March 1995 **Las Cruces, NM**
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Department of Animal and Range Sciences

Management of Mesquite, Creosotebush, and Tarbush with Herbicides in the Northern Chihuahuan Desert

Agricultural Experiment Station • Bulletin 775

New Mexico State University

College of Agriculture and Home Economics

Errata Page

p. 11, line 3
1958 = 1858

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Cooperative investigation of the Agricultural Research Service, U.S. Department of Agriculture, and the Agricultural Experiment Station, New Mexico State University, Las Cruces, New Mexico.

CONTENTS

Management of Mesquite, Creosotebush, and Tarbush with Herbicides in the Northern Chihuahuan Desert

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BACKGROUND

The Problem

Two of the major concepts used to describe sustainability in agriculture are to keep land productive for the long term and to improve our basic resources (Box 1994). One of the primary concerns is to prevent an increase in desertification. The judicious use of herbicides is a principal method to reduce further degradation of, and improve, rangelands in the Chihuahuan Desert.

Mesquite, creosotebush, and tarbush (scientific names of plants are given in Appendix A) are native to the Southwest, but the stands of these plants have increased rapidly and now dominate on at least 62 million ha (conversion from metric to English units is given in Appendix B) (Platt 1959). In addition, these plants occur on large areas in northern Mexico. The increase of these shrubs during the last 150 years has seriously reduced the carrying capacity of infested rangelands and has a deleterious impact on the economy and environment of the region.

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The spread of mesquite, creosotebush, and tarbush is accompanied by soil erosion, sedimentation problems, degradation of wildlife habitat, impaired recreational values, and the loss of forage resources for animals. These shrubs are well-adapted, long-lived, and strong competitors to other plants (fig. 1). Improved grazing management or complete absence of grazing does not reduce these plants: mesquite, creosotebush, and tarbush will increase and dominate additional sites unless positive action is taken, either chemically, mechanically, or biologically. This bulletin describes research conducted from 1958 to 1985. Most of the studies were conducted on the Jornada Experimental Range near Las Cruces, New Mexico; however, some were conducted at other locations in southern New Mexico.

Fig. 1. Sand dune type dominated by honey mesquite. Note the absence of herbaceous plants.

Previous Work

The invasion of brush species in the Southwest during the past 130 years has been well documented (Brown 1950, Gardner 1951, Glendening 1952, York and Dick-Peddie 1969). While overgrazing in the late 1800s and early 1900s is often cited as the major cause for brush invasion, there is ample evidence that invasion has continued even on well-managed, conservatively grazed rangelands (Buffington and Herbel 1965).

Evaluations of brush control efforts are usually related to number of plants killed or to year-end biomass of grass herbage (Herbel and Gould 1970, Herbel et al. 1983). However, the fluctuations in plant cover and biomass caused by variation in precipitation (Paulsen and Ares 1962, Herbel et al. 1972, Herbel and Gibbens 1981, Gibbens and Beck 1988) underline the need for close monitoring of abiotic inputs, particularly precipitation, in any evaluation of brush management.

Previous research with phenoxy herbicides (Valentine and Norris 1960) has determined that honey mesquite should be sprayed in late May or early June. The most effective years occurred when precipitation during winter and early spring was average or above.

Rangeland Herbicides

A great variety of herbicides and formulations have been developed over the last 45 years (Scifres 1989). For many years, 2,4,5-T (chemical names of herbicides are given in Appendix C) was the main herbicide used on Southwestern rangelands. Broadcast applications (primarily aerial sprays) controlled honey mesquite effectively, but were less effective on tarbush and ineffective on creosotebush (Herbel and Gould 1970). Beside 2,4,5-T, other phenoxy herbicides used in these trials were 2,4-D, dichlorprop, silvex, and mecoprop.

The first promising herbicide used in these trials on creosotebush was 2,3,6-TBA. Later dicamba, another benzoic acid derivative, added substantially to the arsenal of effective herbicides.

