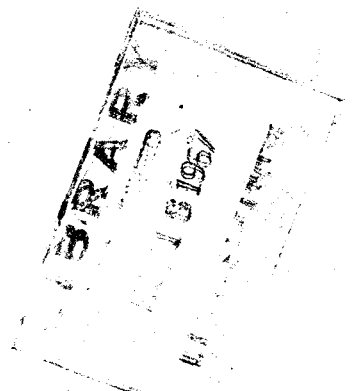


84Ah
W. H. K. # 338



Conversion of

CHAPARRAL AREAS

*Techniques Used
in California*

U.S. Department of Agriculture
National Agricultural Library
Lending Branch
Beltsville, Maryland 20705

235257

**CONVERSION OF CHAPARRAL AREAS TO GRASSLAND:
TECHNIQUES USED IN CALIFORNIA**

**Jay R. Bentley, Supervisory Range Scientist
Pacific Southwest Forest and Range Experiment Station
Forest Service, USDA
Berkeley, Calif.**

CONTENTS

	<i>Page</i>		<i>Page</i>
Introduction.....	1	Bulldozing.....	13
Acknowledgment.....	2	Disking.....	13
The chaparral area.....	2	Prescribed burning.....	13
Chaparral types.....	2	Establishing the new grass cover.....	18
Climatic zones.....	3	Superiority of perennial grasses.....	18
Values and uses.....	4	Preparing the seedbed.....	20
Evaluating the benefits of chaparral con- version.....	6	Sowing perennial grasses.....	21
Increasing water yield.....	7	Selecting and sowing annual grasses.....	23
Increasing grassland range.....	7	Controlling brush regrowth.....	24
Improving fire control.....	8	Nature of brush reestablishment.....	24
Improving game habitat.....	8	Control by herbicidal treatments.....	24
Selecting the conversion areas.....	8	Control by other methods.....	30
Site characteristics.....	9	Summary.....	31
Brush size, density, and species classes....	10	References.....	32
Site priorities.....	11	Appendix A.—Common and scientific names of species mentioned.....	33
Removing the chaparral.....	12	Appendix B.—Estimated costs of conversion operations.....	35
Hand cutting or grubbing.....	12		



Use Pesticides Safely
FOLLOW THE LABEL
 U.S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

Chaparral—as the term is used in California—refers to dense stands of evergreen, shrubby vegetation. The information in this handbook applies to the chaparral within the brushland zone that lies below the State's commercial timber belt (fig. 1). This zone includes about 11 million acres of chaparral and

associated types and 9 million acres of woodland types.

The term "conversion" in this handbook means a permanent change from native chaparral to a new cover that is fairly stable and easily maintained. Conversion to grass on sites below the commercial

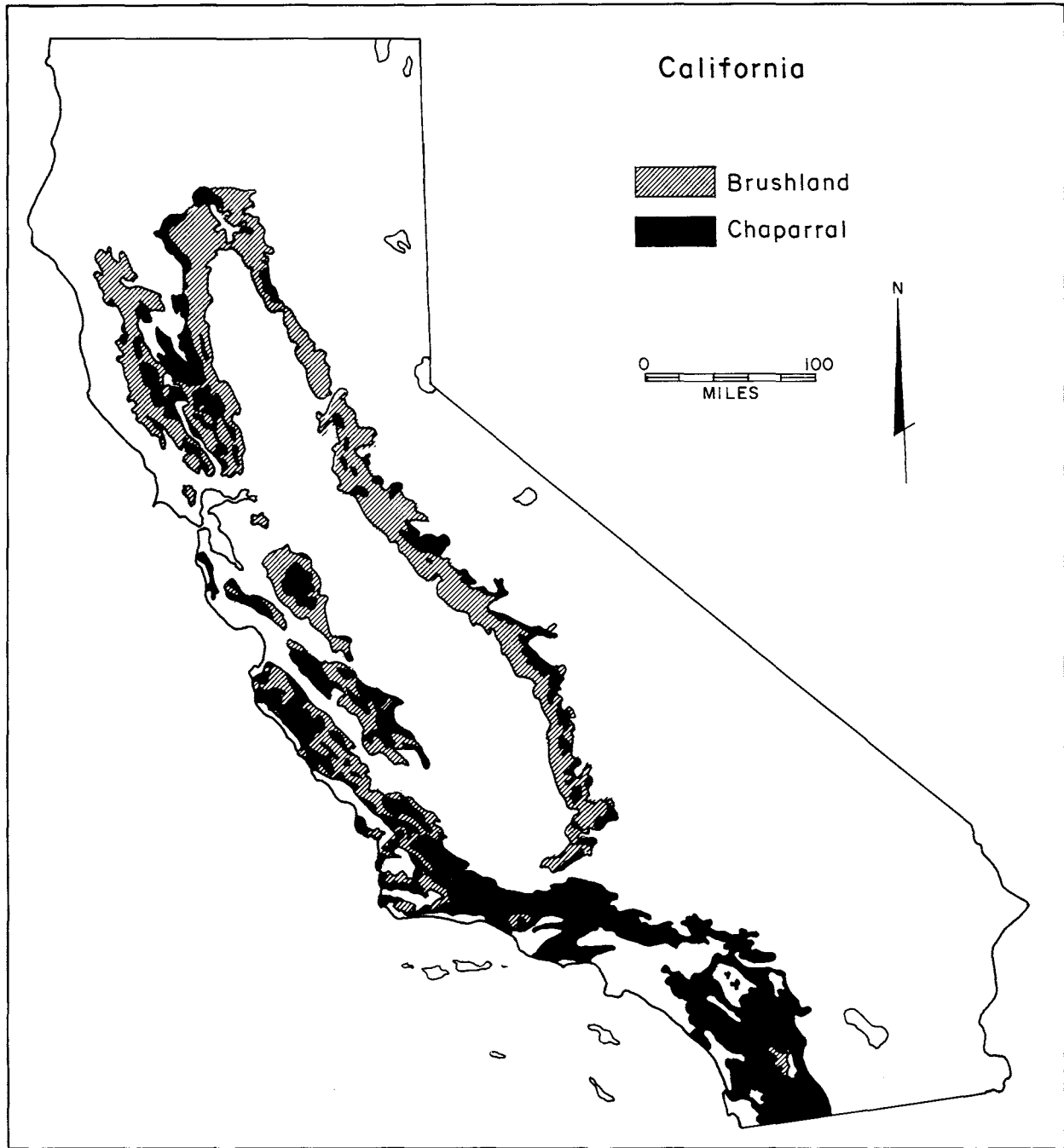


Figure 1.—Location of chaparral in the brushland zone below the commercial timber belt in California.

timber belt is stressed because grass is the only adapted plant for which much seed is commercially available. Furthermore, techniques have been developed for establishing grass while destroying the brush. Grass may not be ideal for all purposes, but it has many desirable attributes: Good soil cover, excellent forage for livestock, good supplement for deer browse, lower water use than brush, and low fuel volume for easier fire control.

In one method of intensive management, conversion to a new plant cover is undertaken on small areas selected for specific purposes. Such purposes include producing more forage for livestock or game, increasing water yield, making recreational resources more usable, or breaking up brush fields for more effective fire control. Adjacent areas—including urban and industrial complexes, irrigated agricultural lands, and forested areas—often benefit from chaparral conversion.

This handbook covers all of the conversion process up to the application of longtime management practices. The conversion process consists of five distinct operations: (a) Evaluation of the needs and benefits of conversion, (b) selection of the area, (c) removal of brush, (d) establishment of a grass cover, and (e) eradication or control of brush regrowth. Each step must be taken at the right time and in the right way. After brush conversion, success depends on proper management that will provide optimum returns.

Techniques for chaparral conversion have been developed through both research and the experience of government agencies and private landowners. They were developed from studies of brush removal or control and of grass seeding aimed at making brushlands more usable for range livestock. During conversion studies, additional knowledge has been gained from rights-of-way, areas cleared for fire control, and other wildland areas. Most of the currently used methods of brush control have been developed since 1950. Practical conversion techniques have been improved by the comprehensive, nationwide research on the use of phenoxy herbicides for weed and brush control.

Caution: Herbicidal chemicals are dangerous. Use them only as directed and heed all precautions on the container label. Check the registration numbers and verify that the directions for use include the target plants to be controlled. Drift from aerial spraying can contaminate nearby crops and forage, lakes, and reservoirs. Improper use and careless disposal of unused portions can lead to poisoning of humans, domestic animals, desirable plants, pollinating insects, and fish and wildlife, and can contaminate water supplies.

As more information becomes available, more efficient, cheaper methods of chaparral conversion will be developed, and potential benefits from conversion will be further evaluated. This handbook summarizes conclusions from research and experience and describes the recommended methods for each conversion job.

ACKNOWLEDGMENT

Several California and Federal agencies have contributed information on conversion. State agencies include the California Division of Forestry and the University of California. Federal agencies include the U.S. Department of Agriculture's Agricultural Re-

search Service, Soil Conservation Service, and Forest Service. Private organizations and individuals also have provided information. Many relevant sources are included under References (p. 32).

THE CHAPARRAL AREA

Chaparral grows primarily on the foothills and lower mountain slopes of the Coast Ranges and on inland mountains of southern California west of the deserts. It is the main woody vegetation there, and makes up broad expanses of almost unbroken cover. Chaparral also occurs intermingled with the woodland types on the foothills of the Sierra Nevada, but in smaller blocks (fig. 1).

CHAPARRAL TYPES

All chaparral formations referred to in this handbook are dense stands of shrubby plants dominated by species that sprout vigorously after removal of the aboveground parts (fig. 2). Many of these species and the nonsprouting species that commonly occur regenerate strongly from seed.

The chaparral formations are grouped into two broad types: *Chamise-chaparral* and *mixed-chaparral*.



F-510582

Figure 2.—Typical vigorous growth of brush sprouts during the second year after removal of chaparral by burning.

Chamise-Chaparral

This association includes the chaparral stands dominated by chamise (*Adenostoma fasciculatum*),¹ also called greasewood or greasewood chamise. This narrow-leaved shrubby species covers thousands of acres in relatively pure formations.

Many species, particularly nonsprouting species of *Ceanothus*, are intimately associated with chamise. The chamise-chaparral in southern California and the southern coast ranges commonly contains black sage (*Salvia mellifera*), white sage (*S. apiana*), California sagebrush (*Artemisia californica*), coyote brush (*Baccharis pilularis* var. *consanguinea*), deerweed (*Lotus scoparius*), California buckwheat (*Eriogonum fasciculatum*), and related species typical of the coastal sagebrush type that occurs within and below the chaparral.

Other chaparral species occur as scattered plants or small thickets within the chamise-chaparral. Typical species are California scrub oak (*Quercus dumosa*) and toyon (*Heteromeles arbutifolia*). Laurel sumac (*Rhus laurina*) and sugarbrush (*R. ovata*) also are common in southern California.

Chamise-chaparral is readily removed, and the regrowth is fairly susceptible to control by herbicidal applications.

Mixed-Chaparral

This broad type, including all chaparral other than chamise-chaparral, consists chiefly of shrubs with stiff

branches and thick leaves. Species composition varies widely. Usually two or more species are codominant, but locally a single species may be dominant.

Among the many sprouting species, some of the most common include: California scrub oak, Eastwood manzanita (*Arctostaphylos glandulosa*), toyon, silk-tassel (*Garrya* spp.), birchleaf mountainmahogany (*Cercocarpus betuloides*), laurel sumac, and sugarbush. Many nonsprouting species, particularly ceanothus (*Ceanothus* spp.) and manzanita (*A. spp.*), also occur. Species typical of chamise-chaparral and coastal sagebrush also grow within the mixed-chaparral formations on south-facing slopes in southern California.

Mixed-chaparral most commonly grows on north-facing slopes and on the better sites, but certain formations are found on southerly aspects and on shallow, rocky soils. At upper elevations of the brush zone, the shrubs typical of mixed-chaparral also grow in association with trees, mainly oaks (*Quercus* spp.) but also minor conifers, such as knobcone pine (*Pinus attenuata*), coulter pine (*P. coulteri*), and cypress (*Cupressus* spp.).

Conversion methods are less well developed and tested for mixed-chaparral than for chamise-chaparral. Initial removal is more difficult, and sprouts of several mixed-chaparral species, particularly California scrub oak, resist herbicidal control.

CLIMATIC ZONES

Most of the chaparral belt has a Mediterranean climate. Precipitation ordinarily starts in fall and extends until spring, mainly as rain, with some snow at the upper elevations. It is hot during much of the dry season.

However, climate differs widely over the chaparral areas. Thus, the difficulty of establishment of a new grass cover varies among areas. Grass sowing generally is most successful at the northern end of the chaparral belt (fig. 1) because fairly dependable precipitation extends from early fall to late spring. Progressing southward, the climate generally becomes less favorable: precipitation becomes more erratic, extends over a shorter season, and commonly has a lower seasonal total.

Climatic variations have been responsible for differences in the adaptation of perennial grass species. In all foothills of northern and central California, one group of species generally is adapted for sowing on good sites. But in southern California and the southern coast ranges, species adaptation is greatly influenced by proximity to the ocean or the desert and by low air temperatures at the upper elevations of the chaparral belt.

¹ Common and scientific names of species referred to in this publication are listed in appendix A.

Five climatic zones, within which different species are recommended, have been delineated and described. These zones could be further subdivided by more intensive study of the climatic factors within each zone. Approximate zone boundaries and the typical climatic conditions are as follows:

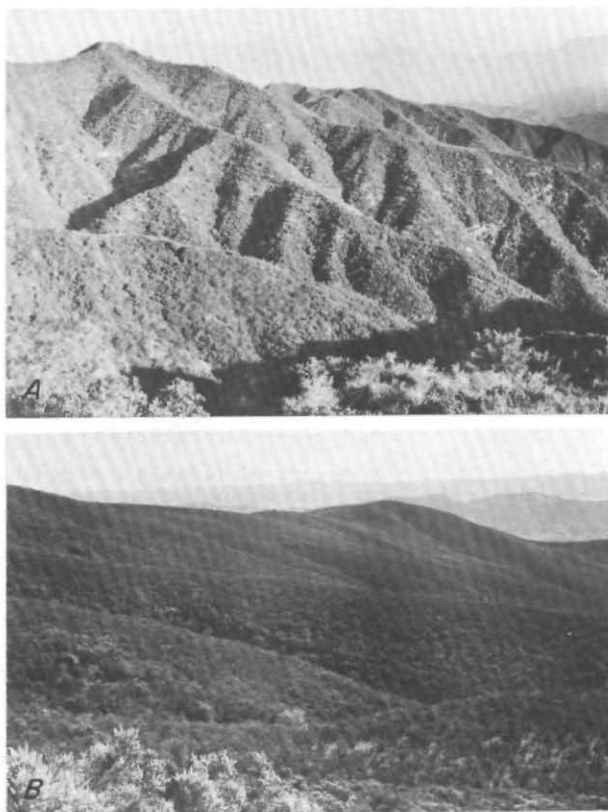
The *Lower Inland Zone* in central California includes the foothills and lower mountain slopes in the Central Valley and the smaller coastal valleys below 2,500 to 3,000 feet. High summer temperatures and low humidity occur during the long, dry season (4 to 6 months). Average yearly precipitation ranges from 20 to 40 inches.

The *Lower Inland Zone* in southern California includes the foothills and lower mountain slopes of the coastal valleys in southern California below 3,500 feet, except areas included in the Coastal Zone. The environment is influenced intermittently by moist air from the ocean and by desiccating air from the deserts. The dry season ordinarily exceeds that in central California. The winters are relatively mild, but cold temperatures and occasional snow occur in most years. Yearly precipitation averages from 15 to 30 inches. Rainfall is more erratic and more apt to be torrential than in central California; drought years occur more often. Plants may suffer long periods of inadequate moisture; drying winds may blow from the desert at any time.

