of the plant cover. Unless these plants are effectively killed at the same time as sagebrush, they may increase sharply and become even more troublesome than the sagebrush. If undesirable plants can be eradicated only at an increased cost, this makes the lands they occupy secondary choices for control work. Care must be taken

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FIGURE 3.—The amount of desirable forage species in the understory determines the need of seeding after sagebrush control. *A*, Desirable forage plants are suppressed. With removal of the competition by big sagebrush and with good grazing management the desirable plants would develop a satisfactory stand. *B*, The desirable forage plants are lacking or make up less than one-fifth of the plant cover. Here seeding is needed after sagebrush eradication to restore a grass cover, prevent reinvasion by sagebrush, and keep out other undesirable plants.

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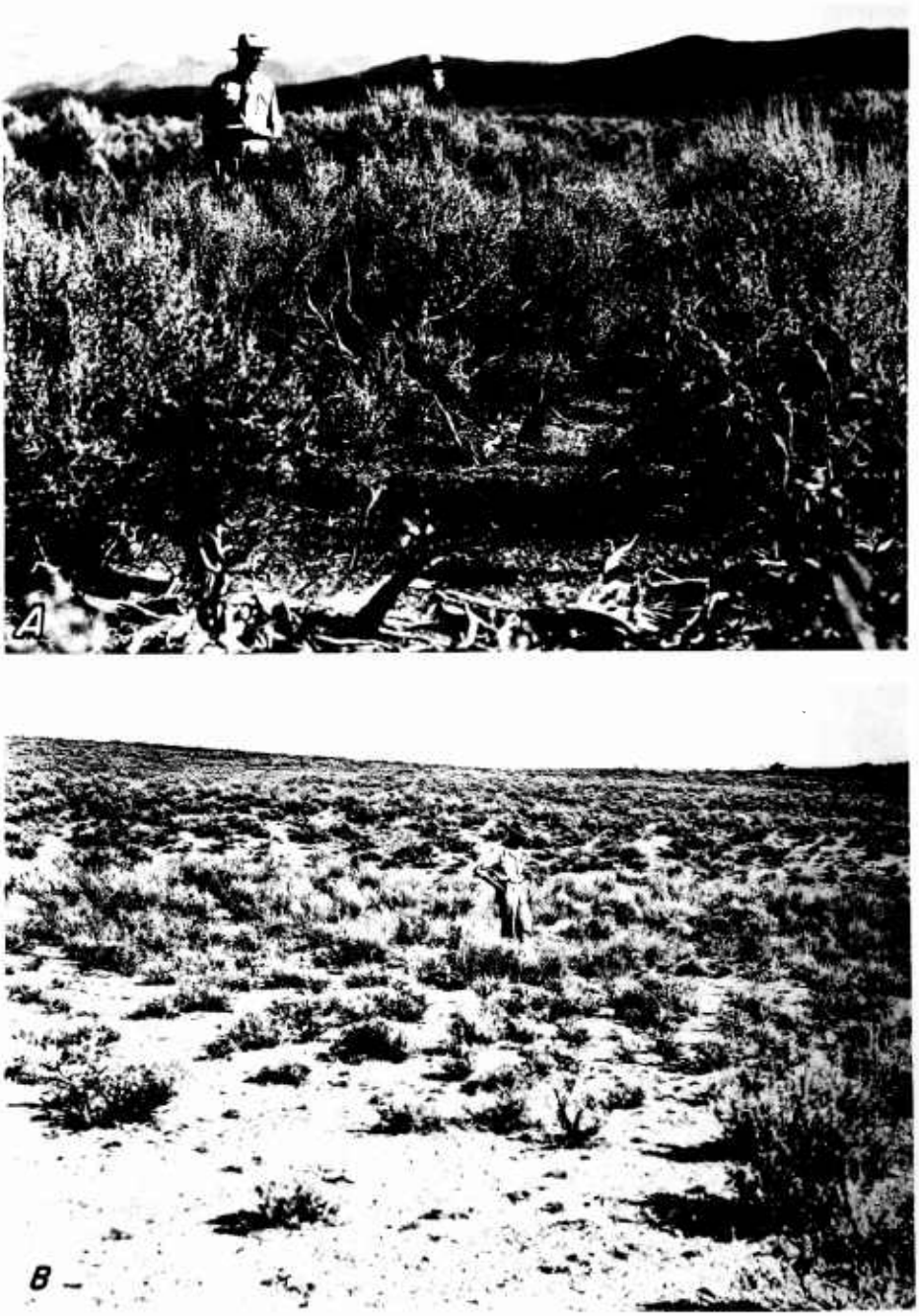

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FIGURE 4.—The density and volume of sagebrush growth is a good indication of the productivity of the site. *A*, Dense, tall stands of sagebrush such as this indicate sites that will produce an abundance of grass and easily repay the costs of sagebrush control. *B*, Scattered stands of short sagebrush usually indicate poor soil or low precipitation. Low forage production can be expected.

in sagebrush control work to avoid exchanging one problem for a more difficult one.

4. *Where good grazing management will be provided.*—Good grazing management will perpetuate increases in grazing capacity and continued freedom from sagebrush; poor management often kills grass plants and encourages the rapid return of sagebrush and other undesirables. Thus, to be sure that the expense of sagebrush control is repaid by increased forage yield, it is necessary to plan and carry out good grazing management as a part of the control program.

5. *Where seeding will be done promptly, if needed.*—Removing the sagebrush is of little value unless a satisfactory stand of grasses can be established by natural or artificial means. Seeding is usually needed where less than one-fifth of the total plant cover is composed of desirable plants. Many sagebrush ranges in this category, however, should not be cleared because their steepness of slope, rockiness, extremely poor soils, or arid conditions do not permit seeding by known methods. It is seldom desirable to remove sagebrush from more range than can be seeded within the first year afterward. If seeding is delayed, undesirable plants become established and reduce seeding success.

6. *Where soils do not erode easily.*—Where danger from wind or water erosion is high, the damage done as a result of sagebrush removal (fig. 5) may more than outweigh the expected improvement in grazing capacity unless a method of sagebrush control is used which

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FIGURE 5.—Sagebrush control should be applied with caution on light soils such as this, where wind erosion may be serious. Here an accidental burn has removed the protective sagebrush cover and allowed the sandy loam soil to blow and form dunes 3 feet high. On adjacent areas, up to 8 inches of soil has been removed by wind.

will not expose the soil dangerously. Practices such as spraying with herbicides, leaving debris on the soil surface, and removal of sagebrush in strips 200 to 500 feet wide along the contour or at right angles to the prevailing wind may be used as safeguards against water or wind erosion. After a good grass cover has been developed on these strips, the brush between should be removed. It should be remembered, however, that sagebrush plants, alone or in strips, are a seed source for potential reinvasion.

7. *Where sagebrush is not needed as forage for livestock and big game, or as upland bird habitat.*—Livestock, especially sheep, depend on sagebrush for browse during the winter and to a smaller extent during spring and fall on ranges where little other browse exists. On some late winter and early spring lambing ranges, the sagebrush also provides protection against blizzards and high, cold winds. On other ranges sagebrush is often a major ration for deer or antelope, especially in winter. On still other ranges, the sage grouse need sagebrush for food and cover. In these places control should not be undertaken except by methods that will only thin the stand, leaving enough sagebrush for the desired balance with grasses and other herbs.

WHEN TO CONTROL SAGEBRUSH

It is extremely important to choose the right season of the year for doing the work. This influences the percentage of sagebrush killed, the length of time that the range remains free of sagebrush, the survival of desirable grasses, the success of seeding, and the cost of the operation. The best season varies with the method used. Following are points to consider in regard to season for control:

1. *Control work should not be done during late fall, winter, and early spring after sagebrush seed starts to ripen and before it germinates.*—Operations during this period may effectively scatter and plant the sagebrush seed. Then the young sagebrush plants will come up before native forage plants have had a chance to thicken up, or at the same time as the seeded species (fig. 6). Studies in eastern Idaho have shown that young sagebrush that comes up the same spring as seeded grass may be initially suppressed but eventually becomes prominent in the stand. Consequently, to increase the chances of keeping the range relatively free of sagebrush for many years, it is desirable to avoid sagebrush control work from the time sagebrush seed starts to ripen until early spring when it has germinated. At the higher elevations at which big sagebrush grows, seed begins to ripen about the middle of September. At lower elevations, it may ripen as late as the last of November. Low sagebrush ripens seed about a month earlier than big sagebrush.

2. *Late summer and early fall is best for such methods as railing, chaining, harrowing, or rolling that uproot, crush, or break off the sagebrush.*—Sagebrush is usually brittle at these seasons and the soil is firm and dry. Under these conditions the kill is more complete than when the same methods are applied while sagebrush plants are willowy and tough.

3. *Late spring and early summer is best for such methods as plowing, disking, or root cutting that tear up or cut off the sagebrush below*

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FIGURE 6.—Thick stands of young big sagebrush such as this frequently result when control follows sagebrush seed ripening. Such stands will eventually dominate the range, and sagebrush control will again be necessary.

the ground level.—Although these methods will kill sagebrush at any time, the equipment works most efficiently and with less breakage when there is still some moisture in the ground. Among other advantages of early season control, moisture in the soil is conserved, the loose soil becomes firmer, and dead roots start the process of decay and conversion into soil organic matter. All of this stimulates better growth of grass following sagebrush control.

4. *Sagebrush is most susceptible to herbicides when it is growing rapidly.*—This closely corresponds to the date when bluegrasses are blooming and wheatgrasses are heading out. This and other points are explained in more detail in subsequent sections.

5. *The period when associated undesirable plants will also be killed is best for reducing overall competition.*—In much of the sagebrush range, associated undesirable plants such as cheatgrass and halogeton are present in substantial amounts. The best time for control of these may differ somewhat from that for sagebrush. For example, where cheatgrass forms a major part of the understory on sagebrush range, plowing should be completed before cheatgrass heads lose their green color. In this case, successful control work cannot be continued as late in the summer as if cheatgrass were absent. Where halogeton occurs, the appropriate period for plowing is after halogeton germinates in May and before it begins to mature in early September.

