Circular No. 908

The Mesquite Problem

on

Southern Arizona Ranges

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Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE
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By KENNETH W. PARKER and S. CLARK MARTIN, *Range Conservationists,*[1] *Southwestern Forest and Range Experiment Station,*[2] *Forest Service*

INTRODUCTION

Southern Arizona range lands constitute an important part of the State's grazing resource. These lands are grazed chiefly by cattle and when in good condition produce abundant nutritious native forage. The range forage produced normally supports upwards of a quarter million cattle valued at some 25 to 50 million dollars. Most of these animals are grazed in the eastern half of the area, including about 15 million acres ; the western part being extremely arid. The climate is so mild as to encourage yearlong grazing use. Only a small amount of supplemental feeding is required. One of the major problems of animal production within this region arises from the reduction of the forage supply due to undesirable competing vegetation.

One of the most serious and perplexing problems in southeastern Arizona is mesquite invasion of grasslands. Mesquite occurs there in varying degrees of abundance on 9 million acres of range land. The problem is likewise serious elsewhere in the Southwest. Mesquite is now firmly established on considerably more than 70 million acres of range in Texas, New Mexico, and Arizona. An estimated half of the area now occupied by mesquite has been invaded since the advent of domestic livestock. The increase of mesquite is viewed with ever-increasing alarm by range operators.

[1] The authors gratefully acknowledge their indebtedness to other members of the Southwestern Forest and Range Experiment Station for constructive criticisms in the preparation of this circular, and to various cooperating stockmen. Especial credit is due Frank Boice and Henry Boice, ranch operators, for helpful assistance in testing control methods; to Matt J. Culley, formerly Superintendent, Santa Rita Experimental Range, for retracing early-day photographs; to Geraldine Peterson, Statistician at the Station. for statistical analysis of data; and to Dr. Walter Phillips, Head, Botany and Range Ecology Department, University of Arizona, for review of the manuscript.

[2] Maintained by the Forest Service, U. S. Department of Agriculture, for Arizona, New Mexico, and west Texas, with headquarters at Tucson, Ariz.

The principal reasons for concern are : (1) Mesquite, even under moderate grazing use, is still persistently increasing both by invading open grassland and by thickening of old stands. (2) Cutting mesquite, especially in bottom-land areas, usually results in an impenetrable thicket of sprout regrowth and new seedlings. In many of these "jungles," grazing has had to be abandoned. (3) Livestock handling costs are increased, especially in dense upland mesquite thickets where it is difficult to gather livestock for market or to find screwworm-infested animals for treatment. (4) Increases in mesquite are usually accompanied by decreases in quantity and quality of perennial grass forage and corresponding reductions in livestock production. (5) Still more serious from a long-time viewpoint is the accelerated erosion generally found on uplands as well as bottom lands wherever mesquite has encroached.

Southwestern ranch owners and livestock producers interested in range improvement have repeatedly requested information on how to eliminate mesquite and how to reclaim mesquite-infested grasslands. In southern Arizona only a few ranchers have made a determined effort to control mesquite. Most ranchers are hesitant in undertaking wide-scale control measures mainly because of lack of information on what benefits can be expected from control and lack of knowledge of practical methods of elimination. In view of the continued deterioration of mesquite-infested range, these needs for information have become urgent and accordingly led to the studies herein reported.

The studies were conducted mainly on the mesquite-infested areas of the Santa Rita Experimental Range, a branch station of the Southwestern Forest and Range Experiment Station located about 35 miles southeast of Tucson, Ariz. The information presented in this circular is based on some 10 years of detailed experimentation with mesquite, practical experience in its control, and observation of the effects of control. Although the benefits to be expected from mesquite elimination and the guides to control as here reported apply specifically to southern Arizona conditions, this information should be generally helpful in solving the mesquite problem elsewhere in the Southwest.

MESQUITE ON THE RANGE

IDENTIFICATION AND GROWTH FORMS

Mesquites *(Prosopis* spp.) are shrubs or trees which belong to the sub-family *Mimosaceae* of the legume or pea family. Stems of the mature shrubs commonly vary in height from 2 to 5 feet or more, whereas the trees are from 10 to as much as 50 feet. Mesquites are deciduous, with dark green leaves divided into numerous leaflets typical of the legume family. The wood is hard and a reddish brown with an outside layer of yellow sapwood. The twigs are armed with straight spines 1/4 to 1 1/2 inches long. Spines on regrowth from stumps are commonly more numerous and better developed, at times attaining a length of 3 to 4 inches. Flowers are small, greenish yellow, and faintly fragrant, and are borne in cylindrical clusters 2 to 3 inches long near the ends of the branches. The flowers appear in successive crops from late April to late July. Fleshy seed pods, or "beans," 4 to 8 inches long, each containing from 10 to 20 seeds, develop and ripen about 6 weeks after flowering.

Except for difference in size and growth form most mesquites in the Southwest appear alike to the layman. Botanists recognize two or more species which intergrade into each other so completely that identification is often difficult. For the purpose of this circular the taxonomy of Benson (3) and Kearney and Peebles *(24)* is followed. These authors consider most mesquites in the Southwest to be one species—*Prosopis julifiora* (Swartz) D. C.—but recognize three varieties, namely : (1) Honey mesquite *(P. juliflora* var. *glandulosa* (Torr.) Cockerill), which is the common variety found in Texas; (2) western honey mesquite *(P. juliflora* var. *Torreyana* L. Benson) , which is common in southern New Mexico, extreme western Texas, and southeastern Arizona, and (3) velvet mesquite *(P. juliflora* var. *velutina* (Woot.) Sarg.) , which occurs in Arizona. The main basis for distinguishing these varieties is the size, shape, and hairiness of the leaflets. These range from the short, hairy, and closely spaced leaflets of velvet mesquite to the long, linear, glabrous, and widely spaced leaflets of honey mesquite. Western honey mesquite is intermediate between these extremes.

Tornillo or screwbean *(P. odorata* Tore & Frem.) is usually included in the mesquite genus. It is easily distinguished from the mesquites by its tightly coiled seed pods. It is confined largely to valley bottom lands where it may form heavy thickets, and is seldom if ever a noxious plant on the uplands.

Depending on the conditions of climate and soil, all three varieties of mesquite vary in character of growth—forming either trees or shrubs. In river bottoms such as the San Pedro and Santa Cruz in southern Arizona velvet mesquite becomes a large tree with a well-defined trunk (commonly up to 2 feet or more in diameter and 40 feet or more in height) . In semiarid, sandy, windswept localities it is a many-stemmed shrub, 1 to 3 feet in height, and often predominates in sand-dune areas. In upland areas of compact soil and moderate moisture it tends to form a scraggy woodland type with individual plants having one to three or more main stems which are intermediate in stature between the dune and large tree forms (fig. 1).

Although the many-stemmed, shrubby form of western honey mesquite, typical of the sand-dune areas of southern New Mexico (fig. 2) is a serious range pest, the tree and intermediate forms of mesquite cover by far the greater area in the Southwest and affect a much larger segment of the livestock industry. Most of the information in this circular applies to the tree and intermediate shrub forms of mesquite.

The character of the mesquite root system depends on soil type, and on the depth of moisture penetration. Cannon's *(10)* studies in southern Arizona led him to the conclusion that the young mesquite characteristically develops a strong tap root, and the

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FIGURE 1.—Typical growth form of velvet mesquite which commonly invades upland areas in southern Arizona. The area shown was open grassland 50 years ago. It is now covered with an estimated 340 velvet mesquite plants per acre. Santa Rita Experimental Range in southern Arizona.

mature plant usually has a massive development of the lateral root system also. Excavation of lateral roots of velvet mesquite at the Santa Rita Experimental Range on deep gravelly loam showed a root spread of 50 feet or more from the tree stems. In the sand hills of southern New Mexico on the Jornada Experimental Range, lateral roots of western honey mesquite were found to reach out as far as 75 feet. On flood plains where the water supply is adequate for deep percolation of moisture, reports show that the taproots of mesquite sometimes grow to a depth of 25 feet or more.

DISTRIBUTION OF MESQUITES

Mesquites reach their best development in warm, dry, subtropical and tropical climates. In the Southwest they are largely limited to altitudes below 5,500 feet and find their best development at elevations below 4,500 feet, where the frost-free growing season is 200 days or more. Temperature appears to exert a greater influence than any other single factor on the geographical distribution of the plant. For example, it is limited latitudinally in the Great Plains to the southern parts of Kansas and Colorado, where winter cold often kills the plants back to the stem base. Present indications are that within its temperature range, mesquite is a potential invader on all soil types and under a wide range of moisture conditions.

Mesquites grow where the annual rainfall is as high as 30 inches as in Texas, and as low as 3 inches as at Yuma, Ariz., where they are confined largely to drainages. Although mesquites occur throughout the drier portions of the Southwest, McGinnies and Arnold *(26)* found in southern Arizona that the plant is an inefficient user of available moisture. They calculated that velvet mesquite has a mean summer water requirement (pounds of water utilized in producing 1 pound of dry matter) of 1,725 pounds, or more than 4 times the requirement for the common perennial grasses of the same vegetational type, e.g., blue grama 387, hairy grama 412, curly mesquite grass 427, and Rothrock grama 418. The most severe droughts may result in self-pruning of the crown but seldom cause death of entire mesquite plants.

FIGURE 2.—Shrubby form of western honey mesquite, characteristic of vast areas of range land in the Southwest, particularly southern New Mexico and extreme western Texas. Very little forage is produced on such range, yet adjacent areas where mesquite does not occur support good stands of black grama grass.

The present known distribution of mesquites in the southwestern United States is indicated in figure 3. Areas where mesquite definitely forms the major vegetation, whether this be the tree, shrub, or dune-former, are delineated as "major distribution." In the remainder of the Southwest "minor distribution" mainly indicates geographical occurrence. In this area mesquite often forms distinctive types too small to show. Scattered stands and individual plants may also occur locally north of the indicated boundary. The section of the map for southeastern Arizona is based on the survey made by Upson, Cribbs, and Stanley (34), and consists largely of velvet mesquite. In New Mexico western honey mesquite is most common and occurs mostly as a shrubby

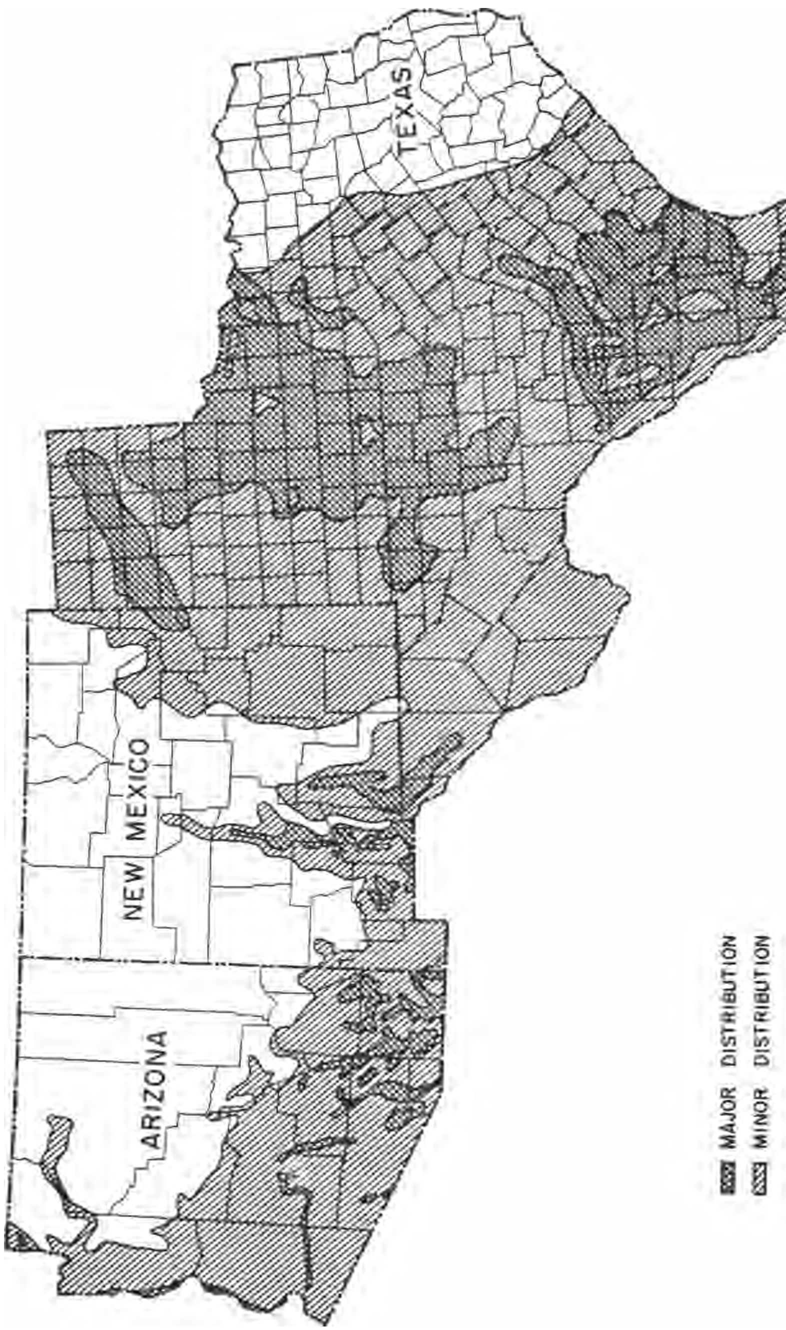

FIGURE 3.—Distribution of mesquites in the Southwest.

dune former. Distribution shown for Texas, where honey mesquite predominates mainly as trees, is adapted from Bray *(6)*, Bell and Dyksterhuis *(2)*, and Allred *(1)*.

VALUES OF MESQUITE

Any appraisal of the mesquite problem in southern Arizona and elsewhere in the Southwest should consider its present and potential values. The chief economic uses for mesquite have been as wood for fuel and posts. In recent years, however, there has been a steadily decreasing demand for mesquite wood as fuel in rural as well as urban centers because of the increasing availability and use of electricity, natural gas, and fuels derived from petroleum. Posts made from the durable heartwood of mesquite have been known to last 50 to 75 years. But the supply of old mature trees with desirable dimensional qualities is limited, and posts from young trees decay within 8 to 10 years. Although still in local use in some areas, mesquite posts commonly cannot compete on the open market with the more durable and straighter posts of juniper or steel.

Mesquite provides protective cover and a food supply for quail, doves, and other wildlife, and the flowers are an important source of nectar for honeybees. Mesquite on the range provide shelter for livestock in winter and shade during the hot days of summer. Its pods, or "beans," contain large amounts of sugar and protein and are highly relished by livestock. Its leafage also provides forage during droughts and in early spring when other forage may be scarce.

In Arizona, Catlin *(11)* found that velvet mesquite leaves were equal in feeding value to the best quality alfalfa hay and that velvet mesquite beans were much higher in nitrogen-free extract and lower in ash than alfalfa hay. In digestibility trials Catlin found that although most range forages were inferior to alfalfa in feeding value, mesquite pods were superior to alfalfa in this respect. Similar results were obtained by Fraps and Cory *(16)* in analyses of honey mesquite leaves and beans from Texas ranges. However, where range cattle are forced to subsist chiefly on mesquite beans and leaves, severe digestive troubles may result from compaction.

Although mesquite furnishes some range forage, studies conducted at the Santa Rita Experimental Range in southern Arizona indicate that this value may be overestimated. A measure of the herbage produced by mesquite was obtained from several plants by stripping, drying, and weighing all leafage within reach of a cow. The total weight of leafage amounted to only about 40 pounds per acre in a moderate stand of mesquite of the characteristic growth habit shown in figure 1. The quantity of mesquite beans produced was also low. During a 5-year period, 13.7 pounds of beans per acre per year were produced. Estimates were made from 25 tagged plants from which the bean crop was harvested, dried, and weighed each year. In 1942 the bean crop on these mesquites failed completely. In general, the bean crop fluctuates greatly and is likely to fail in drought years when it is most needed for forage.

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MESQUITE INVASION—A RANGE PROBLEM

EVIDENCE OF INVASIONS

Overwhelming evidence exists of extensive mesquite invasions of grasslands throughout the present range of the plant in the Southwest. These invasions were viewed with alarm by trained observers of range vegetation as early as the turn of the century *(31, 5, 13).*

The encroachment of mesquites in Arizona started more than 50 years ago. The first recorded observations of mesquite invasions pertain specifically to the Santa Rita Experimental Range and were made by Griffiths *(18)* following his first inspection of this area in 1903, about the time it was fenced to exclude grazing. He said :

> Upon the southern half there are large stretches which have practically no brush at all. Along the washes and arroyos, however, there are invariably found numerous shrubs, some of which attain to the dignity of trees, although very scraggy. A close examination of the broad, gentle, grassy slopes between the arroyos in this vicinity reveals a very scattering growth of mesquite *(Prosopis velutina)* which is in the form of twigs 2 to 3 feet high, (probably less than 10 years old) with an occasional larger shrub in some of the more favorable localities. . . . One can not tell whether this growth indicates that this shrub is spreading or not. The present condition rather suggests this possibility.

In 1910, after having closely observed the advance of mesquite on the Santa Rita, ungrazed after 1903, Griffiths' *(19)* uncertainty was dispelled. He noted in particular an area formerly mowed for hay which 6 years later could not be mowed because of the young mesquite bushes. His general remarks which apply elsewhere in southern Arizona are significant :

> Much has been written about the rapid spread of the mesquite *(Prosopis glandnlosa)* and other shrubby vegetation in Texas since the advent of flocks and herds, but the development of this class of plants is so much slower . . . [in Arizona] that it appears to have been in large measure overlooked. It is, however, taking place just as surely as in Texas; the only difference is that the growth is much less than half as rapid.

The observations of Thornber *(33)* made at the same time on the Santa Rita support the evidence presented by Griffiths :

> It is a fact worthy of note that young mesquite plants are coming in quite thickly over considerable areas of the grassy portions of this tract (35,000 acres).... Young plants that were formerly held in check by close grazing and occasional fires grow undisturbed now, and hence their apparent sudden appearance on parts of this area since completion of the fence.

Evidence in the form of photographs periodically repeated from the same point now supports the conclusions of Griffiths and Thornber relating to the increase in abundance of mesquite on the Santa Rita Experimental Range. Figure 4 illustrates the encroachment over a span of 38 years-12 years ungrazed and 26 grazed—during which the vegetation changed from a predominating grass cover to one with an aspect of mesquite. This example is typical of what has happened on millions of acres of grazing lands elsewhere.

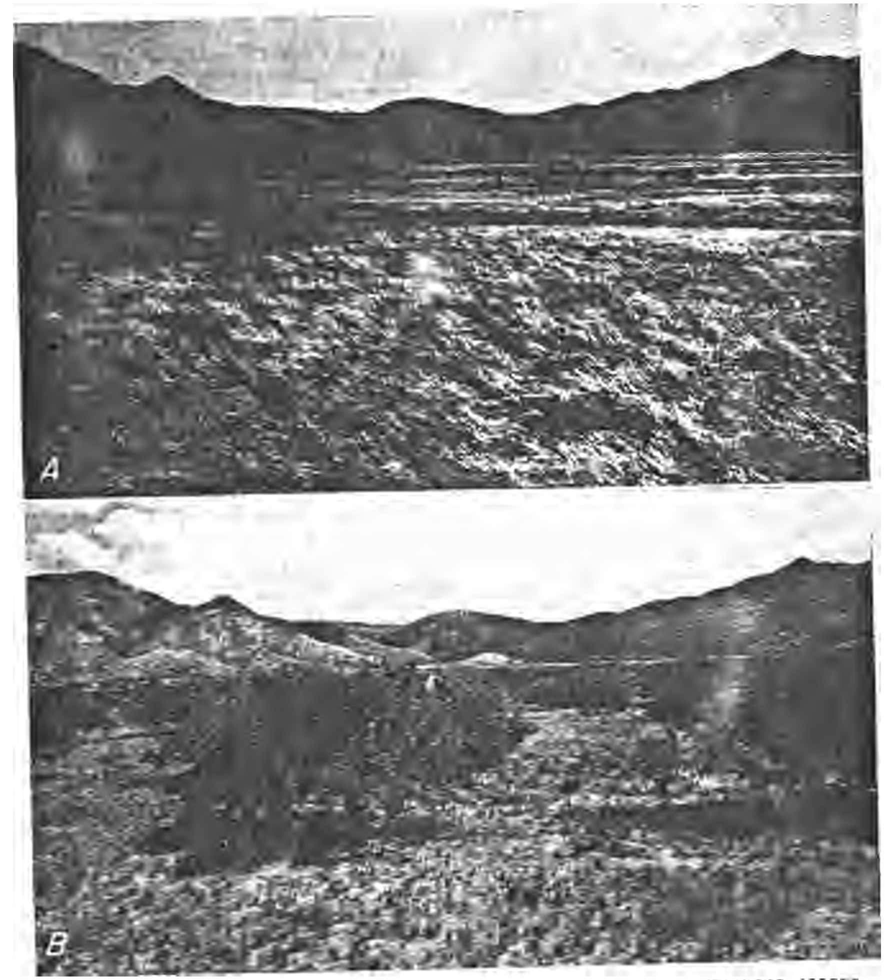


FIGURE 4.—Encroachment of velvet mesquite on the Santa Rita Experimental Range in southern Arizona. *A*, 1903; *B*, 1941. The two pictures, taken from the same point, exemplify the great inroads of mesquite into grassland ranges throughout the Southwest since the turn of the century. Reduction of the grass stand is apparent.