The *Upper Inland Zone* lies mainly between 3,500 and 5,000 feet in the inland mountains of southern California. It is characterized by low winter temperatures and frequent snows, although most precipitation occurs as rain. Yearly precipitation averages 25 to 30 inches; it is more regular, and occurs over a longer period than at lower elevations. But cold winters shorten the plant growing season. Dry winds may occur in all seasons.

The *Coastal Zone*, a narrow zone in southern California and the South Coast Range, includes the foothill and mountain slopes that face directly on the ocean. Cool air and fog produce a more moderate climate throughout the year than persists inland. The elevation is generally below 3,500 feet. Grass grows better and requires less yearly precipitation than inland. Snow seldom occurs. Yearly precipitation averages 15 to 30 inches or more, except at the extreme southern end of the State, which has only 10 to 15 inches.

The *Desert Zone* includes chaparral on mountain slopes above 3,000 feet facing the deserts in southern California. It extends westward from the Mohave Desert south to the Tehachapi Mountains for an undetermined distance. Desiccating winds—hot in summer, cold in winter—make this a severe plant-growing site. Snow often falls. Yearly precipitation averages 15 to 25 inches above 3,000 feet, and about 10 to 15 inches for the small acreage of chaparral below this elevation.



F-510588, 510583

Figure 3.—Chamise-chaparral: A, On extremely rugged terrain with limited acreage well suited for conversion to grass; B, on mountainous terrain where many small areas of suitable slope gradient have high priority for conversion to grass.

VALUES AND USES

Chaparral-covered lands typically have steep terrain and shallow soils (fig. 3). On such land, much of it in government ownership, the primary value of chaparral is as a watershed cover. Flood hazard is extremely high if this cover is removed by wildfire. Grass often is sown to provide temporary cover before native plants regain enough density for effective soil protection.

A major land management effort is in fire prevention and in fire control to prevent destruction of the native cover. Extensive brush fields are being broken at strategic locations by fuel-breaks, wide strips or blocks of land on which native vegetation has been modified (fig. 4). Native shrubs on these breaks are changed to a grass cover of low fuel volume to aid in control of fires.

Areas of productive soil within the chaparral zone make up one of the few potential sources of new grassland ranges in California. Many such areas on terrain suitable for livestock grazing are being converted to stable grassland (fig. 5). This conversion of chaparral to grass also aids fire control and improves wildlife habitat.



F-510601, 510599, 510589

Figure 4.—Fuel-breaks which break up otherwise continuous expanses of brush fuel aid fire control: *A*, Strategic area cleared by hand cutting primarily for fire control, Cleveland National Forest; *B*, ridgetop with productive soil being cleared for livestock range and to aid fire control, Los Padres National Forest; *C*, similar area being cleared and sown to perennial grasses primarily to increase livestock range, Mendocino National Forest.



F-510590

Figure 5.—New livestock range developed by converting chamise-chaparral to an excellent stand of perennial grass on a selected area of moderate slope and productive soil.

EVALUATING THE BENEFITS OF CHAPARRAL CONVERSION

Before a conversion project is undertaken, its purpose and potential benefits must be carefully evaluated. This evaluation will determine the kinds and locations of the chaparral sites to be converted, and the methods that can be economically justified for the conversion.

Conversion should be confined to chaparral areas on which the need and feasibility are well defined. Only a small part of the total acreage of chaparral can be converted simultaneously because the process is costly and there are too few trained personnel to provide the

constant effort needed for many years.

Failure to evaluate these factors has caused controversy over chaparral conversion. At one extreme, some proponents of immediate, wide-scale conversion have given little consideration to its soundness and to the cost, effort, and time required to do a complete job. In contrast, some persons do not realize that conversion of selected chaparral areas is both possible and practical, and that it is needed to provide more intensive management of brush-covered lands in California.

Some kind of benefit-cost analysis is needed for each chaparral conversion project. Only the primary benefits which come directly from the project need be considered. These benefits may include such tangible values as more areas for livestock grazing, increased water yield, or decreased danger of large fires. The benefits also include such intangible returns as the effects of chaparral conversion on control of large fires, the recreational benefits from protecting irreplaceable scenic resources and making them more usable, and the returns from promoting greater production and harvest of deer. Secondary benefits which may accrue because of a conversion project need not be considered—even though they are recognized.

This handbook includes broad estimates of direct project costs that can be justified by net returns for two tangible primary products—water and livestock forage. If other costs, such as fencing, stock water development, or delivery of the product, are necessary to realize a return from the project, such costs must be added to the direct costs per acre. These criteria will help in the determination of some cost limits for conversion of chaparral to grass—to increase water yield, grazing capacity, or both. Additional justifications for investment resulting from intangible primary benefits which may be obtained are described briefly. These justifications should be evaluated in determining the soundness of any conversion project.

INCREASING WATER YIELD

Although conversion of chaparral to grass solely to increase water production is not now a standard watershed management practice, such a return undoubtedly occurs on some improved areas. Therefore, guides are needed for estimating how much of the total conversion costs can be justified by the increased water yield.

The value of delivered water varies according to its location in California. Estimates range from less than \$10 per acre-foot up to \$50 or \$75, depending on the locations of use and the sources of the water. Table 1 shows the net increases in water yield required to repay different initial investments in chaparral conversion for each of three arbitrary values of water. These net increases assume that an annual net return of 10 percent of the initial investment is adequate if the value of the improvement remains permanently equal to the initial investment or if the investment is amortized in about 20 years.

Increased water yield will probably not pay all conversion project costs on most chaparral sites because most sites have rocky, shallow soils less than 2 feet deep. Increases in water yield on areas with such soils appear to be negligible, perhaps less than 0.05 acre-foot per year.

Table 1.—Increases in net water yield required to repay different initial project costs in brush conversion

Initial project cost of brush conversion (dollars/acre)	Average yearly net increase in water yield required at an acre-foot value of—		
	\$10	\$50	\$75
	<i>Acre-foot</i>	<i>Acre-foot</i>	<i>Acre-foot</i>
25	0.25	0.05	0.03
50	.50	.10	.07
100	1.00	.20	.13
500	5.00	1.00	.67
1,000	10.00	2.00	1.33

Significant increases in water yield may be obtained from brush conversion on the small upland areas with deeper soils. Grass roots will extract all or most of the water from the upper 3 feet of soil, but water available for later percolation can be stored in the soil below this depth. Assuming that precipitation is adequate to charge the entire soil mantle and that typical stony soils have a water storage capacity of 1 inch per foot of soil, the potential yearly increases in water yield could amount to 0.1 acre-feet per acre for 4-foot soil, 0.25 acre-foot per acre for 6-foot soil, and 0.5 acre-foot per acre for 9-foot soil. If yearly operation and maintenance costs are low, the net annual return from brush conversion on an area of 6-foot soil would pay for an initial conversion cost of more than \$100 per acre if water is valued at \$50 per acre-foot.

High investment may be justified in clearing woodland-chaparral and riparian vegetation from bottom-land areas. Studies indicate that average yearly water increases of 1 acre-foot or more may be obtained from each acre of such land that is cleared. This return will justify expenditure of the several hundred dollars per acre needed for conversion, if water is valued at \$50 to \$75 per acre-foot (table 1).

However, until watershed management research determines the soundness of converting chaparral areas solely to increase water production, the conversion will be done primarily for other purposes. Any increased water yield will be an additional benefit.

INCREASING GRASSLAND RANGE

The need to increase permanent grassland acreage in California is widely recognized. To justify conversion to grassland range, the area must be suitable for grazing; water, fences, and other improvements must be provided; and good forage management must be obtained.

The returns from the new grassland range can be most easily expressed as animal-unit months (AUM) of grazing capacity. But a wide span of values can

be placed on an AUM, depending upon whether it is evaluated as a grazing fee, as a rental cost, or as livestock gains. Values up to \$3 to \$5 per AUM can be used as a span in rental costs for good rangeland in California. The maximum value for gross livestock gains can be set at \$10. The AUM evaluation probably will be within this span of values for any piece of good grassland range needed to round out a livestock operation.

Table 2 shows the returns in AUM per acre needed to yield a 10-percent annual return on different initial costs for two values per AUM. Increases in grazing capacity of 0.5 to 1.0, commonly obtained from converting dense chaparral to grass on fair to good sites, justify considerable cost (table 2). At a rental value of \$3 per AUM, total costs of \$10 to \$30 per acre may be returned from livestock grazing. At a \$5 rental value, the justified costs can range from \$25 to \$50 per acre. If returns are expressed in terms of gross livestock gains, much higher conversion costs can be justified. Costs will depend on method of brush removal, kind of grass sown, and ease of controlling brush regrowth (see appendix B.).

Table 2.—Increases in net grazing capacity needed to compensate for different initial investments in brush conversion

Initial cost of brush conversion (dollars/acre)	Average yearly net increase in grazing capacity needed in terms of rental values at—	
	\$3 per AUM	\$5 per AUM
	AUM/acre	AUM/acre
10	0.4	0.2
20	.7	.4
30	1.0	.6
40	1.3	.8
50	1.7	1.0
75	2.5	1.5
100	3.3	2.0

The conversion of chaparral to grass on many range areas can be justified because of additional benefits in fire protection, wildlife habitat improvement, and the possible values from increased water yield. Conversely, on all conversion areas grazed by livestock, the forage values can pay a large part of the costs of chaparral conversion undertaken for other purposes.

SELECTING THE CONVERSION AREAS

Soil characteristics largely determine whether an area is to be converted if the primary purpose is to increase range forage, water yield, or both. However, steepness of slope is often equally important; it may determine usability as range, feasibility of an economical conversion, and advisability of conversion. The

IMPROVING FIRE CONTROL

Changing chaparral to grass is an established practice in California to reduce fuel volume on fuel-breaks. Such fuel modification improves the effectiveness of the highly developed firefighting techniques now used. Intensive programs of fire prevention and fire control will reduce the threat of disastrous fires in the expanses of hazardous brush cover.

The long-term benefits from fuel-break systems may result partly from the reduced costs of fire suppression; that is, small fires may be prevented from becoming large project fires that cost hundreds of thousands of dollars in direct suppression alone. But the main benefits may be obtained from the reduction in onsite and offsite damages from fire, achieved by decreasing the average acreage of mature brush burned each year.

The money spent in each locality for fuel-breaks should be determined by the fire control objectives and funds. Certain wide breaks must be made at specific locations even though costs for some portions may be extremely high. Other breaks can be built at relatively low costs. But the average cost per acre for conversion on fuel-breaks will be greater than on other areas because of great benefits which can be provided by making fire control efforts more effective.

IMPROVING GAME HABITAT

Game habitat can be improved, indirectly and directly, by converting brush to grass on selected areas.

Fuel-breaks return indirect benefits to wildlife habitat, for example, by reducing destruction of brush cover and animal life by wildfire. Breaking the native brush into smaller units between grassy fuel-breaks also provides indirect benefits: it sets up a landscape pattern within which other habitat improvement practices can be readily applied.

Direct benefits come from the grass forage on the conversion areas, from the browse supplied by brush regrowth during conversion, from the many miles of "edge" between brush and grass, and from the improved access for hunters. A continuing supply of young browse can be maintained by manipulating the brush cover along the edges of the conversion areas and elsewhere.

The overall benefits to game habitat help justify a sound program of chaparral conversion.

kind of brush is also significant because it governs the removal methods and the costs. Strategic location is important when considering fire control, and certain areas may be selected even if soil productivity, slope gradient, and cost factors are unfavorable.

SITE CHARACTERISTICS

Soil Productivity

Soils that commonly support chaparral are generally poor for production of range forage. But deeper phases of some of these soils have fairly high potential and will produce a continuous grass cover with good yields of herbage. Conversion of chaparral to grass on such soils occurring on moderately sloping land has developed good rangeland (fig. 5).

Chaparral typically occurs on the California brushland soils—soil series commonly associated with a brush cover. Profiles of brushland soils differ considerably from those of highly productive grassland soils. The top layers of brushland soils are low in organic matter and usually slightly or moderately acid. The reaction of the subsoil tends to be more acid than the topsoil; the reverse exists for grassland soils. The water-holding capacity of many brushland soils is low because of shallow depth, coarse texture, high stone content, or a combination of these factors.

However, small acreages of chaparral and much associated coastal sagebrush occur on soils similar to those of the natural grassland. These soils have a fairly high potential for producing grass, especially some soils now occupied by coyote brush in coastal areas.

In this handbook, the brushland soils have been tentatively classified and rated for potential grass production according to their theoretical capacity to hold water for grass growth. The water-holding capacities are based on depth of profile, texture of soil, and content of stones and gravel (table 3). These criteria can be recognized by field examination.

The ratings ignore important factors that can greatly affect soil productivity, but such factors ordinarily do not differ greatly among brushland soils. An exception is soil parent material, which does differ greatly and affects fertility of brushland soils. Consequently, low grass production ratings are given to soils derived entirely from serpentinaceous rock; from heavily leached, reddish material of acid reaction; and from other parent materials of obviously low fertility, regardless of the water-holding capacities of the soils.

Table 3.—*Depth of brushland soils of specified texture and stoniness, for each grass productivity rating and associated theoretical water-storage capacity*

Texture and stoniness class	Productivity rating and water-storage capacity class ¹					
	0	1	2-3	4-6	7-8	9-10
	(0 to 0.5)	(0.5 to 1.0)	(1.0 to 2.0)	(2.0 to 3.0)	(3.0 to 4.0)	(4.0+)
	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>
Sands:	0- 6	6-12	12+			
Moderately stony	0-12	12-18	18+			
Extremely stony	0-18	18-30	30+			
Sandy loams:	0- 6	6-12	12-18	18-24	24-36	36+
Moderately stony	0- 6	6-12	12-24	24-36	36+	
Extremely stony	0-12	12-18	18+			
Loams:	0- 3	3- 6	6-12	12-18	18-24	24+
Moderately stony	0- 6	6-12	12-18	18-24	24-36	36+
Extremely stony	0-12	12-18	18-30	30+		

¹ The tentative grass productivity ratings express the relative potential grass yields and protective plant covers produced by the different soils, except for soils from parent materials of low fertility.

The range in water-storage capacity of each productivity class, in inches of water, is shown in parentheses below the productivity rating.

The theoretical water-storage capacities are calculated for each soil from the following capacity for each textural class (in inches per foot of soil): Sand and fine sand, 0.9; coarse

to fine sandy loam, 1.4; heavy clay loam to clay, 1.6; and loam to clay loam, 2.0. Moderately stony soils are defined as those having about one-third of the profile in large fractions, and extremely stony soils have about two-thirds of the profile in such fractions.

Clays are not shown as a textural class because of the few brushland soils of such heavy texture. The necessary depth for clay loams and clays in each productivity rating is intermediate between sandy loams and loams.

low water-holding capacities of the upper 1 or 2 feet of soil (where grass roots are concentrated). Growth of grass in such soils is greatly retarded by short droughts, which typically occur during the plant growing season.

Soils rating 0 to 3 are expected to produce only poor to fair soil protective cover, and conversion should be undertaken only on small areas where it is essential for

fire control. Soils rating 4 to 10 should produce satisfactory soil cover. Only fair range forage is expected on soils with a productivity rating of 4 to 6, but good forage, mainly perennial grasses, can be grown on soils rated 7 to 10.

The ratings can be used to judge relative productivities of different soils on chaparral lands. However, where rainfall is less than about 15 inches yearly, the grazing capacities of the grass covers probably will be lower (in accordance with specific quantity of rainfall) than the average capacities shown in table 4.