Another class of herbicides became important in the early 1960s with the introduction of picloram, a picolinic acid derivative. Other picolinic acid derivatives, triclopyr and clopyralid, became available for our studies beginning in the late 1970s.

The substituted ureas, fenuron and monuron, were used in studies beginning in 1958. We also examined the usefulness of diuron and bromacil. In the late 1970s, another substituted urea, tebuthiuron, became available.

Research Objectives

Research conducted from 1958 through 1985 in southern New Mexico was organized with several thrusts:

1. To develop treatments with a minimum cost.
2. To determine the efficacy of various herbicides on honey mesquite, creosotebush, and tarbush.
3. To study various herbicide rates.
4. To determine influence of various volumes of aerially applied herbicidal sprays on honey mesquite.
5. To compare various delivery techniques for aerial sprays on honey mesquite.
6. To study the effects of repeated aerial sprays on honey mesquite and creosotebush.
7. To compare yields of perennial grasses and cover on sprayed and unsprayed areas dominated by honey mesquite and creosotebush.
8. To determine the amount of soil deposition by wind erosion on sprayed and unsprayed areas dominated by honey mesquite.
9. To study plant production; soil microorganisms; insect, small mammal, and bird populations; cattle performance, activities, and diets; and herbicide residuals on sprayed and unsprayed areas infested with mesquite.
10. To determine the optimum time of year to spray creosotebush and tarbush with herbicides.

Research Locations and General Evaluation Procedures

Location. The primary location for much of this research was the Jornada Experimental Range, 40 km north of Las Cruces, New Mexico. The abiota and biota are typical of southeastern Arizona, southern New Mexico, western Texas, and northern Mexico. Sites that once supported grassland now are dominated by honey mesquite, creosotebush, and tarbush. The previous

nomenclature assigned to the area (e.g., "Desert Plains Grassland" and "Semidesert Grassland") is not as descriptive as "Semidesert Shrubsteppe."

The average annual precipitation at the Jornada Experimental Range headquarters is about 230 mm, an average of 130 mm occurring in July through September. The spring season is often dry and windy. Most winter precipitation occurs as low-intensity rainfall or occasionally as snowfall, while most summer rainfall comes as localized thunderstorms of high intensity.

The frost-free period on the Jornada averages about 200 days. Temperatures are generally moderate with an annual mean of 15°C. The average annual wind movement at the Range is 17,346 km. High wind velocities in the spring under dry conditions cause sandstorms. Evaporation from a free water surface at headquarters averaged 2,352 mm/yr.

The soils dominated by honey mesquite on the Jornada are primarily Typic Haplargids and Petrocalcic Paleargids, coarse-loamy, mixed, thermic. Some of the soils dominated by creosotebush are Typic Torriorthents, coarse-loamy, mixed, thermic. One of the features of soils dominated by creosotebush is the presence of small pebbles on the surface of the soil. Soils with tarbush are Ustollic Calciorthids, fine-silty, mixed, thermic; Ustollic Haplargids, fine-loamy, mixed, thermic; and Ustollic Haplargids, fine, mixed, thermic. Honey mesquite, creosotebush, and tarbush also occur on other soils on the Jornada. Soil water for several years and a detailed description of the soil at 16 sites are given by Herbel et al. (1994).

Some of the trials were on other rangelands in southern New Mexico. Most abiotic features are similar to those described above except that a higher percentage of the average annual precipitation in southeastern New Mexico occurs in the spring.

Herbicide Evaluations. The effects of herbicidal treatments on honey mesquite, creosotebush, and tarbush were determined in early fall following the third growing season after treatment. On small plots, all treated plants were counted. On larger areas treated aerially, groups of 100 plants were counted to determine the percentage of dead plants. On sand dunes infested with honey mesquite, the number of plants was considered to be one per 0.3 m diameter, e.g., a sand dune 3.6 m in diameter was considered to have 12 plants of honey mesquite. Evacuation of sand dunes showed this to be a conservative estimate of mesquite plants. On aerially sprayed plots infested with creosotebush at the Cuchillo allotment, all plants within a 10-m circle were counted and recorded as dead or alive. These methods determined only the plants killed by the herbicide; no natural mortality of these shrubs was observed.