MAGNITUDE OF INVASIONS

The extent of the spread of the plant from its original habitat is not known precisely. But the invasion must involve many millions of acres. Prior to its encroachment on grassland ranges the plant was confined mostly to the valley bottom lands and drainage courses and to a few scattered trees in the uplands. In fact, most of the upland country in the Southwest, excluding the mountains and higher foothills, was open grassland. The change from these open uplands to shrubby vegetation has been marked.

At the turn of the century, in speaking of the encroachment of woody species in general, Bray (5) pointed out that in Texas :

> The energy and rate of encroachment of woody vegetation during the past half century lead one to believe that there is scarcely an area of consequence in the State that woody vegetation of some type will not occupy and cover more or less completely, granting of course that no artificial means are employed to check it.

In a later publication Bray's (6) remarks were more specific concerning the scope of honey mesquite invasions :

> By its invasion, mile after mile of treeless plain and prairie have been won and reduced to the characteristic orchardlike landscape. In the coast country and likewise in the Black Prairie region it has passed the Brazos. It has pushed northward over the Staked Plains covering half their area. Along their eastern front it has passed over Oklahoma and into southwest Kansas. Miles of the level prairie in the Abilene country are covered by mesquite. Large areas of the fine compact soils of the granite country harbor it. San Antonio is half surrounded by a "mesquite forest." Pastures about Austin are growing up in mesquite.

In 1943 Bell and Dyksterhuis (2), on the basis of extensive surveys conducted by the Soil Conservation Service in Texas, reported that approximately 45 million acres in Texas have enough mesquite to be noticeable to the casual observer and occur in the areas best suited for grass production. Continuation of these surveys in Texas, as reported by Allred (1), indicated the presence of mesquite on 55 million acres in 1949.

Many of the upland-mesquite sand-dune areas in southern New Mexico have been in this condition for several hundred years. But the plant is definitely spreading from these original mesquite-dune areas into adjacent grassland. Western honey mesquite is known to have been introduced into grassland areas by livestock accompanying the early-day caravans.

Of the 12 million acres of range land included in the survey by Upson et al (34) in southeastern Arizona only 24 percent was considered free of velvet mesquite, while 61 percent supported a light stand (less than 30 trees per acre), 11 percent a medium stand (30 to 80 trees per acre), and 4 percent a heavy stand (over 80 trees per acre) . Heavy stands were found to be confined mainly to the bottom-land areas where mesquite has always grown. A large part of the area now covered by velvet mesquite in the State —probably as much as three-fourths of it—can be considered to represent invasion within the past half century.

The area where mesquite forms the main aspect of the vegetation involves more than 70 million acres of range lands in the Southwest. This consists of some 55 million acres in Texas, about 9 or 10 million in New Mexico, and more than 9 million in Arizona. By conservative estimate at least half the total area, or about 35 million acres, represents mesquite invasions which have taken place during the past century.

EFFECTS OF MESQUITE INVASIONS

Most of the upland ranges of southeastern Arizona once supported excellent stands of perennial grasses, which occurred in varying mixtures and included such good forage species as black grama *(Bouteloua eriopoda)*, sprucetop grama *(B. chondrosioides)* sideoats grama *(B. curtipendula)*, slender grama *(B. filiformis)*,

blue grama *(B. gracilis)*, hairy grama *(B. hirsuta)*, Rothrock grama *(B. rothrocki)*, threeawns *(Aristida* spp.), Arizona cottongrass *(Trichachne californica)*, tanglehead *(Heteropogon contortus)*, bush muhly *(Muhlenbergia porteri)*, plains lovegrass *(Eragrostis intermedia)*, Texas timothy *(Lycurus phleoides)*, curlymesquite *(Hilaria belangeri)*, and other grasses. Remnants of these species still occur in greater or less abundance on the lands which have become infested with mesquite.

Browse plants included velvet mesquite (which before its spread was confined largely to drainages), false mesquite *(Calliandra eriophylla)*, baccharis *(Baccharis wrighti)*, shrubby buckwheat *(Eriogonum wrighti)*, range ratany *(Krameria glandulosa)*, catclaw *(Acacia greggi)*, and others.

The present-day ground cover of native grasses is greatly influenced by the quantity of mesquite present on the range. As shown in figure 5, the relationship between ground cover of perennial grasses and mesquite crown cover is nearly linear. Thus with each percentage increase in mesquite there is a corresponding decrease in grass cover. The data upon which this graph is based were obtained from the previously mentioned survey by Upson, Cribbs, and Stanley (34). This survey included ocular estimates of the kinds of plants (including grasses and shrubs) as to relative abundance and area occupied on over 450 widely distributed sample plots, 1/10 to 1 acre in area.

For purposes of analysis these records were screened so as to confine the sampling to formerly open grassland areas in various stages of invasion by mesquite. The critical point beyond which any further increase in mesquite becomes especially detrimental to the grass stand will vary with soil fertility and moisture. However, since the climate of southeastern Arizona will on most soil sites support a grass density which would cover 20 percent or more of the soil surface, it is reasonable to consider reductions in grass cover to less than this density unsatisfactory from the viewpoint of potential range productivity. With a 20-percent grass cover (fig. 5) the mesquite crown cover is about 7 percent. On the basis of field observations of southeastern Arizona upland ranges this is considered to be a fairly conservative estimate of the critical point beyond which mesquite infestations prevent perennial grasses from attaining a satisfactory cover for forage production on most sites.

The depressing effect of increasing abundance of mesquite upon the perennial grass cover has been actually observed over a 17-year period on permanently fenced and adjacent unfenced plots on the Santa Rita Experimental Range. When the study began in 1932, an index of the amount of perennial grasses was obtained by charting 88 one-meter-square quadrats within the experimental areas. The crown canopies of all mesquites present were mapped by plane table. Data obtained from these plots, which were subjected to three different treatments, also indicated that grazing by livestock had no effect on the rate of mesquite increase after the invasion had begun. As shown in table 1, both crown cover and number of mesquite plants more than doubled during the period

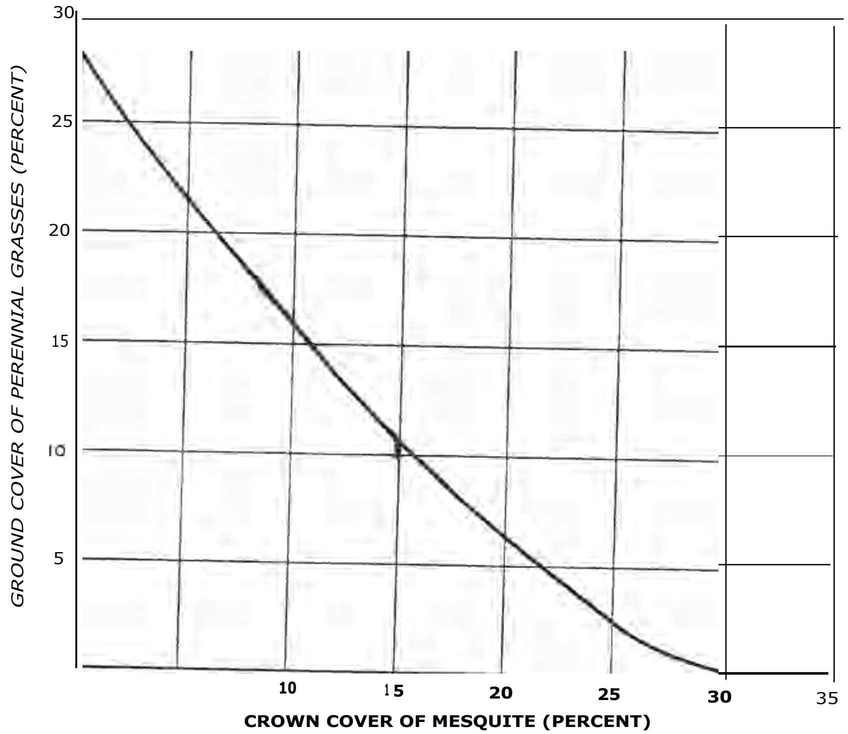


FIGURE 5.—As mesquite increases in abundance the area occupied by grasses declines. Based on survey data of Upson, Cribbs, and Stanley (34).

1932-49. At the same time, by 1949 the cover of perennial grasses was less than 1/10 the cover in 1932, even under complete protection from grazing use by livestock and jackrabbits.

A considerable part of the reduction in *grass* density during the period 1932-35 can be attributed to the 1934 drought. The 1949 observation, showing *grass* density lowered further, was preceded by two drought years. However, field observation of the plots during the period 1935-46, when moisture was generally more favorable, indicated a gradual decline in the grass stand as the mesquites increased in size and abundance. Unfortunately, there are no supporting data for this period. In spite of this, it is noteworthy that only a scanty remnant of grass remained under all three treatments after 17 years, whereas the increase in mesquite was marked.

From the long-time standpoint of conservation of the land resources, the relationship between mesquite and soil erosion is important. Mesquite in itself is of relatively little value in preventing accelerated erosion. In fact, on upland ranges which are generally sloping the encroachment of mesquite is usually associated with accelerated sheet and shoestring gully erosion, doubtless partly the result of thinning grass cover. On the bottom lands, too, where sacaton (*Sporobolus* spp.) has been widely replaced by

TABLE 1.—*Changes in density of perennial grasses and of mesquite, under three different treatments, 1932-49*

Year observed	Protected from cattle and jackrabbits			Protected from cattle but grazed by all rodents			Grazed yearlong by cattle and all rodents		
	Perennial grasses	Mesquite crown cover	Mesquite plants per acre	Perennial grasses	Mesquite crown cover	Mesquite plants per acre	Perennial grasses	Mesquite crown cover	Mesquite plants per acre
	Cm.²[a]	Pct.[b]	No.	Cm.²[a]	Pct.[b]	No.		Pct.[b]	No.
		9.4	84	213.6	3.7	65	287.0	7.3	59
1935	46.8		....	82.5			122.9		
1949	14.3	21.5	192	5.1	12.9	146	9.5	16.0	122

a Density expressed in square centimeters per meter-square quadrat.
b Percent of ground surface shaded by mesquite crowns.
On ocular estimate basis, equivalent to about 10 percent ground cover.

mesquite, there has been severe gully erosion. This gullying causes rapid drainage of areas which formerly flooded and lowers the water table so greatly that in many areas re-establishment of the original grass cover is both difficult and expensive. It usually requires elimination of mesquite as well as the construction of check dams and water spreading devices.

CAUSES OF MESQUITE INVASIONS

The rapid advance of mesquite in the Southwest gives rise to the question : What held these plants in check during ages past and what forces have been released since the introduction of domestic livestock to encourage these invasions? In considering the problem it should be apparent to anyone familiar with the uncertain growing conditions typical of this region that the balance between grassland and woody species is delicate and may be easily upset. Among the more important causes which may upset this balance are: Natural biotic factors, cessation of recurrent prairie fires, drought, and grazing by domestic livestock. These factors may operate either for or against the spread of mesquite insofar as they affect its reproduction.

Mesquite reproduces mainly by seed, although its stems take root readily when covered, as by wind-drifted soil. Migration into grassland sites is thus dependent on dissemination of seed into them. Seed crops vary greatly from year to year and between individual mesquites. Even during years when seed production is generally poor, some plants will produce an abundance of beans. The viability of mesquite seed in mature pods is in general very high. Longevity of seed, an important factor in initial invasions as well as in reinfestation of areas following control of mesquite, is not known. But apparently seed, because of its tough impermeable coat, can remain viable for many years in the soil. Mesquite seeds, collected in 1903 by Professor J. J. Thornber of the University of Arizona, have been tested and found viable after 44 years of storage in the herbarium.

Insects, small mammals (chiefly rodents). birds, and other wildlife exert important biotic influences as either checks or as a means of furthering the spread of mesquite. As checks to further encroachment their chief effect is through reduction of the seed crop and destruction of young seedlings. The seed itself is commonly infested each year by bean weevils (*Mimosestis amicus* and *Algarobius prosopis*), which may kill as many as 90 percent of the embryos.

Production of mesquite beans is lessened to some degree by activities of the Huisache girdler (*Oncideres putator*); described by Howard (*21*). This long-horned beetle has powerful mandibles which easily girdle branches up to 1/4 inch in diameter. The eggs are deposited in the girdled portion of the branch. High (*20*) indicates that the beetle is probably kept in control by predaceous insects which attack both eggs and larvae.

Small seedling mesquites are commonly grazed during spring by jackrabbits (*Lepus* spp.), which often cut off the tops of the same plants year after year or destroy entire plants by digging them out. Paulsen (*29*) reports rodent grazing to be a principal factor in mesquite seedling mortality at least during drought years. Mesquite is commonly infested with mistletoe (*Phoradendron* spp.), which retards the growth of individual plants but seldom kills them. Much mesquite seed remains viable after passing through the digestive tracts of birds, coyotes, and other wild animals. Such natural biotic forces as these have operated through the ages in either hindering or encouraging the spread of mesquite.

Much sound mesquite seed is consumed by rodents or collected into food caches often abandoned or forgotten. Reynolds and Glendening (*30*), for example, found that the Merriam kangaroo rat (*Dipodomys merriami merriami* Mearns) is an important factor in seed dispersal and planting of the seed in surface food caches. They also concluded that (1) kangaroo rats increase markedly in numbers as the range deteriorates, and (2) any system of range management that builds up the grass stand will also result in reduced rodent populations and hence will cut down the rate of mesquite seed planting by rodents. However, Norris (*27*) has shown that on many ranges in very poor condition the pressure of rodent grazing alone is often enough to prevent recovery of perennial grasses even though livestock are excluded. Under such conditions, rodent and jackrabbit control may be needed as a part of any program of range improvement.

The effect of fire or lack of fire on the occurrence of mesquite stands is a moot question. Many early-day observers believed that cessation of formerly recurrent prairie fires greatly encouraged mesquite invasions. This belief was held by Jared Smith (*31*), Bray (*7*), Cook (*13*), Griffiths (*19*), and Thornber (*33*). It is probable that fires became less frequent and less destructive with the fencing of the land and establishment of the livestock industry. The direct result was that flammable material was reduced through utilization by livestock and the grass cover generally became thinner

from long-continued intensive grazing. In South Texas, Cook (*13*) in 1908 noted that:

> Where the grass is thin, seedling mesquites and oaks escape the flames and in a year or two begin to shade the ground—and even though the tops are killed by later fires the roots may send up sprouts again and again to improve every chance of becoming established and joining branches with near neighbors to increase the area of shade.

In southern Arizona, Griffiths (*19*) in 1910 observed:

> The probability is that neither protection nor heavy grazing has much to do with the increase of shrubs here, but it is primarily the direct result of the prevention of fires.

Griffiths' remarks were based on a 7-year study of the effect of total protection from livestock grazing on range vegetation of the Santa Rita Experimental Range. Most of this area was protected from grazing from 1903 to 1915. Griffiths' report indicates that the initial establishment of mesquite on the grassland areas of this range took place prior to fencing. Although the initial invasion was fairly light, these plants undoubtedly formed the seed source for the later, persistent increases.

Thus it is possible that in the early days range fires helped greatly to prevent mesquite encroachment on grasslands by periodically killing such young seedlings as might occasionally become established. However, tests at the Santa Rita Experimental Range during the past 10 years indicate that, although fire will kill some velvet mesquite seedlings and small bushes, it seldom completely kills the older plants. Fisher (*15*) found at Spur, Tex., that grass fires during February on two successive years destroyed only 31 percent of the seedlings of honey mesquite less than 1 year old and none of those older than 1 year. On the other hand, Humphrey (*22*) reported (1949), on the basis of limited data from southern Arizona, estimated kills by fire of 50 to 75 percent on all age classes of velvet mesquite. Obviously needed is further study of the effects of fire on mesquite, perennial grasses, and the soil.

Even if found effective, fire is a questionable tool for control. Construction of safe fire lines is often costly. Fire entails the destruction of a year's forage growth on the area burned, and if uncontrolled, may destroy all the forage on a ranch unit. A satisfactory combination of low moisture content and sufficient volume of flammable material on mesquite-infested areas is seldom obtained. When such a combination does occur, there is usually some other factor that either prohibits or makes inadvisable the use of fire.

Southern Arizona is characterized by intermittent droughts which often result in marked death loss of the perennial forage grasses. As stated earlier, drought seldom causes death of whole mesquite plants. In most areas of the Southwest moisture is probably the most important factor influencing plant growth because the low rainfall will permit only a restricted amount of growth, whether it be grass, weeds, shrubs, or trees. For example, as mesquite becomes larger and more numerous, its demand for moisture likewise increases. The result is that each year, depending on the amount of rainfall, less and less forage is produced. When drought occurs on mesquite-infested areas, the grass is reduced and the cover opened up for establishment of more mesquite seedlings. Also, during drought the forage grasses are grazed more closely and mesquite seed pods probably are eaten more freely. Finally, with mesquite robbing the soil of moisture, recovery of grass after a drought is more difficult.

Transportation of mesquite seed in the dung of livestock is an important means of dissemination. This was noted some 50 years ago by Bray (4). Recent study of this mode of seed dissemination at the Santa Rita Experimental Range indicates that as many as 1,000 sound seeds, of which 13 percent are immediately viable, may be contained in a single cow chip. These seed counts were made in an area where grass forage was plentiful. Likewise in Texas, Fisher *(15)* reports that mesquite seed fed to mules, steer calves, and lambs showed that 54, 45, and 12 percent, respectively, remained viable after passing through the digestive tract. Heavy grazing results in a fuller utilization of the bean crop, and of course the more numerous animals produce a greater number of chips than would be produced under moderate grazing, thus accelerating the rate of mesquite establishment.

Another factor favoring establishment of mesquite is the mode of seed dispersal. Mesquite seed, when deposited in the dung of cattle, is in a favorable medium for growth. The grasses do not generally have this advantage. On range lands in poor condition, with sparse litter, this advantage to mesquite would be especially important.

The difficulty of preventing dissemination of mesquite seed from infested areas to open grassland by livestock varies considerably from one ranch to another, but in general there are two situations : (1) Ranges which are entirely free of mesquite and can be or already are separated from infested areas by fencing, and (2) ranges where mesquite occurs so intermixed with the open grassland that there is no practical means of separating the two areas. The apparent solution for keeping ranges in situation 1 free of mesquite is to avoid moving livestock from mesquite-infested range pastures to open-grassland areas during seasons when mesquite beans are available. If movement of livestock is necessary during this period, they should, according to Glendening and Paulsen *(17)*, be kept on a ration free of mesquite beans for 8 days prior to turning them into the mesquite-free range area. In situation 2, where mesquite is intermingled inseparably with grassland, mesquite seed dissemination cannot be avoided until entire range pastures are cleared of mesquite. At such a time they can be fitted into a management program similar to that stated for situation 1.

Where grazing use has been continuously heavy for years, the perennial grass cover thins out, and the surviving grasses become poor in vigor, so much so that the root system is greatly reduced and seed crops are poor. On many soils the heavy trampling which accompanies overuse results in destruction of the naturally crumb-like structure of the surface soil, compaction takes place, and the soil no longer takes up moisture readily. In the habitat of mesquite, the moisture balance is precarious for long periods during the year and any condition that reduces moisture a few inches below the soil surface results in further decrease of grass cover. Mesquite then has less competition from grass and increase of mesquite is favored.

The aggressive nature of mesquite, together with its low requirements with respect to sites in which it will grow, encourages its increase. Once seedlings of taprooted drought-enduring mesquite are able to reach underground moisture they attain a most favorable position for meeting grass competition. Paulsen *(29)* reported that mesquite taproots measured on the Santa Rita Range developed to 15 inches the first year and to 27 inches in length at the end of the second season of growth. He concluded that this root development was sufficient for the seedlings to survive subsequent droughts and to develop into mature plants.

The spread of mesquite as related to grazing use may be observed along stock driveways and in the vicinity of stock-watering places that have been developed in grassland areas where mesquite was never known to grow before. Differences in abundance of mesquite may be found occasionally along a fence separating a range that has had long-time moderate grazing from an adjacent range subjected to long-continued overgrazing.

Grazing practices in the Southwest do not ordinarily provide for resting the perennial grasses during the active growing season. Here, because the warm open winters make it possible to do so, livestock, year after year, graze yearlong on the same ranges. In many cases the perennial grasses seldom have a chance to build up their vigor or to mature a good seed crop. Although there is little specific information regarding the effects of different grazing systems on the rates of mesquite reproduction, any system which will improve the vigor of the perennial grasses should discourage the establishment of mesquite. Resting parts of the range by elimination of summer grazing in alternate years or even every third or fourth year, coordinated with moderate grazing use of all parts of the range, is a practical means of building up and maintaining vigor and encouraging the natural reseeding of grasses.