Table 4.—*Characteristics of the grass cover and average grazing capacities on brushland soils according to grass production ratings*

Tentative soil rating	Characteristics of typical grass cover	Estimated grazing capacity of grass cover ¹
0	Extremely thin, inadequate grass cover.	$AUM/acre$ (2)
1	Thin, spotty grass cover; inadequate soil protection except in best years; litter cover undeveloped.	(2)
2-3	Thin grass cover; fair soil protection in most years; litter build-up spotty. Annual plants greatly retarded by short droughts; undependable range forage.	0.1-0.3
4-6	Continuous grass cover; adequate soil protection; thin litter layer can develop under moderate grazing. Annual or annual-perennial grass cover retarded by droughts; fair range forage.	.4-.6
7-8	Continuous grass cover; good soil protection; good litter cover under moderate grazing. Good perennial grass growth; stable range forage production.	.7-.8
9-10	Continuous grass cover; good soil protection; good litter cover. Excellent perennial grass growth; stable range forage production.	.9-1.0+

¹ Grazing capacity is estimated for areas with 20 or more inches average annual precipitation; capacity will be lower in areas with less than 15 inches of rainfall. The capacity also will be lower for brushland soils from parent material containing a high proportion of serpentine, or for soils from other parent materials of obviously low fertility.

² Estimated capacity is less than 0.1 AUM per acre for soils rated 0 or 1.

Studies of the fertility and productivity of each major soil series, when combined with more grazing trials, will produce better criteria for rating the various soils; however, these tentative ratings should help in the selection of the most productive soil for converting chaparral to grass.

Slope Gradient

Areas with gentle to moderate slope gradient are best for conversion of chaparral to grass, but brush conversion often may be done on steeper slopes to meet specific needs.

The following descriptions of slope gradient classes indicate some reasons why the gentler slopes are best suited for brush conversion:

Gentle to moderate (0-40 percent).—This gradient presents few limitations to brush conversion and to use of the new grass cover. Tractors can be used safely and efficiently on the contour, except on the most unstable soil. Perennial grasses can be sown with a drill and established consistently on suitable soil. The grass can be utilized without serious reduction of soil stability.

Some recommendations set 30 percent as the maximum gradient on which brush conversion for range use is advisable. This may be the best limit on easily erodible soils, but conversion has been satisfactory on areas of stable soils with a maximum gradient of 40 percent.

Moderate to steep (40-55 percent).—This is a borderline range where brush conversion methods produce inconsistent results. Tractors can be used on only portions of some areas, and with a loss in efficiency. Seed and herbicide spray ordinarily must be applied by helicopter or by hand labor. Erosion is a hazard, particularly on coarse soils. Perennial grasses cannot be so consistently established as on gentle to moderate slopes, and the grass cannot be utilized as much.

Steep (55-70 percent).—Slopes definitely limit the brush conversion methods and the success in establishing a new grass cover. Soils often are unstable and erosion hazard is high. The grass that may be established will not provide good rangeland.

Extremely steep (more than 70 percent).—Effective conversion is very difficult on these slopes. It should be attempted only where essential for fire control. The necessary hand labor is expensive and involves some hazards. Effective aerial applications also are costly and difficult on such steep slopes with rugged and dissected terrain. Soils are unstable and erosion hazard is high.

BRUSH SIZE, DENSITY, AND SPECIES CLASSES

Two major factors determine whether conversion to grass will be economically feasible. First, the size of the individual plants and the total volume of woody material determine the methods and costs of brush removal. Second, chaparral stands differ in the number of plants that sprout after topgrowth is removed

and in the distribution of species resistant to chemical sprays; these differences influence the methods and costs needed after initial brush removal. Therefore, the brush is grouped into four classes, according to (a) size and volume of woody material and (b) density of resistant species.

Light or medium brush with few plants of resistant species.—Light brush is mostly small shrubs with stems less than 3 inches in diameter and less than 4 feet in height. The total volume is less than 15 tons per acre, dry weight. In medium brush, the plants are larger and volume is 15 to 30 tons per acre.

Resistant species form thin stands, averaging less than 50 plants per acre, and are spaced more than 30 feet apart.

This class includes mainly chamise-chaparral. Several inexpensive brush removal and control methods are applicable.

Medium brush with numerous plants of resistant species.—Total volume is 15 to 30 tons per acre, but the stems and root crowns commonly are larger, less brittle, and more difficult to remove than the shrub stands dominated by chamise.

The stands of resistant species are commonly intermediate, with 100 to 400 plants per acre spaced 10 to 20 feet apart, or sometimes dense, with more than 400 plants per acre spaced less than 10 feet apart.

This class includes mixed-chaparral typified by California scrub oak or sprouting species of manzanita. Several methods can be used to remove the brush. Followup brush control costs vary, depending upon the density of resistant species.

Heavy brush with few trees and numerous plants of resistant species.—Total volume is more than 30 tons per acre. The shrubby plants are near tree size; many have a height of 12 to 15 feet and stems about 6 inches in diameter. Trees, if present, are widely spaced and need not be removed.

Stands of resistant species may be intermediate (100–400 plants per acre) or dense (more than 400 plants per acre).

This class includes mainly the mixed-chaparral that is dominated by many plants of California scrub oak or other oak species. Removal methods may be limited to bulldozing or hand cutting; prescribed burning is difficult. Followup control of the resistant species is usually difficult and costly.

Heavy brush with many trees.—This class, with a total volume of more than 30 tons per acre, contains many trees which must be removed.

Stands of resistant species are intermediate or dense.

The class usually is dominated by oak trees, but it also includes some minor conifers intermingled with shrubs. Removal methods are usually bulldozing and hand cutting; prescribed burning seldom is feasible. Chemical control of the resistant species is difficult and costly.

Most stands of chaparral will fit into the above four brush classes, but exceptions occur on limited areas. For example, some mixed-chaparral with dense stands of resistant species of low stature, usually because of poor sites, will fit into the light brush category.

SITE PRIORITIES

Chaparral areas with a favorable combination of soil, slope gradient, and brush cover (table 5) generally have high priority for development as rangeland or for increasing water yield—provided soils on those areas are deep enough for potential water storage below the grass roots.

Areas having soils that can produce a satisfactory protective grass cover (soil productivity rating of 4 to 10) always have highest priority. The areas with soils

Table 5.—General priorities of chaparral areas of different site characteristics and brush cover for conversion to grass

General priority of area for conversion	Site characteristics		Brush class	
	Soil productivity rating	Slope gradient class	Volume of brush	Stand of resistant species
1	4–10	Stream bottom.	All volumes.	All densities.
1	7–10	Gentle to moderate.	Light or medium.	Few or thin.
2	7–10	Moderate to steep.	...do.....	Do.
2	4–6	Gentle to moderate.	...do.....	Do.
3	7–10	...do.....	Medium or heavy.	Intermediate or dense.
3	7–10	Moderate to steep.	...do.....	Do.
3	4–6	...do.....	Light or medium.	Few or thin.
4	4–6	Gentle to moderate.	Medium or heavy.	Intermediate or dense.
4	4–6	Moderate to steep.	...do.....	Do.
5	4–10	Steep.....	Light or medium.	Few or thin.
6	4–10	...do.....	Medium or heavy.	Intermediate or dense.
7	1–3	Gentle to moderate.	All.....	All.
8	1–3	Steep.....	Light or medium.	Few or thin.
9	1–3	...do.....	Medium or heavy.	Intermediate or dense.
10	1–3	Extremely steep.	All.....	All.
11	0	All.....	...do.....	Do.



F-510501, 510597

Figure 6.—Brush classes of different priorities for conversion to grass: A, Medium brush (chamise-chaparral) with few plants of resistant species—readily removed by crushing and burning and controlled by chemical spraying of sprouts; B, heavy brush (mixed-chaparral) with many plants of resistant species—difficult and costly to remove and control.

REMOVING THE CHAPARRAL

In converting chaparral to grass, all the woody topgrowth, except occasional trees or shrubs left for esthetic reasons or as shade for livestock, must be removed; partial brush removal generally has been unsatisfactory. Brush interferes with sowing of grass and spraying of brush regrowth. In addition, the woody fuel is hazardous on grass areas used in fire control.

Open stands of sage species killed by chemical spraying, however, can be left. The dead shrubs break down, and the natural grass between and under the shrubs develops a full cover without artificial seeding.

The methods commonly used to remove chaparral, listed approximately in order of decreasing cost per acre, are: (a) Hand cutting or grubbing, (b) bulldozing, (c) disking, and (d) prescribed broadcast burning. Chaparral is also commonly converted on

of highest productivity usually have first priority for development as rangeland.

Chaparral-covered areas on productive soils that contain few plants of species resistant to chemical spraying, or are on slopes with gentle to moderate gradient—or areas with a combination of these factors—have high priority for conversion (fig. 6). Fairly inexpensive chemical control methods have been developed for this chaparral.

Areas of medium or heavy brush containing many plants of resistant species, such as heavy oak stands, rate lower in priority because control methods are expensive and less effective (fig. 6). Areas of such chaparral on steep slopes are especially low in priority, because hand labor costs are usually high for both initial removal and followup control of the brush cover.

Although the priorities also apply in selecting the best areas for fuel-breaks, these sometimes must be built on low-priority sites. Conversion to a thin grass cover can be done with limited hazard of soil erosion on fuel-breaks with gentle or moderate slopes. However, because of the serious erosion hazard on steeper slopes, the conversion should be limited to the smallest areas that will serve for fire control.

Most areas of chaparral having high priority for clearing are small, often less than 100 acres. The total acreage is not known, because most of the chaparral lands have not been classified and mapped by the priority criteria used in this publication. However, from the little information available from mapping and observations, it is estimated that more than 1 million acres of chaparral is suitable for conversion to satisfactory grass covers on slopes that are not too steep. Additional large acreage should be developed on poorer soils or steeper terrain for fire control.

areas burned by wildfire, often with little additional cost for brush removal.

All the removal methods can be used on gentle to moderate slopes (gradient under 40 percent). All methods except disking also can be used on some moderate to steep slopes (gradient of 40 to 55 percent), but tractor work will be less efficient here. Only hand cutting or burning can be used on steep or extremely steep slopes (gradient greater than 55 percent).

HAND CUTTING OR GRUBBING

Chaparral on all slope gradients and of all brush classes can be removed by hand. Hand cutting or grubbing is used to remove hazardous fuels on many fuel-breaks where cheaper methods cannot be used.

In hand cutting, the stems are cut above the root

crown, and the topgrowth is piled or windrowed for burning under safe conditions in winter or spring. Hand cutting removes the brush without disturbing the soil or destroying the seed of herbaceous plants, and a new protective cover becomes established naturally.

In grubbing, the shrub root crowns are removed to reduce regrowth. Grubbing is necessary if the sprouts are not to be controlled by chemical spraying. Grubbing disturbs the soil, but still allows fairly rapid development of a new cover. It should not be used on extremely steep slopes where the shrub roots and crowns are needed to help hold the soil while a new cover becomes established.

In 1962, the cost of hand cutting, piling, and burning averaged about \$225 per acre for light brush, about \$600 per acre for medium brush with numerous plants of California scrub oak and similar species, and up to about \$1,100 for heavy brush with many oak trees. Grubbing adds about 50 percent to total costs.

BULLDOZING

Bulldozing is well adapted for removing chaparral where slope gradient and absence of rock outcrops permit safe and effective use of a tractor. Costs are reasonable for most brush conversion projects.

Bulldozing should be limited to gentle or moderate slopes if the areas have coarse, erodible soils. It can sometimes be done on steeper slopes with stable soils. Drainage ditches, or terraces, must be installed as needed. Deep scratches in the soil or berms of loose soil, which might channel water down the slope, must not be left.

Bulldozing of chaparral should be done with minimum topsoil disturbance. The blade is set to sever stems at the root crown. The tops are pushed into windrows for burning under safe conditions.

Average estimated costs of bulldozing on gentle to moderate slopes are about \$20 per acre for light brush, \$20 to \$40 for medium brush, and \$40 to \$60 for heavy brush. Bulldozing on steeper slopes or on rocky ground is more expensive. The estimated costs per acre include the costs of brush burning.

DISKING

Disking is more efficient than bulldozing for removing open stands of light brush, or dense stands of young brush plants on areas that have been burned a few years before conversion is started. A single pass of the disk will remove the smaller plants, but double disking is needed for most brush. Chopping brush into the soil with a heavy bog-type disk effectively removes light or medium brush dominated by chamise. The brittle stems are broken up, and many burls are uprooted by the large, scalloped disk blades. In all disking, dead-furrows up and down the slope must not be left.

Disking is not effective for mixed-chaparral with many tough stems and heavy root crowns. Also, it is not suitable for areas with slope gradients of over 30 percent except in the most stable soil.

The average estimated cost for disking is \$12 to \$20 per acre—depending upon the size of the shrubs and the need for single or double disking.

PRESCRIBED BURNING

Preparing chaparral as a good fuel mass and broadcast burning it later by prescribed techniques is recommended instead of bulldozing, *if the areas are located so that burning can be done safely and effectively*. Prescribed burning is usually cheaper than bulldozing, does not disturb the soil, leaves a clean seedbed with few viable seed of competitive annual grasses, and temporarily raises the level of available soil nutrients for better establishment and growth of a new grass cover.

However, prescribed burning of prepared fuel cannot be done readily on areas surrounded by brush containing a high proportion of dry material that may carry a hot, dangerous fire at any time of the year, especially in rugged terrain where control is extremely difficult.

While dense, mature chamise on south-facing slopes often can be burned safely in early spring without fuel preparation, more clean burns can be obtained if the brush fuel has been prepared. Burning of unprepared chaparral is not recommended on areas where followup sowing and spraying are planned for converting chaparral to grass. Burning standing chaparral seldom will remove the brush satisfactorily. *Burning unprepared chaparral in weather that will allow hot fires—attempting to draw a fine line between safe and unsafe conditions—inevitably leads to escape of fires.*

Prescribed burning involves two operations: (a) Proper preparation of the chaparral fuel and (b) safe handling of the broadcast fire.

Preparing the Chaparral Fuels

Chaparral fuels should be prepared to permit safe, clean burning during weather unfavorable for ignition, buildup, and spread of fire in natural fuels. The fuels should be prepared so that they will burn readily when unprepared chaparral will burn slowly if at all.

Brush Crushing

Chaparral will burn more readily and more completely if plants are compacted so that fuels of all sizes lie together, and if their moisture is reduced so that less water must be driven off during burning.

Compaction of the chaparral by crushing, lopping, or felling is the recommended fuel preparation before broadcast burning. Crushing shrubs with a bulldozer blade or a roller will both compact and dry the

fuel (fig. 7). Trees, if present, can be added to the dry, compacted fuel by felling them onto the crushed brush.

Compacting the shrubs in place is essential in preparing a continuous woody fuel mass to carry a hot fire which will leave a uniformly clean seedbed. Compacted fuel can be ignited so that it burns cleanly and steadily at a predictable rate with a minimum of flying embers that can start spot fires. Compacted chaparral fuel of sufficient volume will burn well even if many small stems are not broken off. But in light brush most of the stems must be broken off to provide adequate dry fuel to carry a fire under poor burning conditions.

Crushing of chaparral is best done in old stands of light or medium brush dominated by species with brittle stems, such as chamise, manzanita, and ceanothus.

Young stands of chaparral on recently burned areas seldom can be properly prepared by crushing. The limber stems will not break off; they must be severed with a roller or chopper. The time required for chaparral to recover enough after a fire for easy crushing cannot be forecast. It depends upon the species, site, precipitation cycle, and amount of dead brush skeletons left by the preceding fire. Even 10 years after a fire, chamise may not develop sufficiently for crushing and burning. Removal by disking or other methods is more efficient.

Heavy brush dominated by oak or other large shrubby plants with tough stems is not readily prepared for burning by crushing. Most of the stems are pushed over, instead of being snapped off, and do not dry enough to make good fuel. The amount of small, dry material usually is insufficient to build up a fire that will consume the heavy stems. The stems must be severed by sawing or another method.

A tractor of D-4 size will effectively crush light and medium brush dominated by chamise on easy terrain (fig. 7). Larger tractors are needed for heavy brush or on rough terrain. Tractors should have sufficient power to move forward continuously in the gear best suited to the terrain and rock outcrop. Brush should never be allowed to build up in front of the blade. Attempts have been made to increase crushing efficiency by adding extensions to the dozer blade or by pulling or pushing a wide roller or log. Such additions are advisable if they can be used without dragging the brush.