CHOOSING A METHOD OF SAGEBRUSH CONTROL

Many methods have been used to kill sagebrush. No one method is universally the best because sagebrush grows under widely different conditions and the sagebrush species differ. Suitability of methods varies with density, height, and age of the sagebrush stand, associated shrub species, amount of grass understory, topography, amount of rock on the area, type of soil and its susceptibility to erosion, facilities available for doing the work, size of the area to be treated, personal preference, and many other factors.

In choosing a method the following eight points are important:

1. *Use a method that kills most of the sagebrush.*—As a general rule, the more extensive the kill the better the method. When all sagebrush is killed, its return to the range is very slow because the seed source has been largely eliminated. However, control that leaves fewer than three sagebrush plants per 100 square feet is considered successful.

Exceptions to the general rule of killing as much of the sagebrush as possible occur where some sagebrush on the range has value for protection of or grazing use by domestic livestock or game, or in controlling wind erosion.

2. *Use a method that also kills associated undesirable species.*—Where the associated undesirables are so abundant as to become troublesome after sagebrush control, the method chosen should effectively control them also. Rabbitbrush or horsebrush not killed during sagebrush removal may increase so sharply as to prevent range improvement. Undesirable annuals present on the range such as cheatgrass and halogeton may become a serious barrier to the establishment of seeded grasses following sagebrush removal.

The definitions of undesirable and desirable plants must be flexible enough to allow for differences in species of plants on the range, season of use, class of livestock or game using the range, and other factors. Palatable perennial grasses, broad-leaved herbs, and shrubs such as bitterbrush and fourwing saltbush are generally accepted as desirable. Snowberry, black sagebrush, rubber rabbitbrush, and similar plants may be desirable or not, depending on season, type of use, and location.

3. *Use a method that does little damage to perennial grass remnants and other desirable plants if artificial seeding is not necessary, but if seeding is planned, use a method that kills most of the vegetation.*—On many ranges, enough desirable grasses remain to revegetate the area after sagebrush is removed. They may need only release from sagebrush competition. Seeding will be necessary if these remnants are destroyed; this nearly doubles the cost of treatment. There is also the uncertainty of getting stands from seeding. Therefore, where enough desirable plants are present to produce a good stand, they should be saved if possible.

If the aim is to improve forage quality through seeding, then particular attention should be paid to killing all plants including scattered desirable native plants that might compete with the seeded species. Past efforts to supplement seeded species by leaving desirable natives

have often resulted in poor seedbed preparation and in too much competition for successful establishment of seeded species.

4. *Use a method that leaves the land suitable for seeding, where seeding is necessary.*—In dense stands of sagebrush, such methods as spraying with herbicides or undercutting with root planes leave a barrier of dead woody material that makes it difficult to use grain drills. Additional operations are often necessary to break down or windrow this woody material before drilling.

5. *Use a method that is widely applicable.*—Where extensive tracts of range are to be treated, a method that is effective for killing young and old brush of various size, and on terrain varying in slope and stoniness, is much more useful than a method applicable only to restricted conditions.

6. *Use a method that utilizes readily available equipment adapted to other uses.*—Unless a large amount of sagebrush control work is to be done, purchase or construction of expensive equipment for this purpose alone may not be warranted. Often, however, the cost of recommended machinery is more than repaid by the more efficient eradication achieved. In many instances several individuals can purchase more costly machinery cooperatively, thereby reducing cost per acre and securing better sagebrush control. Contracting for sagebrush control by experienced operators with efficient equipment is often most economical for the landowner. This is particularly true for spraying operations.

7. *Use a method that will not increase erosion hazards.*—Some methods destroy all woody material and litter or cover it with soil to such an extent that wind and water erosion become serious hazards. Where soils are light and subject to drifting, or on slopes where water erosion is likely to occur, it is advisable to choose methods that will leave litter and plant material as a protective covering on the soil surface. In addition, a method that helps fill gullies and break down existing erosion patterns is desirable.

8. *Choose a method that is economical but also satisfies any of the seven points above that may apply to the area to be treated.*—Supervision and labor; transportation of men, equipment, and materials; interest on investment; initial costs of new equipment; and equipment operation, repair, and depreciation are all to be considered in calculating costs.

Costs vary with method. However, costs of applying a single method can vary more widely as a result of differences in experience, care in planning the job, and size of area treated.

Other values of rangeland must be examined when considering relative costs of different methods. For example, where watershed values are high and danger of erosion is present, it may be desirable to choose a method that leaves sagebrush litter on the soil surface, even though it costs more than some other adaptable method.

METHODS FOR SAGEBRUSH CONTROL

Both mechanical and nonmechanical methods have been used for the control of sagebrush. Most methods are mechanical. Some employ equipment such as the one-way disk (wheatland type), plow

and the offset disk, the anchor chain or the road ripper, all of which were built for other purposes; some employ equipment such as the brush cutter and beater that were built for other types of brush; and a few employ such equipment as the sagebrush rail, pipe harrow, and brushland plow that were designed specifically for sagebrush control. Some methods, including burning, flooding, and spraying with herbicides, are essentially nonmechanical. In recent years, spraying has become the most popular method for control of big sagebrush where seeding is not planned.

The most widely used methods for control of sagebrush on rangelands include burning, spraying, plowing or disking, chaining, cutting, and harrowing. A summary of their advantages and limitations is presented in table 1. These six methods are fully described and seven other methods are briefly considered in the following sections.

Planned Burning

Fire is one of the oldest, most widely adaptable, and least expensive methods for controlling sagebrush. It is also the most frequently misused. To insure range improvement it must be used skillfully. Proper precautions must be taken in selecting the area to be burned and the time of burning, and in controlling the fire; otherwise, range deterioration may easily result.

Simple, practical rules and guides on where, when, and how to burn and the grazing management to use after burning are presented in U.S. Department of Agriculture Farmers' Bulletin No. 1948, "Sagebrush Burning—Good and Bad." This bulletin will be helpful for anyone considering the use of fire for sagebrush control.

Thousands of acres of sagebrush range are burned over by accidental fires each year. Proper grazing management and seeding, where needed, may be effective methods for restoring a good forage cover to these areas.

The advantages and limitations of planned burning for sagebrush control are evaluated under the eight points previously listed under "Choosing a Method of Sagebrush Control," as follows:

Kill of sagebrush.—If burning is done properly, it gives a complete kill of young and old plants of big, low, and black sagebrush. Kill of threetip sagebrush is high, but a small percentage of the bushes may sprout from the base. Kill of silver sagebrush, which sprouts readily from the stem base and roots, is generally low.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush, horsebrush, and snowberry are usually not killed by planned burning. Good kills of rubber rabbitbrush have been obtained from late summer burning, but this result is not consistent. Early or midsummer burning of cheatgrass will bring out a much reduced stand in the following spring; burning in the late summer or early fall is less effective.

Effect on desirable forage plants.—Damage to most desirable forage plants is fairly low. If burning is done after the principal perennial grasses mature seed, reduction in their vigor the following year is not likely to exceed 30 or 40 percent. On the other hand, Idaho fescue and bitterbrush (at some locations) have been severely damaged by

burning, regardless of the season. In eastern Idaho and parts of Utah, high percentages of bitterbrush have later sprouted from the stem base, particularly with light burning or on moist soil.

Ease of seeding afterward.—Where seeding is necessary afterward—except on rough and rocky areas or on slopes over 30 percent—seed is easily planted by use of a grain drill (fig. 7). Where land is too rocky or steep for drilling, the seed can be broadcast and covered by anchor chains or a heavy pipe harrow with fair success. Sagebrush ashes alone are not deep enough to adequately cover seed.

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FIGURE 7.—Planned burning on this area removed a dense stand of sagebrush that had little value for grazing. After burning, the more level, relatively rock-free areas were drilled without further preparation. Good stands of grasses resulted.

Adaptability to terrain and soil.—Excluding hazard of erosion, burning is widely applicable regardless of rockiness of soil, steepness of slope, or irregularity of terrain. It must be possible, however, to construct a wide, safe fireline.

Availability of equipment.—Bulldozers or graders for clearing firelines and torches for setting fires are readily available.

Effect on erosion hazard.—Debris and litter are largely consumed by the fire, and the soil is seriously exposed to erosion. Consequently, burning should not ordinarily be used on steep slopes or on soils that blow or wash readily.

Cost of control.—For tracts of 1,000 acres or more, the cost of sagebrush control by planned burning is $1 to $4 per acre, on the basis of 1962 wages and equipment rental rates. This includes up to $200 per mile for constructing firelines, the direct cost of burning the area, and the cost of leasing additional range for 1 or 2 years to permit protection of the burned area.

General adaptability of planned burning for sagebrush control.—Planned burning is most useful on fairly level tracts of 1,000 acres or more, either to permit the increase of perennial grasses and broad-leaved herbs already present or to prepare the land for seeding. Many

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TABLE 1.—*Summary of limitations and advantages of the six most common methods of big sagebrush control*

Item	Method of control		
	Planned burning	Spraying with herbicides	Plowing or disking once over
Kill of big sagebrush	95 to 100 percent of all ages	50 to 99 percent of large old; slightly less of young.	70 to 99 percent of old; slightly less of young.
Kill of associated undesirable plants.	Not effective on sprouting shrubs and some annuals.	Good on rabbitbrush resprouted after fire.	Usually not effective on sprouting shrubs; good on cheatgrass.
Effect on desirable forage plants	Low kill of grass, 30 to 40 percent loss in vigor first year. Nonsprouting shrubs killed.	Grass not damaged; some broadleaved herbs and nonsprouting shrubs may be damaged.	Kills all except those that sprout or spread by rootstocks.
Ease of seeding after treatment	Easily done with drills; seed can be aerially broadcast and covered with anchor chain or pipe harrow; firm seedbed.	Standing dead brush may be barrier to drilling. Seed can be aerially broadcast and covered with anchor chain or pipe harrow.	Easily done with drills; seedbed may require packing.
Adaptability to terrain and soil	No limit except as imposed by fire danger and erosion hazard.	Virtually unlimited	Limited to little or no rock except with brushland plow.
Availability of equipment	Equipment generally available; brush rake useful; experience primary need.	Commercially available	Plows and disks commercially available; brushland plow is custom made.
Effect on erosion hazard	Exposes soil, destroys litter (unsuited to highly erosive areas).	Slight if any	Exposes soil to moderate degree.
Cost of control (1962)	$1 to $4 per acre on tracts of 1,000 acres or more.	$2 to $6.50 per acre	$4 to $7 per acre.