The percent rootkill from 2 or more treatments is not calculated as the sum of the results from multi-year treatments. The percent killed is the sum of the first year's kill plus the product of the second year's kill and the percentage of live plants remaining from the previous year. For example, if 30% of the targeted plants were killed in year 1 and 35% of the remaining plants were killed in year 2, the overall kill would be calculated as follows:

overall kill = 30% + (35% x 70%) = 54%.

A shortage of resources prevented replicating these trials. However, on many aerial plots the treated area was large enough that at least 20 observations (one observation is a 100-plant group) were taken per treatment. The data shown in the tables are the average of all observations. While the confidence intervals were calculated in many instances, these are not shown on the tables. However, in our discussion of results, variability is considered. Response of perennial grasses and mesquite canopy to herbicidal application were evaluated using a 30.50-m line.

HONEY MESQUITE

Evaluation of Liquid Herbicides Applied with Ground Equipment

Prior to 1960, phenoxy herbicides were the only materials showing promise on honey mesquite. Dicamba and picloram were introduced for use on range plants in the 1960s. Initially, only small amounts of these herbicides were available for testing so we applied them with ground equipment on small plots.

This research was conducted on 6.3 x 6.3 m plots on the Jornada Experimental Range. The spray material was applied in early June at the rate of 0.6 kg/ha.[3] For the first 3 years of the 6-year study, the herbicide mixture was applied with a paint sprayer (see fig. 10, p. 30); the last 3 years the herbicides were applied with a hand-carried boom equipped with nozzles (fig. 2).

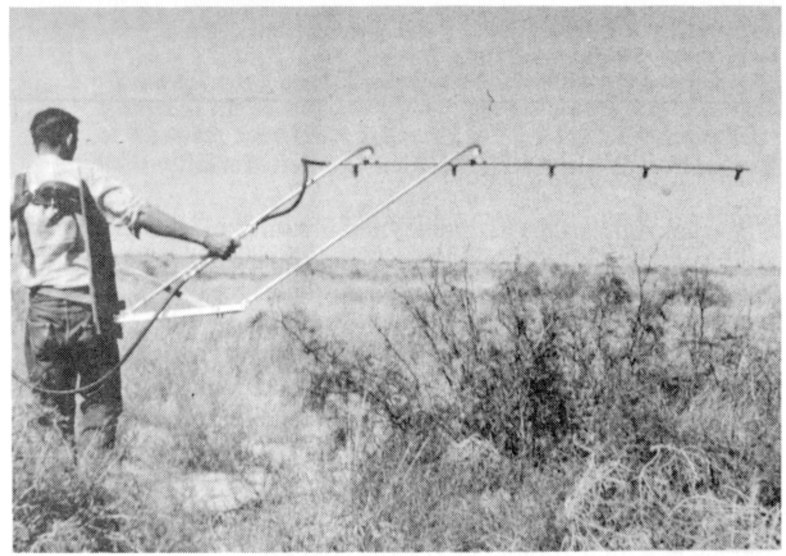

Fig. 2. Hand-carried boom equipped with nozzle for spraying land infested with brush.

[3] In liquid herbicide formulations, herbicide amount refers to acid equivalent (a.e.); in dry herbicide formulations, herbicide amount refers to active ingredients (a.i.).

The greatest rootkills of honey mesquite were obtained with 2,4,5-T + picloram (1:1); 2,4,5-T; 2,4,5-T + dicamba + picloram (1:1:1); dicamba; and 2,4,5-T + dicamba (1:1) (table 1). Less effective treatments were dicamba + picloram (1:1) and picloram alone. Because 2,4,5-T is no longer manufactured in the U.S. and is not available, the results of these trials indicate that dicamba can be effective in controlling honey mesquite.