Smashing down chaparral with a heavy chain drawn between two large tractors is effective on mature, medium brush and on heavy brush on fairly smooth terrain. This technique is not effective for young, open brush, and is costly on rough terrain. However, it has good application for areas of suitable terrain and brush cover where the acreage to be crushed is great enough to warrant assembly of the necessary heavy equipment.



F-510600, 510603

Figure 7.—Preparing brush fuel for prescribed burning: A, Crushing medium brush (mature chamise-chaparral) with the smallest suitable type of bulldozer; B, rolling light brush (chamise-chaparral) to snap as many stems as possible.

Some chaparral is covered with much light, dusty material which may clog the radiator and cause overheating and loss of efficiency. This material may build up on the motor and be ignited, causing damage to the tractor or setting a fire in the brush. Therefore, a fire extinguisher should be carried, and brush should not be crushed during high fire-danger weather.

All brush can be burned more cleanly if a high proportion of the fuel is dry. Light or medium brush that has been crushed will dry rapidly during clear weather. Often it can be burned readily a few hours after crushing, but drying for a few weeks before burning is advisable. Heavy brush with many large stems should be left to dry during an entire summer before burning.

The costs of crushing chaparral with a bulldozer have been as low as \$4 to \$5 per acre (1962 rates) for light or medium brush on smooth terrain. Costs have been \$12 to \$15 for heavier brush, or for light or medium brush on areas of steeper slopes, where a

heavy tractor is required. An average cost is about \$7 per acre. The work can be done more cheaply on large areas if a roller, log, or chain can be used to increase efficiency.

Chemical Spraying

Chemical spraying makes standing chaparral burn more readily. The spray desiccates the leaves and twigs and sometimes kills most of the stems.

When only the leaves and twigs have been dried, the spread of fire is much like that in untreated chaparral at the end of the dry summer season. Many brush snags are left unless the chaparral is mature and contains much old dead material. In contrast, chaparral in which most of the woody material has been killed by spraying becomes a flashy fuel; fire spreads quickly, and intensity of burning cannot be accurately predicted. Consequently, until the techniques of spraying and burning become better developed, spraying for fuel preparation is recommended only in light or medium brush.

Two chemical treatments can be used to prepare brush fuels for burning: (a) Quick-acting contact herbicides that kill only leaves and twigs and (b) slow-acting systemic herbicides that kill part of the stems as well as the leaves and twigs.

Quick-acting desiccants should be used when the interval between spraying and burning is brief. The contact chemicals are effective if applied during clear weather only a few days before burning.

Toxic weed oils, with such chemicals as pentachlorophenol added to increase the contact killing, are effective desiccants. Aerial applications of 20 gallons of weed oil and one-half gallon of 5 percent pentachlorophenol per acre have been used to reduce moisture content of brush in the spring to a level typical of untreated chaparral in the late summer. At this moisture content, brush will burn readily in moderate fire weather in the late spring, when hazard of fire in untreated brush is minimal.

When applied by helicopter, such applications cost about \$10-\$12 per acre. Applications twice as great may be needed to prepare dense, medium brush for burning under poor burning conditions.

Studies are being carried on to develop more effective desiccation techniques. Recent tests have shown that certain herbicides, such as paraquat, are rapid-acting, effective desiccants that will replace weed oil and penta compounds for use on woody vegetation.

Slow-acting desiccants.—Phenoxy-type herbicides can be applied at the height of plant growth in spring to prepare the brush for burning the next fall or spring.

Low-volatile esters of either 2,4-D or a mixture of 2,4-D and 2,4,5-T, at 4 pounds acid equivalent, are applied in 10 gallons of water-oil emulsion per acre. Using helicopters, the cost is about \$7.50 per acre.

Broadcast Burning the Brush Fuel

Suggestions by government agencies and by rancher committees for planning and approving controlled burns do not include all precautions and skills needed for safe and effective use of fire in removing brush. Burning can be safely conducted only by men who thoroughly understand fire behavior. They should observe the following recommendations. Although each burn has its own hazards, a few basic guides apply to all *prescribed* burning of chaparral:

1. Make sure that the prepared brush within the area to be burned is more burnable than the woody fuels outside of the area.

2. Prescribe the weather conditions that will allow burning of prepared fuels within the area, and that will assure continuous control of the fire with the firefighting force and equipment available.

3. Break the area to be burned into small burning units surrounded by good control lines, so that only a small acreage will burn intensely at any one time.

4. Prepare a complete plan for the entire burning operation, have it approved by all persons concerned, and follow it rigidly.

5. Never start burning until all desired conditions are met, even though the burning must be rescheduled at considerable cost.

6. Provide for safety of the crews at all times.

Control Lines

Locate control lines around the boundaries of the area to be burned according to the principles described in fire control manuals. Where possible, the control lines should be accessible to motorized firefighting equipment.

Interior lines should divide the area into burning units as small as 10 to 20 acres. If possible, each unit should be a "natural burning unit," within which topographic features will aid the effectiveness of burning and control of fire. If the units cannot be determined by terrain, they should be nearly square or rectangular, with the long axis parallel to upslope drafts or to the prevailing wind direction. This formation can restrict the length of line to be held on the hazardous side of the unit; it also will permit a small firing crew to limit the intense fire to a small area at all times.

The units may be burned in a manner that will aid in effective burning of the entire area. The unit, or units, on the most hazardous side of the area should be burned first, and under conditions of low fire danger (index 0-5). This procedure provides a wide safety barrier, and it determines the kind of burning conditions needed for effective burning of the remaining units.

The control lines should be wide enough for the safety and working comfort of the crews who will be firing and holding the lines. Also, the width should be adequate to prevent extreme radiation and easy ignition across the line. Lines on the hazardous side, or sides, of a unit ordinarily should be 20 to 50 feet wide in light or medium brush, and wider in heavy brush. They may be considerably narrower in safe positions where the lines can be quickly fired and easily held.

Remove all hazardous fuels, such as snags, near the control line. The brush removed in preparing control lines should be pushed inside the area to be burned instead of being left as dry fuel outside the line. This brush should be moved with a minimum of soil, and spread out so that large piles are not left to hold heat near the line long after the units have been burned.

Season of Burning

Properly prepared chaparral is continuous dry woody fuel that will carry fire if properly ignited during suitable weather conditions at any time of year. But few days are appropriate for burning in summer or winter.

Spring or fall burning, before or after the summer-fall fire season, is recommended for prepared chaparral fuels. The danger of possible escape fires developing into disastrous wildfires is less than in summer; prescribed burning can be scheduled under a fairly wide range of weather conditions because of the lower hazard in the surrounding fuels. Also, crews are less apt to be needed for other firefighting activities.

Burning in early spring—before mid-April—must be done with caution because the surrounding natural brush fuels still have a low moisture content. Although the natural brush fuel will not readily ignite in early spring, it may burn intensely after a hot fire has started, especially on south slopes. Burning in early spring has two disadvantages in the conversion of chaparral to grass. First, chaparral sprouts vigorously during the first few weeks after burning and may require chemical spraying during the summer. Second, the soil surface may become compacted before grass seed is sown in the fall, making a poor seedbed for broadcast sowing.

Late spring—May in most years—is the safest period for burning because the surrounding brush is then highest in moisture content. Fires, which are not readily started in the natural brush, are more easily controlled than during other seasons. To best reduce brush regrowth, crushed brush should be burned in late spring. The resulting seedbed usually is satisfactory for early fall sowing of grass seed.

Fall burning—after the start of the rainy season—

is relatively safe if done during periods of cool weather when air and fuel moistures are high. However, clean burning of the prepared chaparral fuel may be difficult unless ignition points are closely spaced. Successful fall burning leaves good seedbeds for grass sowing.

Summer burning of chaparral under suitable weather conditions in the foothills is possible if the area to be burned is located where the fire can be readily controlled. But summer burning in the mountains ordinarily is not advisable because of the proximity of large areas of heavy fuels on steep terrain, where control of possible escapes may be most difficult.

Weather Conditions

Prescribed burning of prepared chaparral fuel should ordinarily be done under moderate burning conditions. The upper limits of temperature, humidity, wind, and fuel moisture under which burning is advisable and permissible are prescribed for each area by the fire control agency responsible for approving the burning plan. These burning conditions are determined by a comprehensive fire danger rating system used by all agencies in California.

A broad principle, applicable to all operations, is to burn only after a reliable forecast of favorable weather. Avoid unstable weather conditions; for example, do not burn if passage of a weather front is predicted within the next 12 hours. Burn when downward trends are predicted for the fire danger index.

In burning prepared, thoroughly dried chaparral fuel that is enclosed by adequate control lines, it is important to burn only in weather under which spot fires will not start from embers flying across the lines. Danger from spots is low on days when moderate burning conditions occur during the entire day. On days when the danger rating is higher, burning can be done at the end of the day, or at night, after temperature has dropped and humidity has risen. The conditions of temperature and humidity required to prevent spotting in fine fuels, however, will vary with the season and with the weather during the hours immediately preceding the start of burning.

During summer or fall, when grass and similar fine fuels are dry and relative humidity during the preceding hours of the day stays above 30 percent, danger of spotting is minimal under the following combinations of air temperature and relative humidity: 80° F. and 60 percent humidity; 60° to 70° and 55 percent; and 50° and 50 percent. Under these conditions the ignition index for fine fuels is approximately 24. A reading from a xerometer, a device for following changes in fine fuel moisture, will show about 350.

If humidity has dipped below 30 percent earlier in the day, higher levels of relative humidity are required to bring the ignition index for fine fuels and the xerometer reading down to a satisfactory level. If humidity has dropped below about 20 percent during the day, the fire danger index probably will be too high for safe burning, even at night.

During spring, when grass is green and high in moisture content, burning may be done at lower levels of relative humidity without danger of spot fires. The ignition index for fine brush fuels usually is up to 50, and burning is safe at relative humidities as low as 30 to 40 percent. Danger of serious escape of the fire is minimal if the control lines are adequate and the firing is done properly.

Windspeed of not more than 5 m.p.h. is recommended in burning prepared chaparral fuel. Good clean burns result from fire carried across the unit by a proper ignition pattern, rather than by wind. On some burning units with difficult topographic situations, a "favoring" wind of 5 to 10 m.p.h. that will aid in controlling the fire may be desired. Prescribed burning should not be attempted if wind velocity exceeds 10 m.p.h. across major ridges in the vicinity.

Ignition Techniques

Closely spaced ignition points ordinarily are required to build up the intense fire needed to obtain a clean burn when danger of spot fires is minimum.

The most widely applicable method for obtaining an area-ignition effect on small acreage is an intensification of the strip firing technique (fig. 8). The firing crew starts at the upslope or downwind side of the unit and sets closely spaced fires along the line. When the line can be easily held, the firing is sped up until the many small fires pull together and burn as a single intense fire over a few acres. The firing progresses downslope or against the wind at the speed required to keep a small acreage burning intensely, until the entire burning unit has been covered.

The spacing of individual "sets" and the number of men required to burn a unit by this ignition method depend on current burning conditions. Under the poorest conditions, when the soil and fine fuel are damp, space the sets every few feet. Under the best burning conditions that are safe, sets may be 50 to 100 feet apart; after an intense fire has been started, it can be carried along with little more than line firing.

Use of electrical ignition devices which are fired from outside the burning unit is desirable in firing crushed chaparral if adequate escape routes cannot be prepared for a firing crew, or in firing standing chaparral fuel that is too dense for safe movement of a crew. Under poor burning conditions, however, the

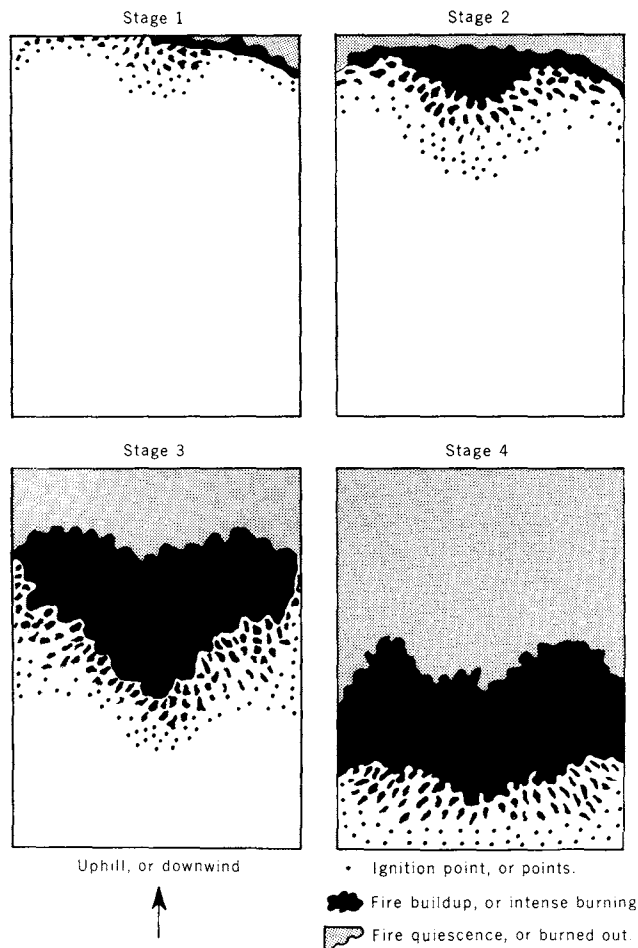


Figure 8.—Four stages in progressive area-ignition of a burning unit.

need to space the electrical devices very closely may make their costs prohibitive; some kind of flammable fuel is needed at each set to build up large fires.

Simultaneous area ignition of an entire burning unit requires rapid center firing, by a crew or by electrical ignition, followed by rapid firing of the control lines as soon as indrafts occur. A strong convection column builds up in the center of the unit and remains until the fuel supply is nearly exhausted. The elapsed time from start of ignition to dissipation of the column may be only 10 to 15 minutes for a 5-acre unit of crushed chamise fuel, but longer for heavier fuel.

Although it is effective, the firing of an entire unit at one time can be hazardous if the unit is too large or the fuel too heavy. The fire storm may be so large that it creates wind effects which cause the fire to move across control lines and do great damage. Ignition of an entire unit at one time is seldom necessary; a progressive method of firing usually will develop the desired area-ignition effect on less acreage.

ESTABLISHING THE NEW GRASS COVER

All effort should be made to establish an improved grass cover during the critical first year after brush removal. The best grass stands are obtained from sowing when the seedbeds are still nearly free of competing vegetation. Attempts to sow new species later, after a natural grass cover has developed, are seldom successful.

The main reason for sowing grass soon after brush removal is to establish vegetation that will fully cover the soil more quickly than the natural herbaceous covers which develop gradually on unsown areas. A second objective on many areas is to establish perennial grass that provides more and better forage than the annual grass and weeds which come in naturally.

Three or 4 years is needed to establish naturally a continuous ground cover after removal of dense chaparral. Buildup of a grass cover is particularly slow after dense chaparral has been removed by fire that destroys the slight amount of grass seed under the brush (fig. 9). Grass establishment also is commonly retarded after dense chaparral has been removed by bulldozing, which scrapes the grass seed from the soil surface.

Native and naturalized annual grasses establish a stand more rapidly after removal of semidense chaparral or other types in which many small grass plants grow between or underneath the shrubs. The amount of natural grass seed is sufficient to produce a fairly continuous grass stand during the first year if the chaparral has been removed by hand or machinery. But if semidense chaparral has been removed by burning, which reduces the seed supply, and the area is left unsown, at least 2 years will be required to develop a continuous grass cover.

Thus, grass sowing is essential, and is successful, on areas where dense chaparral has been removed by fire. Sowing is less needed, and is usually less successful, after removal of semidense chaparral by hand or machinery.

If sowing after removal of chaparral produces only a partially successful new grass stand, the resident annual grasses will fill in between the sown species. The sown species also may increase in density. On a productive site, the final stand will be sufficiently dense for adequate soil protection, and it can provide fair to good forage. Thus, if sowing gives less than the desired results, resident annual grasses will help develop a fairly satisfactory plant cover.