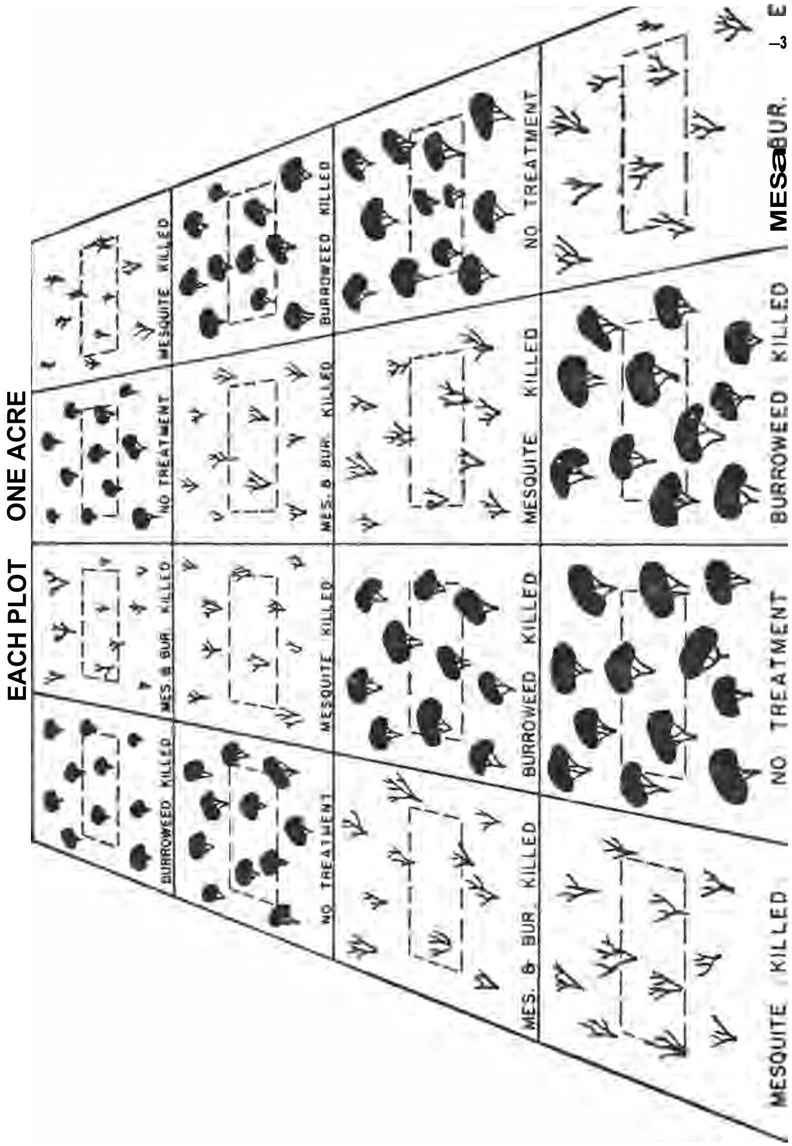
Consideration of the numerous reports by observers and research workers, together with the personal experience and observations of the authors throughout the Southwest, indicates that mesquite encroachment cannot generally be attributed solely to any single cause. It would seem, therefore, that mesquite encroachment into grassland can be most logically ascribed to several possible combinations of the causative agents mentioned.

EFFECTS OF MESQUITE ELIMINATION

HOW THE PROBLEM WAS STUDIED

Studies to determine how elimination of mesquite affects the subsequent growth and forage production of native grasses were begun by the Southwestern Forest and Range Experiment Station

[a] Many range workers have attributed the spread of mesquite largely to overgrazing. *(1, 5, 6, 7, 8, 12, 13, 23, 31, 33, 35, 36).*



in 1940. The work was centered in the Santa Rita Experimental Range in areas infested by velvet mesquite.

The main site selected for study was open to yearlong grazing by cattle and was located about 1 mile from permanent stock water, with an average annual rainfall of about 14 inches, and 3,800 feet in elevation. The forage species on this site are typical of the previously described upland ranges of southern Arizona.

The plot layout consisted of 16 plots, each nearly an acre in size (200x200 ft.) with four different treatments each replicated on four different plots (fig. 6) . Treatments were made in July 1940 and consisted of:

1. No treatment.
2. All mesquite killed by poisoning with sodium arsenite.
3. All burroweed plants eliminated by grubbing.
4. Both mesquite and burroweed killed.

The series of plots with no treatment was necessary to determine changes that might occur naturally in the perennial grass vegetation as influenced by weather and the presence of live competing vegetation such as velvet mesquite and burroweed *(Aplopappus tenuisectus).* Burroweed, also a noxious range plant, grew in profusion on the experimental area and like mesquite it utilizes moisture and soil nutrients that would otherwise be available to desirable forage plants. Hence it was included in the treatments in order to determine more accurately the effects of mesquite competition. Reinfestation of the areas cleared of burroweed required a second grubbing in 1947.

Data on the herbaceous vegetation were collected prior to treatment and each year thereafter in the early fall after the summer growth period. The line-intercept method as described by Canfield (9) was used, with randomized-line transects. Additional data were obtained on the yield and composition of the grass forage species by harvesting and weighing the herbage from belt transects (long narrow sample plots) . Photographs were taken periodically from established points within each plot. Measurements of vegetation were confined to a tenth-acre sampling plot (33x132 ft.) centrally located within each acre-size treatment plot in order to avoid border effects from adjacent plots.

The initial measurements also included plane-table mapping of all mesquite plants on the acre plots (table 2). The mesquites varied in size and growth form from small shrubs a few years old and about ¼ inch in diameter to trees some 40 years old with trunks well above 12 inches in diameter. Mesquite density expressed in terms of percent crown cover is a more reliable measure of the degree of competition mesquite might offer to perennial grass growth than is the number of mesquite plants. On the whole. all treatments were considered to be well stratified with respect to the mesquite present.

The population of burroweed in 1940 (table 3) was determined by counting the plants within the tenth-acre sampling plots. Individual burroweed plants vary in size of course, and although the plots differed somewhat in numbers of plants, all were considered to support a uniformly dense stand of burroweed.

TABLE 2.-S▯▯▯▯ of mesquite in numbers per acre and density of crown spread in percent, by plots, when the experiment began in 1940

Plot treatment	Plot group 1		Plot group 2		Plot §roup		Plot group 4		Average'	
	Pla	Crow ove	P ant	Crown cover	Pla o	Crown cover	P an	Crown cover	P a d	Crown cover
	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.
None-mesquite and burroweed alive - -	75	10.8	97	8.5	134	23.8	201	22.9	126.7	16.5
Mesquite killed	70	10.6	118	13.0	97	16.5	120	12.0	101.2	13.0
Burroweed killed	73	8.5	109	14.2	138	13.2	134	21.6	113.5	14.4
Both burroweed and mesquite killed	88	12.1	111	14.9	145	18.4	116	25.7	115.0	17.8

' Average of four plots each 200 x 200 feet in size.

TABLE 3.-S▯▯▯▯ of ▯▯▯▯▯▯▯▯ in number of plants per acre, by plots, when the experiment began in 1940

Plot treatment	Plot group 1	Plot group 2	Plot group 3	Plot group 4	Average per acre
None-mesquite and burroweed alive	14,310	15,870	7,300	8,530	11, 502. 5
Mesquite killed	15, 370	20, 610	11,720	8, 110	13, 952.5
Burroweed killed	9,450	19, 400	12, 980	18,970	15, 200.0
Both burroweed and mesquite killed - - - - - - -	13, 110	16,530	13,320	17,960	15, 230 .0

EFFECTS ON PERENNIAL GRASS DENSITY

Perennial grasses showed a favorable growth response when velvet mesquite was eliminated, indicating that the mesquite has a marked influence on the total grass density (fig. 7). Response in grass density followed immediately and in spite of natural fluctuations in weather was sustained during the subsequent 8-▯▯▯▯ period of observation.

The influence of rainfall was carefully considered in determining the changes in grass density on treated and untreated areas. More than 90 percent of the perennial grass growth on southern Arizona ranges occurs in summer. Perennial grass cover fluctuated with summer rainfall (June to September, inclusive) as well as with the total yearly amount. Exceptional droughts occurred in three summer growth seasons on the Santa Rita study area-1942, 1947, and 1948-during the 8-▯▯▯▯ period following control (fig. 7). In three seasons-1941, 1945, and 1946-rainfall exceeded the 10-▯▯▯▯ seasonal average of 7.99 inches as determined from the record of a nearby rain gage.

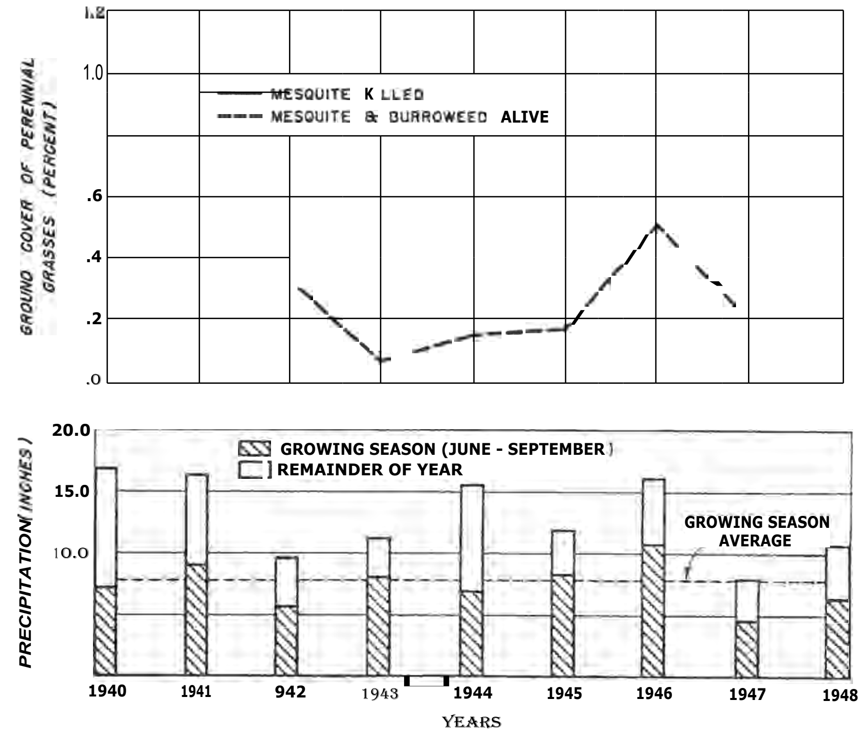


FIGURE 7.-Density of perennial grasses as affected by mesquite control and fluctuations in precipitation as shown here. Major study area, Santa Rita Experimental Range, 1940-48.

In general, the percentage of ground covered by perennial grasses fluctuates with the varying amounts of summer rainfall regardless of the presence or absence of mesquite. Thus perennial grass density on the untreated plots decreased from 1940 to 1943 and increased thereafter until 1946. Summer rainfall in 1941 was poorly distributed, although the seasonal total was above average, and drought followed in 1942. The effects of insufficient moisture on grass vigor in 1942 carried over into 1943, even though the latter year was more favorable to plant growth. In 1947 a sharp decline in density occurred, even though 1946 was an unusually favorable year for perennial grass growth. The spring of 1947 was exceptionally dry and the summer rainfall of about 5 inches was much less than the seasonal average. Death loss of grasses, especially R▯▯▯▯▯▯▯ ▯▯▯▯▯ and the perennial ▯▯▯▯▯▯▯▯▯, was noticeable in the late spring of 1947 and further losses occurred in the spring of 1948.

Influence of Mesquite Elimination

Within 3 years following the killing of mesquite the stand of perennial grasses was double that of adjacent untreated range (fig. 7). Comparison of before and after photographs (figs. 8 and

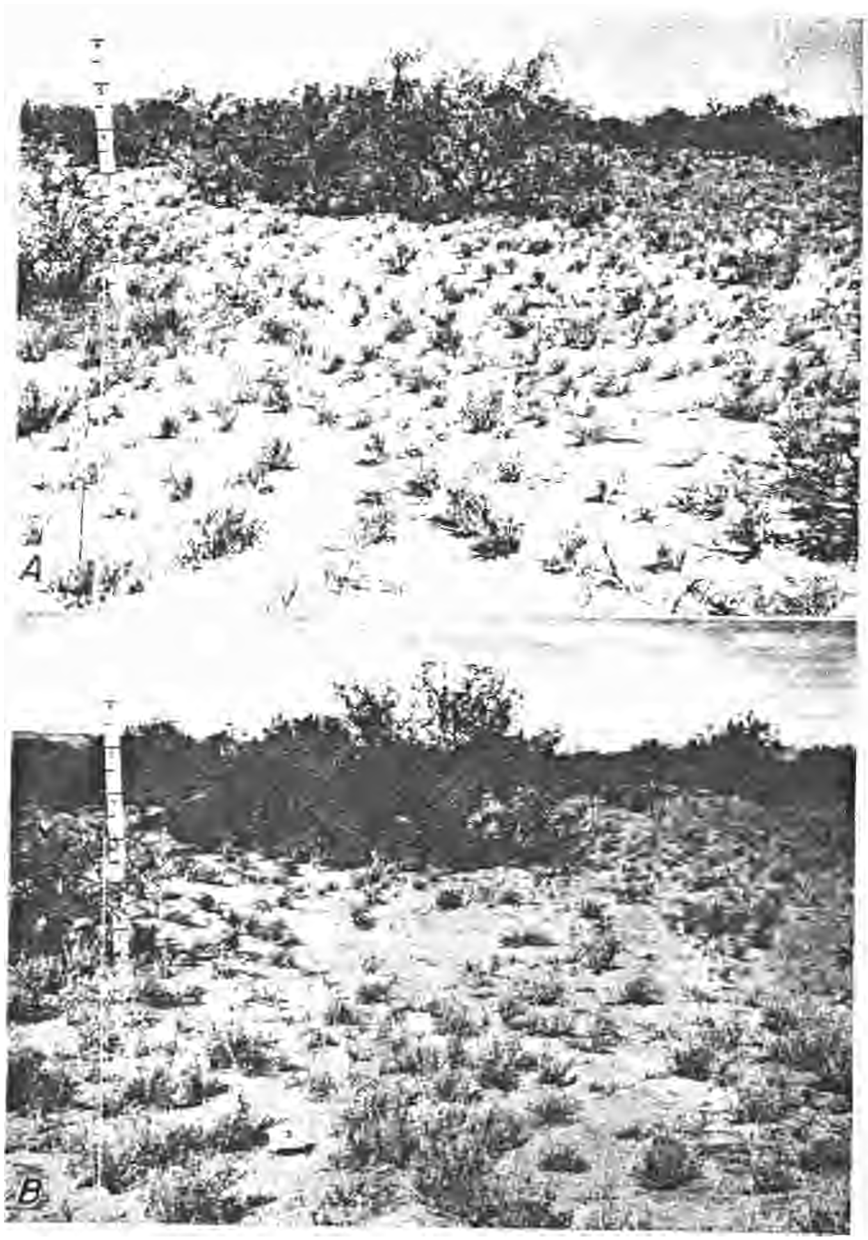


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FIGURE 8.—*A*, One of the acre-sized untreated areas involved in the Santa Rita velvet mesquite study, in 1940. *B*, The same area in 1944. During this period very little change in the appearance of the vegetation occurred. Burroweed, although somewhat less abundant, is still the most conspicuous component of the vegetation. Area open to yearlong grazing use by cattle. Compare with figure 9.

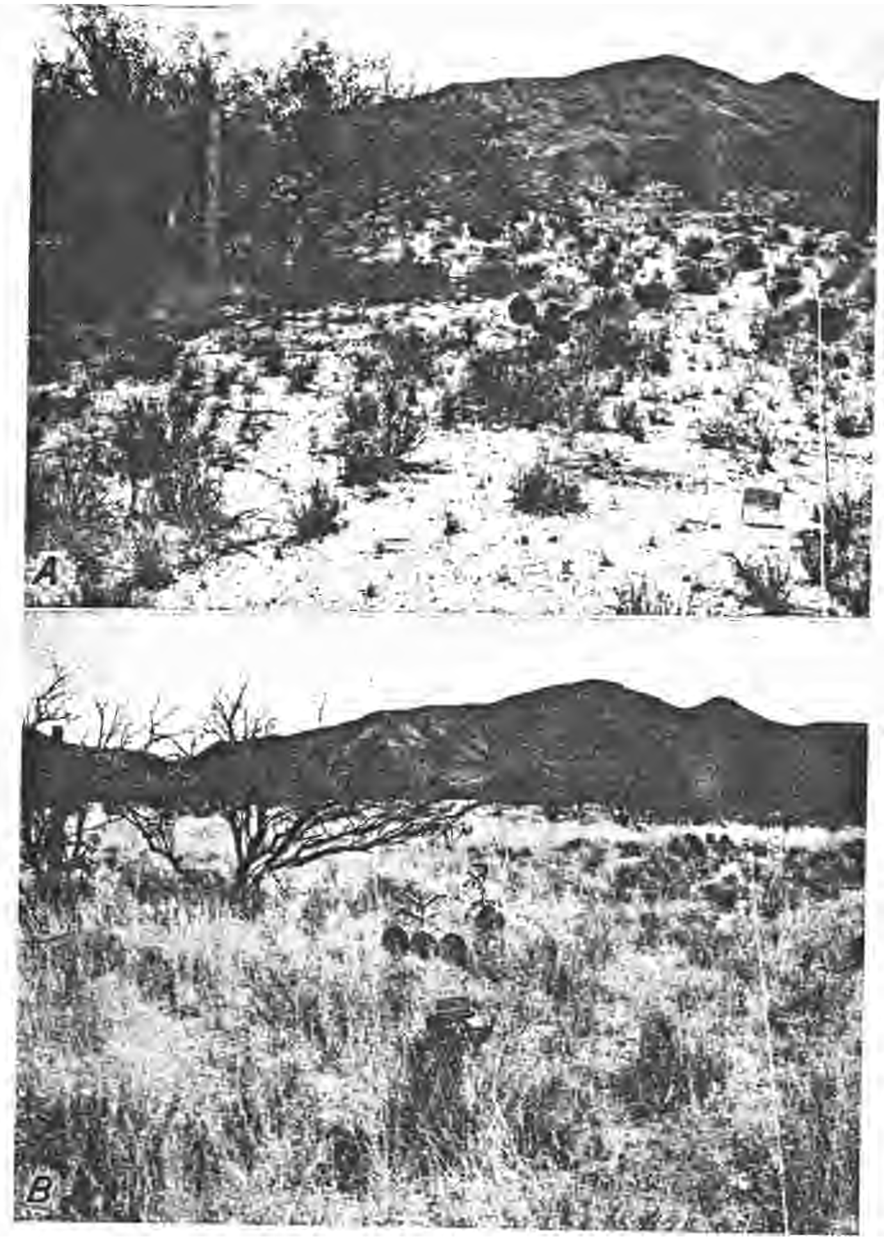

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FIGURE 9.—One of the acre-sized Santa Rita study areas where velvet mesquite was killed. *A*, In 1940 prior to mesquite control, burroweed is the dominant herbaceous plant. *B*, Photographed from the same point in 1944, the perennial grass cover has doubled following mesquite control, and the burroweed plants are almost obscured. Photos taken on same dates as those in figure 8. Area open to yearlong grazing use by cattle.

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9) leaves no doubt that killing of the mesquite resulted in a greater stand and growth of grass.

In general, the perennial grasses suffered more from deficient summer rainfall in areas with live mesquite and burroweed than where mesquite alone had been eliminated. Although fluctuations of perennial grass density occurred on areas where mesquite was killed, the effects of drought were apparently less severe, even though these areas without exception supported twice the grass cover of untreated areas from 1943 to 1948. For example, death loss of perennial grasses from the drought of 1942 was 42.8 percent where mesquite was killed but was 88.6 percent on untreated areas. Similar declines occurred with the 1947 and 1948 droughts, but again the loss was less severe on areas where mesquite was eliminated (73 percent) than on those with live trees (85 percent). Conversely, during the more favorable rainfall period of 1943 to 1946, there was a greater response of perennial grasses on range where mesquite had been killed than on that with live trees.

At the beginning of the study in 1940 there was no significant difference in total perennial grass density between the areas to be given the four different treatments. In all succeeding years, however (except the drought year 1942), there were significant differences in the ground cover of perennial grasses between the mesquite-free areas and the untreated areas where both mesquite and burroweed remained alive. The word "significant" is used in the statistical sense throughout this circular and means that the differences are real and not due to chance.

I[illegible] Burroweed E[illegible]

In contrast to the effects of mesquite control, response of perennial grass density to the elimination of burroweed was not significant for the period as a whole (fig. 10). Thus during the years 1942 to 1945 grass density on treated areas coincided closely with that of the untreated areas, and in 1946 it was even less.