Table 1. Rootkills (%) of honey mesquite treated with herbicides at a rate of 0.6 kg/ha acid equivalent (a.e.) applied with ground equipment.

Herbicide	Mesquite rootkill (%)
2,4,5-T	53
Dicamba	48
Picloram	19
2,4,5-T + dicamba	46
2,4,5-T + picloram	59
Dicamba + picloram	17
2,4,5-T + dicamba + picloram	50

Evaluation of Liquid Herbicides Applied Aerially

We applied various herbicides and mixtures of herbicides aerially as they became available in sufficient quantities for large plots. The ground applications were used as guides for this phase of the research.

This research was conducted on the Jornada Experimental Range. The plots were 61 m x 797 m for a total of 4.9 ha. We primarily evaluated 2,4,5-T, dicamba, and picloram in 1965–72. In the mid-1970s, we added the new herbicides, clopyralid and triclopyr, to our trials. The oil-soluble herbicides were mixed with 1.2 l/ha diesel oil before water was added. All treatments were applied at a total volume of 9.4 l/ha (fig. 3).

The herbicide treatments applied aerially in 1965 to 1972 that were superior to 0.6 kg/ha 2,4,5-T were 2,4,5-T + dicamba, 2,4,5-T + picloram (0.6 + 0.6 kg/ha), and dicamba + picloram (at the higher rates) (table 2). Other rates and mixtures of 2,4-D, 2,4,5-T, dicamba, and picloram were also studied but they did not give the rootkills obtained with an application of 0.6 kg/ha 2,4,5-T. The treatments applied from 1977 to 1983 that were superior to 0.6 kg/ha 2,4,5-T were dicamba + picloram, the higher rates of 2,4-D + mecoprop + dicamba, 2,4-D + dichlorprop + dicamba, dichlorprop + dicamba (0.3 + 0.3 kg/ha), a mixture of triclopyr + 2,4-D + picloram, clopyralid (0.5 kg/ha), clopyralid + 2,4-D, and clopyralid + picloram. Based on these trials and because 2,4,5-T was not manufactured after 1984, dichlorprop + dicamba at 0.6 kg/ha, a mixture of 2,4-D + mecoprop + dicamba at about 1.1 kg/ha, a mixture of 0.3 kg triclopyr + 0.1 kg 2,4-D + 0.1 kg picloram, 0.5 kg clopyralid, clopyralid + 2,4-D at 0.6 kg/ha, and clopyralid + picloram at 0.6 kg/ha gave >50% rootkill of honey mesquite. Some of the results of trials with 2,4-D, dichlorprop, silvex, dicamba, and picloram were omitted from table 2 because they gave lower kills of mesquite. Clopyralid at 0.5 kg/ha was effective but it is expensive. Considering costs and efficacy, we would suggest a mixture of clopyralid, triclopyr, or picloram and a phenoxy herbicide. This mixture was not included in these trials, but our results indicate it is effective. The phenoxys could be 2,4-D, dichlorprop, or mecoprop.