TABLE 1.—*Summary of limitations and advantages of the six most common methods of big sagebrush control*—Continued

Item	Method of control		
	Anchor chaining	Cutting, heating, or shredding	Harrowing
Kill of big sagebrush	60 to 80 percent of old rigid brush, 10 to 20 percent each additional time over; 10 to 40 percent of young flexible brush.	50 to 90 percent of large old; 30 to 60 percent of young flexible.	30 to 70 percent of old rigid; 10 to 30 percent of young flexible.
Kill of associated undesirable plants.	Not effective on sprouting perennials or on annuals.	Not effective on sprouting shrubs or herbaceous species.	Not effective on sprouting shrubs or annuals.
Effect on desirable forage plants	Nonsprouting shrubs are damaged; sprouters recover; little damage to herbaceous species.	Little damage to herbaceous plants; nonsprouting shrubs damaged.	10 to 20 percent of bunchgrasses uprooted; damage to bitterbrush slight.
Ease of seeding after treatment	Broadcast before second chaining, or drill after final chaining where feasible.	Broadcast before cutting or beating heavy brush; drill after treating light brush.	Seed broadcast ahead of harrow well covered; drilling difficult.
Adaptability to terrain and soil	Feasible on all soils and on slopes exceeding 30 percent. Breakage rare.	Limited to sites without protruding rocks.	Particularly suited to rocky ground and rough terrain.
Availability of equipment	Commercially available through coastal salvage companies, or new.	Commercially available	Not commercially available; can be built in machine shops.
Effect on erosion hazard	Erosion usually decreased when approximate contours followed.	Mulch left decreases hazard	Usually decreases hazard.
Cost of control (1962)	$0.75 to $2.50 per acre each time over.	$4 to $10 per acre	$4 to $7 per acre.

stands of sagebrush, however, can be burned only under conditions of extreme fire hazard. Under weather conditions that make burning relatively safe, such stands cannot be burned because they are too open and lack an understory of grasses to carry the fire. Where the erosion hazard is high or the dominant perennial grasses are subject to serious damage, burning should not be used.

Although burning sounds simple, it is one of the most difficult and dangerous methods. To use fire properly and safely, it is necessary to have experience in the behavior of fire, the conditions suitable for ignition, and methods of fire control. Moreover, ample equipment and men with some experience must be on hand to insure keeping the fire under control. All burning operations should comply strictly with State and county laws regarding burning. *Fire is a dangerous tool for the inexperienced person to handle*, but is a valuable one when intelligently used.

Spraying With Herbicides

Herbicides should be applied only when needed, and should be handled with care. Follow the directions and heed all precautions on the container label. If herbicides are handled or applied improperly, or if unused portions are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, fish, and wildlife, and may contaminate water supplies.

Both experimental and practical spraying with 2,4–D and 2,4,5–T have produced good kills of big, low, black, and silver sagebrush. Kills of 50 to 99 percent of big sagebrush plants have been reported from most Western States.

The recommended procedure varies somewhat from place to place and with different species of sagebrush. In general, results show that spraying should be done when sagebrush is actively growing and there is still ample soil moisture for growth. Usually this is when native understory bluegrasses are flowering and the wheatgrasses are just heading out. The effective spraying season begins when small bluegrasses are heading out and ends when they are losing green color rapidly and the surface foot of soil is dry.

One or two pounds (acid equivalent rates) of ester formulations of 2,4–D or one pound of 2,4,5–T in 5 to 10 gallons of water or 3 to 5 gallons of diesel oil per acre are the rates of herbicide and carrier ordinarily used. Early in the season 1 pound of 2,4,5–T is equal to 2 pounds of 2,4–D on big sagebrush. Later in the season both are equally effective. At present prices, 2,4–D gives cheaper control of big sagebrush than 2,4,5–T. If water is used as the carrier, a wetting agent at 0.1 to 0.5 percent by volume is needed to improve the wetting properties. An oil-water emulsion at 1 : 5 to 1 : 10 ratio can also be used. Low-volatile esters are recommended because they are less dangerous to use near valuable timber and cultivated crops.

Since the chemicals do not appear to be translocated radially in woody portions of sagebrush branches and stems, degree of kill depends largely upon how well the spray solution covers the herbage. The more dense the brush, the greater the volume of spray material needed. Application of the spray solution is by ground rigs, airplanes, or helicopters (fig. 8).

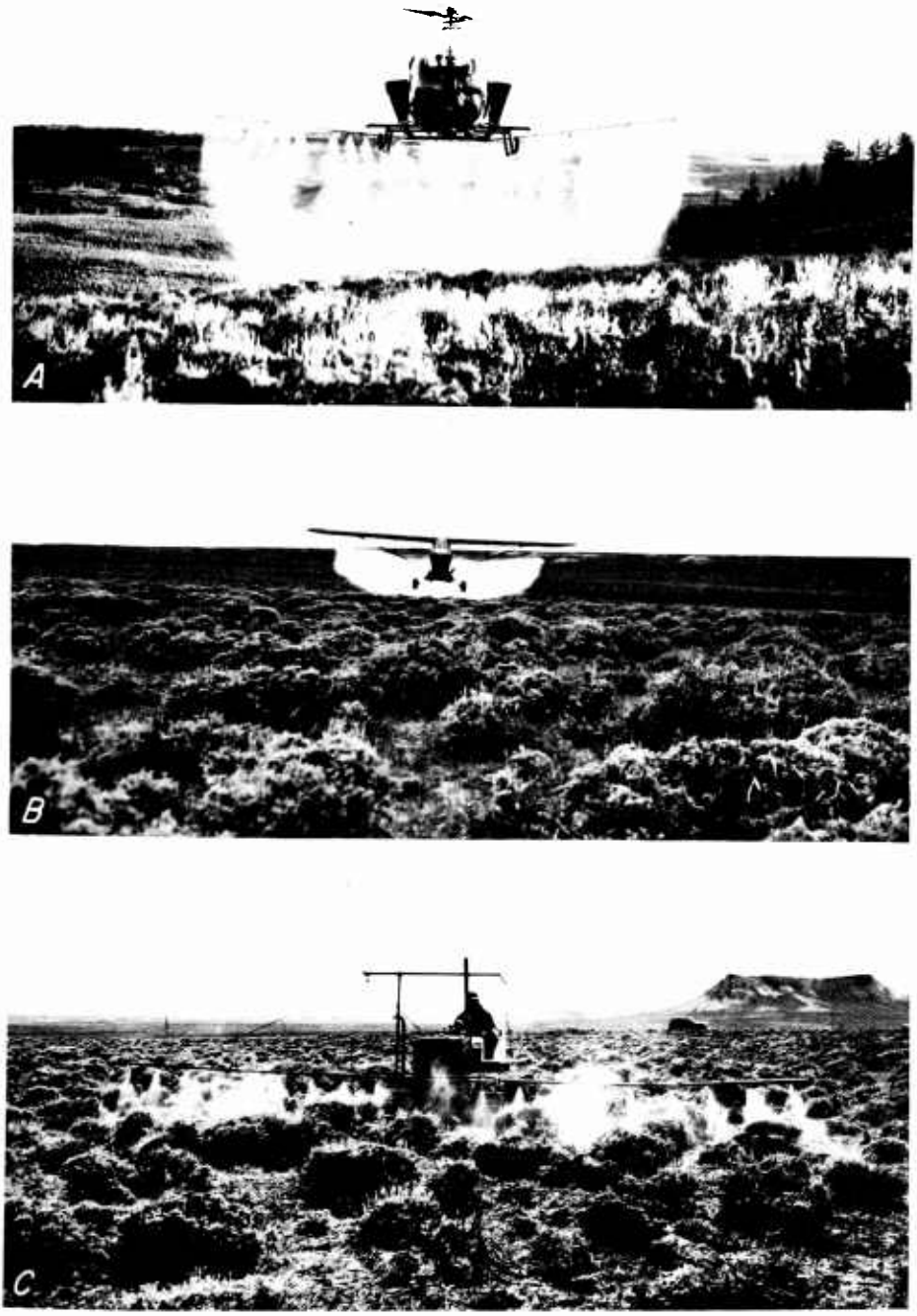

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FIGURE 8.—Herbicides may be sprayed by air or ground applicators. *A*, Helicopter spraying in Utah. *B*, Airplane spraying herbicide on sagebrush in Wyoming. *C*, Ground spray outfit mounted on a crawler tractor. This outfit covers a 30-foot swath and travels 3 miles per hour.

The advantages and limitations of spraying with herbicides for sagebrush control are as follows:

Kill of sagebrush.—While results are variable, satisfactory kills of big, low, black, and silver sagebrush of all age classes have been reported. In stands of mixed ages the younger plants are least injured. Silver sagebrush is best killed near the end of the effective season for spraying big sagebrush.

Kill of associated undesirables.—Rabbitbrush and broom snakeweed can be killed along with sagebrush by increasing the 2,4–D ester to 3 pounds per acre and spraying towards the last of the season that is effective for killing big sagebrush, and when soil moisture is still adequate for growth of rabbitbrush. This is when new twig growth on rabbitbrush exceeds 3 inches in length and when wheatgrasses are heading out. Earlier application would kill the tops only and encourage sprouting. One to two pounds per acre is sufficient on rabbitbrush sprouts the year following burning. This spray kills prickly-pear on some areas but not on others; it does not damage spineless horsebrush.