The increased density of grasses following elimination of burroweed in 1941 is attributed mainly to increased vigor and size of the individual grass clumps. This increase may have been stimulated in part by removal of the burroweed competition. It is probable, however, that this response was due in greater part to the cultivation effects of grubbing. Grubbing was an important factor in soil disturbance because, as shown in table 3, the burroweed population on these plots varied from 9,450 to 19,400 plants per acre. Although grubbing of burroweed inadvertently destroyed 14 percent of the perennial grass cover (as determined from 24 permanently located meter-square quadrats charted both before and immediately after grubbing), the operation also served to loosen the soil surface and to pit it with small pockets, thus promoting moisture infiltration. The increased soil moisture favored an increase in perennial grass growth. It was, however, a temporary effect lasting only for a year as shown by the trend of grass density from 1942 to 1947.

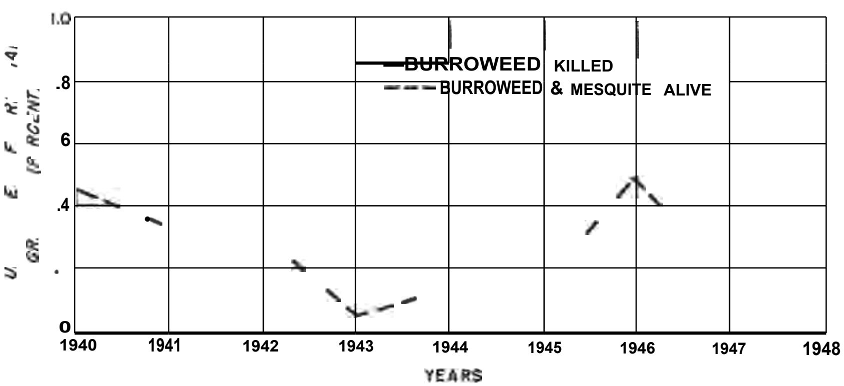

FIGURE 10.—D[illegible].

In June 1947 the areas on which burroweed had been killed in 1940 were again grubbed because of reinvasion. The reinvasion subsequent to 1940 had amounted to 8.1 percent of the original stand. Although the density of perennial grasses on these areas increased slightly in 1947, the density for the same year on the areas with live burroweed dropped precipitously because of drought. Here again the effect of burroweed control appeared to be temporary.

I[illegible] E[illegible] B[illegible] M[illegible] B[illegible]

Where both burroweed and mesquite were killed (fig. 11), the grass density greatly exceeded that of the untreated areas in all years 1941-48. It closely paralleled that of the areas on which mesquite alone was killed, except 1941 and 1947, the years immediately following burroweed grubbing. In these 2 years, the grass was markedly benefited, as it was on plots where burroweed alone was killed.

Conclusions drawn from these results are that mesquite plants present the major hindrance to perennial grass growth, and that

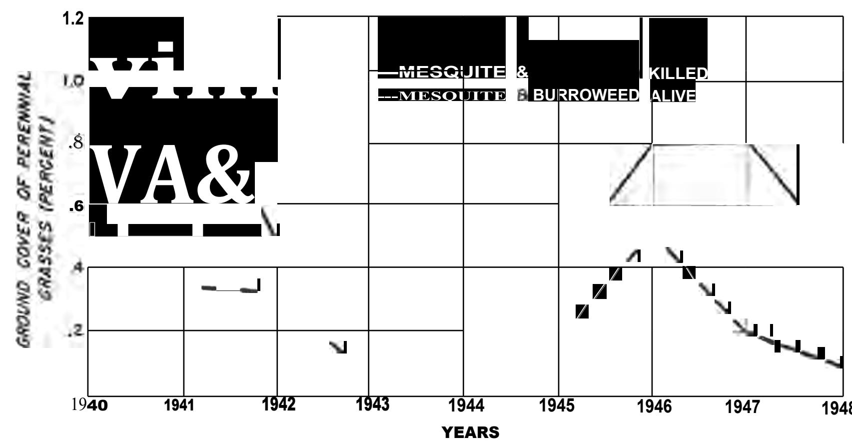

FIGURE 11.—D[illegible].

competition from burroweed is of less importance. In fact, elimination of the latter appears to bring about only a temporary response from perennial grasses.

EFFECTS ON DENSITY OF INDIVIDUAL GRASS SPECIES

As in the case of total perennial grass density, the density of individual grass species was affected by the several shrub-control treatments applied in 1940. As shown in table 4, Rothrock grama was the dominant grass at the start of the study. Several more desirable species including black grama, Arizona cottongrass, and perennial threeawns, although less abundant, were important constituents. Tanglehead, plains bristlegrass, sprucetop grama, bush muhly, and slender grama were of rare occurrence and are listed as "other" perennial grasses.

TABLE 4.–Ground cover of perennial grasses, 1940–48, under different shrub-control treatments

Species and treatment	1940	[illegible]	[illegible]	1943	1944	1945	1946 (favorable)	[illegible]	[illegible]
Rothrock grama:	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Untreated	0.270	).219	0.035	0.004	0.048	0.031	0.223	0.063	
Mesquite killed	.294	.293	.205	.177	.344	.211	.542	304	0.031
Burroweed killed	.269	.298	.060	.029	.033	.028	.037	.082	
Both noxious species killed	.243	.523	.250	.186	.264	.201	.275	.383	119
Black grama:									
Untreated	070	.065	078	.031	.029	044	012	.012	.007
Mesquite killed	077	077	096	.054	.045	.024	031	050	082
Burroweed killed	088	088	065	.024	.048	.042	062	019	.032
Both noxious species killed	064	016	024	.029	.053	.022	050	043	.019
Arizona cottongrass:									
Untreated	.032		090	002	.035	.054	.266	082	.040
Mesquite killed	.024	031	026	.003	031	006	200	062	063
Burroweed killed	.053	104	012	018	011	.024	161	138	051
Both noxious species killed	.067	.201	.056	.025	.067	.086	.218	192	.157
Perennial threeawns:									
Untreated	.068	.056	.113	.013	018	.021	.019	012	.006
Mesquite killed	025	.039	025	006	030	.073	187	068	038
Burroweed killed	.105	.217	.203	025	038	.075	.080	132	.077
Both noxious species killed	.077	.257	102	.038	044	.084	.137	.049	075
Other perennial grasses:									
Untreated			.004					.001	.027
Mesquite killed			.018		.003	.026		.006	006
Burroweed killed	005			.014		.001	.020	.001	
Both noxious species killed	.019	073	.048	.032	.032	.017	.120	.143	.050
All perennial grasses:									
Untreated	.440	.340	.320	050	.130	.150	.520	.170	080
Mesquite killed	420	440	370	.240	.453	340	.960	.490	.220
Burroweed killed	.520	.700	340	.110	.130	170	360	.372	.160
Both noxious species killed	.470	1.070	.480	310	.460	410	800	.810	.420

[1] Data collected before shrub-control treatments were applied in 1940 (fall).
[2] Burroweed was grubbed again in June 1947.

Effect on Rothrock Grama

Rothrock grama, which is moderately relished by livestock, is shallow-rooted, short-lived, and very responsive to variations in rainfall. Commencing in 1940, ground cover of this species on the untreated areas decreased to a negligible amount in 1943. The cover then increased with better seasons of moisture through 1946 to about its initial density, but with two successive dry seasons fell to a mere trace in 1948. In contrast, on areas where mesquite was eliminated, the amount of Rothrock grama held up fairly well (with some seasonal fluctuation because of weather) until the second successive dry season of 1948. The temporary effect of grubbing burroweed is reflected on areas where both mesquite and burroweed were killed in the years of 1941 and 1947, when the highest densities were attained. Hence, mesquite elimination enabled Rothrock grama, which has an average life span of 3 years, to better reproduce itself during favorable seasons and to better survive droughts than where the noxious plants were not controlled or where burroweed alone was killed.

Effect on Black Grama

The density of black grama, a long-lived, drought-enduring, choice forage species, showed less yearly fluctuation because of weather than did Rothrock grama. On untreated areas, density of black grama gradually decreased from 1940 to a negligible percent in 1948. This was likewise true on the burroweed-killed areas except for minor annual variations, but the decrease was less pronounced than on the untreated areas. Where mesquite alone was eliminated, black grama density also decreased but during the dry years it held up better. It held up less well, for some unexplained reason, where both noxious species were killed, but still maintained a greater density than on untreated plots in 1946-48.

Effect on Arizona Cottongrass

Arizona cottongrass is a long-lived, drought-enduring, and highly palatable species. It is shade tolerant and commonly occurs under mesquite crowns. It, too, apparently responds when mesquite competition is removed, as shown by its higher density at the end of the study period in comparison with its initial stand in 1940. Because of the inconsistency of the data during the intervening years and similar changes on the untreated areas, the data from these plots are not considered strongly indicative as to the effects of mesquite eradication. On many other areas on the Santa Rita, however, this species has made great increases in density following removal of mesquite.

Effect on Perennial Threeawns

Perennial threeawns are long-lived and rate high in forage value. These grasses exhibited minor but significant responses, as measured by density, to the different shrub-control treatments. On the untreated areas density by 1948 had increased to a negligible amount. By contrast, on all the areas with mesquite control, the density of threeawns held up fairly well in most years except for variations caused by weather. During the favorable weather of 1946 these species increased about twofold on mesquite-controlled areas, whereas on the untreated areas there was little or no response. On burroweed-control areas density of threeawns showed a net decline from 1940 to 1948. Where both mesquite and burroweed were eliminated the response in density was somewhat like that where mesquite alone was eliminated.

Effects on "Other" Grasses

Probably because the grasses designated as "other" perennials were very scarce even taken together, the data on changes in their density under various shrub-control treatments were inconclusive.

EFFECTS ON HERBAGE YIELDS

Effect on Herbage Yield of Perennial Grasses

Mesquite control applied in 1940 brought about distinct improvement in the total herbage yield of perennial and annual grasses. The perennial grasses receive the most attention in this circular, however, because they contribute the bulk of the forage consumed by livestock, whereas the annuals are of inferior value for grazing use even while green.

The elimination of mesquite competition resulted in significant increases in the total herbage yield of major perennial grasses (table 5) . Where mesquite alone was killed, the 8-year average total herbage production by these species was more than double that of the untreated areas (301.7 vs. 143.0 lb.) . Furthermore, total herbage production on the areas with only mesquite eliminated was invariably greater than that of the untreated areas, and in 5 of the 8 years it was at least double. The difference in yield in 1942, a drought year, represented only about a 3 to 2 ratio, but in the drought seasons of 1947 and 1948 the superiority in yield was more than 2 to 1. It will be recalled that grass density continued to decline the year following the drought of 1942, on all the treated and untreated plots. This is reflected in the small herbage yield on the untreated areas-53.9 pounds in 1942 and 45.0 pounds in 1943. In contrast to this, total yield of perennial grasses trebled on the mesquite-cleared areas with the better moisture conditions of 1943. Where both mesquite and burroweed were killed, the yields also held up better than on the untreated areas during the dry years of 1947 and 1948 (fig. 7) . The data thus show that although densities may decline during droughts, herbage yields tend to be sustained on areas where mesquite has been killed.

The elimination of burroweed alone had little or no beneficial effect on herbage production, except for the temporary response in 1941.

The response of the dominant species, Rothrock grama, to the different shrub-control treatments was similar to that for the total yield of all grasses. This is true of the yields by individual years as well as the average for the 8-year period. During the

TABLE 5.-*Herbage yield per acre of perennial grasses, 1941-48, under different shrub-control treatments applied in 1940*

Species and treatment	1941	1942 (drought)	1943	1041	1945	1946	1947 (drought)	1948 (drought)	1941-48 average
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
Rothrock grama:									
Untreated	70.9	7.2	11.2	49.4	21.2	67.8	17.0	20.8	33.2
Mesquite killed	150.1	41.9	143.7	337.4	132.4	277.6	62.3	98.8	155.5
Burroweed killed	141.0	5.0	27.3	29.0	14.4	24.8	8.8	7.4	32.2
Both noxious species killed	175.0	26.8	116.3	194.4	90.1	117.4	48.6	38.1	100.8
Black grama:									
Untreated	19.0	10.6	17.4	26.9	48.0	23.1	11.8	14.5	21.4
Mesquite killed	43.5	16.7	32.1	48.0	20.2	51.8	19.8	31.4	33.0
Burroweed killed	88.9	7.6	10.7	13.6	12.9	15.0	1.0	.8	18.8
Both noxious species killed	8.9	2.4	7.1	22.1	6.6	11.8	6.8	5.3	8.9
Arizona cottongrass:									
Untreated	3.5	17.7	7.3	68.1	126.0	130.2	52.1	63.9	59.7
Mesquite killed	6.2	8.3	7.4	62.8	119.0	134.5	52.5	83.3	59.2
Burroweed killed	38.8	3.3	7.4	13.0	100.4	84.5	25.8	21.7	36.9
Both noxious species killed	82.2	14.2	24.0	40.3	134.0	95.8	69.5	54.5	64.4
Perennial threeawns:									
Untreated	15.4	17.3	8.1	54.5	33.6	67.8	6.5	6.9	26.3
Mesquite killed	45.7	11.1	17.5	71.8	32.6	98.5	32.7	50.8	45.1
Burroweed killed	80.8	10.0	20.5	25.3	52.0	46.0	13.0	11.6	33.5
Both noxious species killed	82.6	9.3	16.6	46.5	29.3	44.1	11.3	13.9	31.7
Other perennial grasses:									
Untreated	3.1	1.1	1.0	5.1	4.2	2.1	.6	1.8	2.4
Mesquite killed	26.4	.9	.2	7.9	21.8	.6	4.8	8.7	8.9
Burroweed killed	4	.1	.1	.1	.2	10.7	1.4	.5	1.7
Both noxious species killed	39.2	5.2	6.0	21.8	27.0	57.9	20.7	11.2	23.6
All perennial grasses:									
Untreated	111.9	53.9	45.0	204.0	233.0	300.0	88.0	107.9	143.0
Mesquite killed	271.9	78.9	200.9	527.9	326.0	563.0	172.1	273.0	301.7
Burroweed killed	349.9	35.0	66.0	81.0	179.9	181.0	50.0	42.0	123.1
Both noxious species killed	387.9	57.9	170.9	325.1	287.0	327.0	156.9	123.0	229.5

[1] Burroweed was grubbed again in June 1947.

same period Rothrock grama accounted for more than half of the total herbage production where mesquite alone was eliminated, and nearly half where both mesquite and burroweed were killed. In contrast, it made up only about one-fourth of the herbage on the areas where burroweed alone was killed and also on the untreated areas.

Elimination of mesquite competition is especially beneficial to Rothrock grama. Mesquite control apparently enables a greater number of plants of this typically short-lived perennial to survive droughts such as 1942. Furthermore, when growth conditions are more favorable, the response in yield is greater. For example, on the untreated areas production was only 7.2 pounds per acre in 1942 and only 11.2 pounds under the higher rainfall of 1943.

On the mesquite-cleared plots the 1943 yield, 143.7 pounds, was over three times that of 1942. Where both mesquite and burroweed were killed, the herbage production, 116.3 pounds, showed a four-fold increase from 1942 to 1943. In the drought season of 1947 yield on the untreated range was again low (17 lb. per acre) and increased only slightly with the somewhat better but still droughty season of 1948. In comparison, where mesquite alone had been eliminated, a significant increase in yield was measured.

In 6 of the 8 years following treatment the best yields of black grama were obtained on the range where mesquite alone was killed. Except for the termporary increase of 1941, yields on the burroweed-controlled areas were less than those of the untreated ranges. The areas with control of both mesquite and burroweed were low in herbage yield in all years. It will be recalled that density of black grama on all these areas decreased but held up better where mesquite alone was killed.

Differences in yield of Arizona cottongrass and the threeawn grasses between methods of treatment were highly erratic, though mesquite elimination apparently favors the herbage production of threeawns.

In the group of grasses listed as "other" the yields were small and varied considerably as between treatments. However, it will be recalled from the discussion on density that this group of grasses included the species of rare occurrence and that these were concentrated in greatest abundance on the areas where both mesquite and burroweed were killed. The unusual variation in yield of "other" species (as well as with Arizona cottongrass and threeawns) from one year to the next, such as the decline from 21.8 pounds in 1945 to 0.6 pound the next year on the range with mesquite killed, may be attributable, at least in part, to error of sampling, or to other factors such as the difference between species in resistance to grazing use.

Effect on Herbage Yield of Annual Grasses

The main annual grasses found in the study area are needle grama *(Bouteloua aristidoides)* and sixweeks threeawn *(Aristida adscensionis).* In the summer, whenever moisture conditions become favorable, these grasses complete their entire growth cycle from germination to seed maturity in the space of a few weeks. They are extremely shallow rooted and obtain most of their moisture from the surface 6 inches of soil. Although not dependable forage, annuals do contribute litter which is of value in improving soil fertility and soil-moisture relationships. Furthermore, where stands of perennial grasses have been greatly reduced, a cover of annuals intermixed with the remnant perennials is of material value in reducing accelerated erosion.

As with perennial grasses, the yield of annual grasses was greatly influenced by summer moisture conditions (table 6). In the drought seasons of 1942 and 1947 yields were negligible regardless of treatment. Although 1948 was also considered a drought year the rains were better spaced, which was reflected in significantly greater yields than those of the other two drought

TABLE 6.—***Total** herbage yield per acre of annual grasses, 1941-48, under different shrub-control treatments applied in 1940 for the 8 years following application of shrub control*

Year	Untreated	Mesquite killed	Burroweed killed [1]	Mesquite and burroweed killed
	Pounds	*Pounds*	*Pounds*	*Pounds*
1941	10	109	35	189
1942.	T	7	T	10
1943	17	199	62	279
1944.	T	23	2	72
1945	6	90	34	145
1946.	124	322	329	650
1947.	1	8	5	15
1948	7	53	20	59
Average	20.6	101.4	60.9	177.4

Burroweed was grubbed again in June 1947.

seasons. Production of annuals was greatest in the season of 1946 which was above average in rainfall. In the near-average rainfall seasons of 1943 and 1945 yields on the mesquite-freed areas were 90 pounds per acre or greater as contrasted to the greatly reduced production of annuals on the areas with live mesquite present. In spite of fluctuations occasioned by variations in rainfall there was in most years a direct and significant response in yield of annuals resulting from both mesquite and burroweed control.

Elimination of mesquite brought about significant increases in the total yield of annuals over the 8-year period following treatment. There were significant differences between all treatments as well as between successive years. The average yield per acre where mesquite alone was killed was five times greater than that of the untreated areas. Yields were negligible on the untreated areas in all years except 1946. On the mesquite-cleared areas, in 3 of the 8 years following control, the yield per acre exceeded 100 pounds and in 5 of the 8 years it was greater than 50 pounds. Where both mesquite and burroweed were killed, the average yield was more than eight times greater than that of the untreated *range.*

Burroweed control alone was considerably less effective than mesquite control in promoting growth of annual grasses, the average production being three times that of the untreated range. This is all the more remarkable in view of the originally large burroweed population and much smaller mesquite population—about 15,000 burroweed and slightly over 100 mesquite plants per acre, before treatment. One might expect that root competition in the surface layers of soil would be much greater from the more widely occurring burroweed than from the less frequently spaced though larger mesquites.

Another striking feature of the data presented in table 6 is that the yield of mesquite-cleared areas plus that of burroweed-cleared

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areas closely approaches the yield of the areas where both these plants were eliminated. This is true not only in the average yield for the 8 years (101.4 and 60.9 as against 177.4) , but also by several individual years. Apparently, burroweed elimination released enough extra moisture to be reflected in growth of the annuals but not enough to materially benefit the deeper rooted perennials.

EFFECT ON SOIL MOISTURE

The previously stated increases both in density and herbage yields of the perennial forage grasses and in the yields of the annual grasses are attributable in large measure to elimination of mesquite competition for soil moisture.

Soil moisture data' were obtained during the exceptionally good summer rainfall season of 1946 on the same experimental plots described in earlier sections of this circular. The data presented here are for areas with live mesquite and immediately adjacent *range* where the mesquite was killed. Only in a few instances during the study did available soil moisture in the areas with live mesquite exceed that on mesquite-cleared areas, in spite of the fact that perennial grasses and burroweed were present on both areas.

Available moisture is defined as the amount of water in the soil that can be utilized by plants for maintenance of life and growth. The areas in figures 12, 13, and 14 shown as "available moisture" represent the amount of moisture above the wilting coefficient (the point where plants permanently wilt) , which was determined by dividing the moisture equivalent by 1.84. The moisture equivalent (moisture content after centrifuging at 1,000 times force of gravity) for the three soil layers was as follows : 0- to 6-inch layer, 6.62 percent ; 6- to 12-inch layer, 9.08 percent ; and 12- to 18-inch layer, 10.05 percent. These figures represent the average of moisture-equivalent determinations for two soil samples—one taken where mesquite was dead and one taken where mesquite was alive. Although the available soil moisture as calculated by this method is not precise, it is considered to be a fair basis for making comparisons as to effect of treatment. The upper 18 inches of soil was selected for study because that is where competition for moisture between mesquite and grasses is most intense. Most perennial grasses have some roots extending to two or three times this depth, but moisture from summer rains seldom penetrates deeper than 18 inches.