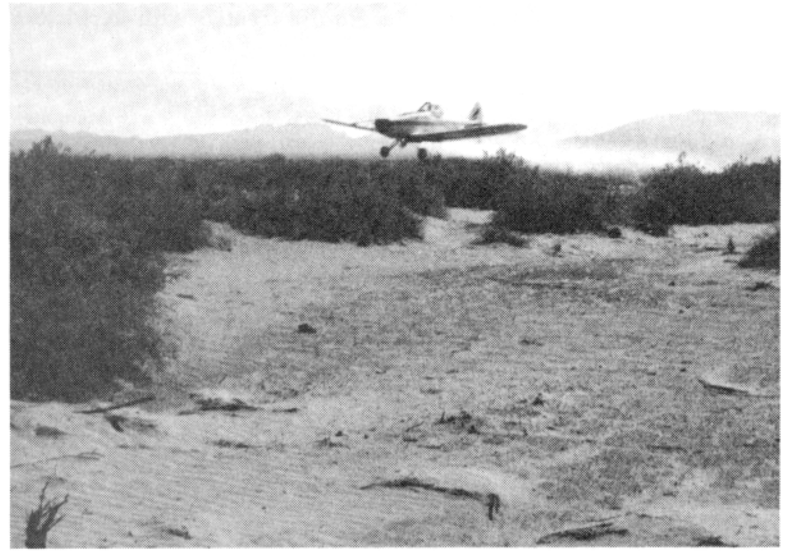

Fig. 3. Aerial spraying of sand dunes dominated by honey mesquite. Note that the airplane is flying near the ground so that most of the spray solution is delivered to the targeted plants and to minimize drift.

Table 2. **Rootkills (%) of honey mesquite treated with herbicides applied with fixed wing aircraft.**

Years of treatment and herbicide	Rate of herbicide per hectare (kg)	Mesquite rootkill (%)
1965–72		
2,4,5-T	0.6	36
Dicamba	0.6	26
Picloram	0.6	13
2,4,5-T + dicamba	0.3 + 0.3	40
2,4,5-T + dicamba	0.6 + 0.6	53
2,4,5-T + picloram	0.3 + 0.3	32
2,4,5-T + picloram	0.6 + 0.6	44
Dicamba + picloram	0.3 + 0.3	23
Dicamba + picloram	0.6 + 0.6	40
2,4-D + dicamba	1.1 + 0.6	26
1977–83		
2,4,5-T	0.6	36
2,4-D	0.6	12
Dichlorprop	0.6	14
2,4-D + picloram	0.3 + 0.3	38
2,4-D + dichlorprop + dicamba	0.5 + 0.5 + 0.1	45
2,4-D + mecoprop + dicamba	0.5 + 0.5 + 0.1	61
2,4-D + mecoprop + dicamba	0.7 + 0.4 + 0.1	72
Dichlorprop + dicamba	0.3 + 0.3	71
Dicamba + picloram	0.3 + 0.3	50
Triclopyr	0.6	26
Triclopyr + picloram	0.3 + 0.6	37
Triclopyr + 2,4-D + picloram	0.3 + 0.1 + 0.1	81
Clopyralid	0.3	36
Clopyralid	0.5	67
Clopyralid + 2,4-D	0.3 + 0.3	72
Clopyralid + picloram	0.3 + 0.3	68

Field-Scale Aerial Trials with 2,4,5-T

Honey mesquite has increased rapidly on the northern Chihuahuan Desert. On the Jornada Experimental Range, dense stands of mesquite occurred on 4.8% of the study area in 1958 and 50.2% in 1963 (Buffington and Herbel 1965). As mesquite begins to dominate, sand dunes form on coarse soils, thus reducing or eliminating herbaceous plants.

The herbicide, 2,4,5-T, was aerially applied in June at a number of locations in southern New Mexico. The sprayed areas ranged from 40 ha to 1,000 ha. The spray mixture from 1958 to 1965 was a 7:1 water to diesel oil mixture applied at 47 l/ha. The spray mixture from 1966 to 1970 was 1.1 l 2,4,5-T (0.5 kg/l), 1.1 l diesel oil, and 7.1 l water for a total volume of 9.4 l/ha.[4]

A 30% rootkill was considered adequate for one application of 2,4,5-T; 50% for two applications. On the Jornada Experimental Range, five of the 11 single applications of 2,4,5-T resulted in rootkills of at least 30% of the honey mesquite plants (table 3). The January through May precipitation in 1959 and 1963 was very low, but precipitation during the previous October and early November

Table 3. Rootkills of honey mesquite resulting from applications of 2,4,5-T at 0.6 kg/ha on the Jornada Experimental Range.

Year	Precipitation Jan–May (mm)	Rootkill (%)
1958	92	18
1959	8	35
1960	18	8
1961	20	13
1962	37	15
1963	13	57
1966	51	22
1967	21	9
1968	121	46
1969	143	33
1970	77	30

[4]Some figures *are not additive* because of rounding.

was considerable in both years so soil water was available during the spring period. Conversely, during the six years when rootkills were below 30%, only one year had above-average precipitation during January through June. It is possible that an unstable formulation of 2,4,5-T resulted in the low rootkills in 1958.