Effect on desirable forage plants.—Perennial grasses are not damaged by spraying with 2,4–D although grass seedlings are damaged with heavy rates. Damage to broad-leaved herbs varies from light to heavy. Important forage species that are damaged moderately to severely include arrowleaf balsamroot, milkvetch, oneflower helianthella, bluebell, and tailcup lupine. Important forage plants unharmed or slightly damaged are tapertip hawksbeard, penstemon, geranium, and groundsel. Spraying is not recommended where many desirable broad-leaved herbs are present that will be damaged by 2,4–D.

Associated desirable shrubs on arid sites such as shadscale, winterfat, and Gardner saltbush are readily killed by 2,4–D.

On mountains and foothills, aerial portions of most shrubs are killed, but most of them resprout vigorously. Serviceberry and chokecherry are among the most susceptible shrubs. Damage to bitterbrush from spraying is light to moderate. Damage to bitterbrush growing in sagebrush is reduced by spraying 2,4–D at low rates early in the effective season for spraying big sagebrush. Douglas-fir is little damaged, whereas lodgepole pine shows more damage. 2,4–D kills aspen tops, but there is abundant sprouting following spraying.

Ease of seeding afterward.—Where sagebrush is short or stands are open, drilling has been successful after spraying. Ordinarily, dense tall stands of big sagebrush must be knocked down by an anchor chain, rail, or harrow before drilling. The newly developed, rugged Rangeland drill will effectively plant following spraying on all sagebrush areas except those having exceptionally large and dense brush. Information regarding the purchase of this drill may be obtained from the U.S. Forest Service Equipment Development and Testing Center, Arcadia, Calif.

Adaptability to terrain and soil.—Spraying is widely applicable. Use of ground rigs is limited to relatively level areas, but airplanes and helicopters permit application of spray to nearly all sites. There are rather clear indications that big sagebrush control by spraying may be more effective in swales or on level bottom lands than on ex-

posed slopes or ridgetops, because of variations of soil moisture. Care should be taken to avoid letting the spray reach valuable timber or cultivated crops near the areas being treated, especially with high-volatile esters.

Availability of equipment.—Many companies specialize in spraying with ground rigs, airplanes, or helicopters. Several types of equipment for ground application are readily available. Ground sprayers usually need reinforcement of the booms for use on rough and rocky ground.

Effect on erosion hazard.—The erosion hazard usually is not increased by spraying. The dead standing brush, undisturbed litter cover, and undisturbed soil and grasses normally check erosion. Care should be taken in spraying streambanks and slopes where erosion may increase as the result of the loss of plant cover.

Cost of control.—Costs of spraying are about the same as for plowing or disking. Based on present prices of 2,4–D and 2,4,5–T or mixtures of the two, and the present cost of the carrier and of application by airplane, the total cost of spraying sagebrush from aircraft ranges from $2.50 to $6 per acre. Application by ground rigs is likely to cost about $2 more.

General adaptability of spraying for sagebrush control.—Present indications are that spraying is most useful either on ranges that have a good understory of native grass to thicken up and replace sagebrush, or on seeded areas that have been invaded by sagebrush (fig. 9). It may also be useful for killing sagebrush preparatory to seeding on areas where sagebrush is short or sparse. Spraying is sometimes used to prepare perimeters of areas for burning. Sometimes spraying in May or June can be followed by burning the next March or April when the fire hazard is low. The interior may then be burned more safely in July or August.

Widespread spraying of sagebrush should be undertaken with caution. Numerous large-scale spraying jobs have been failures or poor successes. Lack of knowledge about effects of herbicides on the associated desirable broad-leaved forage plants and shrubs, and on animal life depending upon this vegetation, gives further reason for caution. Since new information on chemicals and methods is constantly becoming available, anyone considering this method should get the latest information from county agricultural agents, State agricultural colleges, or representatives of Federal agencies acquainted with range-improvement work. Most States have laws governing the use of herbicides for plant control. Consequently, anyone planning to use herbicides for sagebrush control should check his county and State laws.

Plowing or Disking

Despite the improvement in herbicides, plowing and disking continue to be the most valuable methods of sagebrush clearing where seeding is to be done—especially by drilling. The three implements used widely are the brushland plow, the one-way disk plow (wheatland type), and the heavy offset disk (figs. 10, 11, and 12).

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FIGURE 9.—*A*, Sagebrush range with a good grass understory just before it was sprayed with 2,4–D in 1960. *B*, Two years later grass production had increased severalfold as the result of spraying and suspension of grazing.

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FIGURE 10.—The brushland plow is especially useful for the control of big sagebrush preparatory to seeding where some rock is present. The pair of disks on the left side is rising over a rock. Sturdy construction and the separate mounting of each pair of disks permit this implement to be used on moderately rocky land without excessive breakage.

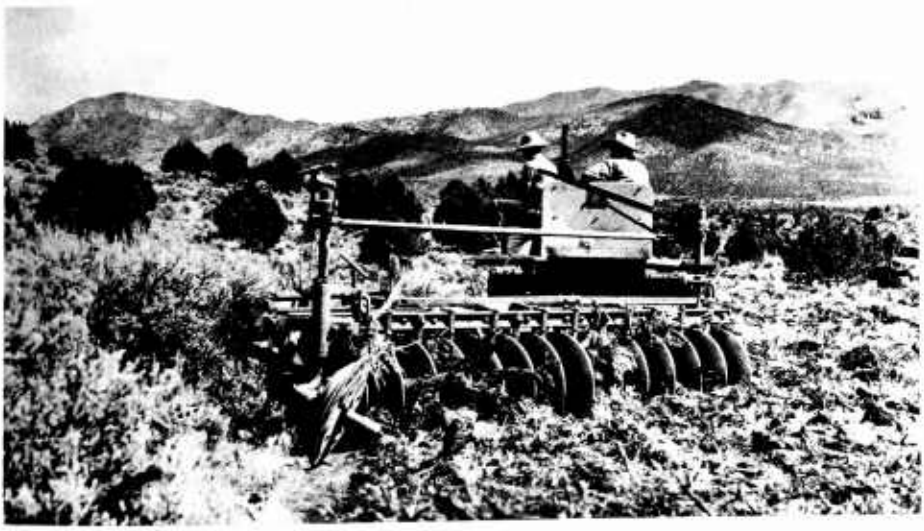

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FIGURE 11.—One-way disk plow being used on rock-free ground to eradicate big sagebrush in preparation for seeding.

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FIGURE. 12.—Heavy offset disks effectively kill sagebrush and prepare a good but loose seedbed. They cut well in hard-packed soils. They should be used only on relatively rock-free areas.

A 40- to 45-horsepower tractor and a plow or disk with a 10-foot cutting width form a convenient unit for killing sagebrush under most conditions. The plow or disk should weigh at least 300 pounds per foot of cutting width and be equipped with disks preferably 28 inches in diameter. However, implements with 24- and 26-inch disks have done good jobs. Use of a tractor with 3 to 5 horsepower per foot of cutting width is ordinarily advisable, but the power requirement varies widely with soil conditions, amount of soil moved, density of brush, and topography.

The heavy offset disk, especially one weighing 500 pounds or more per foot of cutting width, requires more draft power than either the one-way or the brushland plow because, lacking adequate depth control, it usually moves more soil and moves it twice. This heavy disk is practically the only implement that is effective in killing sagebrush on heavy, compact, crusted soils, such as those in the dry-lake bottoms of northeastern California. Such lands are much more easily plowed when moisture is present near the soil surface than at other times. Crawler-type tractors are the most satisfactory, but wheel tractors of equivalent power—especially if their traction is augmented by wheel weights, large tires, or solution in the tires—may be substituted where the ground is fairly level and the soil is firm. Though smaller tractors can be used on level or moderately sloping ground, the greater

speed and power of larger tractors usually more than offset their higher operation costs.

In order to save power, the plow or disk should cut to the least depth that will provide an adequate kill. Three to four inches deep is usually sufficient. Allowing disks to cut too deeply should be avoided on heavy land where a clay subsoil may be turned up and cause surface crusting, or on sites where a shallow soil lies over coarse sand or gravel. Moreover, deep plowing or disking loosens the seedbed too much. Grass seedlings root themselves better in firm seedbeds. Deep plowing followed by packing may be advisable where mineral soil can be brought up to cover fluffy, organic surface soil sometimes found in valley bottoms where sagebrush has replaced native meadows.

All plows and disks cut better, require less power, and give better brush kills in the late spring and early summer, or at other times when the ground contains moisture than when it is dry. Spring plowing also allows loose soils to settle to some extent and part of the plant material to decay before seeding is done later in the year.

Since the one-way disk plow, offset disk, and brushland plow are in general similar, their advantages and limitations will be described together.

Kill of sagebrush.—Plowing or disking, correctly done, will kill 70 to 99 percent of all except silver sagebrush. The bigger the sagebrush and the softer the ground, the better the kill. This applies even to stands 8 to 10 feet in average height. Unless plowing is deeper than is recommended for ordinary work, thick stands of young plants and silver sagebrush will not be satisfactorily eradicated. If plows and disks are properly adjusted, one plowing effectively kills young and old sagebrush alike, except on heavy, compact, dry soil where these plows do not cut, and many of the younger plants are skipped. It may be necessary to plow such areas twice. Light-colored, heavy-textured soils, however, tend to puddle and crust when tilled excessively.

The brushland plow gives a slightly higher kill of brush than the one-way disk plow or ordinary offset disk. However, the heavy offset disk, weighing 500 pounds or more per foot of cutting width, often equals the brushland plow in brush control. Heavy disk plows now available also equal the brushland plow in effectiveness unless rocks prohibit their use.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush are not killed unless the disks cut much deeper than the customary 3 to 4 inches. In some instances, fairly effective rabbitbrush control has resulted from plowing an area twice. This doubles the cost, but is usually justified where rabbitbrush covers small areas in extensive sagebrush stands. Cheatgrass and other undesirable annuals generally are effectively thinned if the work is done in the spring after seed germination but well before seed ripening; control will be ineffective if work is done after seed starts to ripen. Cheatgrass can also be satisfactorily controlled by plowing after fall germination, but this is usually too late for sagebrush control because its seed is ripe by then.