Effect on Moisture in the 0- to 6-inch Soil Layer

The moisture content of the surface 6 inches of soil is especially important in the germination and initial establishment of perennial grass seedlings as well as of other plants. This moisture content fluctuates greatly in the hot summer months—rising with rainfall and declining with evaporation and use of water by plants. For example, in clear, warm weather moisture in the surface

Martin, S. Clark. The Effect of Mesquite Control on the Soil Moisture Content of Mesquite-Infested Range Land in Southern Arizona. Unpublished M. S. thesis on file Univ. of Arizona Library, 30 pp., May 1947 (typed).

2 inches may drop from field capacity to below the wilting point within a few days. The most favorable soil moisture for plant establishment occurs when weather is cloudy and rains follow one another every day or so for a period of a week or longer. For germination and initial establishment of seedlings of most grasses, soil moisture in the surface soil layer must be considerably above the wilting point for an unbroken period of at least a week, so that seedlings can develop root systems long enough to reach the lower layers of the soil where moisture content is more stable and less affected by evaporation.

As soil moisture increases, the facility with which plant roots extract it likewise increases. Hence the greater the percentage of moisture (up to field capacity) the more effectively is plant growth promoted. Roots extract moisture simultaneously at all depths in the soil they occupy.

Soil moisture in the surface 6 inches, as shown in figure 12, differed widely on areas with and without mesquite control up to a distance of 20 feet from each plant. At 10 feet from each mesquite for the entire summer growth period of 98 days (first effective rainfall, July 11), there were only 7 days (August 18 and September 5-10) when moisture was not available for growth on the mesquite-controlled plots. During the same period there were 19 days of moisture deficiency where mesquite was alive. At 20-foot distance soil moisture was below the wilting coefficient for 7 days on areas with dead mesquite as against 25 days on areas with live mesquite. Furthermore, at both distances, the percentage of soil moisture above the wilting point was significantly greater where the mesquite was killed. Thus, where mesquite was eliminated, conditions were more favorable both for initial establishment of grass seedlings and for prolonged growth of established grass clumps.

At a distance of 30 feet from each mesquite soil moisture of the 6-inch surface layers showed no significant differences between the areas with and without mesquite control. In the shallow surface soil layer and at this distance mesquite roots apparently were not plentiful enough to bring about measurable differences in soil moisture.

The effect of rainfall and growth of vegetation on soil moisture in the surface layer of soil is also illustrated in figure 12. Soil moisture increased rapidly to more than 8 percent with the rains in July when growth of grasses was barely started. In early August when plant growth was at its peak, soil moisture declined in spite of good rains. The drain on soil moisture by the annual grasses was particularly great at this time. Herbage yields of annuals were greater in 1946 than in any other of the 8 years following treatment (table 6) . Soil moisture during the remainder of the summer fluctuated largely in accordance with rainfall and intervening dry weather.

Effect on Moisture in the 6- to 12-inch Soil Layer

Moisture in the 6- to 12-inch soil layer is utilized by newly established as well as older plants. Hence, the available moisture in this

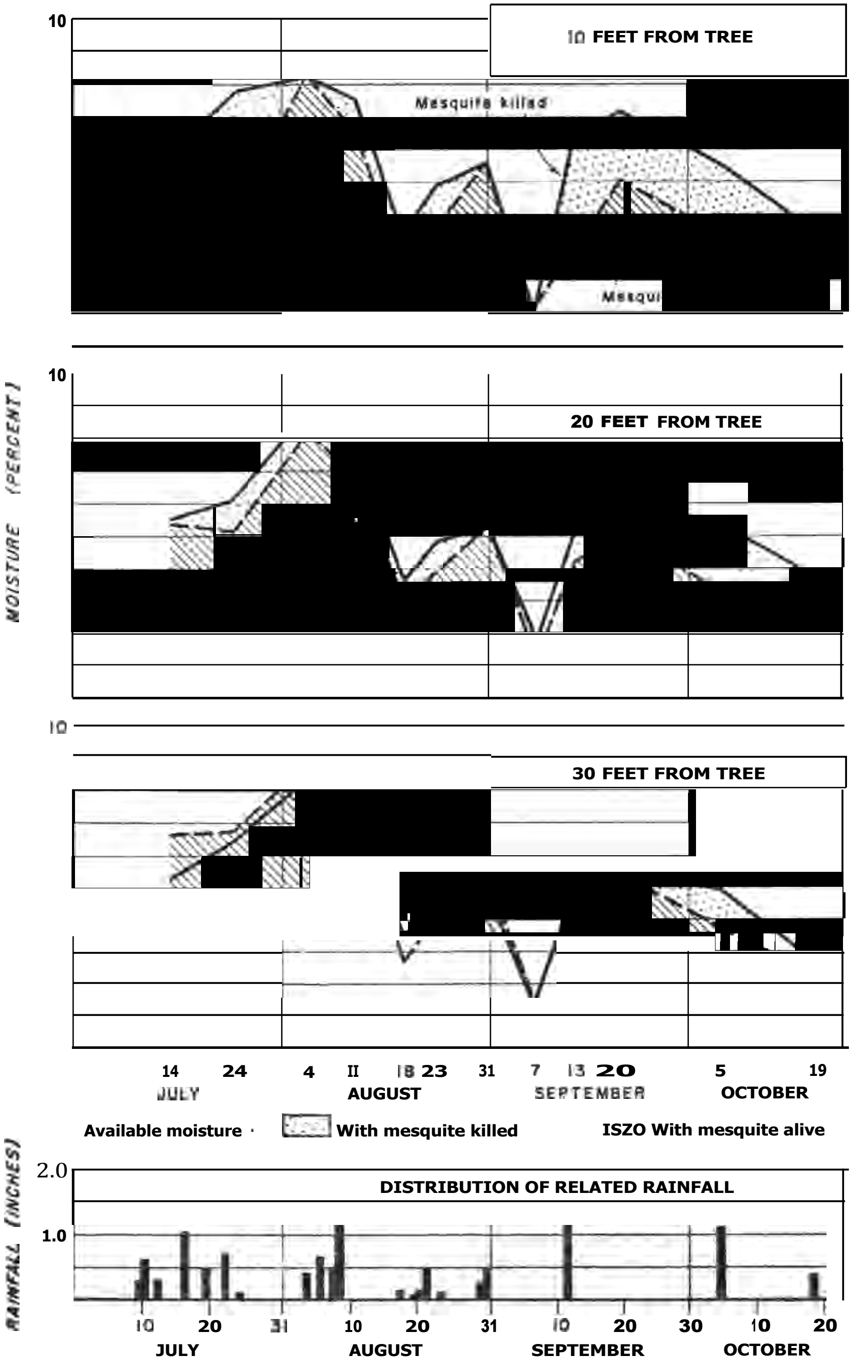

FIGURE 12.—Effect of mesquite elimination on soil moisture during summer growing period 1946, in the 0- to 6-inch soil layer at various distances from trees.

layer and below it, is a critical factor influencing the continued growth and ultimate herbage yields of both new and older plants.

Striking differences in soil moisture occurred in the 6- to 12-inch soil layer as a result of killing mesquite. As indicated in figure 13, soil moisture where mesquite was controlled greatly exceeded that where it was alive, up to a distance of 20 feet from mesquite stems. At the 10-foot distance, moisture was nonavailable for only 10 days (Aug. 31 to Sept. 9) of the 98-day period on the mesquite-killed plots as compared with 81 days where mesquite was alive. At 20 feet from the mesquite stems these differences in duration of unavailable moisture were 14 and 72 days respectively.

Except for a slightly longer duration of available moisture where mesquite was killed, at 30 feet there was no significant difference in soil moisture at the 6- to 12-inch depth. This would indicate that, as in the 6-inch surface level, mesquite competition for soil moisture at the 30-foot distance was not great.

In the Southwest about 40 days of continued available moisture during the growth season is generally regarded as the minimum period necessary for effective establishment of new seedling grasses and enlargement in size of the older plants. Precipitation during the season of 1946 was the best of the 9 years of study and the density of perennial grasses was the highest of record (fig. 7) . Likewise, forage yields (table 5) were the best of any year for both the untreated and mesquite-killed areas. Apparently, however, on the untreated areas with live mesquite the period of continuous available moisture in the 6- to 12-inch soil level was inadequate for optimum growth of grasses, and the increases which did take place depended largely on moisture obtained from the soil layer above. In contrast, where mesquite was killed, the additional moisture made available in the 6- to 12-inch layer and below it was used by the perennial grasses in sustained growth throughout the season, and this growth was reflected in higher plant densities and greater yields of herbage.

Effect on Moisture in the 12- to 18-inch Soil Layer

Moisture in the 12- to 18-inch soil layer is of especial importance to plant growth because when the surface foot of soil becomes dry, as between rains in spring and summer, the deeper soil may serve as a reservoir upon which well-established plants may draw. Furthermore, the moisture at this soil level is more stable than in the upper levels because evaporation losses are less. Consequently, a larger part of the moisture may be utilized by plants for continued growth.

Significant differences in the moisture content of the 12- to 18-inch soil layer occurred at all distances up to 30 feet from the mesquite plants. As indicated in figure 14, the difference in soil-moisture content between plots with dead mesquite and those with live mesquite was as great as 30 feet as at 10 or 20 feet.

The duration of available moisture was strikingly greater at all sampled distances from mesquite stems where mesquite was dead than where it remained alive. At 10 feet there were only 13 days

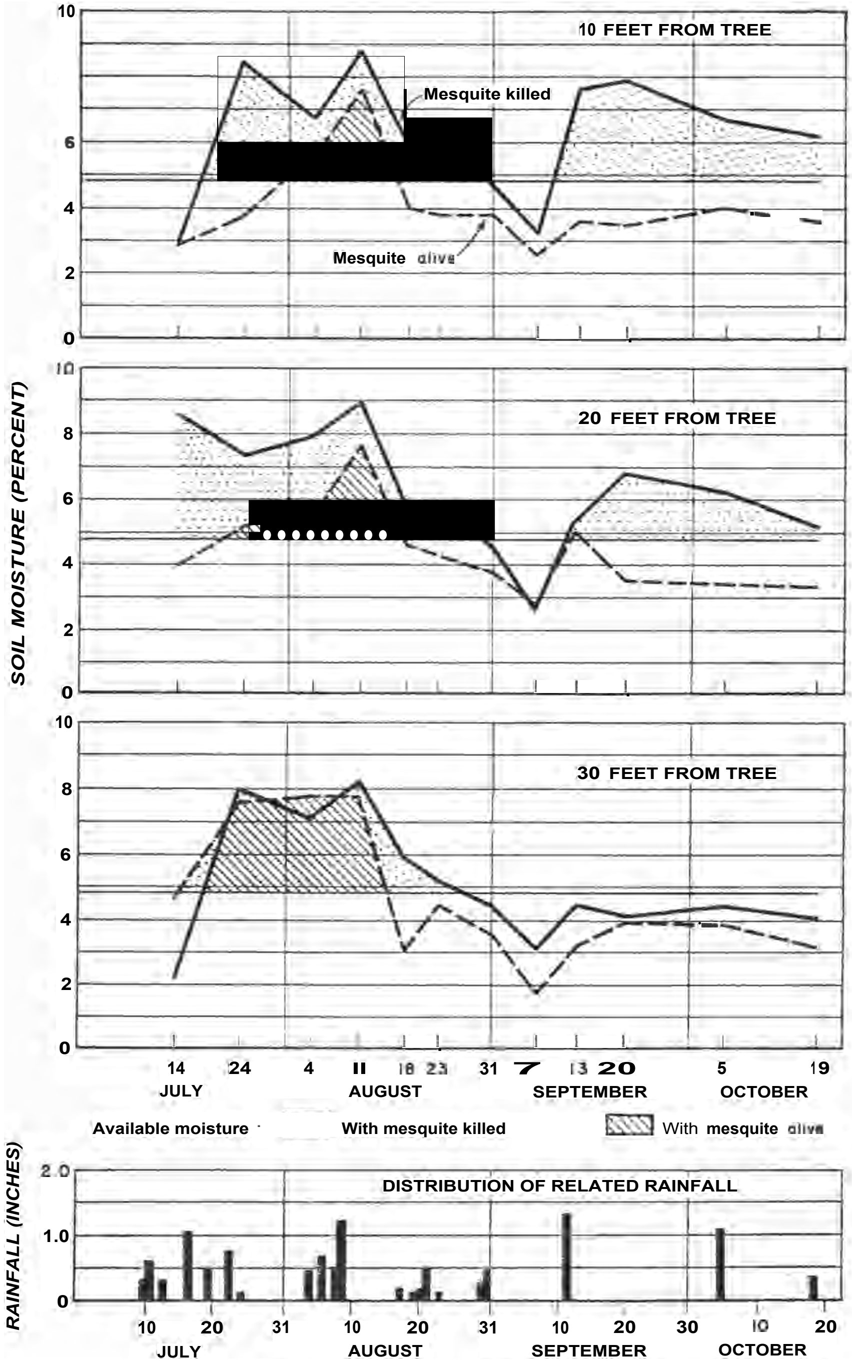

FIGURE 13.—Effect of mesquite elimination on soil moisture during summer growing period 1946, in the 6- to 12-inch soil layer at various distances from trees.

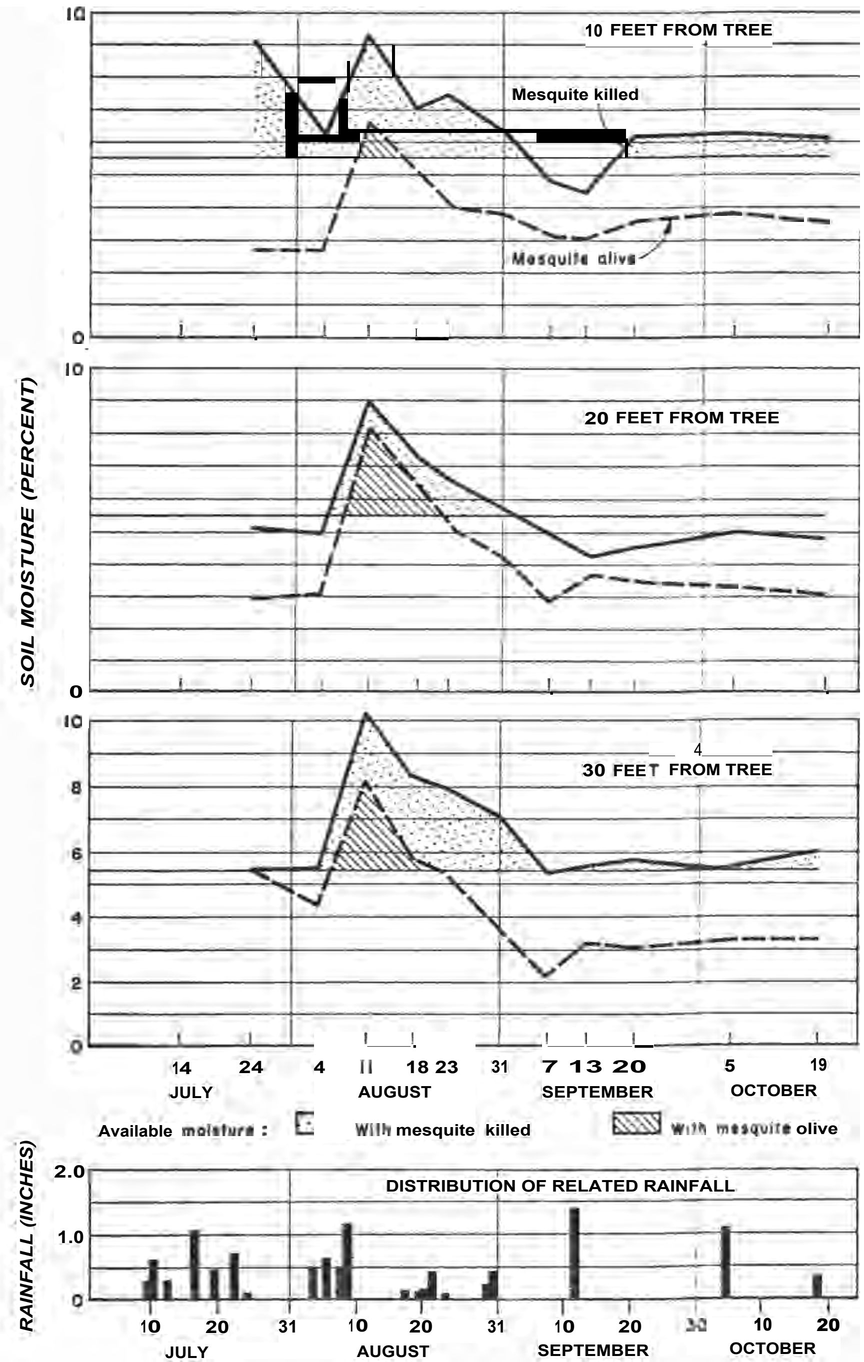

FIGURE 14.—Effect of mesquite elimination on soil moisture during summer growing period 1946, in the 12- to 18-inch soil layer at various distances from trees.

(September 4-17) when moisture content on the mesquite-cleared areas was too low to be utilized by plants, in contrast with 81 days on the areas with live mesquite. At 20 feet there was less difference, the respective periods of moisture shortage being 56 days and 71 days. The much shorter period of available moisture at this distance compared with 10 feet and 30 feet may be ascribable to sampling error in determination of the moisture content, because similar inconsistencies did not occur in the 0- to 6- and 6- to 12-inch soil layers. The greatest difference in duration of available moisture occurred at 30 feet-4 days of inadequate moisture on the mesquite-eliminated areas as compared with 73 days where mesquite was alive.

Thus, where mesquite was alive, the duration of moisture availability was extremely short. At no sampled distance from the mesquite stem was it more than about 15 days, which is an entirely inadequate period for the sustained growth of perennial grasses. In contrast, where mesquite was killed, the duration of moisture availability was adequate for continued grass growth at all distances, with the possible exception of the 20-foot distance.

Mesquite Control Releases Soil Moisture for Forage Production

Results from the study indicate that velvet mesquite adversely influences soil moisture to a distance of at least 30 feet from the plant. Information regarding use of moisture by mesquite at greater distances from the plant and in deeper soil levels was not obtained, but 40-year-old trees and shrubs are known to have roots which extend as far as 50 feet or more from their bases. These data indicate that stands of mesquite as light as 15 trees or shrubs to the acre (where the plants have root systems reaching out 30 feet) should be killed if the ranch operator wishes to increase forage production. The data also indicate that mesquite probably prevents the full establishment of new grass seedlings, since their roots cannot penetrate into the lower soil levels where the moisture supply is more stable. Therefore, if range reseeding is to be successful, it must be accompanied by mesquite control.

EFFECT ON SOIL EROSION

On southern Arizona upland ranges, which in the foothills are usually sloping, the encroachment of velvet mesquite is ordinarily accompanied by a thinning grass cover and accelerated erosion. In the present study it was not possible to measure differences in rates of soil movement between areas cleared of mesquite and those where it remained alive. However, certain observations which bear on the subject were made. Prior to application of the several shrub-control treatments in 1940 sheet and rill erosion were evident over the entire study area. The killing of mesquite resulted in a significant increase of perennial and annual grass growth. This increased vegetation cover materially lessened the rate of sheet erosion (fig. 15) . In fact, accelerated erosion as brought about by raindrop-splash erosion and surface flow of water appeared to have been completely arrested on the mesquite-cleared areas ; whereas it continued unabated on adjacent mesquite-infested areas.

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FIGURE 15.—A contrast in soil erosion rates on the Santa Rita mesquite-study area. The foreground above, located in a stand of velvet mesquite, is almost devoid of grass cover and the soil is bare. Accelerated erosion, as indicated by the small rill, exposed roots, and pedestaled plants, is evident. In the background the killing of mesquite brought about a fair cover of grassy vegetation. Here practically no evidence of active erosion appears.

Aside from the benefits of increased herbage production, the reduction of accelerated erosion through elimination of mesquite infestations is well warranted from the standpoint of soil conservation and the permanent use of these lands for grazing purposes. Mesquite control, together with proper range management and in some instances reseeding, offers a practical means of attaining this objective.

EFFECTS OF THINNING MESQUITE STANDS

Thinning mesquite stands to varying numbers of plants was done on the Santa Rita Experimental Range in order to determine : (1) How great an abundance of mesquite is necessary to affect herbage production, and (2) how the presence of mesquite affects the success or failure of artificial reseeding.

The study was conducted at four different sites about 2 miles apart which varied in elevation, average annual precipitation, and abundance of mesquite. At each of the four sites five plots (each plot of 2 acres) were established in 1945. Mesquite on four of these plots was thinned to represent the following conditions : 25 plants per acre, 16 plants per acre, 9 plants per acre, and complete elimination. In addition, there was no thinning of original stand on one series of plots. The live mesquite plants left on the thinned plots were selected so as to obtain uniform spacing and size. All mesquites left were above 5 feet high, with stem diameter exceeding 2 inches at the base. The stands were all less than 50 years old. All areas were open to grazing by cattle.