Establishment of introduced long-lived grasses is the most difficult step in the conversion process. Because the weather may be unfavorable for establishing grass seedlings the first year, effective methods of sowing must be used for the best chance of success. Follow three steps: Select grass species well adapted to the



F-510586-87

Figure 9.—The need for sowing grass after burning of dense chaparral: A, Bare soil on unsown plot 2 years after burning; brush sprouts killed by spraying with 2,4-D; B, dense protective cover of grass litter on adjacent plot sown to perennial grasses.

site, prepare a clean seedbed, and cover the seed by drilling or other means.

SUPERIORITY OF PERENNIAL GRASSES

Perennial grasses, on sites where they can be established, are preferred over annuals for revegetating former chaparral areas. Perennial grasses successfully established in full stands will produce superior plant covers (fig. 9). The perennials, having deeper, more extensive root systems, provide more consistent production and better soil stabilization. The most desirable perennial grasses start growth earlier in the fall and mature later in the spring or summer. Consequently, green forage adequate for livestock grazing is available longer. Also, the time when the grass cover is highly flammable is shorter; therefore, a better cover for fuel-break areas is provided.

Although perennial grasses are preferred for stabilizing soil on watersheds, they may be less effective than

shallow-rooted annuals for increasing the yield of water from converted areas. The deeper root systems of the perennials may extract more water from the soil profile by the end of the plant-growing season and leave less water for potential discharge into the streams. However, until conversion of chaparral solely to increase water yield becomes more widespread, and the relative merits of annuals and perennials on watersheds are determined by research, the perennial grasses are recommended for all conversion areas with sites suitable for their growth.

Sites Suitable for Perennial Grasses

Suitability of chaparral-covered sites for growth of perennial grasses depends primarily on depth, texture, and stoniness of the soil, and also on average yearly precipitation and its distribution.

The best stands of perennial grasses have been established on fine sandy loam, loam, or clay loam soils more than 2 feet deep. Such soils, with a storage capacity of more than 3 inches of available moisture in the upper 3 feet of soil, have a tentative grass production rating of 7 to 10.

Borderline soils for perennials are shallower and stonier and have a storage capacity of about 2 to 3 inches of available moisture. They have been given a rating of 4 to 6. Available perennial grasses will grow fairly well on the borderline soils of loam or clay loam; they are recommended on such soils if the seedbed is clean and the seed can be covered. Hardy native perennial grasses, such as nodding stipa (*Stipa cernua*) and blue wildrye (*Elymus glaucus*) grow well on borderline soils with sandy loam texture, but seed of these species is not commercially available. Sowing of commercial perennials on sandy loam borderline soils is recommended only on a trial basis.

On soils with adequate water-holding capacity, adaptation of the different perennial grasses is determined by climatic factors—average yearly precipitation, drought frequency, winter temperatures, and drying winds. Conditions under which sowing of perennial grasses is recommended in each major climatic zone are:

1. The best soils, with a rating of 7 to 10, and average annual precipitation of 15 inches or more. When rainfall is less, sowing perennials is questionable.

2. Borderline soils (except sandy loams), with a rating of 4 to 6, and average annual precipitation of at least 20 inches. It is probably better to sow annual grasses if average rainfall is less than 20 inches on soils of this rating.

Average yearly precipitation and its distribution determine which perennial grass species may be best adapted. They indicate the probability of favorable or unfavorable moisture during the year of seedling establishment. The chances of encountering periodic

drought during the critical establishment period are much greater in low-precipitation areas in the southern half of California than in areas of higher precipitation in the northern half. Thus, expensive perennial grass seed should seldom be sown on borderline sites in southern California, especially on areas where the best methods of sowing cannot be used.

Perennial Grass Mixtures Recommended for Sowing

The perennial grass mixtures recommended for sowing in the different climatic zones are listed in table 6. Mixtures of four or more species, instead of simpler mixtures or single species, are recommended for several reasons. Adaptation of each species to specific sites is not fully known. Site conditions seldom are uniform throughout an area to be sown. Secondary species may be better established than the primary species in the mixture if unfavorable weather or seedbed conditions occur. Finally, seed of some species is too expensive or too scarce to be used in great amounts.

Hardinggrass (*Phalaris tuberosa* var. *stenoptera*) is the primary species for perennial grass mixtures in the coastal and lower inland zones. Once established on productive soils, it grows vigorously; it is long lived, although it may be less drought resistant than some of the other recommended species, and it produces excellent forage. Where adapted, Hardinggrass can be sown as the only perennial grass, or with smilgrass (*Oryzopsis miliacea*) as a basic part of the perennial grass mixture. But, mostly because of costs, secondary species should usually be added.

Three species of wheatgrass—intermediate (*Agropyron intermedium*), pubescent (*A. trichophorum*), and tall (*A. elongatum*)—are highly adaptable as primary species in the upper inland and desert zones, and as secondary species in all zones. The three species often are sown in mixtures because the specific site adaptation of each is not known. Tall wheatgrass should be replaced by intermediate wheatgrass on areas to be used primarily for livestock grazing. Intermediate is preferred over pubescent in the coastal and lower inland zones, but pubescent should be included in the upper inland and desert zones. Crested wheatgrass (*A. desertorum*) is added on areas near the desert.

Three other species—Veldtgrass (*Erharta calycina*), Goars tall fescue (*Festuca arundinacea*), and Sherman big bluegrass (*Poa ampla*)—are recommended as secondary species in certain zones (table 6).

A small amount of bland brome (*Bromus mollis*), a commercial strain of the annual softchess, should be added to the perennial grass mixture. It is used to fill in the spaces between perennials after the first season, before less desirable annuals occupy the site. Bland brome in thin stands is not severely competitive with the first-year perennial grass seedlings, even when

Table 6.—Rates of drill sowing on suitable sites, by species and climatic zones

[Pounds per acre ¹]

Species	Climatic zone				
	Coastal	Lower inland		Upper inland ²	Desert
		Central California	Southern California		
Hardinggrass (<i>Phalaris tuberosa</i> L. var. <i>stenoptera</i> (Hack.) Hitchc.)....	2	2	2	—	—
Smilgrass (<i>Oryzopsis miliacea</i> (L.) Benth.).....	1	1	1	—	—
Veldtgrass ³ (<i>Erharta calycina</i> Sm.).....	1	—	1	—	—
Wheatgrass:					
Intermediate (<i>Agropyron intermedium</i> (Host) Beauv.), pubescent					
(<i>A. trichophorum</i> (Link) Richt.), tall (<i>A. elongatum</i> (Host)					
Beauv.), or any combination.....	1	2	2	5	3-4
Crested wheatgrass (<i>Agropyron desertorum</i> (Fish.) Shult.).....	—	—	—	—	1
Goars tall fescue (<i>Festuca arundinacea</i> Schreb.).....	1	1	—	1	—
Orchardgrass (<i>Dactylis glomerata</i> L.).....	—	—	—	.25	—
Sherman big bluegrass (<i>Poa ampla</i> Merr.).....	—	.5	—	—	—
Blando brome (annual) (<i>Bromus mollis</i> L.).....	.25	.25	.25	—	—
Total.....	6.25	6.75	6.25	6.25	4-5

¹ Double rates for broadcast sowing.² Above 3,500 feet (mainly in southern California).³ Recommended only for sandy loam soil in southern Cali-

fornia. Replace by Hardinggrass or a wheatgrass on other areas.

it produces large plants. But a dense stand of brome to provide a quick cover the first year is not desired, and it should be avoided on areas being converted to a perennial grass cover. Orchardgrass (*Dactylis glomerata*), a perennial, is recommended instead of blando brome in the upper inland zone.

Annual legumes under certain conditions are a valuable addition to the grasses. They build up and maintain soil fertility. Legumes such as rose clover (*Trifolium hirtum*), subterranean clover (*T. subterraneum*), crimson clover (*T. incarnatum*), and bur-clover (*Medicago hispida*) should be sown where local experience indicates they will grow. Legumes are not recommended for general sowing because success in establishing them on areas cleared of chaparral has been very poor and herbicides used for brush control often kill them. The latter problem may be solved by delaying the spraying date, or by establishing annual legumes within the grass stands after the brush has been controlled.

PREPARING THE SEEDBED

The degree of seedbed preparation differs with the kind of chaparral and the brush-removal method (fig. 10). The purpose of seedbed preparation is to eliminate the existing vegetation and to reduce the seed supply of competitive annual plants, especially grasses. Many sowing failures have been caused by failure to recognize that the seed supply of resident annuals must be almost completely destroyed in preparing

seedbeds for perennial grasses. Scattered plants of the most competitive annuals can produce enough seed the season before perennial grasses are sown to provide a fairly continuous stand of competitive plants the next year.

Establishment of perennials may fail because such thin, continuous stands of annuals can extract much moisture from the surface soil by the end of the rainy season. Competition is most severe and most apt to cause failure on sandy loam soils and in areas of low rainfall. On fine soils in areas receiving more than 30 inches of precipitation, the perennial grass seedlings can survive considerable competition.

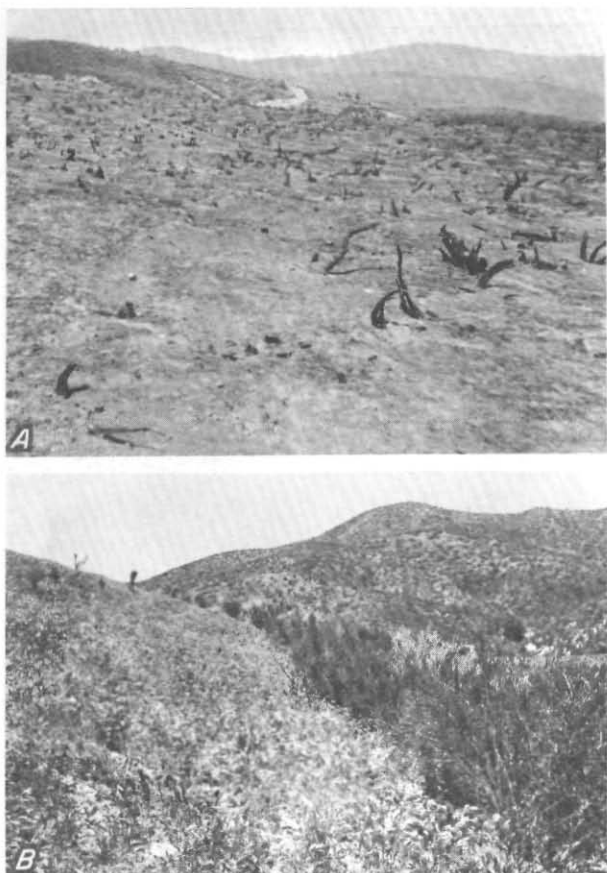
Burning of dense chaparral, by wild or prescribed fire, destroys most seed of undesirable competing grasses. Burning also increases available soil nutrients and provides a firm seedbed with a soil surface favorable for covering seed. To produce a satisfactory seedbed, the fire must be hot enough to consume at least the leaves, twigs, and small stems of the shrubs, and all of the ground litter. Such areas have a so-called "white ash" appearance immediately after the fire. The best seedbeds occur where all the chaparral stems have been consumed. Low-intensity fire that only scorches or chars much of the ground litter leaves many grass seeds undamaged. And fire in light, open brush seldom produces a clean seedbed. Such burned areas usually have a "black ash" appearance from charred grass and other light ground fuel.

A satisfactory seedbed is produced by crushing chaparral and broadcast burning it in place when the brush

SOWING PERENNIAL GRASSES

Drilling is the most consistently successful method for establishing grasses on areas from which chaparral has been removed, even though good perennial grass stands sometimes can be obtained by broadcasting seed on burned areas.

Tests started in 1949 with a standard farm drill showed the main advantages of drilling over broadcast sowing. Development of the heavy-duty rangeland drill greatly helped establish drilling as the better sowing method (fig. 11). On all seedbeds, the seeds in drilled rows have been placed near or in favorable soil moisture, promoting more uniform and more complete seed germination and seedling establishment than was obtained by broadcast sowing. On seedbeds with a hard soil surface, good seed coverage has been obtained in drilled rows, but little seed has been covered in broadcasting. Losses of seedlings due to frost heaving or cold, dry winds have been minimum in the



F-510584-85

Figure 10.—Seedbeds after different methods of brush removal: *A*, Clean, firm seedbed prepared by crushing and burning dense, medium chamise-chaparral; *B*, weedy seedbed not suited for sowing perennial grasses, showing first-year growth of competitive resident annual grasses after disking of semidense, light chamise-chaparral.

has enough density and volume to carry a fire under moderate burning conditions. In medium or heavy brush, the burning produces an exceptionally clean seedbed. Burning of crushed light brush leaves a patchy seedbed, but it is acceptable for sowing. Brush should not be partially piled or bunched before broadcast burning because heat radiated from the piles will not kill the grass or grass seed on the ground surface between the piles. Also, crushed brush should be burned before a new crop of native annual grass seed has matured and added to the seed supply.

Hand cutting or grubbing of chaparral seldom makes a seedbed sufficiently clean for sowing of perennial grasses. However, one of these methods can be used in the heaviest chaparral that contains almost no grass plants before cutting. Ordinarily the annual plant competition must be removed by cultivation or chemical treatment before perennials can be successfully established. Consequently, few hand-cleared areas have been sown with perennial grasses.



F-510592, 510594

Figure 11.—Positive establishment of perennial grass on cleared chaparral land: *A*, Drilling grass seed on a clean seedbed prepared by crushing and burning chamise-chaparral; *B*, typical continuous stand of grass in the drill rows.

drilled rows but have been excessive during cold winters on broadcast-sown areas. In mild, rainy winters, however, the grass stands from broadcast sowing on good seedbeds often have been adequate even though less uniform than those obtained by drilling.

In general, drilling has produced more consistent grass stands under unfavorable seedbed and weather conditions. Less seed has been required to obtain a full stand than in broadcast sowing; this saving may compensate for the extra cost of drilling. Sowing perennial grasses with the rangeland drill is recommended on cleared chaparral land where the drill can be efficiently used, and where rugged equipment is essential.

Where and When To Drill Perennial Grasses

The nature of the terrain and the amount of rock outcrop determine where drilling can be done efficiently. On smooth, firm, rock-free terrain with gentle to moderate slopes (up to about 40-percent gradient), the heavy drill can be used safely and efficiently behind a D-4 size crawler tractor (fig. 12). The drill is not well adapted for use on steeper slopes or on loose soil; a larger tractor must be used, and extra care must be taken to avoid damage to the drill. Drilling should be done on the contour to reduce the chance of soil erosion.

Bulldozed or disked areas or areas of suitable terrain on which the chaparral has been removed by hot fires can be efficiently sown with the rangeland drill. Generally the remaining unburned brush stems are small and brittle and therefore do not interfere with drilling. Where numerous stems remain or plants of tough species persist, they should be broken down or removed before attempting to use the drill. Pulling the drill over heavy brush stems will result in costly breakage and delays.

In contrast to broadcast sowing, drilling can be done successfully after the seedbed surface has been compacted by heavy rains; in fact, such compaction is desirable on some disked or bulldozed areas. Unless the seedbed is extremely loose and requires firming by rain, drilling should be planned for the fall—September or early October in central California, and October or November in the southern part of the State. If undertaken later, the job may be delayed by storms; and the benefits of drilling may be greatly reduced.

Using a small tractor on gentle terrain, drilling costs about \$5 per acre. It may cost considerably more on rough terrain or with use of a large tractor. Because of labor and equipment transportation costs, small jobs are usually more costly per acre than large jobs. The average cost of seed of perennial grass mixtures



F-510593, 510602

Figure 12.—Two methods of sowing and covering grass seed on burned-over chaparral land: A, Sowing with rangeland drill on smooth terrain; B, covering broadcast seed with use of a roller specially designed for rough land where the drill is not adapted.

is about \$4 per acre; therefore, the total seeding cost is at least \$9 per acre.