Effect on desirable forage plants.—Nearly all perennial plants except those that spread by rootstocks or sprout from roots, are killed by plowing or disking at a depth adequate for effective control of sage-

brush. These methods should be limited, therefore, to ranges that are to be seeded.

Ease of seeding afterward.—Grain drills can be used after plowing or disking, especially on rock-free or slightly rocky soils where the cover of big sagebrush was not extremely dense before the plowing. Considerable difficulty in drilling may be experienced where the brush was big and dense; here it may be necessary to broadcast the seed. There may also be some difficulty in controlling depth of drilling seed on areas plowed in summer and early fall because the soil may be rather loose. Compaction by heavy rollers when the soil is damp greatly improves such seedbeds. Efforts at compaction when the soil is perfectly dry not only fail but damage soil structure and encourage wind erosion. Spring plowing helps to overcome this difficulty.

Adaptability to terrain and soil.—Plowing or disking with conventional farm implements is limited to rock-free or slightly rocky sites on slopes of less than 20 percent. Otherwise breakage will be unduly high. The brushland plow permits treatment of more rocky sites without undue breakage. Plowing or disking effectively reduces the existing stand of sagebrush during any season of the year when weather and soil conditions permit the work.

Availability of equipment.—Heavy one-way offset disks equipped with large-sized disks are made by several companies and are readily available. The brushland plow was developed by the U.S. Forest Service, after the design of an Australian stump-jump plow, for brush control on rough, rocky lands. It is now available on a custom-made basis. Addresses of suppliers of this plow may be obtained from the Forest Service, U.S. Department of Agriculture, Washington, D.C., 20250.

Effect on erosion hazard.—Part of the debris may best be left on the surface to protect the soil. This and loose, absorbent soil ordinarily decrease the erosion hazard. In some situations, on the other hand, the hazard of wind or water erosion is high because of slope or lightness of soil; here the use of other methods should be considered.

Cost of control.—Usually the cost is moderate. One well-trained operator with a 40- to 45-horsepower crawler tractor and a 10-foot disk or plow can average 1½ to 2 acres per hour, with a minimum of 1 and a maximum of slightly more than 3 acres. Accomplishment is at its lowest where the sagebrush range is in tracts of 10 acres or less, or the terrain is rough with steep slopes. Maximum acreages per hour are possible on large tracts of 1,000 acres or more where the ground is only slightly rocky, practically level, and not gullied.

Costs are slightly different for the three implements and must include original purchase price, power required to pull the disks or plows, and costs of maintenance and depreciation. The purchase price of the heavier, noncommercial brushland plow is at least twice that of offset disks or one-way disk plows of equivalent cutting width. Extremely low breakage, maintenance, and depreciation largely offset the greater initial cost and difficulty of transportation. The greater adaptability of the brushland plow to rough and rocky rangelands sets it apart as the most widely useful machine for plowing rocky land. Maintenance and depreciation costs are much lower for the heavy-duty offset disk than for the one-way, if rocky land is treated.

Careful operation and frequent maintenance are important in keeping breakage of all implements at a minimum.

Average costs for plowing or disking under ordinary conditions, based on 1962 wages and rates for equipment rental, range from $4 to $7 per acre. Costs are generally least with the brushland and highest with the one-way disk plow because of differences in amounts of breakage and maintenance. Because it requires approximately one-third greater draft power, the offset disk costs more to operate than the one-way disk plow or the brushland plow. On large tracts, use of two or three implements pulled by a single 60- to 130-horsepower tractor can reduce plowing costs by one-fourth to one-third.

General adaptability of plowing or disking for sagebrush control.—Plowing is primarily useful on rock-free to slightly rocky ranges where seeding is to be done afterward. The heavy offset disk and one-way disk plow have proved effective in eradicating all types and ages of sagebrush, except silver sagebrush, on soils that are rock-free or have only a little rock. An extra heavy offset disk has proved the best implement for use on heavy, crusted soils. The brushland plow has proved effective not only on rock-free sagebrush lands but also where scattered large rocks are likely to cause breakage of one-way disk plows and offset disks.

In order to obtain satisfactory control of tenacious brush under difficult soil conditions, it is sometimes desirable to allow the ground to lie fallow for a year between plowings.

Anchor Chaining

Anchor chaining, a common method of controlling juniper and pinyon in the West, has proved to be a rapid, low-cost method for reducing competition of big sagebrush (fig. 13). It provides only

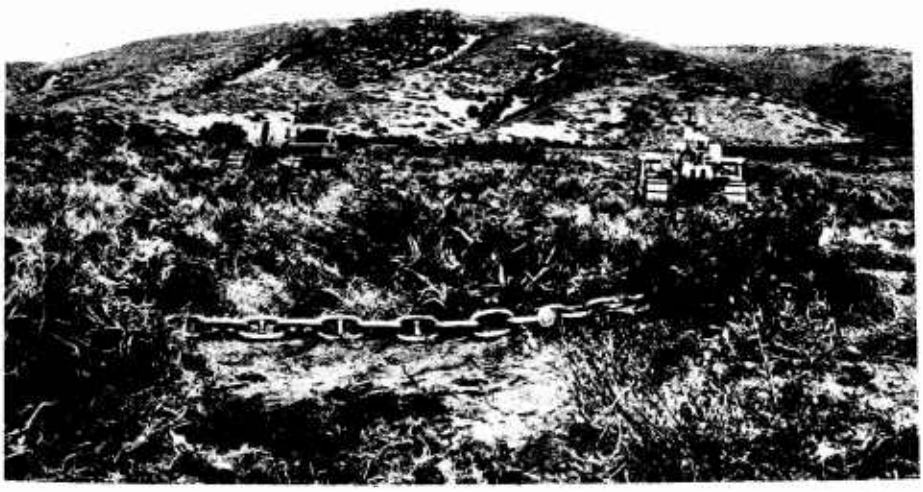

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FIGURE 13.—Heavy anchor chains looped between large tractors readily uproot or break off brittle sagebrush. However, for young flexible sagebrush two to three times over may be needed to remove satisfactory amounts of the brush.

partial control, but costs less than other methods. It is especially useful where a mere thinning of the brush stand is desired, and for the removal of juniper and pinyon trees as well.

Chains weighing from 25 to 90 pounds per link have been used. Chains with links heavier than 70 pounds eliminate more sagebrush than lighter chains. Twice over is usually desirable. The second chaining not only removes additional brush, but also facilitates seeding operations by covering seed broadcast between the two chainings or by breaking down the brush to ease subsequent drilling.

Two crawler tractors of at least 40 horsepower each, with a 200-foot heavy chain looped between them, can cover a swath about 150 feet wide. Up to 600-foot lengths of lighter chain, with links weighing 50 pounds or less, have been used successfully to thin and break down sagebrush and make more forage available. The lighter chains permit more rapid treatment, but heavy chains remove more brush.

Advantages and disadvantages of chaining follow:

Kill of sagebrush.—Up to 90 percent control of big sagebrush has been obtained from once-over treatment using heavy chains on even-aged, old, brittle brush, but 50 to 70 percent is more common. On younger, flexible stands of sagebrush, from 10 to 40 percent kills are accomplished with once-over chaining. Two or three times over generally are required to control more than 50 percent of flexible sagebrush; the second and third times over, in opposite directions, usually increase control 10 to 20 percent. Chaining generally is more effective on rocky ground than on rock-free ground.

Kill of associated undesirables.—Low kills result on woody species that sprout from the crown such as snowberry, horsebrush, broom snakeweed, and rabbitbrush. However, these shrubs are usually broken down enough to permit herbaceous perennials or seeded grasses to establish and gradually increase. Annuals increase markedly immediately after sagebrush competition is reduced, but within a 3- to 5-year period perennial herbs usually increase enough to largely suppress the annuals. Where desirable perennials are scarce, seeding of adapted perennials should be a part of the restoration operation in conjunction with chaining.

Effects on desirable forage plants.—Damage to the desirable herbaceous plants is negligible, but varies on desirable browse species. Damage to tall bitterbrush plants appears to be high the first year, but these shrubs recover rapidly and within 2 to 3 years usually are more vigorous and productive than before. Chaining can be highly destructive to tall-growing single-trunk cliffrose and curlleaf mountain mahogany. But bushy plants of these shrubs show little damage after a year's growth; in fact, they usually respond with greater growth and seed crops that compensate for the loss of the larger upright plants. True mountain mahogany, fourwing saltbush, and saskatoon serviceberry are knocked down but usually recover.

Ease of seeding afterward.—Broadcasting, by either airplane or mechanical broadcasters, is the most practical method of seeding in conjunction with chaining. Good stands usually result from broadcast seeding between two chainings. The second chaining, in the direction opposite to the first, is helpful in getting a desirable amount of seed coverage. Drilling is usually possible following twice-over with

a heavy chain. Where brush is exceptionally heavy, a third time over may be necessary to prepare for effective operation of a drill.

Adaptability of terrain and soil.—Chaining is adapted to wide variation in terrain, and is useful on areas too rocky and sloping for other mechanical methods. It has been found feasible on slopes exceeding 30 percent. Chaining that approximately follows the contour is preferable. One tractor often can work on a ridgetop and the other in the canyon bottom, so that the chain is pulled across the slope. Where the slope is steep and too long for this maneuver, a tractor with a bulldozer can cut out a trail for the uphill track.

Availability of equipment.—Anchor chains of various weights can be readily purchased from coastal salvage companies at much lower prices than new chains, which are available from steel companies.

Effect on erosion hazard.—Chaining usually decreases erosion, especially where treatment is at right angles to the prevailing drainage and gully patterns. Considerable brush and debris are usually dragged into the gullies; this checks erosion.