The four sites designated in table 7 as A, B, C, and D varied considerably between sites both as to the original stand of mesquite and the amount of perennial grasses present. In general as elevation and average annual precipitation increased, both mesquite and perennial grass cover likewise increased in abundance. Thus site A, which is at the highest elevation and in the highest rainfall area, had the greatest number of mesquites in the original stand, whereas the mesquite on site D was relatively sparse. The initial grass cover on site A had about 30 percent ocular density. Grasses covered about 10 percent of the soil surface on site B, and on the other two sites the grass cover was negligible. On the different sites the individual perennial grass species also varied in relative abundance and included the following : Arizona cottongrass, slender grama, Rothrock grama, black grama, sideoats grama, plains bristlegrass, sprucetop grama, and perennial threeawns. These species are typical of southern Arizona grasslands.

TABLE 7.-*Initial stand of mesquite, elevation, and precipitation at the four Santa Rita thinning-study areas*

Site designation	Mesquites per acre in original stand	Elevation (approximate)	Average annual precipitation[1]	Precipitation in growing season[2]					
				Average[1]	1946	1947	1948	1949	1950
	Number	*Feet*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
A	358	4,100	17.45	11.98	12.32	5.67	6.67	7.75	10.41
B	138	3,900	14.75	8.88	11.75	6.11	6.72	6.41	10.64
C	164	3,600	13.39	8.09	13.25	4.49	6.22	5.30	10.41
	44	3,300	12.80	7.74	11.60	4.54	6.76	4.21	9.71

[1] Long-time averages.
[2] Precipitation June-September.

Effect of Thinning on Herbage Yields of Native Grasses

Herbage yields were increased materially as a result of thinning mesquite. This response began in the first growing season following control in 1945, as shown by comparison of figures 16, 17, and 18. (Because of shortage of manpower no field data were collected in 1945 and data were incomplete in 1946 and 1947.) As shown in table 8, the increases in herbage production on these sites began with the lightest thinning, which left 25 mesquites per acre. Furthermore, yields increased largely in accordance with the degree of thinning : the fewer the mesquites left, the greater the yield of grass. This was true in most years as well as for the

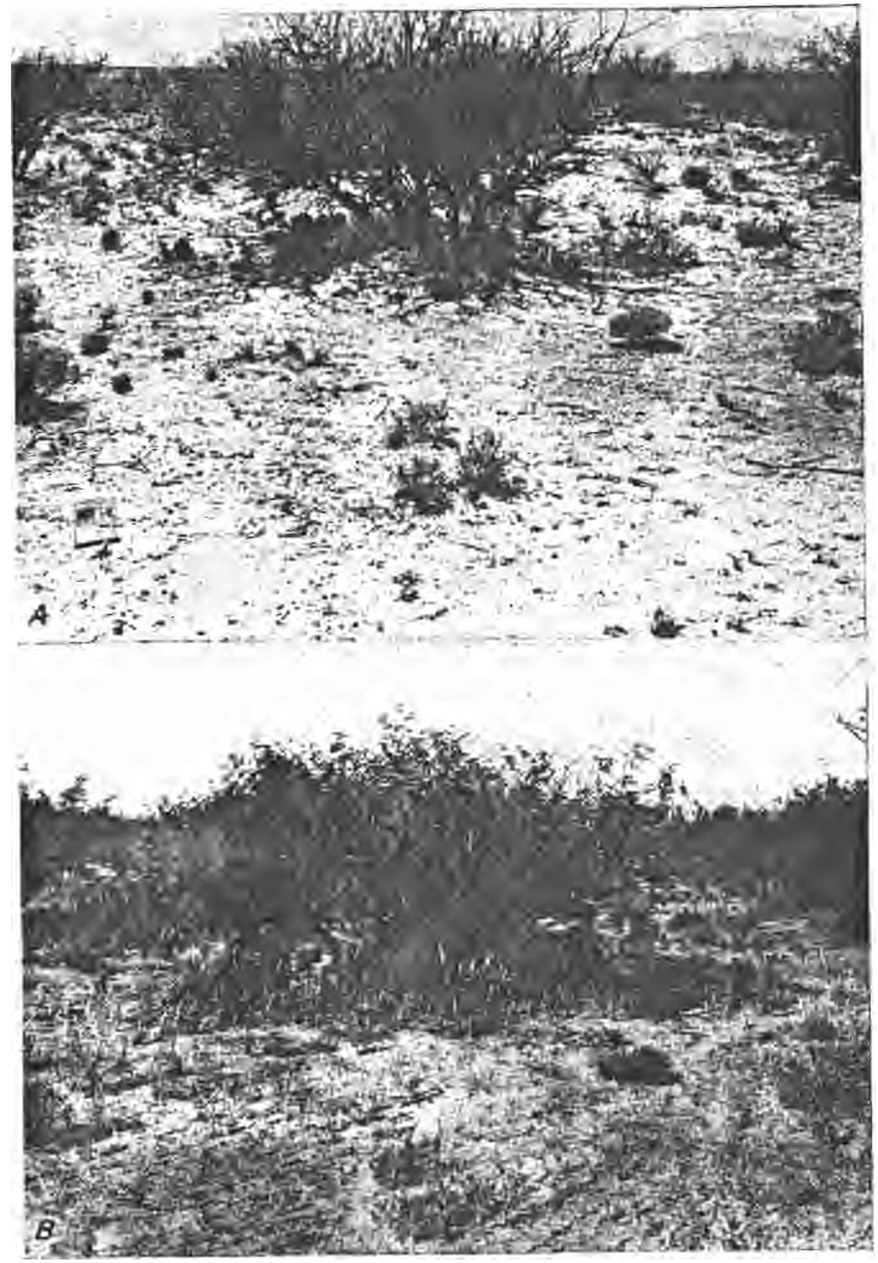

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FIGURE 16.-A, This undisturbed stand of mesquite open to yearlong cattle grazing consists of 138 plants per acre. Photographed in April 1945. *B,* The area in September 1945, at the close of the growing season. Photographed from the same point.

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FIGURE 17.—A, Mesquite on this plot was thinned to 16 plants per acre in March 1945 just before the picture was taken. *B*, The response of grass in the first growing season. Photographed in September 1945 from the same point.

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FIGURE 18.—A, Area in foreground was cleared of all mesquite in March 1945. *B*, Following mesquite elimination, Arizona cottongrass showed a striking response in the first growing season. Photographed in September 1945 from the same point.

TABLE 8.—*Herbage yields of native grasses, 1946-50, following mesquite thinning treatments on four different sites*

Site designation	Original mesquite stand	Mesquite thinning treatment	Herbage production per acre					
			1946	1947	1948	1949	1950	Average
	No./A.	*No./A.*	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
		No thinning	124	----	*11*	32	90	64
		25 left			54	149	325	176
A...	358	16 left			50	154	296	167
		9 left			67	166	327	187
		All killed	684	----	100	185	390	340
		No thinning	72	104	46	52	331	121
		25 left		249	203	80	637	292
B.	138	16 left		348	276	386	685	424
		9 left		437	400	142	1, 107	522
		All killed	416	578	483	343	795	523
		No thinning	19	54	13	6	16	22
		25 left	66	103	99	27	278	115
	164	16 left	116	188	180	1	200	137
		9 left	214	180	116	3	149	132
		All killed	108	214	175	45	271	163
		No thinning	36	111	81	2	36	33
		25 left	48	88	91	3	7	47
D......	44	16 left	88	217	128	33	139	121
		9 left	107	110	155	29	399	160
		All killed	68	63	158	2	55	69

5-year average. The largest increase in herbage was on site B, where average increases were three and four times that of the unthinned plot. Increases resulting from thinning were generally smaller on site D than on the other areas. On this site significant increases in herbage production began with the level of thinning that left 16 plants per acre.

The initial abundance of mesquite as it occurred on the four different sites apparently had little influence on the degree of response resulting from thinning. Although the major part of the responses in herbage yields within each site can be attributed in most instances to the effect of thinning, differences in yields between sites are attributed mainly to site characteristics and to the nature of grazing use.

The effect of site, as defined mainly by initial amount of grass cover and precipitation, is well illustrated by comparing sites B and D. Although sparse in both areas the initial cover of grass was greater and better dispersed on site B than on D. Furthermore, summer precipitation (table 7) was significantly greater on site B in 3 of the 5 years of study, and especially so during the drought years of 1947 and 1949 but not in the dry year of 1948. Difference in yields arising from site is also evident in the higher yields of sites A and B as compared with sites C and D. The first two sites are higher in elevation and receive more rainfall than the latter two. These differences in site were accordingly reflected in the herbage yields obtained from the various sites.

The nature of the grazing use also influenced the response to thinning. This may be seen when the herbage yields from sites A and B are compared. Although rainfall is potentially higher at A than at B, it was similar during the 5 years of the study. The main initial difference between these sites was in the amount of grass cover. Site B, with a markedly smaller initial stand of grass, is grazed for only a few weeks each year, mainly in the late fall after growth has ended. In contrast, site A is close to stock water where grazing use is heavy and continues yearlong. Such use adversely affects forage plant vigor, and consequently reduces herbage production.

The differences in yields arising from thinning are especially striking when one considers that 3 of the 5 years of the study were characterized by drought. Drought prevailed in 1947, 1948, and 1949 (table 7) at all four sites but varied in severity. It was most severe at sites C and D. In spite of this, it was not until the third consecutive drought year, 1949, that differences in yields between the differently thinned areas became negligible. In this same year at the higher elevations, mesquite thinning on sites A and B still resulted in appreciably increased herbage production in contrast to negligible production on the unthinned plots. From the standpoint of livestock production, the significance of this finding is that mesquite control would be especially beneficial during years of drought.

When the average production under the five treatments is charted, the results are shown rather strikingly (fig. 19). In comparison with the yields of the untreated plots, greater herbage production occurred with each degree of thinning and with total elimination of mesquite. The difference was small on the plot at site D where 25 plants per acre were left, but in all other cases it was considerable. The advantage of reducing the stand to as few as 9 to 16 plants per acre is well reflected on sites B, C, and D.

The finding that herbage yields are increased as numbers of mesquite are reduced should apply elsewhere in southern Arizona where the precipitation, elevation, and age and abundance of mesquite are similar to conditions encountered on the Santa Rita range. However, the effects of mesquite elimination will vary greatly between different ranges, being greatest on the sites that are favored by more rainfall and have sufficient remnant grass cover to respond to control. Aside from this, the data and observations indicate that where stands of mesquite exceed 9 to 16 plants per acre, herbage yields will eventually be adversely affected. To be most effective, a program of control should eliminate all or nearly all mesquites.

Effect on Artificial Reseeding

Where mesquite stands are dense, the chances for successful artificial reseeding are greatly reduced. At sites A and B narrow strips (50 x 202 ft.) across all the differently thinned plots were reseeded to Lehmann's lovegrass (*Eragrostis lehmanniana*) in July 1945 by broadcasting and raking the seed into the soil. Lehmann's lovegrass is one of the most promising plants for re-

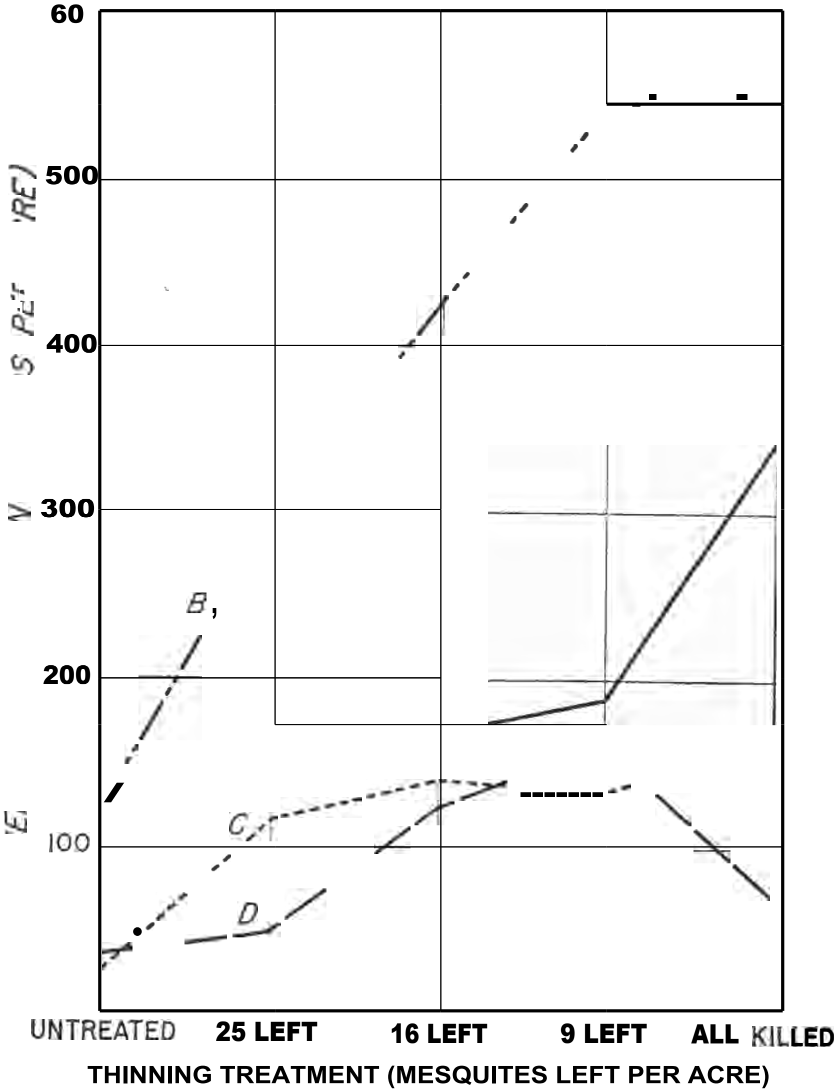

FIGURE 19.—Average herbage production for 5-year period following three levels of thinning and complete elimination of mesquite on four different sites.

seeding in the warmer parts of the Southwest. Since it did not occur naturally on the sites, the observations on herbage production and on numbers of seedlings could not be confused with the native grasses. Seasonal rainfall in 1945 at the two sites was short, covering a period of about 5 weeks, but the timing and sequence of rains was good—with no intervening periods of dry weather to reduce soil moisture below the wilting point, so that conditions for seedling establishment were generally favorable.

Lovegrass seedling establishment varied with the presence or absence of mesquite and also with the site. Where the original stand of mesquite was unthinned, seedling establishment was poor. In 1946 at site A there were 23 seedlings established per 100 square feet and only 3 seedlings per 100 square feet at site B. No seedling counts were made on the mesquite-thinned plots, but where mesquite was completely killed the counts were 528 and 21, respectively, for sites A and B.

The low seedling establishment rate on site B was at first believed to indicate reseeding failure because at least one established plant per square foot is considered the minimum for a successful reseeding. However, it subsequently proved rather satisfactory, as shown by the production figures given in table 9.

TABLE 9.—*Herbage yields of Lehmann's lovegrass following various mesquite thinning treatments on two different sites*

Site	Original mesquite stand	Mesquite thinning treatment	Herbage yields per acre[1]				
			1946	1948	1949	1950	Average
	Number/A.	*Number/A.*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
A	358	No thinning	26	45	40	33	36
		25 left		139	252	293	228
		16 left		110	198	543	284
		9 left		137	214	650	334
		All killed	558	286	200	1, 154	550
B	138	No thinning	8	22	15	15	15
		25 left		95	85	80	87
		16 left		150	105	180	145
		9 left		370	120	174	221
		All killed	55	170	105	312	160

[1] No data collected in 1947.

At both sites average herbage production during the period of study generally increased with the degree of mesquite thinning. Yields from the plots completely cleared of mesquite were many times those of the untreated plots.

It will be recalled that the response of native grasses (table 8) to release from mesquite competition was greater on the site with an initial stand of 138 mesquites per acre than it was on the site with 358 mesquites per acre. In contrast, herbage yields from Lehmann's lovegrass were markedly greater on the latter area. An explanation of this apparent paradox is that site conditions on site A were more favorable for lovegrass seedling establishment. For example, on this area, there was more litter than on site B because of the better initial cover of native grasses. Litter has a beneficial influence on moisture retention, an important factor in grass seedling establishment. Even though the remnant herbaceous cover was greater, 30 percent on site A as compared with 10 percent on site B, it still was not sufficient to offer effective competition to establishment of Lehmann's lovegrass.

In spite of the differences in the yields from reseeded plots on sites A and B, these data strongly indicate that elimination of mesquite is necessary for successful artificial reseeding in moderate to heavy mesquite stands. The difficulty of establishing Lehmann's lovegrass in the presence of mesquite competition suggests that natural revegetation from native grass species is probably just as difficult under similar circumstances.

MESQUITE CONTROL METHODS

Studies to determine the most effective and practical methods of killing velvet mesquite were begun on the Santa Rita Experimental Range in 1937. Significant findings from this initial experimental work were reported a few years later by Parker *(28).* Sodium arsenite was found to be most effective in killing mesquite. But Diesel oil and kerosene were also recommended because of the low hazards involved in their application. Following the publication of this information, tests were continued on the Santa Rita with these chemicals as well as many others, including the recently developed 2,4-D and 2,4,5-T herbicidal preparations. As yet arsenic and petroleum oils remain the best for control of velvet mesquite. *The use of petroleum oils is now generally favored over arsenic in control work because hazards involved in application are greatly reduced.* Additional information on the manual application of both these substances in mesquite control is now available and is here reported.

FACTORS AFFECTING SUCCESS IN MESQUITE CONTROL

Mesquite is a notoriously vigorous sprouter (fig. 20). To eliminate mesquite from the range, the control method must either remove the plant bodily from the soil (which can be done by hand grubbing or machinery) or kill the top and the stem base and thus effectively prevent sprouting.

As yet, no one control method has been found adaptable to all sites and degrees of infestation. Nor is it always possible for a ranch owner to utilize a method even though it may be the most effective. For example, power machinery has been found fairly effective in eliminating mesquite, particularly in moderate to heavy stands where the soil is not too rocky or the terrain too rough. But the cost of power equipment may be beyond the means of the rancher, unless available through rental. Even then, the stands of mesquite may be so sparse or the terrain so unsuitable to use of machinery that manual methods can be applied at less cost. The factors affecting mesquite control and the advantages and limitations of the various manual methods available are described here as an aid to the ranch owner in planning an effective mesquite-control program.

There are many ways of killing the top growth or crowns of mesquite, but methods that consistently prevent regrowth or sprouting from the stem base are few. To achieve successful kills of mesquite with chemicals applied manually, two basic principles must be observed concerning: (1) The origin or source of the

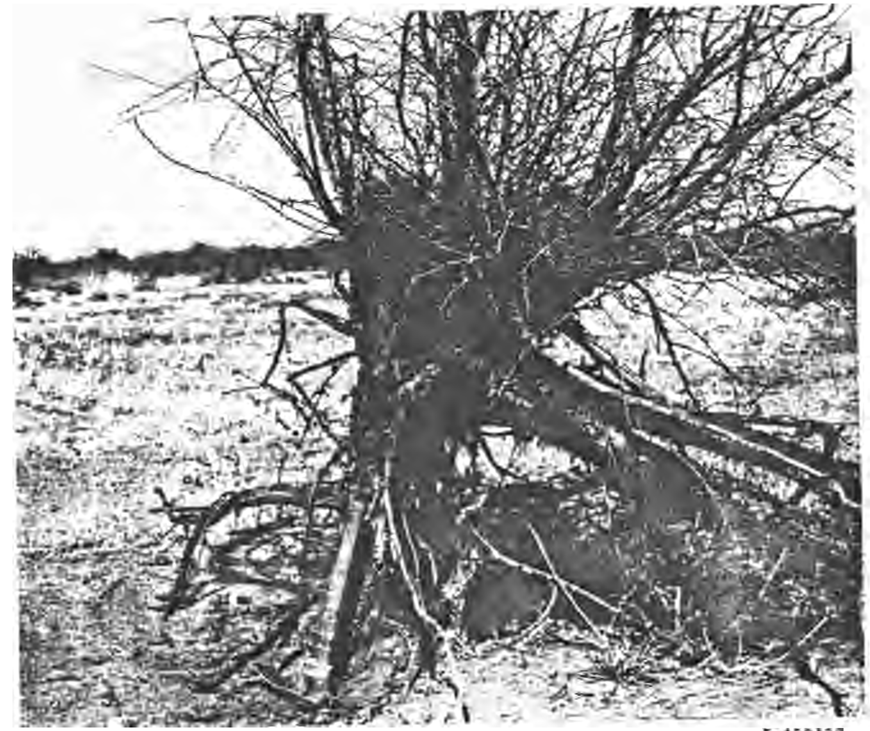

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FIGURE 20.—Vigorous sprouting is characteristic of velvet mesquite. A heavy sprout growth formed even after this stump was uprooted by bulldozer tractor.

sprouts, and (2) the extent and means of movement of chemical solutions within the plant. Many attempts to kill mesquite have been unsuccessful because the treatments failed to meet the requirement of making direct contact with the potential sprouting tissue, or the herbicidal solutions were improperly applied for effective transportation within the plant.