On terrain broken by numerous steep-sided, small drainages not easily crossed with a tractor, the drill cannot be used efficiently. Constant turning slows the job and puts the drill under excessive strain. This may cause costly breakdowns, especially if a heavy tractor is used. Although the drill may be used on the smoothest portion of such rough areas, aerial broadcast sowing is preferable.

Where and When To Broadcast Perennial Grasses

Broadcast sowing of perennial grasses is worth trying where drilling of cleared areas is prohibited by terrain or rock outcrops, even though success is uncertain. But as much broadcast seed as possible should be covered on all portions of an area. A roller or drag can

be used to cover seeds on areas too rough for efficient use of a drill.

The best chance for obtaining a good stand of perennial grasses occurs after a hot fire in dense old brush that had a fairly continuous thin layer of litter on the ground. The soil surface is mellow, and much of the sown seed will be covered by a mixture of soil, charred organic matter, and ash. Without litter on the ground before burning, the soil surface usually is too hard for covering of seed after the brush has burned; mechanical covering is needed.

Covering broadcast seed by mechanical means has improved perennial grass stands on all kinds of seedbeds. But consistently successful methods for covering broadcast seed on cleared chaparral lands still must be developed.

A heavy, flexible roller is especially designed for covering broadcast seeds on burned-over chaparral land (fig. 12). Other rollers, such as a sheepfoot roller or a farm cultipacker, can be used. Also, drags can be pulled by horses or tractors. Even tractor tracks will cover much of the seed.

Timing is much more critical for broadcast sowing than for drill sowing. Early fall is recommended. Seed may be germinated and seedlings established by the first fall rains, while temperatures are still favorable for plant growth. The risk of losing grass seedlings during succeeding dry weather appears to be less than the risk of damage from cold winter weather on late-sown areas.

Sowing before the first fall rains is especially important on areas of fine soil that are quickly compacted by rain. Such early sowing is not so essential on sandy loam soil, which may remain fairly mellow after receiving a few inches of rain.

The cost per acre of broadcasting 10 pounds of seed by helicopter is about \$1. Transport of the helicopter to the job site may add to this cost on small areas. The cost of covering seed with a roller is estimated at about \$3 per acre, making sowing costs about equal to drilling. But the seed for broadcast sowing costs twice that for drill sowing.

SELECTING AND SOWING ANNUAL GRASSES

Annual grasses should be selected primarily for their capacity to produce a good cover during the first 2 years. Blando brome is a good annual species for establishment and growth on poor seedbeds. It has been established on hard seedbeds with fair consistency in central California. Wimmera 62 ryegrass has shown more promise than the common commercial



F-510508

Figure 13.—Establishment of cereal grain in contour rows that were hand sown and fertilized—an expensive procedure which may be needed to assure a cover on steep slopes on portions of fuel-breaks in critical watersheds.

strain of ryegrass (*L. multiflorum*) for sowing under low rainfall and on low production sites. A mixture of Blando brome and Wimmera 62 ryegrass, at 5 to 10 pounds per acre, is recommended for sowing on cleared areas where perennial grasses will not be sown. The mixture is much more easily sown by helicopter than the fluffy seed of brome alone.

Cereal grains are not recommended for broadcast sowing on cleared chaparral land, although good temporary cover may be produced on some sites if the seed is covered. On steeply sloping land, sowing of barley (*Hordeum vulgare*) by hand in contour rows with heavy fertilization provides good soil stabilization (fig. 13). This type of intensive and expensive sowing may be necessary to establish an adequate plant cover on portions of some fuel-breaks in critical watersheds.

After dense chaparral has been removed from sites not suitable for perennial grasses, annual grasses should be sown to establish a plant cover for soil protection or forage during the first 2 years. But sowing of annuals usually is not needed on areas where a relatively open stand of brush has been removed by fire or mechanical means, and on some areas cleared by hand cutting. Such areas will revegetate naturally.

Extra costs for preparation of a clean seedbed are not warranted on areas planned for sowing to annual grasses. Even though much better stands of annuals can be obtained by covering the seed, drilling is seldom practical except on the most critical watersheds where the best possible stand is desired the first year. Early fall sowing is recommended for annual grasses.

The total cost of sowing, by helicopter, a brome-ryegrass mixture and common ryegrass alone, including the cost of seed at 10 pounds per acre, is about \$4 and \$1.50 per acre, respectively.

CONTROLLING BRUSH REGROWTH

Open stands of brush left uncontrolled in the chaparral zone usually will develop into a full cover in 5 to 10 years. Reinvasion is sometimes more gradual, but brush eventually replaces grass if control is not adequate.

Adequate brush control on areas converted from chaparral to grass requires elimination of almost all small brush sprouts and seedlings. All the more aggressive species, such as chamise and ceanothus, must be killed. Widely scattered plants of oak and other slow-spreading species can be left. The brush stand should be reduced so that grass remains a stable cover requiring minimum maintenance.

NATURE OF BRUSH REESTABLISHMENT

During the first growing season after removal of the aboveground parts, most chaparral species produce new sprouts from buds in the root crowns (fig. 2). If brush topgrowth is removed during summer or fall, the sprouts grow most vigorously during the next spring. If it is removed during late winter or early spring, the new sprouts grow most vigorously during the same year in late spring and early summer. Many chaparral plants may start producing sprouts within a few weeks after their tops have been removed, but under extreme drought—especially in southern California—some plants may remain dormant for more than a year before producing sprouts.

The method of brush removal affects the number of sprouting plants. Some control of brush regrowth always is needed, however, regardless of the method of brush removal. Disking greatly reduces the number of plants and sometimes almost eliminates them. Burning often kills more than half the plants of sprouting species, but the remaining plants always develop a full brush cover. Deep bulldozing, which removes almost all shrub root crowns, greatly reduces the number of chaparral plants, but still leaves many buried crowns or roots which will produce sprouts. Shallow bulldozing usually leaves numerous sprouting plants.

A new brush cover also can generate from viable seed in the soil. Burning in summer or fall, when the soil is dry and radiated heat penetrates into the soil, is most likely to start a new crop of brush seedlings. In the spring following the fire, thousands of seedlings per acre will start growing. Brush burning during spring may produce few seedlings—possibly because the radiated heat does not penetrate into moist soil. Removal of brush by cutting or grubbing or by mechanical means usually does not greatly stimulate

brush seed germination. Nevertheless, on some areas many seedlings become established within a year.

The surge in germination of brush seeds usually occurs within 2 years. Exceptionally dense stands of chamise seedlings may occur in 2 successive years after burning. The seeds in the soil are a potential source of brush plants that persists indefinitely.

Maintenance checks will be necessary to determine whether brush seedlings have become established, so that these seedlings, when young, can be easily killed by herbicide spraying or other methods.

Numerous brush seedlings may become established in occasional years when heavy rainfall continues late into the spring. Such years can provide ideal conditions for germination of brush seed and a chance for brush seedlings to become fully established before the grasses extract the available moisture from the upper soil. The possibility of successful brush establishment under such favorable moisture conditions probably will be greatest on sites that ordinarily support a thin grass cover.

Successful conversion of chaparral to grass is achieved when few brush seedlings survive in the grass cover after it is fully established. By then, brush control measures have killed the original chaparral sprouts and seedlings, and a full grass cover has been established to compete with new brush seedlings. Any requirements for control of brush in the future should be minor. This assumption appears justified by several successful conversions on good sites, where no brush has reinvaded in 10 years.

CONTROL BY HERBICIDAL TREATMENTS

Controlling brush regrowth with herbicides, the least expensive brush control method, has become standard practice in converting chaparral to grass since phenoxy-type herbicides were developed. Older chemicals were not widely used because they were not selective, some were poisonous to animals, large amounts were needed, and application was expensive. The chemicals now commonly used—2,4-D and 2,4,5-T—are selective: they kill brush and other broadleaved plants without damaging the grasses. Thus, control of brush regrowth can be started while the grass cover is being established—a key feature of current brush conversion techniques.

A few pounds of active agent per acre applied and reapplied as recommended will kill most brush plants. The effect of a single application may be limited by unfavorable weather conditions. Also, some resistant species may require several applications.

When To Apply Herbicides

Timing of chemical treatments includes the year of initial application, the number and frequency of followup applications, and the season of spraying.

Year of Initial Treatment

Chemical treatment should be started when brush regrowth is young and small, and before it can have an adverse effect on seeded grasses. Areas on which most brush sprouts are more than 3 feet tall ordinarily should be recleared before a spray program is started. Some reasons why the spray program is started the first or second year after brush clearing follow: Spray material is likely to be deposited on all leaves if topgrowth is limited; spraying is easier and a smaller amount of chemicals is required; the brush plants have not regained vigor after removal of the topgrowth; and the growth of excessive woody material, which would remain as hazardous fuel after being killed by chemicals, will be prevented. In summary, the job is less costly and more effective.

The best year to start treatment usually is during the first growing season after removal of the brush. However, spraying programs on publicly owned lands often must be delayed for fiscal reasons until the second year. Spraying of 2-year-old sprouts of chamise and sage species has sometimes given excellent results.

Delay of spraying until the third growing season is not recommended; 3-year-old chaparral sprouts usually are too large to obtain the maximum effect from spraying. Unless brush control spraying is started by the second year on areas seeded to perennial grasses, brush competition will become excessive; it may even destroy the grass stand (fig. 14).

In hand cutting that includes application of chemicals to freshly cut stumps, sprout control should be started when the brush is initially removed.

Continuity of Followup Treatments

Herbicide treatment is optimum only if followup treatments are used until the unwanted brush plants are dead. Plant susceptibility to spray increases with each application; therefore, the job becomes easier as it progresses. Removal of chaparral should be limited to the acreage on which complete chemical control can be planned and financed.

While two herbicide treatments often produce full control of brush regrowth, three or four treatments should be planned—two or three broadcast sprays plus one or two hand sprays if needed. In chamise-chaparral, but not in mixed-chaparral, the followup hand spraying of individual plants should be easy because most plants are killed by broadcast spray.



F-510595

Figure 14.—Effect of competition from 2-year-old chamise sprouts shown by successful grass establishment in sprayed plot on left, and by grass failure in unsprayed plot on right.

Season of Application

In foothill and lower mountain areas, spraying is most effective when done after leaves are fully developed and sprouts are about 12 inches high in chamise and 18 to 24 inches high in scrub oak. Spraying during the spring period of active plant growth should be delayed until the emergence of new brush seedlings is complete or nearly so. Ordinarily, this date coincides with adequate development of the sprouts.

Because young sprouts of most chaparral species do not have a normal seasonal cycle of flowering and fruiting, such growth stages cannot be used to judge the physiological stage of growth that is best for effective spraying. Consequently, the stage of growth should be judged in relation to soil moisture and current twig growth.

The best stage for spraying is in the later part of the most active growth period, when soil moisture is still adequate for shrub growth, the plants are still growing, and the surfaces of the twigs and leaves have not hardened off. More definite criteria may be developed by studies of the length of the active growth period and depletion of root reserves before spraying.

Timing of chemical application is greatly influenced by the method of spray application. The timing is most critical for broadcast foliage spraying, and it is less for foliage-stem applications made by high-volume spraying of individual plants.

Broadcast foliage spraying.—Broadcast spraying—a low-volume application over an entire area—must be done during a short period in spring. The best starting date depends on the age and size of the sprouts.

Small, first-year sprouts do not extract soil moisture as rapidly as large, old sprouts. Thus, the young

sprouts continue to grow actively until late spring or early summer. If sprayed too early, the plants will resprout after the first shoots have been killed by spray. These new sprouts may die from delayed chemical action or drought, but usually many will survive.

Broadcast spraying of first-year sprouts may start May 1–15 in most years in southern California and about June 1 in the northern portion of the brush zone. Older, larger sprouts, which extract soil moisture rapidly during the spring, should be sprayed about 3 weeks earlier in both portions of the zone. Such spraying may be done sooner or later in years of extremely early or late drying of the soil. Delay of spraying until the hot, dry season can greatly reduce the kill obtained on old sprouts.

Because broadcast spraying is often delayed by unforeseen difficulties, or may require a few weeks, the planned starting date should be the earliest effective date.

Individual-plant, foliage-stem spraying.—Heavy application by hand spraying on individual plants can be done over a longer portion of the year, but the most effective period is the same as for broadcast spraying. Good results also have been reported from spraying during the dormant growth period in late fall and winter. Spraying during drought dormancy in summer and early fall is considered least effective.

In field practice in southern California, however, hand spraying of individual plants has been done effectively throughout the year. Chamise has consistently been killed by hand spraying on any date, provided the sprouts were well developed and at least 12 inches tall. California scrub oak also has been killed by hand spraying in all months, including August, but regardless of the month the degree of kill from a single application has generally been poor and has varied considerably.

Hand spraying should be started after the sprouts are well developed and should be continued as long as they are growing. If the job cannot be completed during late spring and early summer, the hand spraying should be continued later that year.

Individual-plant, stump treatments.—These treatments must be made when the chaparral is cut. Cutting should be done in late winter when the chemical applications are most effective.

Recommended Herbicide Applications

The low-volatile esters (l.v.e.) of 2,4-D and 2,4,5-T have proved effective chemicals for killing almost all the chaparral species, and are widely used for stem and leaf sprays. Other selective herbicides that may be effective at lower rates are being developed.

Some chaparral species are more sensitive to 2,4,-D than to 2,4,5-T. However, the various species usually occur in association, and the chemical to be used is determined by the dominant species.

In spraying chaparral dominated by chamise and sage species, 2,4-D is used alone. In some tests addition of a small amount of 2,4,5-T was more effective than 2,4-D alone, but in several tests a moderate addition did not kill more chamise. For mixed-chaparral, a mixture of 2,4-D and 2,4,5-T should be used.

Broadcast Foliage Sprays

Broadcasting spray material over an entire area is a foliage treatment because most of the material is deposited on leaves and twigs, with small amounts reaching the lower stems.

Broadcast spraying is intended to kill brush seedlings and sprouts of the susceptible species, particularly chamise. Broadcast sprays will also kill some plants of the resistant species and will retard the growth of the remaining plants so they can be more easily killed by followup spraying.

A major advantage of broadcast spraying is rapid coverage of large areas, which is necessary in the expanding herbicide control program. Maximum use of broadcast spraying, by ground rig or helicopter, will limit the necessary hand spraying. Broadcast spraying, which is much cheaper than hand spraying, should be used as an initial treatment on areas with more than 100 to 200 brush plants per acre. It is also recommended as a followup treatment as long as numerous plants of susceptible species are still alive.

Methods of broadcast spraying.—Three methods, or modifications of them, are used: (a) Boom spraying by ground rig, (b) aerial spraying, and (c) mistblower spraying.

Spraying with a boom mounted on a tractor (fig. 15) or on a trailer pulled by a tractor is an effective method. On gentle and moderate slopes (under about 40-percent gradient) with few rock outcrops and with smooth soil, it is efficient and inexpensive. Ground-rig boom spraying is not restricted by fog, and it can be done when wind prevents aerial application.

Aerial application is adapted for broadcast spraying of many chaparral areas, including all areas suitable for ground-rig spraying (fig. 15). Helicopter spraying is often preferable to ground-rig spraying because it covers large areas quickly and is adapted to rough terrain. If fog or wind interferes, however, use of a helicopter may prove more expensive.

Helicopters are widely used instead of airplanes because the application of the spray can be better controlled from helicopters. Also, some agencies prohibit flying of fixed-wing aircraft as low as is required for effective spraying.

Effectiveness of mistblower spraying on chaparral areas has not been determined. Applications with large blowers have not been as satisfactory as other methods of broadcast spraying. Small backpack mistblowers, however, appear suited for broadcast spraying



F-510608-09

Figure 15.—Two commonly used methods of broadcast spraying to kill brush regrowth: A, Boom mounted on a heavy tractor adapted for spraying in open areas of suitable terrain; B, boom on a helicopter that can be efficiently used on most areas, including rocky or steep slopes, if the areas are of adequate size.

on areas too rough for ground-rig boom spraying and too small for efficient aerial spraying. But broadcast spraying with a mistblower can be done only when brush regrowth is small because the spray material must be blown over the tops of the plants. It will not penetrate through dense crowns of large plants; an individual-plant application from all sides of the crown is required for a large plant.