Cost of control.—On large areas, costs of $0.75 to $2.50 per acre are usual for once-over chaining where swaths 100 to 150 feet wide are possible. Twice-over treatment approximately doubles this amount. Actually, chaining is the least costly mechanical treatment for large areas.

General adaptability for sagebrush control.—Chaining is a satisfactory, low-cost method of removing old, mature, brittle stands of sagebrush from extensive areas. Adapted to a wide range of terrain conditions, chaining can be applied to areas where mechanical treatment previously has been considered uneconomical because of rocks and steep slopes. The method also is useful for knocking down and scattering dense brush killed by herbicides, and for covering seed broadcast into such areas. It is not an efficient method for controlling young, flexible sagebrush.

Cutting, Beating, or Shredding

In recent years the cutter, beater, or "shredder" type of implement has been widely used in sagebrush control. These machines cut and shred the woody and herbaceous top growth. They leave a coarse litter layer on the soil surface.

Cutters and beaters or "shredders" are mainly of two types. The type most widely used works like a rotary lawnmower. It consists of horizontal cutting blades fastened to the lower end of one or more vertical shafts (fig. 14). The second type of machine is a beater consisting of a rapidly revolving drum or shaft, mounted between two wheels. To the drum are attached flexible arms or flails of chain, cable, or metal bars that swing straight out from the rapidly revolving drum. Both machines are driven from the power takeoff on the tractor or by separate motor.

For killing sagebrush these implements are adjusted so that blades or flails just miss hummocks or projecting rocks. Occasional contact with the soil surface is unavoidable on uneven ground, but it should be kept to a minimum. The machines operate most efficiently and with the least maintenance and repair if the ground clearance averages 3 inches. Setting blades or flails too high results in a poor kill of

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FIGURE 14.—Brush cutters give a good kill of old, large plants of big sagebrush without injuring herbaceous plants. Small or low-growing sagebrush is little damaged.

small plants; setting too low results in high breakage costs. One trip over an area is ordinarily sufficient.

Advantages and limitations of the method are as follows:

Kill of sagebrush.—Cutting is effective in tall old stands of big sagebrush; kills of 90 percent or more of old brush are often obtained. Highest kills are on rock-free level ground. Young plants of big sagebrush are usually missed or little damaged by cutters and flails. Control of threetip, low, and black sagebrush is only partially satisfactory because of their low, spreading branches and the tendency of threetip sagebrush to sprout from the base. Kills of silver sagebrush are unsatisfactory because of strong sprouting from the stem base and roots.

Kill of associated undesirables.—Sprouting shrubs such as rabbitbrush and horsebrush and annual grasses such as cheatgrass are not controlled.

Effect on desirable forage plants.—Grasses and broad-leaved herbs growing beneath the sagebrush are not damaged. Bitterbrush is badly damaged, but in some localities it is stimulated into vigorous sprouting from the root crown.

Ease of seeding afterward.—Grain drills may be successfully used for seeding grasses following the cutter on sites where the brush is not heavy, but furrow openers do not penetrate an unusually heavy layer of woody litter. In some trials seed broadcast before brush treatment has been covered by the mulch, and good seeded stands have resulted; but this method is not reliable.

Adaptability to terrain and soil.—Cutters should not ordinarily be used on soils where rocks protrude more than 3 inches above the soil surface. Maintenance and repair costs are high if the blades or flails come into frequent contact with rocks. Moreover, cutters must be operated carefully where the soil surface is uneven or is cut up by small gullies.

Availability of equipment.—Implements of this type are commercially available. Only machines of sturdy construction can be purchased for range use. Cutters with their own power units are preferred for heavy brush.

Effect on erosion hazard.—The woody plant material left as a protective mulch on the soil surface should decrease the erosion hazard. Thus, cutting is a good method of sagebrush control where the probability of wind and water erosion is fairly high and watershed values must be guarded.

Cost of control.—The cost of sagebrush control with cutters is at least $1 more per acre than with plows or disks. Using a 40-horsepower wheel tractor, as much as 2 acres per hour have been covered, but 1 to 1½ acres per hour is average. Higher rates of travel are possible, but it is important that speed not exceed 3 miles per hour if maintenance costs are to remain low and efficiency of control high. Actual costs on several operations during 1962 were $4 to $10 per acre.

General adaptability of cutting for sagebrush control.—Brush cutters work well on stands of big sagebrush that are uniformly old and large, and where rocks are absent or protrude less than 3 inches above the soil surface. They are especially useful for the release of native perennial grasses growing beneath the sagebrush or of seeded stands being suppressed by sagebrush, or where hazard of wind or water erosion is high.

Harrowing

Self-clearing pipe or log harrows, sometimes called Dixie drags, have occasionally been used for sagebrush control, but are most useful for covering grass seed on burned rangelands that are too rocky or rough for the use of other types of implements. They have been used to cover seed on weedy alpine areas and to control rather open stands of old, brittle sagebrush on uneven ground, especially on ranges with numerous rock outcrops.

A 40- to 45-horsepower crawler tractor and a 14-foot pipe harrow make a convenient unit for harrowing. The pipe harrow is simply a series of spiked iron pipes, usually 4 inches in diameter, trailing behind a spreader bar. The pipes, being swiveled, can rotate freely and thus clear themselves of trash (fig. 15). Pipe troughs, fitted over the lead end, prevent the pipes from jumping across one another, especially on sloping ground.

Green logs 6 to 10 inches in diameter can be substituted for the iron pipes, but will last only one season. The fore ends of the logs are notched for holding the chain and swivel. Discarded drill steel or similar bar steel can be used for teeth. The bars are driven through holes of slightly smaller diameter bored in the log. The teeth are held tightly until the log dries.

Harrowing the area once usually suffices to cover the grass seed. Harrowing twice will increase sagebrush kill.

Advantages and limitations of pipe harrowing are as follows:

Kill of sagebrush.—Only 30 to 70 percent of old, brittle big sagebrush and a much lower percentage of younger plants are killed. Higher kills are usually obtained on rocky ground. On rocky sites,

OREGON EXTENSION SERVICE PHOTO

FIGURE 15.—The self-clearing pipe harrow is useful for thinning sagebrush and covering grass seed on sagebrush ranges that are so rocky or rough that other implements cannot be used.

harrowing gives a much poorer control of low sagebrush than of big sagebrush, and negligible kills of threetip and silver sagebrush.

Kill of associated undesirables.—There is little eradication of such associated sprouting woody species as rabbitbrush and horsebrush. Fall treatment, after seed has germinated, results in fair control of cheatgrass.

Effect on desirable forage plants.—About 10 to 20 percent of the bunchgrasses will be uprooted by the pipe harrow. Damage to bitterbrush is low unless it is tall and brittle. Few plants are killed. Bitterbrush plants examined 2 or more years after treatment showed stimulated sprouting and twig growth, particularly on low, spreading bushes.

Ease of seeding afterward.—Grass seed broadcast ahead of the harrow used for sagebrush control is covered rather effectively in the same operation. Sites where the pipe harrow is necessary are usually too rocky for the grain drill.

Adaptability to terrain and soil.—Pipe harrowing is a practical method on areas where rocks protrude. The harrow clogs badly when used on rock-free or slightly rocky sites and becomes quite ineffective. It is readily usable on sites that are badly cut up by small gullies.

Availability of equipment.—Pipe harrows are not commercially available, but can be constructed in any fairly well equipped machine

shop at a reasonable cost. In areas not reached by roads, log harrows can be readily constructed in the field at low cost with logs cut from green trees nearby; and teeth, swivels, and cable can be brought in by packhorse. Designs and specifications for the pipe harrow can be obtained from the U.S. Forest Service, Washington, D.C., 20250.

Effect on erosion hazard.—Harrowing usually decreases erosion. Litter and debris from uprooted and broken sagebrush left on the loosened ground surface and deposited in gullies, along with the standing brush, protects the soil better than standing brush on untreated areas.

Cost of control.—Harrowing and plowing, on sites to which they are adapted, should cover about the same number of acres per hour at a similar cost. On 125 acres of the Manti-LaSal National Forest in Utah, an average of 1.8 acres per hour was treated with a 28-horsepower tractor and a 10-foot pipe harrow. Computed at 1962 rates, the cost would be $4 to $7 per acre, or about the same as for plowing. Breakage and maintenance costs for harrowing are negligible.

General adaptability of harrowing for sagebrush control.—This implement was devised for soil disturbance, seed covering, and control of open stands of mature sagebrush on moderately to extremely rocky ground. It does a better job on rocky than on rock-free areas. The ripping and gouging action caused by the toothed pipes bouncing along among the rocks tears out some of the sagebrush, loosens rocks, and disturbs the soil enough for seed coverage. The harrow is useful for covering broadcast seed on rocky alpine areas, sagebrush burns, or on areas where sagebrush has been killed by herbicides.

The pipe harrow is an excellent complement to a plow or disk for treating interspersed areas that are too rocky for the plow or disk. By the alternate use of the two implements, all of the area that requires seeding can be treated at one time. The harrow is misused for sagebrush eradication if other machinery gives better results without undue breakage.

Other Methods

Many other methods have been tried in clearing sagebrush for farming or range improvement. Because some of these methods may be useful for sagebrush control, especially if the equipment is readily available, they are briefly described here together with their advantages, limitations, and possible application.

Railing or dragging.—Uprooting or breaking off sagebrush by dragging a heavy rail across it is one of the oldest and cheapest methods of control (fig. 16). This method, widely used in the early days to clear land for farming, has been used for range improvement. The average power requirement for several areas was 1 to 1.8 drawbar horsepower per foot of rail at 2 to 2½ miles per hour.

Even though kill of mature big sagebrush is 30 to 80 percent, the kill of willowy bushes seldom exceeds 50 percent and may be as low as 10 percent. It is usually necessary to rail twice in opposite directions to obtain satisfactory control. Railing has little effect upon crown-sprouting shrubs such as rabbitbrush or horsebrush, and on most grasses and broad-leaved herbs.