Origin of Mesquite Sprouts

The basic requirement for success in killing velvet mesquite is to prevent sprouting. To overcome regrowth one must know exactly where to apply the poison or how deep to grub. Numerous buds, appearing as wartlike structures, cover the surface of the stem base directly above the juncture (root collar) of root and stem (fig. 21). These perennial dormant buds are not found on the roots. The bud zone itself extends from the basal part of the tree to the root collar, about 6 inches beneath the soil surface.

Each year as the plant grows the buds likewise grow and, although dormant, are always present beneath the bark, awaiting favorable conditions for emergence as sprouts. Sprouting will take place whenever injury or destruction of the stem above ground occurs. Thus to prevent sprouting, all stem tissues within the bud zone at the base of the plant must either be poisoned or

FIGURE 21.—Section of honey mesquite taken near juncture of stem and root showing the numerous dormant buds. Bud formation on velvet mesquite is similar. All buds must be killed to prevent sprouting. (Photo courtesy Chas. Fisher, Texas A & M College).

removed (as by grubbing). These findings on the origin of mesquite sprouts confirm those of Fisher et al. (14) for honey mesquite in Texas.

Knowledge of the nature of the bud zone tissue is essential to effective control work. For example, mesquite commonly forks or branches near the soil surface. If the whole plant is to be killed by poisoning with arsenic, the frill into which the poison is poured must be below the fork. Otherwise, if each stem is frilled separately, sprouting from buds located within the crotch area is likely to occur. If the grubbing method is used, the plant must be cut below the bud zone to prevent sprouting.

Movement of Solutions in Mesquite

In order to kill the entire mesquite plant, toxic chemicals must either be absorbed and transported within the plant or applied so as to make contact with all tissues capable of forming new growth, i.e., the dormant buds. Although the exact nature of translocation is not perfectly understood, a few inferences regarding the process have been obtained by tracing the movement of artificially introduced organic dyes within the mesquite plant.

Some of the first experimentation of this type with mesquite was done on the Santa Rita Experimental Range by Day,[5] with dye solutions of eosin and lithium. Principal findings, confirmed by later studies conducted by the Southwestern Forest and Range Experiment Station, were : (1) Tangential and radial (around and across) movement of solutions in the stem is extremely slow ; (2) injected chemicals move mainly within the outer layers of wood in the stem and apparently not at all within the inner layers or heartwood area ; (3) both lateral and vertical movement of solutions is greatest in the fall and least in the spring ; (4) internal conditions in mesquite are such that injected chemicals will move vertically in the stem as much as several centimeters within a few seconds when directly injected. Then these internal conditions become less favorable for movement and the transportation of materials slows down greatly.

These findings have several practical applications in mesquite control by chemical herbicides. Because lateral movement of materials in the stem is extremely slow, chemicals must be applied so as to completely encircle the stem in the bud zone area. If the chemicals are placed in frills cut with an ax, the frills must encircle the stem but need be no deeper than is necessary to hold the prescribed dosage, since the inner heartwood is inactive in translocation. Application of chemicals in holes or randomly made ax cuts is ineffective in killing mesquite because of the naturally poor lateral distribution of the solutions. Chemicals should be applied immediately after cutting, while wood surfaces are still moist, to insure best absorption.

CHEMICAL METHODS OF CONTROL

The principal advantages of killing mesquite with chemicals are : (1) Labor costs are less than with hand grubbing, and in sparse stands are less than with machinery ; (2) suitability to any type of terrain ; (3) expensive equipment is not required ; and (4) disturbance or destruction of desirable range forage plants is minimized. For mesquite control in Arizona, the most effective and commonly recommended materials are sodium arsenite and Diesel oil. Various methods of application have been described by Parker (28), Martin (25), and Streets and Stanley (32).

Control with Sodium Arsenite

Sodium arsenite is one of the most reliable mesquite poisons because it is very toxic to plant tissue and travels readily in the translocation system. It is also the cheapest proved poison that is soluble in water. The principal objection to the use of sodium arsenite is that it is extremely poisonous to all forms of animal life. Therefore, sodium arsenite must always be handled by careful, competent workers and livestock must be prevented from getting at it.

[5] Day, Boysie E. Translocation in the mesquite. A thesis submitted to the faculty of Dept. of Botany in partial fulfillment of the requirements for the degree of Master of Science in the Graduate College, University of Arizona, 55 pp. (typed) May 1940.

The principal factors which may affect the percentage kill of mesquites treated with sodium arsenite are: Method of application, quantity of chemical used, size and character of mesquite growth, and season of year treated.

Methods of applying sodium arsenite.—In brief, the most effective methods of applying sodium arsenite are : (a) Application of a concentrated solution of sodium arsenite to the moist sapwood, exposed by cutting a frill which completely encircles the mesquite at its base (fig. 22), and (b) pouring a dilute sodium arsenite solution into a shallow earthen basin which encircles the base of the plant (fig. 23) .

In the frilling method, correct cutting of the frill is important. If the frill does not completely encircle the main stem, sprouting is likely to occur from the uncut sectors. The frill should not be more than 1 inch deep and the chips should be left in place to help retain the poison solution and to prevent licking by grazing animals.

Basins must be dug so that the arsenite solution will completely surround the stem base and permit maximum efficiency with minimum waste in making contact with the bud zone. Better mesquite kills are obtained by using a basin than by merely pouring arsenite solution on the ground encircling the stem. To test the two methods, two groups of 20 mesquites each, with and without basins, were treated on the same day, receiving equal amounts of arsenite solution. In the group with basins, the kill was 95 percent, whereas in the group without basins, it was only 40 percent.

Methods of application that proved ineffective in treating mesquite with arsenicals are: Application to foliage by sprays (even if effective, it would be of doubtful value because of high hazards to

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FIGURE 22.—Applying sodium arsenite to a frilled mesquite with a 1-quart pump-type engineer's oil can. This quantity of arsenic solution is usually sufficient to treat about 20 trees of the size shown.

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FIGURE 23.—Small mesquites such as this and the several-stemmed form of mesquite can be killed with a minimum of labor by employing the basin method for applying sodium arsenite. A pint can attached to a long wooden handle is used to pour sodium arsenite into shallow basin made around the base of the plant.

humans and livestock) ; application in auger holes or randomly made ax cuts ; application by tree-killing tools especially designed to inject the chemical into the tree ; and brushing the solution on freshly cut stumps.

Size and character of mesquite growth.—In a control program, both the girdling and basin methods, as well as grubbing, can all be used advantageously because of the natural variation in size, character of growth, and abundance of the mesquite. The girdling method is most practical for single-stemmed trees more than 3 inches in diameter. The basin method is best for multiple-stemmed mesquite or plants with low-hanging branches difficult to girdle, and for plants 1 to 3 inches in diameter. Seedlings up to 1 inch in diameter are most effectively removed by grubbing. The girdling method requires more labor but less chemical per plant than the basin method. For example, the average worker can treat about 12 mesquites per hour by frilling as compared with 25 by the basin method. But a given amount of arsenite is sufficient to treat about five times as many mesquites by frilling as by the basin method.

Sodium arsenite is a powerful soil sterilizer. When applied by the girdling method, only the plants treated are killed. On the other hand, when applied to the soil, as in the basin method, not only the mesquites are killed but all other plant growth in the poisoned spot is prevented for some time. This toxic effect is produced in a circular area, with a radius of up to 12 inches, around the plant base. Soil sterility will persist in this area until rainfall leaches and disperses the arsenite to a concentration that is no longer toxic. In tests with Santa Rita soils, the arsenic content 6 years after application was enough to prevent normal growth of barley plants. Even though the basin method of applying sodium arsenite sterilizes spots up to 2 feet in diameter around each mesquite, the total area affected is small, even in a heavy stand of mesquite. For example, if 400 plants per acre were treated, about 3 percent of the total soil area would be sterilized. However, even if it were economically feasible, it is questionable whether the basin method should be used exclusively on mesquite stands of more than 400 per acre, because of the increased poisoning hazard to livestock.

Preparation of arsenite solution.—Sodium arsenite is available commercially and is usually sold in liquid form with an arsenic trioxide content of 4 pounds to the gallon. It can usually be prepared more cheaply on the ranch. The following precautions must be observed strictly.

Sodium arsenite can be made up by mixing thoroughly the three ingredients given below in any desired multiple of the proportions indicated. This basic prescription makes 1 gallon of stock solution:

White arsenic (arsenic trioxide powder)	8 pounds
Caustic soda (sodium hydroxide flakes)	2 pounds
Water	3 quarts

The chemicals are first weighed out and mixed dry. To the dry mixture of arsenic and soda add about a third of the water required, constantly stirring with a long wooden paddle and adding more water to reduce the violent boiling which will occur. *Always add water slowly to chemicals; never add chemicals to water.* The stock solution is left in this concentrated form for transportation to the field, where it may be diluted as required. For the frilling method, liquid laundry starch is preferred to water alone as a diluent, because of its greater cohesiveness and because it evaporates less rapidly.

Precautions with arsenic compounds.—White arsenic and caustic soda, as well as the sodium arsenite compound, are powerful skin irritants and extremely poisonous internally to animals or humans. Neither dry nor liquid forms should be handled without thorough protection, not only from any possible bodily contact with the chemicals, but also from inhaling either dust or vapors arising from them.

Workers should at all times wear gauntlet rubberized gloves or cloth gloves that have been dipped in hot paraffin. In mixing or pouring either the stock or diluted solution, the worker must always stand to windward and wear a coverall—or better, a sleeved apron of shoe length—of stout cloth dipped in hot paraffin, of oilcloth, or one that is otherwise impervious to the chemicals. The face and eyes must be protected with goggles and a mask.

Arsenite solution that is spilled on the clothes and soaks through to the skin may cause ulcers. When an arsenical penetrates the clothing, the skin should be washed immediately with soap and water. *Any person suffering from skin irritation should immediately discontinue the handling of arsenic and receive prompt medical treatment from a physician.* The greatest danger of skin irritation comes from small quantities of the stock solution which are splashed on unprotected clothing and dry there. Perspiration may later redissolve the chemicals and allow them to come in contact with the skin and cause ulcers, most often about the groin or belt line. Daily change to clean laundered clothing is an effective preventive. Still better, wear outer clothing so protected that the solution cannot get through.

Keep all equipment and materials out of reach of children and animals; best under lock and key. Mark all equipment plainly, as with red paint. Prevent livestock from licking any chemical from basins or frills, and cover spilled chemicals with earth and brush. *Wood from poisoned trees must not be used as fuel, since the smoke may be poisonous.*

There is apparently no danger to livestock from browsing the leaves, stems, or seed pods of poisoned trees if the chemicals have been confined to a basin or frill, as proved in feeding trials made by the Arizona Agricultural Experiment Station. Either method of poisoning can be used in pastures grazed continuously by cattle. There will be no death loss or sickness so long as the livestock cannot reach soil or plant surfaces to which the poison has been applied.

Quantity of sodium arsenite.—The quantity of sodium arsenite applied to each mesquite by either the frilling or basin method determines in large measure the percentage kill obtained.

In practice, the quantity of sodium arsenite applied by the frilling method is governed largely by the concentration of the solution used because of the limited reservoir capacity of the frill. One quart of solution is sufficient to treat about 20 plants with an average diameter of 6 inches, if undue waste from leakage out of the frill can be avoided.

As shown in table 10, the percentage kill obtained by the frilling method declines as the concentration of stock solution is reduced. For example, with 1 part of the solution to 1 part liquid laundry starch, the kill in 2 trials averaged 87.5 percent; whereas with a dilution of 1 to 7, percentage kill on 7 trials ranged from 20 to 65 percent, with an average of 31.4 percent. Widescale application

TABLE 10.—*Percentage of mesquites killed by the frilling method with different concentrations of sodium arsenite*

Concentration of arsenite solution	Trials [1]	Highest kill	Lowest kill	Average
	Number	*Percent*	*Percent*	*Percent*
1 to 1 [2]	2	90	85	87.5
1 to 3.	8	95	30	62.5
1 to 7	7	65	20	31.4
1 to 10	6	30	10	15.8
1 to 31	2	5	0	2.5

[1] Trials made during period 1939-41 A trial consist of 20 trees or shrubs in a group.

[2] 1 part of 8 pounds (As_2O_3) per gallon stock solution diluted with 1 part liquid laundry starch.

of a 1 to 2 concentration of arsenite by the frilling method on several sections of mesquite-infested range in southern Arizona resulted in a percentage kill exceeding 90 percent. Applications were made during the winter months of the period 1939-43. A minimum concentration of 1 part stock solution to 2 parts liquid laundry starch is recommended.

With the basin method of applying sodium arsenite, concentration of the solution is important since it governs the quantity of arsenic applied. The recommended dosage on mesquites up to about 12 inches basal stem diameter is 1 quart of 1 to 12 solution. This is as effective as 1 pint of a 1 to 6 solution and possibly more so, since with the larger sized mesquites better distribution of the poison around the plant base is obtained with the larger volume of solution. For basal stem diameters exceeding 12 inches, still larger volumes of solution are required for complete wetting of the soil around the base of the mesquite.

Season of applying arsenite.—The best season for applying sodium arsenite in Arizona is during the cooler months from about December to March, preferably in January and February. Control work should not be done during hot weather, because of the increased hazard of arsenic poisoning to workers. Danger of skin poisoning is especially high when pores of the skin are open and perspiration great.

Sodium arsenite is most effective in the winter months (table 11) . With the basin method, the percentage kills were 90 percent or better in January, late February, and April, but dropped to 15 percent in June and 20 percent in October. With the frilling method, the January treatment also gave the best kill (90 percent) . No satisfactory explanation is available for the somewhat better kills (70 and 80 percent) with both methods in August than in the preceding June or succeeding October. Experience with widescale application also shows that the winter months are best for effective kills with sodium arsenite applied in either the frill or basin. Several hundred acres on a southern Arizona ranch treated in January gave kills exceeding 90 percent with either method, whereas treatments in June resulted in kills of less than 10 percent.

TABLE *11.—Percentage kill obtained with sodium arsenite at different times of year (1941)*

Method of application	Date of trial					
	Jan. 15	Feb. 25	Apr. 16	June 18	Aug. 7	Oct. 5
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Frilling [2]	90	65	55	50	70	65
Basin [2]	90	95	95	15	80	20

[1] 20 trees or shrubs in each trial.

[2] Concentration of arsenite—Frilling method: 1 part stock solution to 3 parts liquid laundry starch—1 quart to 20 trees. Basin method: **1** to 4 of water, 1 pint per tree.

Control **with Light Petroleum** Oils

Various light petroleum oils, such as Diesel oil and kerosene, have been widely used to kill mesquite because they are relatively effective, cheap, and safe to use. Although not generally as applicable under as wide a range of conditions as sodium arsenite, oils properly used may effect kills of 85 percent or more. *Oils are less hazardous than sodium arsenite, and their use requires less labor than arsenite solution applied by the frilling method.* Of the many petroleum oils used to kill mesquite, Diesel oil, stove oil, and kerosene are the most popular. In recent years several proprietary herbicidal oils have been placed on the market. These are also effective but most of them are more expensive.

All petroleum oils kill by direct contact with the plant tissues and are not translocated within the mesquite plant like arsenite. The principal factors affecting the kill obtained with petroleum oils are : Method of application, kind of oil, quantity of oil, character of soil, and size and character of mesquite growth.

Method of applying oils.—To kill mesquite, an oil must completely envelop the main sprouting bud zone underground. Several satisfactory methods of application have been developed. The common 3-gallon orchard spray tank is recommended. Its effectiveness for oil applications can be greatly increased by removing the spray nozzle or enlarging the orifice of the disk to eliminate clogging. Use of a spray tank keeps wastage of oil to a minimum because the oil is applied directly to the bud zone and the rate of flow may be regulated to that of absorption by the soil.

On steeply sloping ground dig a basin at the base of the mesquite and pour in the oil with a dipper. The basin must encircle the plant and should be narrow and level to prevent runoff of the oil. Such a basin insures maximum vertical penetration in the soil occupied by the bud zone and minimum loss through leakage or lateral spread. Only a narrow-bladed mattock is needed to make the basin, and the extra effort expended is usually repaid with better kills.

Basins are most effective with single-stemmed, erect trees. The labor required to make basins under low-spreading, bushy, and multiple-stemmed mesquites is usually prohibitive. Such growth is more easily treated with a liberal dosage of oil applied to the plant base with a 4-foot length of 3/8-inch pipe or tubing attached to a 5-gallon pail (fig. 24) . On relatively level ground oil may be applied more cheaply without digging a basin by carefully spraying or pouring the oil around the base of the mesquite with either the spray tank or pail equipped with pipe.

Kind of oil.—Any of the common light petroleum oils that have been mentioned are toxic enough to kill mesquite, provided the oil is applied skillfully. Several kinds and combinations of oil were tested in applications to the bases of second-growth velvet mesquite at two different rates : 1 pint and 1 quart per mesquite plant. Each treatment was applied to 20 plants on August 8, 1946. The percentages of plants killed are shown in the following tabulation.

Kind of oil	1 pint per plant (percent killed)	1 quart per plant (percent killed)
Kerosene	100	100
Stove oil	100	100
Diesel oil	75	100
Waste crankcase oil	25	65
75% Diesel oil and 25% crankcase oil	75	95
50% Diesel oil and 50% crankcase oil	40	80
25% Diesel oil and 75% crankcase oil	40	95

At the 1-pint dosage, kerosene and stove oil were superior to Diesel oil but with the heavier dosage of 1 quart, all three oils were 100 percent effective. However, in numerous other tests over several years at the Santa Rita range, Diesel oil has proved more toxic than kerosene or stove oil. Futhermore, in southern Arizona Diesel oil is priced about 25 percent less than other light petroleum oils.

Waste crankcase oil was decidedly inferior to the lighter oils, probably because its higher viscosity retards soil penetration and because it has a lower content of tissue-killing hydrocarbons. Application of 1 quart per mesquite plant resulted in a kill of 65 percent, which is considered unsatisfactory for effective control. Waste crankcase oil is usually free for the hauling, and it may be mixed with Diesel oil to reduce costs of material. Where soils are light and sandy, a mixture of 75 percent Diesel oil with 25 percent waste crankcase oil is nearly as effective as pure Diesel oil. For tight, heavy soils, which are difficult to penetrate, undiluted Diesel oil is preferable.

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FIGURE 24.—A simply constructed device for application of oil to mesquite. It consists of a 5-gallon pail to which is attached, with oil-resistant rubber hose, a 6-foot length of %-inch tubing. A 4-foot length of tubing is better.

Quantity and time of application.—The quantity of Diesel oil required will vary with the size of the main stem, the complexity or degree of branching at the soil surface, the texture of the soil, and the depth to which accumulation of soil has buried the underground stem. In a field application, the penetration of the oil should be inspected frequently by excavating the soil around several treated plants. If the oil pattern is reaching all parts of the underground bud zone, the quantity is adequate. Otherwise, sprouting is likely to occur.

Three gallons of oil for 20 plants proved adequate for killing velvet mesquite at the Santa Rita, where the soils are classed as sandy l ams. The kills obtained by applications at different dates, from one spring to the following spring, ranged from 80 to 100 percent, as shown in the following tabulation.

Date treated	2 gallons per 20 plants (percent killed)	3 gallons per 20 plants (percent killed)	4 gallons per 20 plants (percent killed)
Apr. 2	65	80	65
May 5	70	80	65
June 1	85	95	95
July 6	30	85	80
Aug. 4	45	80	70
Sept. 10	95	100	100
Oct. 31	80	90	85
Jan. 8	100	100	100
Mar. 9	90	100	100

For the heavier application rate of 4 gallons per 20 mesquites a slightly lower percentage kill was recorded. This is probably attributable to experimental error arising from such factors as poor application and differences in bud zone areas of the plants.

Diesel oil is apparently most toxic to mesquite during the winter months. Best kills, 100 percent, with as little as 2 gallons to 20 mesquites, were obtained in January. With the heavier applications in September to March the kill ranged from 85 to 100 percent.

In upland soils of the Santa Rita, soil moisture content had little or no effect on the toxicity of Diesel oil—equally good results being obtained when wet (near field capacity) and when dry (below the wilting coefficient) . Kills exceeded 90 percent in trials on sandy soils wet from melting snow. A few weeks later, similar kills were obtained with Diesel oil applied to trees on both dry and artificially watered soils.

Size and character of mesquite growth.—Observation and experience have shown that large mesquites are more likely to survive treatment with oil than small ones, and plants with several stems are more likely to survive than those with a single trunk. In most instances, these differences can be attributed to the field worker's failure to adjust the dosages to the size and complexity of the mesquite growth. Hence, in a control program, it is wise to give special attention to checking thoroughness of application on the larger, more complex forms of mesquites.