Volumes of spray applied.—Enough volume of spray emulsion should be used to cover the crowns of sprouting chaparral plants. The volume should be limited to an amount that can be economically applied. This amount will differ with the method of broadcast spraying.

For ground-rig boom applications, apply at least 20 gallons per acre under most conditions. In remote areas, where water supply is a major expense, the volume can be reduced to 10 gallons per acre.

For helicopter applications, in which costs are directly related to volume applied, a minimum effective volume is desired. A total of 10 gallons per acre is

applied. For best coverage, the flight lines should be approximately 1.2 times the length of the boom. Use flagmen to direct the flight lines when possible.

For efficient application with a backpack mistblower, the lowest effective volume must be used. Start with 10 gallons per acre, but make trials with 5 gallons per acre to see whether the lower volume is effective.

Rates of chemical applied.—Apply a moderate rate of 4 pounds acid equivalent (a.e.) of chemical per acre for most conditions. A higher rate of 6 pounds a.e. per acre is recommended for the initial spray on areas with dense stands of resistant species. Followup sprays can be applied at 2 to 4 pounds a.e. per acre.

Recommended chemical mixtures for broadcast spraying of chamise-chaparral and mixed-chaparral on different kinds of terrain are shown in table 7.

Table 7.—*Spray mixtures per acre for three methods of broadcast spraying of chamise-chaparral and mixed-chaparral*

Method of application and type of chaparral	Chemical (low-volatile ester)		Diesel oil	Water	Total emulsion
	2,4-D	2,4,5-T			
	Lbs. (a.e.)	Lbs. (a.e.)	Gals.	Gals.	Gals.
Ground-rig boom:					
Chamise-chaparral...	4	.....	1	18+	20+
Mixed-chaparral....	2-3	2-3	1	17½+	20+
Helicopter or mistblower:					
Chamise-chaparral...	4	.....	1	8	10
Mixed-chaparral....	2-3	2-3	1	7½-8	10

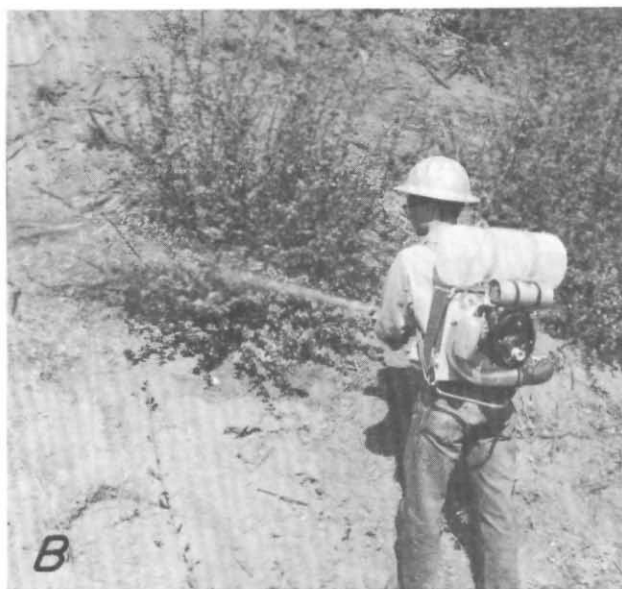
Individual-Plant, Foliage-Stem Sprays

Applying chemicals to each brush plant instead of to the entire areas is commonly called hand spraying because the spray is applied with a hand-held applicator (fig. 16).

The spray emulsion is applied to the entire shrub, both stems and foliage, until it starts running off the plant surfaces. This "saturation spraying" is the proven individual-plant treatment for the evergreen chaparral species.

The main advantage of individual-plant hand spraying is that effective results are obtained *if the spray crews are well trained and supervised*. Results can be disappointing if spraying of most plants is spotty and many plants are missed entirely. Even in the best supervised jobs, a few plants will be missed.

Hand spraying sometimes is necessary to prevent damage to trees or other plants within the area to be sprayed. It is a good followup procedure after one or



F-510606, 510607, 510605, 510604

Figure 16.—Some methods of individual-plant treatment: *A*, Foliage-stem spraying with a back-pump sprayer; *B*, foliage spraying of large sprouts with a backpack mistblower; *C*, spraying a stump with a pack-pump sprayer; *D*, painting undiluted herbicide on a cut stump.

two broadcast sprayings have killed almost all susceptible species and reduced the vigor and size of the resistant species. However, hand spraying requires much time and expense. Consequently, it is not recommended for an initial spray except where trees or other obstructions, or danger from drift of chemical, preclude broadcast application.

Chemical concentration.—A concentration of 4 pounds acid equivalent of chemical in 100 gallons of water-oil emulsion is used for most foliage-stem spray-

ing of chaparral. Although this concentration is recommended for use with a power sprayer, more trials should be made with heavier concentrations on the most resistant species, such as California scrub oak. Heavy concentrations in straight diesel oil, applied mainly as a basal stem spray, also should be tried.

A concentration of 8 pounds of chemical in 100 gallons of emulsion should be used with back-pump sprayers. A higher concentration of 4 pounds in 10 gallons is recommended for mistblower application (fig. 16).

Volume of spray material.—The volume applied per acre in hand spraying depends on the number and size of sprouting plants and on the method of application. If applied with a power sprayer, the volume may be about 50 gallons per acre for relatively light stands and for small plants, and up to 200 or 300 gallons for dense stands of large sprouts. Less volume usually is applied with a back-pump sprayer. The volume required for mistblower spraying will be lower than for other methods of hand spraying.

Recommended spray mixtures for hand spraying by different means are shown in table 8.

Table 8.—*Spray mixtures for three machines used in individual-plant hand spraying*

Machine	Chemical (l.v.e.)		Diesel oil	Water	Total emul- sion
	2, 4-D	2, 4, 5-T			
	Lbs. (a.e.)	Lbs. (a.e.)	Gals.	Gals.	Gals.
Power sprayer.....	2	2	1	98	100
Back-pump sprayer.....	4	4	1	97	100
Backpack mistblower....	2	2	1	8	10

Other Individual-Plant Treatments

Chemical treatment of hand-cut chaparral stumps is recommended only for reducing the amount of foliage spraying by hand that may be required later. Thus, cut-stump treatment should be limited to oak and other hard-to-kill species with a single stem or a few stems from each root crown. Plants with many stems from the crown cannot be treated effectively. Chamise and other susceptible species can be left for control by broadcast foliage spraying.

On stumps of the chaparral species to be treated, use a concentrated mixture of 4 pounds a.e. of 2,4-D and 4 pounds a.e. of 2,4,5-T low-volatile esters, in 48 gallons of diesel oil. The material should be sprayed on immediately after the brush is cut. The back-pump sprayer should be used to apply the mixture over the entire stump until it flows down the stump onto buds at the ground surface (fig. 16). Effectiveness is increased by raking away the litter and surface soil to expose the bud regions before spraying.

Painting of freshly cut stump surfaces with an undiluted formulation of 2,4-D amine is another useful method (fig. 16).

Treating chaparral stumps with ammonium sulfamate (ammate) may give effective control, but the material is corrosive and is more difficult to handle than 2,4-D and 2,4,5-T.

Application of a soluble soil sterilant in granular form around the stumps of hard-to-kill species is another promising method for reducing the later job of foliage spraying. Trials are underway to determine the necessary amounts to apply. Other information required for using nonselective sterilants to control individual chaparral plants is also being sought.

Costs of Herbicide Treatments

Chemical control of chaparral regrowth always is expensive, but the costs vary with the vegetation types, the methods of spraying, and the effectiveness of each application. The following estimates, used for planning, are based on costs of efficient projects, using 1965 price levels. Costs (given below) usually will be greater than the estimates on small projects, on inaccessible areas where costs for delivery of materials and personnel are excessive, and on projects using more manpower than is required.

Broadcast spraying.—For tractor-boom spraying chamise-chaparral with 4 pounds a.e. of 2,4-D in 20 gallons of emulsion, the estimated cost per acre for a single application is about \$7.50. For spraying mixed-chaparral, the costs per acre are about \$9 for 4 pounds a.e. and \$12 for 6 pounds a.e. Costs for helicopter spraying of 10 gallons per acre are approximately the same as for tractor spraying in each chaparral type.

Individual-plant hand spraying.—Costs of hand spraying are only broad estimates because of the great variation in number and size of plants to be sprayed. Initial hand spraying may cost \$20 to \$45 per acre for chamise-chaparral and \$30 to \$80 for mixed-chaparral. Labor requires about two-thirds of the cost and chemicals about one-third. Costs of the first followup hand spraying are estimated at \$3 to \$8 per acre for chamise and \$15 to \$30 for mixed-chaparral. The second and third followup sprayings should be cheaper—\$3 to \$4 for chamise and \$5 to \$15 for mixed-chaparral.

Complete spray programs.—The total costs of complete spray programs can vary widely, as indicated by these estimates:

	<i>Approximate costs per acre</i>	
	<i>Chamise-chaparral (dollars)</i>	<i>Mixed-chaparral (dollars)</i>
Number and kind of sprays:		
One broadcast, one hand.....	10-15	-----
One broadcast, two or three hand..	13-24	29-57
Two broadcast, one hand.....	18-23	23-36
Three broadcast, one hand.....	25-30	32-45
Two to four hand.....	23-61	45-140

The lowest estimates are for areas of moderate slope on which almost all regrowth can be killed by low-cost broadcast spraying with a ground rig or helicopter. The higher estimates are for dense stands of resistant species on steep slopes where heavy broadcast applications are recommended, and for areas where all spraying must be done by hand.

At least two broadcast sprays should be included in estimates of complete spraying costs, even though one spray often will kill almost all susceptible species. In drought years in particular, the first broadcast spray often kills only 50 to 70 percent of the susceptible species. A safe estimate for controlling regrowth in chamise is about \$20 per acre; however, half this estimate may suffice. Total spray costs for mixed-chaparral should be about \$40 per acre. In the most dense stands of the most resistant species, control may cost more than \$100 per acre. These are very rough figures because successful spraying of such areas has not been sufficiently extensive for more precise estimates.

CONTROL BY OTHER METHODS

Other brush control methods have limitations herbicidal treatments do not have. But one or more of these methods often can be used with herbicide applications in the conversion or maintenance of a converted cover.

Grass competition.—Quick-growing annual grasses heavily sown to choke out brush regrowth during the first year after brush removal do not provide adequate initial control of chaparral. Competition of grass for soil moisture will reduce the total brush seedlings, but some seedlings always survive. Grass competition does not kill brush sprouts—the dominant regrowth in chaparral.

Perennial grasses, usually recommended for sowing, are not competitive the first year. Herbicide applications should be used to kill the first crops of brush seedlings. Then competition from a full grass cover will limit reinvasion of brush seedlings. Thus, grass competition is an essential control measure in the long-term maintenance of a converted area.

Reburning.—Repeated burning generally is not used in the initial conversion of chaparral to grass now that herbicidal control techniques have proved successful. While some stands of chaparral have been greatly thinned by repeated burning, usually by wildfire, the literature does not contain a report on the successful use of fire to kill all brush sprouts. Supplementary brush control methods are needed to eliminate brush regrowth and to establish a stable plant cover. The conditions of fuel and weather required for successful reburning are not easily obtained.

After the brush sprouts have been killed by chemical spraying or other methods, occasional burning may maintain an annual grass cover. Young brush seed-

lings that become established in annual grass can be killed by a hot fire if the grass fuel is continuous and adequate in volume. Heat from burning grass fuel does not penetrate deeply into the soil, and ordinarily will not stimulate additional germination of brush seed.

Maintenance burning should be limited to areas on which fire in dry grass can be safely handled during summer or fall. *Remember that this is a period when fire, if it escapes, can do great damage.* Also, the lower cost for brush control compared with herbicidal control must be weighed against the loss of forage and the reduction in plant cover.

Burning is not recommended for control of brush seedlings in good stands of perennial grasses. The grass may be severely damaged by the fire.

Browsing.—Heavy browsing by livestock or deer can control chaparral regrowth on small cleared areas, but browsing alone is ineffective on most conversion areas. Yet, browsing by deer and in some cases by livestock can significantly supplement herbicidal treatment. The browsing can control scattered plants that survive herbicides, and it may eliminate or greatly retard new brush seedlings in the grass cover.

Hand reclearing.—Brush control by grubbing can eradicate the chaparral plants if the work is done intensively each year for several years. However, manpower needs are great, and costs exceed the highest estimates for chemical control. Periodic regrubbing of medium mixed-chaparral over a 20-year period requires about 55 man-days, or \$800 per acre. The costs range from \$200 for light brush to \$1,500 for the heaviest brush.

Mechanical reclearing.—Annual removal of brush regrowth by scraping or disking for a few years will eventually kill brush plants. This method is best suited for the limited areas which are dry farmed for a few years before being converted to grass cover; it has little use on other areas.

Combination methods.—Areas of chaparral have been converted to annual grass range by intensive application of several brush control methods. Cutting, burning, and browsing have been used effectively in combination, particularly in woodland types. On many chaparral areas, however, brush has quickly reoccupied the sites after intensive treatments were ended.

Based on current objectives and economic conditions, combinations of brush control methods can best be used when they supplement the major herbicide control effort.

SUMMARY

Most of the 11 million acres of chaparral—dense stands of evergreen, shrubby vegetation—below California's timber zone lie on steep terrain with shallow, rocky soils. These sites generally are unfavorable for cultural treatment of vegetation. But on selected areas, the native brush can be converted to a new plant cover, usually grass, that is stable and easily maintained.

Areas for conversion from chaparral to grass may be selected because of their strategic location—to break up extensive brush fields for better fire control; because of good soil depth—to help increase water yield; or because of productive soil—to develop new forage for livestock and deer. Multiple benefits usually can be obtained. The purpose and expected benefits should be evaluated before specific sites and applicable methods of conversion are selected.

Areas with good soil ratings (water storage capacity in the upper 3 feet greater than 3 inches of water) are best for conversion to rangeland, if terrain is suitable. Areas with fair soil ratings (capacity of 2 to 3 inches of water) also will produce a grass cover satisfactory for soil protection, but with lower grass yields. On areas with poor soil ratings (capacity less than 2 inches of water), conversion should be limited to that essential for fire control. Water yield can best be increased where soils are deeper than 3 feet. On areas of suitable soil, first priority for conversion of chaparral to grass is on gentle to moderate slopes (0–40-percent gradient) and on a chaparral cover that is easily removed and controlled, and second priority is on such slopes having a cover more difficult to remove and control. Lower priority is given to moderate to steep slopes (40–55-percent gradient), except for areas with high soil ratings and a chaparral cover that is easily converted. Areas on steep slopes (55–70-percent gradient) have low priority, except as needed for improving fire control, and possibly for increasing water yield. Areas on very steep slopes (greater than

70-percent gradient) should not be considered for conversion, except on limited acreage essential for fire control.

The chaparral that is most readily removed and controlled is light brush (5–15 tons per acre) and medium brush (15–30 tons) with few plants of species resistant to chemical spraying. Such brush is mainly chamise-chaparral and associated sage types for which chemical control methods are well tested and relatively cheap. More difficult to control is medium and heavy brush (more than 15 tons per acre) with many plants of resistant species. This kind of brush mainly is mixed-chaparral and associated types containing oak trees or minor conifers; herbicide control methods for this kind of brush are costly and not thoroughly tested.

The most difficult phase of the conversion process is establishment of perennial grasses. Success requires preparing a clean seedbed and covering the grass seed sown during the year of brush removal. Drilling grass seed is the most effective method.

Conversion to a stable grass cover requires eradication—usually by herbicide spraying—of the brush sprouts and seedlings which start growth soon after the brush has been removed. A grass cover fully established during the first 2 years is expected to prevent or greatly retard future reestablishment of brush as seedlings.