Burning is often feasible after one railing where it was not possible

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FIGURE 16.—Rails are useful in breaking off old, mature, and brittle stands of sagebrush. An "A" sagebrush rail which throws the brush in windrows around the ends of the rail is shown here. Later models have been equipped with serrated edges on the side members and two rolling coulters on the cross member to keep the rail from swinging from side to side. Designs and specifications for several types of sagebrush rails can be obtained from the Forest Service, U.S. Department of Agriculture, Washington, D.C., 20250.

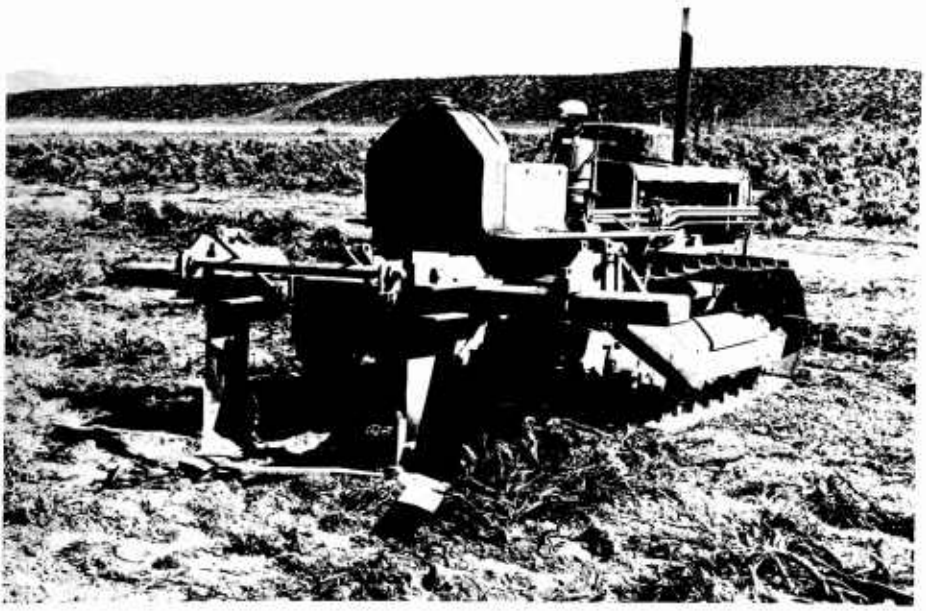
before, and can improve control of uneven-aged stands and make subsequent drilling easier. The piles or windrows of broken and uprooted brush left by railing burn readily.

Breakage of the drag is sometimes excessive on areas that have occasional boulders or rock outcrops.

Railing usually provides poor covering of prebroadcast seed. Drilling is difficult unless the piles of debris are burned beforehand.

Root cutters.—Many types of root cutters, also called planes, blades, grubbers, or cultivators, are available commercially. Root cutters have been widely used for clearing sagebrush land preparatory to farming. The heavier types should be used on rangelands. They consist of from one to five straight or V-shaped blades, mounted on a heavy frame suspended between two wheels or mounted at the rear of a tractor (fig. 17). The blades can be raised or lowered by either a lever or a hydraulic lift, and are set to cut all roots at 4 to 5 inches below the soil surface.

Nearly a complete kill of big, low, and threetip sagebrush of all ages and a fair kill of silver sagebrush can be obtained when cutters are carefully operated. Perennial grasses, broad-leaved herbs, and shrubs that do not spread by rootstocks are almost completely killed. Sprouting shrubs such as rabbitbrush and horsebrush are effectively controlled. Unless sprouting shrubs are mixed with sagebrush, other methods of control may be more suitable. Brush is normally left standing. In heavy rabbitbrush, a chain or cable pulled in a U-shaped loop behind the root cutters overturns the plants. This makes drilling easier and prevents the rerooting of rabbitbrush plants.



BUREAU OF LAND MANAGEMENT PHOTO

FIGURE 17.—Rear view of one type of implement that cuts sagebrush roots effectively on rock-free land. This implement has been particularly effective for controlling rabbitbrush or horsebrush and the clearing of brush preparatory to farming. The blades are usually set to cut 4 to 5 inches below the soil surface.

Root cutters are useful mainly on relatively level and rock-free areas that have deep soils and where the potential production of seeded grass justifies the cost. They are also useful where there is a heavy clay subsoil. They loosen the surface soil but do not turn up the heavy subsoil to form a surface crust, as sometimes occurs with plowing.

With most machines, breakage is excessive wherever large rocks are embedded near the soil surface. It is difficult to keep the blades cutting at a satisfactory depth on uneven ground.

Mowing.—An ordinary power-takeoff mower having a heavy cutter bar, snub-nosed guards, heavy-smooth sections, and a double set of clips to hold the sections snugly against the blunt guards has been found successful for sand sagebrush control in the southern Great Plains. Mowing must be done in June or early July. It has not, however, proved useful for other sagebrush species. Stems of mature big sagebrush are too thick, while small plants and most other species have too many branches near the soil surface that are missed by the mower. It cannot, moreover, be used without excessive breakage if there is much rock lying on the soil surface. The only application that mowing seems likely to have, other than for sand sagebrush, is in the control of young plants that have invaded seeded ranges. For this purpose, herbicides would generally be more satisfactory.

Ripping.—A heavy self-clearing road ripper with teeth spaced 14 to 16 inches apart, pulled by a 30- to 45-horsepower crawler tractor, has been used for thinning sagebrush. With ripper teeth digging 4 to 6 inches, it breaks down or tears up much of the large and old sage-

brush, but kills only about one-third or less of the young plants. About a third of the perennial bunchgrasses are killed. Though some successful stands of crested wheatgrass have resulted from broadcasting on ripped areas, usually not enough of the sagebrush is killed for successful seeding. The ripper can be used with very little breakage on sites that are too rough and rocky to plow, or for loosening up the surface of heavy, tight soils. Ripping is too costly for more than limited use.

Rolling brush cutter.—The heavy type of rolling brush cutter has been tried for sagebrush control. It crushes and cuts up the larger and older bushes of big sagebrush, but kills only a few of the younger plants. Associated sprouting shrubs such as rabbitbrush and horsebrush and annual grasses are not killed. The blades on the rollers are dulled quickly, especially if there is much rock. The rolling brush cutter does not prepare the site adequately for seeding. The roller with spiked teeth instead of cutters appears to be even less effective in killing sagebrush. It is doubtful that these rolling implements have any real value for eliminating sagebrush.

Road graders or bulldozers.—These implements have been used widely on small tracts of land, primarily for clearing sagebrush preparatory to farming. Ordinarily, almost all sagebrush is killed, but the plants are mixed with dirt in windrows and subsequent disposal is difficult. Shrubs, perennial grasses, and other plants, except those that sprout from the roots or spread by rootstocks, are completely destroyed. The method is not effective on rocky ground or rough terrain unless much time is expended. In general, the use of these implements is too costly except on very limited tracts where other more suitable equipment is not available. Both are widely used in constructing firelines before burning.

Flooding.—This is one of the oldest but least widely applicable methods of sagebrush control. It is limited to areas where high spring runoff waters are available. Good kills of big and low sagebrush have been obtained and excellent stands of grass restored by the use of spreader ditches or similar methods for keeping the ground covered or saturated with water for 2 weeks or longer in the spring. Where spring runoff is readily available, this can be done through efficient spreading systems. Silver sagebrush is relatively resistant to flooding. Seed broadcast just before flooding sometimes produces good stands.

REGRASSING AFTER SAGEBRUSH CONTROL

Eradicating sagebrush for range improvement is of little avail unless a good stand of desirable forage plants promptly reoccupies the area. There is great need to get such a stand as soon as possible to protect the soil from erosion, prevent the early return of sagebrush in large quantity, prevent invasion by other undesirable plants, and repay the costs of sagebrush control through a rapid increase in grazing capacity.

Rapid revegetation is needed especially where burning or other methods have destroyed or buried most of the litter. The longer the soil remains exposed, the greater the difficulty to be expected in getting a stand of reseeded grass, and the greater the likelihood of serious

erosion, especially if the soil is somewhat sandy or light or the slopes moderate to steep.

A good stand of perennial grasses is necessary to prevent the early return of heavy stands of sagebrush. Eradication of sagebrush is seldom complete. Plants left alive produce seed that will reinfest adjoining areas unless enough grasses are present in the understory, or are established by seeding, to control the sagebrush seedlings (fig. 18).

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FIGURE 18.—Good stands of grass reduce reinvasion by sagebrush. This range was accidentally burned. The area on the left was seeded immediately to crested wheatgrass. The area on the right remained unseeded; and the next spring it bore an abundant crop of sagebrush seedlings. The unseeded area had over 16,000 plants per acre 11 years later compared with about 4,000 sagebrush plants on the seeded range.

Good stands of perennial grasses also prevent serious invasion by other undesirable plants after sagebrush control. Halogeton, an introduced poisonous annual weed, often invades areas that have been cleared of sagebrush for range improvement or burned. Cheatgrass, an aggressive annual grass, is also quick to occupy areas that have been disturbed by mechanical means or by fire. Successful seeding to perennial grasses may not entirely prevent establishment of undesirable annuals, but these are likely to be so sparse as to provide little competition to perennials. By the second or third year native or seeded perennials should fully occupy the site.

Where there are sufficient undesirable native plants in the understory to reoccupy the land quickly, a sagebrush control method should be used that either selectively controls the undesirable species or destroys most of the understory and permits establishment of seeded grass.

On ranges near irrigated farmlands of Idaho, Utah, and other States, sagebrush control on lands lacking an adequate perennial grass understory may permit invasion of Russian-thistle, tumblemustard, and tansymustard halogeton. These are alternate breeding hosts for the beet leafhopper (*Circulifer tenellus*), an insect that spreads curly top disease to nearby sugarbeet, tomato, and bean crops.

Some ranges have enough desirable perennial grasses and other forage plants growing beneath the sagebrush to revegetate the area quickly after the sagebrush is killed. If these are not destroyed by control operations, and if good grazing management is used after-

ward, there is little need for range seeding. As a general rule seeding is not needed where more than one-fifth of the total plant cover is made up of desirable plants, provided they are fairly well distributed (fig. 3, *A*).