Light petroleum oils, properly applied, will kill well-established mesquite plants, second growth, or freshly cut stumps equally well. However, uncut mesquites and newly cut stumps are ordinarily easier to treat than old second growth because there is less mechanical obstruction from stems and branches to contend with. Very old second growth may also have unusually spreading and complex underground stem structures. Unless the top growth can be utilized for wood or posts, cutting of mesquite before treatment is not justified.

Control with 2,4-D and 2,4,5-T

Various formulations of 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) have been tested on velvet mesquite at the Santa Rita Experimental Range since 1946. These chemicals are selective in that they kill broadleaf plants including many undesirable shrubs, and do not injure grasses seriously. They are nontoxic to livestock and other animals. The low volume of material required per acre makes them well adapted to spraying from aircraft. Further, these chemicals are relatively inexpensive. Unfortunately, the results from a great number of tests with velvet mesquite have so far been highly erratic. Usually, foliage applications of these chemicals on velvet mesquite have resulted in nearly complete defoliation, partial top-kill, and a very low percent of actual kill. Further findings from these tests, which included applications by airplane, indicate :

1. Effectiveness of 2,4-D and 2,4,5-T is closely related to the seasonal growth stage of mesquite, being greatest in the spring when leaves have just reached full development.
2. 2,4,5-T is definitely more toxic to mesquite than 2,4-D ; and each appears to be most toxic when soil moisture is abundant.
3. The ester and amine salt forms of 2,4,5-T appear about equal in toxicity ; but the low-volatile ester forms are most likely to be available commercially.

Although some results obtained from foliage sprays of 2,4,5-T are promising, to date they are not considered sufficiently positive to warrant general recommendation for arid areas similar to the Santa Rita. However, in the semihumid areas of Texas, results appear to be good. As stated in previous sections of this circular, the point of infestation at which mesquite seriously competes with grass is about 15 plants per acre, where the mesquite roots extend out 30 feet or more from the root crown. Hence, any control method, to be effective, must reduce the numbers of mesquite considerably below this density.

Future research and experience no doubt will reveal more efficient and less costly methods for killing mesquite. Until such time, however, the methods recommended herein—hand grubbing of seedlings, manual application of arsenite or Diesel oil, or in dense stands elimination by machinery—are on a practical level for many situations. Their immediate application will often mean the difference between conserving the range for profitable long-time grazing and uncertain lower returns where mesquite is permitted to increase.

COSTS AND BENEFITS OF MESQUITE CONTROL

In starting a program of mesquite control the ranch manager is interested in both immediate costs and ultimate benefits. In other words, will mesquite control pay? To answer this question requires careful consideration of the costs involved and the several benefits which accrue from mesquite elimination.

Costs of Control

Costs of controlling mesquite by the previously described manual methods will vary with the method employed, and with the abundance and character of the mesquite growth. The amount of labor and quantity of chemicals required will depend on the number of mesquites per acre. Also, the tree form of mesquite is less costly to kill than the several-stemmed shrub forms, because the tree is easier to treat and requires less material per plant. Ordinarily, too, there is less sprouting and hence less need for follow-up control work.

The tabulation below shows the average costs in 1947 for killing velvet mesquite, which included both tree and simple-stemmed shrub forms, with sodium arsenite and with Diesel oil. These costs are based on labor at 79 cents an hour and arsenite stock solution at $1.73 a gallon.

Treatment	*Total (cents per plant)*	*Material (cents per plant)*	*Labor (cents per plant)*
Sodium arsenite in frills	**7**	[1] 1	[1] 6
Sodium arsenite in basins	**6**	**3**	**3**
Diesel oil in spray	**4**	**2**	**2**

[1] **Approximate.**

Labor accounted for 91 percent of the cost with frilling and 56 percent with the basin method. An individual rancher might choose to disregard labor costs, if he did the work himself during slack periods. In view of the benefits expected, these costs, including labor, are not considered to be prohibitive for most Arizona ranges. The survey conducted by Upson, Cribbs, and Stanley (34), showed that of 9,187,000 acres affected by mesquite, more than 8,700,000 acres had less than 80 trees per acre in 1937.

Benefits of Mesquite Control

Money expended for mesquite control should be considered as an investment in range improvement. Whether mesquite control by the methods described will pay is, of course, a question for the individual rancher to decide. The liquidation of control costs should be thought of in terms of increased forage crops, better quality forage, reduced soil erosion, healthier livestock, and greater ease in handling livestock. Some of these benefits arising from mesquite control are intangible and difficult to evaluate. Costs of control may in some instances be met by first harvesting the wood for fuel, fence posts, or other purposes, or may be counterbalanced by less tangible benefits such as reduction in losses from screwworms and other pests and reduction of labor required to handle livestock.

Tangible benefits can be reckoned where mesquites occur in such abundance as to materially reduce the moisture available to the perennial grasses. The herbage yield data in table 5 give a means of computing the tangible benefits arising from mesquite control in the form of increased capacity for grazing. As previously pointed out, these data were obtained from an area considered typical of many Arizona ranges as to precipitation, abundance of mesquite, and perennial grass species. In order to compute the value of the herbage for grazing use, the herbage yields must first be converted to a forage basis. "Forage" is the percent of herbage that may be safely consumed without undue injury to the vegetation. For most of the grasses present on this range the degree of grazing use should not exceed 50 percent of the herbage yield each year. The herbage yields converted to tons of forage per section are presented in table 12. The forage furnished to livestock by mesquite, 10 percent of the total leafage within reach of a grazing animal (5 feet) and 50 percent of the weight of beans, is included in the total forage yield for the range without mesquite control. For both ranges, a forage requirement of 20 pounds a day per breeding cow was used in estimating the grazing capacity per section, expressed in animal-unit-years. With these data the animal production to be expected from the two areas can be computed.

A comparison of the beef production per section of range with and without mesquite control is shown in figure 25. These estimates are based on a yearly production figure of 354 pounds of beef per breeding cow. This figure is conservative and is readily attainable with good range management. For example, at the Santa Rita during the past 10 years the average calf crop has been

TABLE 12.—*Actual herbage yields (from table 5) converted into grazing capacity per section (640 acres) of range with and without mesquite control*

Year	Mesquite killed			Mesquite untreated		
	Grass forage yield		Grazing capacity per section	Grass forage yield	Total forage yield	Grazing capacity per section
	Pounds/acre	Tons/section	Animal-years	Pounds/acre	Tons/section	Animal-years
1941	136	43.5	11.9	56	21.4	5.9
1942	40	12.8	3.5	27	12.2	3.3
1943	100	32.0	8.8	22	10.6	2.9
1944	264	84.5	23.1	102	36.2	9.9
1945	163	52.2	14.3	116	40.6	11.1
1946	286	91.5	25.0	150	51.5	14.1
1947	86	27.5	7.5	44	17.6	4.8
1948	136	43.5	11.9	52	20.2	5.5
Average	151	48.3	13.2	72	26.2	7.2

[1] Includes forage from mesquite leaves and beans.

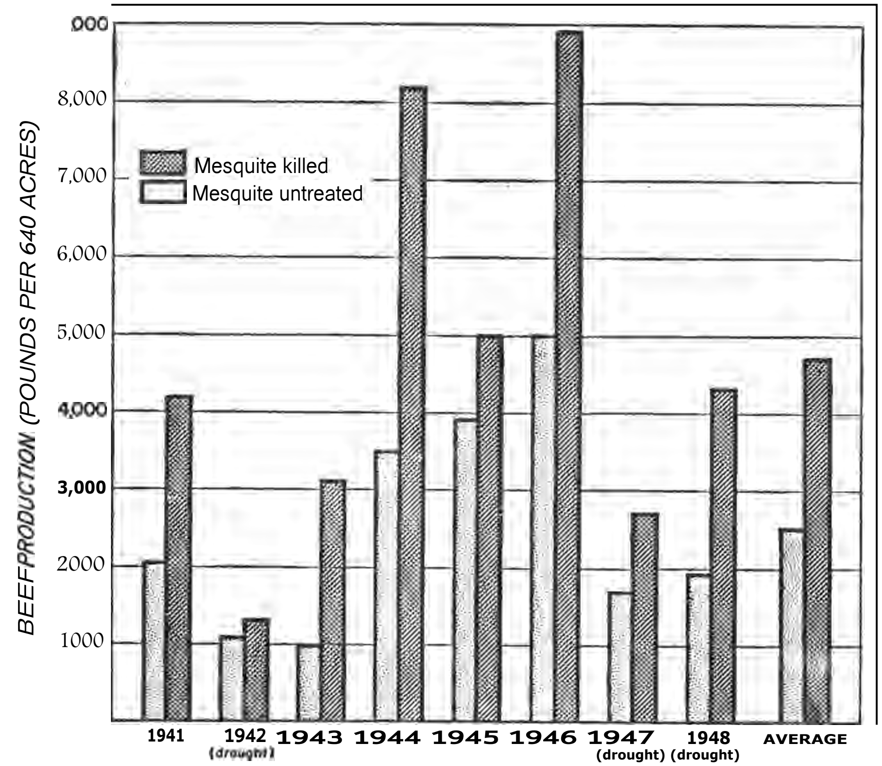

FIGURE 25.–Estimated production of beef on range with and without mesquite control.

88.5 percent and the average weight of calves at 8 months of age has exceeded 400 pounds. Additional production per breeding cow is realized from the sale of overage cows, bulls, and culls, but this is not included in the calculation, since it may be impracticable to adjust livestock numbers quickly enough to take full advantage of the forage crop each year. This would be equally true on ranges with and without mesquite.

Whether or not management can be sufficiently flexible to take advantage of the good years and be adjusted to avoid overstocking in the dry years is a pertinent question. Fortunately, most of the rainfall on yearlong ranges in Arizona and New Mexico falls during the summer months, and more than 90 percent of the perennial *grass* growth is in that period. By the end of October the ranch operator knows how much forage is available on the ground. Accordingly, by skillful marketing at that time, he can adjust the numbers of livestock to what the range will carry until the following summer. If he has more than the usual volume of forage he can hold calves over as yearlings. In case of drought he can dispose of most of the calves, and aside from the usual current sale of steers and culls, he can sell the older breeding animals, replacing them with heifer calves and yearlings, which require only about half as much forage and will probably thrive better.

The forage yields recorded in table 12 were obtained from an area with an original stand of 101 mesquites per acre, which was eliminated in 1940 at very low cost. The control costs in 1947, given previously, are nearer to present prices. On the 1947 price basis, mesquite control on the same area by use of Diesel oil (the cheapest method) would cost $4.04 per acre or $2,585.60 per section. Mesquite control is estimated to result in an average beef production increase of 2,150 pounds per year per section of land. The value of this increased production is $365.07, figured on the basis of $16.98 per hundredweight, the 10-year (1941-50) average selling price of calves at the ranch in southern Arizona. If the investment of $2,585.60 per section for mesquite control is compounded at a 5 percent interest rate, the increased returns realized from mesquite control would liquidate this capital outlay in about 9 years. Assuming that the control work would be effective for 25 years, the benefits of control would be available for 16 years after paying off the investment. The foregoing calculations disregard the investment in additional cattle required to stock the range to its increased capacity, but this probably would be offset by income (likewise not calculated) from the sale of overage cows, bulls, and culls.

RECOMMENDATIONS FOR A CONTROL PROGRAM

Mesquite control undoubtedly will be needed as a permanent feature of ranch operations in large areas of the Southwest, but as yet there is no easy way to kill mesquite. All methods require labor, materials, and equipment.

The most practical time to control mesquite is at the beginning of the encroachment when eradication costs are comparatively low. Invasions, if not attacked in the early stages, may later require many dollars for control. The main purpose of mesquite control is to release the growth of good forage plants from competition for moisture and to prevent further thickening of the mesquite stand by seeding. Controlling small colonies and sparse, scattered stands of mesquite will not noticeably increase forage production, but it will insure against further spread of mesquite and consequent deterioration of the range.

Where ranges have become heavily infested with mesquite, success in bringing about worth-while improvement of the land through its elimination will depend on a number of factors. Points which should be considered before starting a program of control are presented herein.

Begin control work where it will be of most immediate value.—Where mesquite control work is undertaken to increase the grazing capacity of the range, the stockman should consider the locations where this will be of most advantage in his herd or range management plan. For example, the control work may be best started in special-use pastures reserved for weaning or for heifer or bull segregation, or in a pasture that is indispensable in applying a deferred or rotation plan of grazing. A plan of improvement worked out for several years in advance will assist materially in making an effective attack on the mesquite problem.

A good place to start is in a holding trap or pasture near headquarters, since mesquite removal in such areas has the additional value of making it much easier to handle livestock. There are several advantages in beginning the work near ranch headquarters ; a minimum of time is lost in beginning the work, effectiveness of the control method is readily observed, and after the work is finished here the rancher will know what equipment and crew organization is most efficient.

Where an entire pasture is solidly covered with dense mesquite, clearing lanes or strips through it will greatly aid in gathering livestock. These lanes can later be used to advantage for gaining access to and blocking off areas to be treated in the over-all control program.

Mesquite control is practical only on grassland sites that formerly produced good forage. Desert areas, such as those in southwestern Arizona where potential grass production is low and where low-value trees and shrubs have always dominated the vegetation, offer poor prospects for mesquite control. In Arizona the greatest possibilities for increases in grass production are on areas that have annual rainfall of 12 to 20 inches, good soil, and a substantial remnant of perennial grasses.

Where the remnant of forage grasses covers less than 10 percent of the soil surface by ocular estimate, mesquite control should be accompanied by reseeding to adapted grasses. Otherwise, accelerated erosion may continue after the removal of the mesquite. Reseeding where feasible is also a comparatively quick means of increasing forage production.

Choosing the method.—The most suitable method of mesquite control depends on the age, size, growth form, and number of plants per acre. Mesquite of seedling size, as in the first stage of invasion of grassland, is easily and cheaply killed by grubbing with a heavy mattock.

Power machinery which bodily lifts and tears the plants from the soil is sometimes practical, but such mechanical methods cause considerable soil disturbance. Where soil blowing is a problem, as on sandy soils, control work with machinery should not be undertaken unless the remnant vegetation is sufficient to prevent abnormal erosion or control can be followed with reseeding.

In valley bottoms and comparable sites with good soil and moisture conditions, which may be economically converted into productive range by reseeding, mesquite is eliminated by power machinery. Upland mesquite in stands heavier than 300 plants per acre is probably also best attacked with power machinery, provided the costs in relation to the land values are not too high. For complete elimination, machine methods usually must be supplemented with manual follow-up work.

Several methods are practical for killing stands of less than 300 plants per acre. The advantages and limitations of the arsenic and Diesel oil methods have been stated previously. In choosing between the two methods, costs, hazards, and effectiveness in killing the trees on different sites should be carefully considered.

Organize the control work efficiently.—The range area should be covered methodically in strips in order to avoid missing some plants. Strip boundaries can be marked easily by tying pieces of red cloth to trees at intervals or stretching string through the area.

If arsenic is selected as a plant poison, it may be of advantage to use a combination of methods, including frills, basins, and grubbing of seedlings. If two or more methods are used, the crew should be organized so that men are assigned to specific jobs. For example, in a crew of five men, two might apply the frilling method and three be assigned to the basin method and grubbing seedlings. Each man of the latter group should grub seedlings en route from tree to tree. Another way is to make grubbing the special job of one or more men. Similarly if petroleum oils are used for killing mesquite, one or more men should be assigned to grubbing and the remainder of the crew to applying the oil.

Choose the most effective time of year.—The winter months are probably best for any method of mesquite control requiring hand labor. This is true because higher percentage kills of mesquite are usually obtained. Also, pressing ranch jobs are usually fewer at that time. Besides, workmen accomplish more in cool weather than in the summer. Furthermore, if arsenic is used in control there is less danger to the worker from skin poisoning because the body is more fully covered with clothing in cool seasons and sweating is at a minimum. If there are only mesquite seedlings to be eliminated, the best time is while they are in green leafage and the grass dormant (as in early winter or late spring) because the young mesquites are then most easily seen.

SUMMARY

Invasions by velvet mesquite *(Prosopis juliffora* var. *velutina)* constitute an important range problem in southeastern Arizona, where the plants now cover some 9 million acres. This variety, with western honey mesquite ***(P.*** *julifiora torreyana)* and honey mesquite ***(P.*** *juliflora glandulosa),* occurs on some 70 million acres of range land in the Southwest. Such encroachment has markedly reduced grazing capacity, hampered recovery following drought, caused accelerated erosion, increased the difficulty and cost of handling livestock, and consequently has severely affected the economy of the livestock industry. Mesquite control in Arizona and elsewhere in the Southwest is destined to become a much more important part of the average ranching operation than it has been in the past.

The growth form of all varieties of mesquite varies from many-stemmed dune-forming shrubs to trees up to 40 or 50 feet tall on bottom lands where the water table is near the surface. Mesquite grows where the annual precipitation is as little as 3 inches and as high as 30 inches. Temperature limits its northern extension to approximately the southern borders of Kansas, Colorado, and Utah. Within its temperature range mesquite is a potential invader of all soil types under a wide variety of moisture conditions. Root development of mesquite varies. On deep soils with adequate moisture, a strong taproot develops; but on upland soils where soils are more shallow and moisture seldom penetrates deeply, the taproot is small and laterals may reach out in all directions for 50 feet or more just beneath the soil surface.

The chief nongrazing values of mesquite are for firewood and fence posts. The flowers are a valuable source of nectar for honey bees. In Arizona the velvet mesquite leaves are palatable and are a source of emergency forage in time of drought. The mesquite beans are very palatable and nutritious. However, forage values are usually overestimated and are not great enough to offset the detrimental effect of mesquite on perennial grass density and yield.

In Arizona mesquite invasion of grasslands began more than 50 years ago. It is estimated that half of the range land now occupied by mesquite elsewhere in the Southwest has been invaded since 1850, a date which for practical purposes coincides with the coming of livestock in large numbers. Furthermore, most of the older stands of mesquite are rapidly becoming thicker. The critical point on upland ranges where further increase of mesquite is detrimental to grass growth is when the crowns of the trees cover about 7 percent of the soil surface. The advance of mesquite is attributed to a combination of influences including cessation of range fires, the dissemination and planting of seed by livestock, birds, game animals, jackrabbits, kangaroo rats, and other rodents, and the reduction of grass vigor and density by heavy grazing and drought. Once established in quantity, mesquite thickens whether the range is grazed or not.

Because the encroachment of mesquite has been most rapid since the introduction of livestock, the idea of controlling mesquite by better range management has often been proposed. Although it is doubtful that any type of practical management would completely eliminate the need for more direct control methods once mesquite is firmly established, any grazing management system which builds up the vigor and density of perennial grasses is likely to discourage establishment of mesquite seedlings.

In a study conducted over the period 1940-48 at the Santa Rita Experimental Range, in southern Arizona, the density and yield of perennial grasses on treated range was double that on adjacent untreated range within 3 years after the killing of velvet mesquite. This response took place on a site having average annual precipitation of about 14 inches and bearing such choice forage species as black grama, Arizona cottongrass, and threeawn grasses, and the more abundant but less palatable Rothrock grama. Furthermore, death loss of forage plants from drought was less on the areas *where* mesquite was killed. The yield of annual grasses under mesquite elimination was over five times that on untreated areas.

Velvet mesquite adversely influences soil moisture up to a distance of at least 30 feet from the stem in the soil layers occupied by grass roots. Where mesquite has roots developed to this extent, stands as light as 15 plants to the acre will adversely affect forage production. Mesquite, through its use of water, also greatly shortens the period of moisture availability.

Accelerated erosion, very active on mesquite-infested range, was completely arrested on mesquite-cleared areas by the subsequent increase in grass cover.

Thinning studies indicated that herbage yields will increase as the numbers of mesquite are reduced, but that mesquite elimination is necessary for successful artificial reseeding. Further, the response to thinning will vary with the site, as defined by precipitation, initial grass cover, and character of grazing use. This emphasizes the necessity of obtaining a high percentage kill in control work.

When the crowns of mesquite are cut off or killed, the stumps sprout. These sprouts originate from perennial dormant buds located on stem tissue in the zone immediately above the root collar. No such buds occur on the roots and no sprouting from roots has been reported. Effective chemical control methods must kill these buds. Mechanical methods must uproot all tissue on which such structures occur and sever its root connection with the soil. For small plants, grubbing to a depth of 4 or 5 inches is effective and practical but grubbing larger trees and shrubs requires too much labor. Mesquite can be killed by any of several hand application methods with sodium arsenite or by spraying or pouring light petroleum oils around the base of the plant. The application of 2,4-D and 2,4,5-T chemicals resulted principally in defoliation of mesquite and on the basis of results to date is not recommended for control on the arid and semiarid ranges of Arizona. Further studies, now in progress, may develop economical and rapid control procedures with such herbicides.

Costs of control using arsenite or Diesel oil applied by manual methods can be repaid within 9 years in many situations through increased forage production. The advantages of improved productivity should be available for 16 additional years before mesquite elimination again becomes necessary.

To preserve open grassland for profitable long-time grazing use, persistent removal of mesquite seedlings as they invade is essential. Also, on upland ranges where mesquite crowns cover 7 percent or more of the soil surface, immediate application of proved manual methods is recommended.

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