Many methods and combinations of methods can be used to remove chaparral, sow grass, and kill brush regrowth. They depend on terrain, chaparral type, need for grass sowing, adaptation of perennial grasses, resistance of brush regrowth to herbicides, and success of the individual spray treatments.

Total costs of conversion differ greatly, depending on the methods used. Some typical combinations of operations recommended for different situations are listed in the appendix. Costs shown are for efficient operations, and may be higher for difficult jobs.

REFERENCES*

- Anonymous.
1958. Wildland research in California—the key to better resource management. Calif. Div. Forest., Univ. Calif., and U.S. Forest Serv., 27 pp., illus.
- Arnold, R. K., Burcham, L. T., Fenner, R. L., and Grah, R. F.
1951. Use of fire in land clearing. Calif. Agr. 5(3): 9–11; 5(4): 7–8, 13, 15; 5(5): 11–12; 5(6): 13–15; 5(7): 6, 15.
- Bentley, Jay R.
1961. Fitting brush conversion to San Gabriel watersheds. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Pap. 61, 8 pp., illus.
- and Fenner, R. L.
1956. Range species recommended for sowing on cleared brushland in California. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 111, 10 pp., illus.
- and White, Verdie E.
1958. Soil temperatures during burning related to post-fire seedbeds on woodland range. J. Forest. 56: 737–740, illus.
- and Green, Lisle R.
1961. The fuel-break system for the San Dimas Experimental Forest. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Pap. 63, 9 pp., illus.
- and White, Verdie E., and Green, Lisle R.
1961. Helicopter sowing of burned watersheds on the San Dimas Experimental Forest, 1960. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Pap. 62, 7 pp., illus.
- Biswell, H. H., Taber, R. D., Hedrick, D. W., and Schultz, A. M.
1952. Management of chamise brushland for game in the north coast region of California. Calif. Fish & Game 38: 453–484, illus.
- Blanford, Robert H.
1960. Spring treatment as an aid in controlling chamise. Calif. Div. Forest. Range Impr. Stud. 3, 6 pp., illus.
- 1962. Preburn treatment of chamise by crushing. Calif. Div. Forest. Range Impr. Stud. 9, 4 pp., illus.
- Burcham, L. T.
1957. California rangelands. Calif. Div. Forest., Sacramento, Calif., 261 pp.
- Buttery, Robert F.
1958. How to crush chamise-brush for prescribed burning. U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Leaflet, 2 pp.
- Bentley, J. R., and Plumb, T. R.
1959. Season of burning affects follow-up chemical control of sprouting chamise. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 154, 11 pp., illus.
- California Department of Fish and Game.
1961. Improving chamise brushlands for deer and other game. Game Manage. Leaflet 4, 27 pp., illus.
- California Division of Forestry.
1960. The brush problem in California. Sacramento, Calif., 30 pp., illus.
- 1964. Brush control—"Ammate X" trial at mile high. Fire Control Exp. 6, Sacramento, Calif., 4 pp., illus.
- Carlson, C. E.
1962. The use of the xerometer in predicting burning conditions.* Calif. Div. Forest., Sacramento, Calif., 3 pp.
- Coleman, E. A.
1953. Fire and water in southern California mountains. U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Misc. Pap. 3, 7 pp.
- Davis, James B., Dibble, Dean L., and Singer, Kenneth L.
1962. Tests of fire retardant chemicals at Plum Creek. A report for California air attack coordinating committee. Calif. Div. Forest., Sacramento, Calif., 26 pp., illus.
- Dodge, Marvin, Bawcom, Richard, and Pierce, Cecil.
1963. Chemical control of brush and weeds on the Ranchita range study. Calif. Div. Forest. Range Impr. Stud. 10, 6 pp., illus.
- and Pierce, Cecil.
1962. Anchor chain improves brush rangeland. Calif. Div. Forest. Range Impr. Stud. 7, 8 pp., illus.
- Edmunson, George C., and Cornelius, Donald R.
1961a. Ryegrasses for southern California fuel-breaks. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 186, 6 pp., illus.
- and Cornelius, Donald R.
1961b. Promising grasses for southern California fuel-breaks. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Pap. 58, 13 pp.
- Evanko, A. B.
1959. Manipulation of brush cover on California National Forests. U.S. Forest Serv., Calif. Region, San Francisco, Calif., 70 pp., illus.
- Fenner, R. L., Arnold, R. K., and Buck, C.C.
1955. Area ignition for brush burning. U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Tech. Pap. 10, 10 pp., illus.
- Fuel-Break Executive Committee.
1963. Guidelines for fuel-breaks in southern California. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Fuel-Break Rep. 9, 25 pp., illus.
- Grace, Harry, Asplund, Rupert, Ely, Joe, Intorf, Phil, and Droge, R. F.
1956. Fireman's guide. Fire handbook. U.S. Forest Serv. Calif. Region, San Francisco, Calif., 343 pp., illus.
- Graham, Charles A.
1958. Killing brush sprouts on open woodland range in California. U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Res. Note 136, 5 pp., illus.
- Green, L. R., Edmunson, G. C., Cornelius, D. R., and Evanko, A. B.
1963. Seeding fuel-break areas in southern California. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Fuel-Break Rep. 10, 17 pp., illus.
- White, V. E., and Plumb, T. R.
1963. Some brush conversion costs on southern California fuel-breaks. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Fuel-Break Rep. 12, 18 pp., illus.
- Hill, L. W.
1963. The cost of converting brush cover to grass for increased water yield. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 2, 7 pp., illus.
- and Rice, Raymond M.
1963. Converting from brush to grass increases water yield in southern California. J. Range Manage. 16: 300–305, illus.
- Hopkins, Walt, Bentley, Jay, and Rice, Ray.
1961. Research and a land management model for southern California watersheds. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Pap. 56, 12 pp., illus.
- Horton, J. S., and Kraebel, C. J.
1955. Development of vegetation after fire in the chamise chaparral of southern California. Ecology 36(2): 244–262, illus.
- Jepson, W. L.
1925. Flowering plants of California. Berkeley: Univ. Calif., 1238 pp.
- Jones, Milton B., and Laude, Horton M.
1961. Relationships between sprouting in chamise and the physiological condition of the plant. Calif. Agr., June 1961: 9–10, illus.

*Address requests for copies to the originating office.

- Leonard, O. A.
 1956. Studies of factors affecting the control of chamise (*Adenostoma fasciculatum*) with herbicides. Weeds 4(3): 241-254, illus.
 ——— and Carlson, C. E.
 1957. Control of chamise and brush seedlings by aircraft spraying. Calif. Div. Forest., Sacramento, Calif., 27 pp., illus.
 ——— and Harvey, W. A.
 1965. Chemical control of woody plants in California. Calif. Agr. Exp. Sta. Bull. 812, 26 pp., illus.
- Love, R. M., and Jones, B. J.
 1952. Improving California brush ranges. Calif. Agr. Exp. Sta. Circ. 371: 1-38.
- Neuns, Alva G., and Simpson, Albert.
 1957. Brush control with chemicals on forest roads and trails. U.S. Forest Serv. Calif. Region, San Francisco, Calif., 25 pp., illus.
- Plumb, T. R.
 1961. Sprouting of chaparral by December after a wild-fire in July. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Tech. Pap. 57, 12 pp., illus.
 ———
 1962a. Three years of broadcast spraying chamise sprouts in Southern California. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 197, 9 pp., illus.
 ———
 1962b. Four tests of broadcast spraying in killing first-year chamise sprouts. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 200, 6 pp., illus.
 ——— and Bentley, J. R.
 1960. Rate of broadcast 2,4-D spraying on second-year chamise sprouts. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note 163, 7 pp., illus.
 ——— Bentley, J. R., and White, V. E.
 1963. Chemical control of brush regrowth on fuel-breaks. U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Fuel-Break Rep. 41, 41 pp., illus.
- Rowe, P. B., Countryman, C. M., and Storey, H. C.
 1954. Hydrologic analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds. U.S. Forest Serv. Calif. Forest & Range Exp. Sta., 49 pp.
 ——— and Reiman, L. F.
 1961. Water use by brush, grass, and grass-forb vegetation. J. Forest. 59: 175-181, illus.
- Sampson, A. W.
 1944. Plant succession on burned chaparral land in northern California. Calif. Agr. Exp. Sta. Bull. 685, 144 pp.
 ——— and Burcham, L. T.
 1954. Costs and returns of range improvement in northern California. Calif. Div. Forestry Range Impr. Stud. 1, 41 pp., illus.
 ——— and Jespersen, Beryl S.
 1963. California range brushlands and browse plants. Univ. Calif. Div. Agr. Sci. Manual 33, 162 pp., illus.
 ——— and Schultz, A. M.
 1956-57. Control of brush and undesirable trees. Unasylva 10(1): 19-29; 10(3): 117-29; 10(4): 166-82; 11(1): 17-25.
- Schultz, A. M., Launchbaugh, J. L., and Biswell, H. H.
 1955. Relationship between grass density and brush seedling survival. Ecology 36: 226-238.
- U.S. Forest Service.
 1958. The Grindstone Canyon chamise conversion project. Wash., D.C., 4 pp., illus.
- Vlamis, J., and Gowans, K. D.
 1961. Availability of nitrogen, phosphorus and sulfur after brush burning. J. Range Manage. 14(1): 38-40.
- Wieslander, A. E., and Gleason, Clark H.
 1954. Major brushland areas of the coast ranges and Sierra-Cascade foothills in California. U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Misc. Pap. 15, 9 pp., illus.

APPENDIX A

COMMON AND SCIENTIFIC NAMES OF SPECIES MENTIONED

Grasses and Forbs

Barley -----	<i>Hordeum vulgare</i> L.	Ryegrass, Wimmera	
Bluegrass, Sherman big--	<i>Poa ampla</i> Merr.	62 -----	<i>Lolium rigidum</i> Gaud.
Brome, blando		Smilgrass-----	<i>Oryzopsis miliacea</i> (L.)
(softchess) -----	<i>Bromus mollis</i> L.		Benth.
Burclover -----	<i>Medicago hispida</i> Gaertn.	Stipa, nodding -----	<i>Stipa cernua</i> Steb. & Love
Clover, crimson-----	<i>Trifolium incarnatum</i> L.	Veldtgrass -----	<i>Erharta calycina</i> Sm.
Clover, rose-----	<i>Trifolium hirtum</i> All.	Wheatgrass, crested-----	<i>Agropyron desertorum</i>
Clover, subterranean----	<i>Trifolium subterraneum</i> L.		(Fish.) Shult.
Fescue, Goars tall-----	<i>Festuca arundinacea</i>	Wheatgrass,	
	Schreb.	intermediate -----	<i>Agropyron intermedium</i>
Hardinggrass -----	<i>Phalaris tuberosa</i> L. var.		(Host) Beauv.
	<i>stenoptera</i> (Hack.)	Wheatgrass,	
	Hitchc.	pubescent -----	<i>Agropyron trichophorum</i>
Orchardgrass -----	<i>Dactylis glomerata</i> L.		(Link) Richt.
Ryegrass, common		Wheatgrass, tall-----	<i>Agropyron elongatum</i>
(Italian)-----	<i>Lolium multiflorum</i> Lam.		(Host) Beauv.
		Wildrye, blue-----	<i>Elymus glaucus</i> Buckl.

Shrubby Plants and Trees

Brush, coyote -----	<i>Baccharis pilularis</i> var. <i>con-</i> <i>sanguinea</i> (DC.) C. B. Wolf.	Mountainmahogany, birchleaf -----	<i>Cercocarpus betuloides</i> Nutt, ex T. & G.
Buckwheat, California --	<i>Eriogonum fasciculatum</i> Benth.	Oak -----	<i>Quercus</i> spp. L.
Ceanothus -----	<i>Ceanothus</i> spp. L.	Oak, California scrub ---	<i>Quercus dumosa</i> Nutt.
Chamise -----	<i>Adenostoma fasciculatum</i> H. & A.	Pine, coulter -----	<i>Pinus coulteri</i> D. Don.
Cypress -----	<i>Cupressus</i> spp. L.	Pine, knobcone -----	<i>Pinus attenuata</i> Lemmon.
Deerweed -----	<i>Lotus scoparius</i> (Nutt, in T. & G.) Ottley.	Sage -----	<i>Salvia</i> spp. L.
Manzanita -----	<i>Arctostaphylos</i> spp. Adans.	Sage, black -----	<i>Salvia mellifera</i> Greene.
Manzanita, Eastwood --	<i>Arctostaphylos glandulosa</i> Eastw.	Sage, white -----	<i>Salvia apiana</i> Jeps.
		Sagebrush, California ---	<i>Artemisia californica</i> Less.
		Silktassel -----	<i>Garrya</i> spp. Dougl.
		Sugarbush -----	<i>Rhus ovata</i> Wats.
		Sumac, laurel -----	<i>Rhus laurina</i> Nutt, in T. & G.
		Toyon (Christmasberry) -	<i>Heteromeles arbutifolia</i> M. Roem.

APPENDIX B

ESTIMATED COSTS OF CONVERSION OPERATIONS

Operations Adapted to Gentle to Moderate Slopes

Operations Adapted to Steep Slopes

Operation	Light or medium brush, chamise-chaparral	Medium or heavy brush, mixed-chaparral
	<i>Dollars/acre</i>	<i>Dollars/acre</i>
Brush removal:		
1. Burning by wildfire.....	0	0
2. Burning by wildfire and breaking down by tractor.....	5	10
3. Crushing and burning by prescribed methods.....	11	30
4. Disking.....	15	.....
5. Bulldozing.....	25	40
Grass sowing:		
6. None; excessive resident annuals.....	0	0
7. Broadcasting annuals; poor sites.....	3	3
8. Drilling perennials; good seedbed and sites.....	9	9
Chemical spraying:		
9. Two sprays (one broadcast and one hand).....	12	.....
10. Three sprays (two broadcast and one hand).....	20	30
11. Four sprays (three broadcast and one hand).....	27	40
Combination operations:		
1, 6, 9.....	12	.....
1, 6, 10.....	20	30
1, 6, 11.....	27	40
1, 7, 9.....	15	.....
1, 7, 10.....	23	33
1, 7, 11.....	30	43
1, 8, 9.....	21	.....
1, 8, 10.....	29	39
1, 8, 11.....	36	49
2, 8, 9.....	26	.....
2, 8, 10.....	34	49
2, 8, 11.....	41	59
3, 8, 9.....	32	.....
3, 8, 10.....	40	69
3, 8, 11.....	47	79
4, 6, 9.....	27	.....
4, 6, 10.....	35	.....
4, 8, 9.....	36	.....
4, 8, 10.....	44	.....
5, 6, 9.....	37	.....
5, 6, 10.....	45	70
5, 8, 9.....	46	.....
5, 8, 10.....	54	79

	<i>Dollars/acre</i>	<i>Dollars/acre</i>
Brush removal:		
1. Burning by wildfire.....	0	0
2. Burning by wildfire and hand slashing.....	150	300
3. Hand cutting.....	350	700
Grass sowing:		
4. None; excessive resident annuals.....	0	0
5. Broadcasting annuals (poor sites).....	3	3
6. Broadcasting perennials (good seedbeds and sites).....	5	5
Chemical spraying:		
7. Two sprays (one broadcast and one hand).....	17	.....
8. Three sprays (two broadcast and one hand).....	25	40
9. Four sprays (three broadcast and one hand).....	33	50
Combination operations:		
1, 5, 7.....	20	.....
1, 5, 8.....	28	43
1, 6, 7.....	22	.....
1, 6, 8.....	30	45
1, 6, 9.....	38	55
2, 5, 7.....	170	.....
2, 5, 8.....	178	343
2, 5, 9.....	186	353
2, 6, 7.....	172	.....
2, 6, 8.....	180	345
2, 6, 9.....	188	355
3, 4, 7.....	367	.....
3, 4, 8.....	375	740
3, 4, 9.....	383	750