There are extensive areas of sagebrush range without enough desirable plants beneath the sagebrush to revegetate the area quickly (fig. 3, *B*). In these areas, it is advisable to make seeding a part of the sagebrush control job.

Seeding to desirable forage plants should also be planned where sagebrush eradication methods such as plowing or disking, root cutting, ripping, scraping, or burning destroy a high percentage of the stand of perennial grasses.

Seeding may also be desirable to improve forage quality. Where perennial grasses and other forage plants furnish forage of inferior quality or are low in production, more valuable species should be planted after eradicating the sagebrush. Where earlier spring grazing is needed than would be provided by the native grasses, it may also be desirable to seed early-growing grasses. In both these cases, sagebrush control methods that destroy a large part of the understory grasses will be needed to permit establishment of the seeded species.

Information on where seeding is likely to succeed, what species to use, how and when to plant, and what equipment to use in planting can be obtained from several State and Federal publications such as USDA Agriculture Handbook 71, "Seeding Rangelands in Utah, Nevada, Southern Idaho, and Western Wyoming," or from county agricultural agents, State colleges, local Federal officials, or neighboring ranchers who are acquainted with seeding work.

MANAGEMENT OF RANGES AFTER SAGEBRUSH CONTROL

The major aim of management of ranges after sagebrush control should be to encourage continued maximum production of forage consistent with soil protection. This requires that grazing use discourage rather than favor the return of sagebrush, and thus avoid the need of frequent sagebrush removal. Careful management of grazing and the judicious recontrol of sagebrush where objectionable stands recur are the principal means of achieving this aim.

Historical records reveal that a large part of the present sagebrush type had sagebrush as a part of the natural plant cover. Although sagebrush plants were not as thick as at present, their presence indicates their adaptability to the site. Therefore, unless the climate changes, or man alters the site or puts in more competitive plants, the sagebrush will gradually return. Studies to date show that when sagebrush is removed, usually it will again form a sparse to dense stand of brush in from 5 to 20 years after control. The speed and amount of sagebrush reestablishment depends upon the completeness of the stands of native or seeded forage plants, grazing management, and the percentage of the sagebrush that was destroyed. The chances for reinvasion are lessened considerably if the source of sagebrush seed is eliminated over vast areas. This is seldom accomplished with avail-

able methods; burning is virtually the only method that may give complete initial eradication.

Even where initial eradication is complete and good stands of grass develop, sagebrush sometimes returns. This sagebrush may originate from seed stored in the soil or on its surface, or from seeds windblown or carried in by animals. Usually the reestablished sagebrush stands are sparse and not objectionable; but in about 1 year out of 5, conditions favor a dense stand. Poor grazing management, of course, permits the sparse stands to thicken and gradually form dense stands again.

Eradication of newly established sparse or dense sagebrush stands is a major problem. In some cases it pays to get rid of even the sparse seedling stands within 3 to 7 years, before the young sagebrush plants have produced a crop of seed, thereby discouraging establishment of a still thicker stand. Where a good grass understory is present, it is advisable to use spraying, burning, cutting, or other methods that do not seriously damage the grass.

Good grazing management is indispensable after sagebrush eradication, regardless of the method of control or the method of regrassing. *The kind of grazing management practiced is the most important single factor determining whether sagebrush control results in range improvement or deterioration, and how long the range remains free of dense sagebrush* (fig. 19).

In grazing ranges after sagebrush control the following three recommendations have proved worthwhile:

1. *Avoid trailing livestock the first fall and winter across areas where sagebrush has been eradicated.* Trailing the first fall stirs up the soil and speeds erosion. After sagebrush seed has ripened, livestock are likely to carry sagebrush seed from uncleared areas, mostly in their fleece or hair, and scatter it over the cleared areas. Sagebrush seedlings that come up early the following spring will be firmly established before the perennial grasses are big enough to prevent it. Thus, trailing alone can be responsible for the early return of sagebrush.

2. *Delay grazing until native grasses are vigorous and seeded forage plants are well established, as evidenced by seed production.* Where the natural increase of native grasses is being relied upon, it is advisable to delay grazing for at least a full year. An appearance of abundant green growth the first spring is misleading. The dense sagebrush formerly screening the grass and weed understory from view has been broken down or removed, and most of the herbaceous plants on the area are now visible at a glance. Thus there appears to have been a striking increase in forage production, when actually there may have been a decrease. Grazing the first spring usually delays an increase in size and abundance of the perennial grass remnants and keeps the plant cover so open that sagebrush can successfully return. Furthermore, grazing the sparse plant cover disturbs the inadequately protected soil and may speed wind and water erosion.

It is advisable to delay grazing of a seeded range until the first grass seed crop is cast. Earlier grazing may severely damage or even pull out many of the young and weakly rooted grass seedlings. Two full years are usually required for young plants to become firmly rooted,

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FIGURE 19.—A complete sagebrush kill, a good cover of native or seeded forage plants, and good grazing management all prevent or help delay reinvasion by sagebrush. *A*, This area of former sagebrush range seeded to crested wheatgrass is still sagebrush free, largely as result of good grazing management. *B*, A good stand of seeded grasses was established on this range, but extremely heavy grazing for 5 years weakened the grasses. Sagebrush is invading and increasing rapidly.

make vigorous top growth, and produce their first seed crop. In rare instances this stage may be reached and grazing permitted by the end of the first year, but more often it takes at least 3 or more years for seeded grass to attain this stage of development.

3. *Practice good grazing management after the new forage stand is well established.* Whether seeded or native, the stand can easily be damaged by improper grazing practices, especially in drought years. Good grazing management will lengthen the period of good forage production following sagebrush control. To obtain proper grazing intensity, to insure grasses being grazed at the proper season, and to help secure proper distribution of livestock, it may be necessary to fence the seeded and improved areas and to provide better stockwater facilities. Adequate water may be provided by the development of springs, drilling wells, or hauling water by truck to portable troughs. Other recommended practices include open herding, proper location of salt grounds, and rotation grazing. These and all other practices that further good range use should be employed to help maintain the increased grazing capacity and maximum usability of the range resulting from sagebrush control.

Season of grazing use can help maintain a desirable balance between herbaceous and woody plants on sagebrush ranges. Grazing during the fall and winter, when herbaceous species are dormant, does little damage to these species. Sagebrush and other browse species are more readily eaten during this period and are reduced in volume and vigor. Concentrates are often fed to encourage animals to eat browse and dry forage. Care must be taken to avoid trampling wet soil by livestock.

What constitutes good grazing management will vary somewhat throughout the broad range of the sagebrush type with the different classes of livestock being grazed and different seasons of grazing. Additional information can be obtained from county agricultural agents, range extension specialists, State colleges, local Federal officials, or neighboring ranchers who are familiar with good grazing management.

COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES MENTIONED [1]

Grasses and Grasslike Plants

Brome, cheatgrass	*Bromus tectorum*
Fescue, Idaho	*Festuca idahoensis*
Wheatgrass, crested	*Agropyron desertorum*
Wheatgrass, fairway	*A. cristatum*

[1] Nomenclature according to "Standardized Plant Names," Ed. 2, by Harlan P. Kelsey and Wm. A. Dayton, McFarland Co., Harrisburg, Pa., 1942 (except halogeton, recognized later); or "Check List of Native and Naturalized Trees of the United States (including Alaska)," by Elbert L. Little, Jr., Agr. Handb. No. 41, Forest Service, U.S. Dept. of Agriculture, 1953.

Annual and Perennial Herbs

Balsamroot, arrowleaf	*Balsamorhiza sagittata*
Bluebells	*Mertensia* spp.
Geranium, sticky	*Geranium viscosissimum*
Groundsel	*Senecio integerrimus*
Halogeton	*Halogeton glomeratus*
Hawksbeard, tapertip	*Crepis acuminata*
Helianthella, oneflower	*Helianthella uniflora*
Lupine, tailcup	*Lupinus caudatus*
Milkvetch	*Astragalus* spp.
Penstemon	*Penstemon* spp.
Russian-thistle	*Salsola kali* var. *tenuifolia*
Tansymustard	*Descurainia sophia*
Tumblemustard	*Sisymbrium altissimum*

Shrubs and Trees

Aspen, quaking [2]	*Populus tremuloides*
Bitterbrush, antelope	*Purshia tridentata*
Chokecherry [2]	*Prunus* spp.
Cliffrose, Stansbury	*Cowania stansburina*
Douglas-fir	*Pseudotsuga menziesii*
Horsebrush, spineless gray [2]	*Tetradymia canescens* var. *inermis*
Juniper, Utah	*Juniperus osteosperma*
Mountain mahogany, curlleaf	*Cercocarpus ledifolius*
Mountain mahogany, true	*C. montanus*
Pine, lodgepole	*Pinus contorta*
Pricklypear	*Opuntia engelmannii*
Rabbitbrush	*Chrysothamnus* spp.
Rabbitbrush, rubber [2]	*C. nauseosus* and several variants
Sagebrush	*Artemisia* spp.
Sagebrush, big	*A. tridentata*
Sagebrush, black	*A. nova*
Sagebrush, fringed	*A. frigida*
Sagebrush, low	*A. arbuscula*
Sagebrush, sand	*A. filifolia*
Sagebrush, silver [2]	*A. cana*
Sagebrush, threetip	*A. tripartita*
Saltbush, fourwing	*Atriplex canescens*
Saltbush, Gardner	*A. gardneri*
Shadscale	*A. confertifolia*
Serviceberry, saskatoon [2]	*Amelanchier alnifolia*
Snakeweed, broom	*Gutierrezia sarothrae*
Snowberry [2]	*Symphoricarpos* spp.
Winterfat	*Eurotia lanata*

[2] Plants sprout heavily from stem base and roots.

U.S. GOVERNMENT PRINTING OFFICE: 1965 O—747-298