Single applications of 2,4,5-T on most sites in southeastern New Mexico gave mesquite rootkills of 30% or more when the estimated precipitation for January through May of the spray year was 80 mm or more (table 4). Less than 80 mm precipitation resulted in effective kills on the Brinnenstool allotment from applications in 1965 and 1966, and on the Browning and Dinwiddie allotments sprayed in 1965. The treatment on Section 27 of the Bogle allotment in 1961 resulted in a 21% rootkill of honey mesquite, even though the estimated precipitation for January through May was 155 mm. Single applications gave less than 30% rootkill on 15 treatment areas, and all but one of them had less than 80 mm precipitation during January through May. Of the seven areas sprayed in more than one year, only two resulted in a rootkill of 51% or more (table 4). One of those two was sprayed three times.

Comparison of Helicopter and Fixed-Wing Aircraft

Because rootkills of honey mesquite treated with 0.6 kg/ha 2,4,5-T from 1958 to 1960 applied with fixed-wing aircraft averaged only 20%, we compared helicopter and fixed wing aircraft applications from 1961 to 1963.

This research was conducted on the Jornada Experimental Range for three years. The herbicide, 2,4,5-T, was applied at 0.6 kg/ha in a 1:7 diesel oil to water emulsion at a total volume of 47 l/ha with a helicopter and fixed-wing aircraft. Each aircraft sprayed 5 ha (figs. 4 and 5).

The average rootkill of honey mesquite for the three years was 18% for the areas with the helicopter applications and 24% for the applications by fixed-wing aircraft (table 5). Higher rootkills were obtained with helicopter applications only one year. It is generally less expensive to use fixed-wing aircraft for aerial applications; therefore, these results would indicate the use of fixed-wing aircraft for aerial applications.

Table 4. Percent rootkill of honey mesquite resulting from one or more applications of 2,4,5-T in southeastern New Mexico.[1]

Year of treatment	Allotment[2]	Estimated precipitation Jan–May[3] (mm)	Rootkill (%)
1959	Bates	131	38
	James	87	46
1961	Bogle (S.27)	155	21
	Bogle (S.13)	155	36
	James (S.19 & 30)	80	42
	James (S.7)	80	51
	Merchant	80	44
	Sacra (S.13)	73	5
	Sacra (S.27)	73	24
1962	Daniels	42	13
1964	Alexander	41	26
	Bates	51	7
	G. Bingham	51	6
	Smith	51	11
1965	Brinnenstool	46	50
	Browning	64	45
	Dinwiddie	46	48
	Robbins	46	7
	Smith	84	42
1966	Bates	70	20
	G. Bingham	70	25
	T. Bingham	70	25
	Brinnenstool	72	41
	Ross	70	11
	Smith	71	22
	Snyder	70	28
1959 + 1961	James	87 + 80	30
1959 + 1961 + 1964	Bates	131 + 79 + 51	63
1959 + 1964	Bates	131 + 51	43
1961 + 1964	Bates	79 + 51	38
1962 + 1963	Bates	59 + 68	36
1962 + 1965	Daniels	42 + 51	48
1965 + 1966	Brinnenstool	46 + 72	80

[1]In cooperation with the Bureau of Land Management.

[2]S. = section number.

[3]Precipitation was estimated from precipitation data from the nearest Weather Bureau rain gauge. The treated area may have received more or less precipitation.

Fig. 4. Equipment for mixing the spray solution and loading the aircraft to minimize time on the ground for the aircraft. The equipment includes water tanks with a pump, diesel and herbicide with barrel pumps that accurately measure liquids, and a mixing-loading tank equipped with a pump. The mixing-loading tank has both paddle and by-pass agitation to keep the oil and water phases of the spray solution properly mixed.

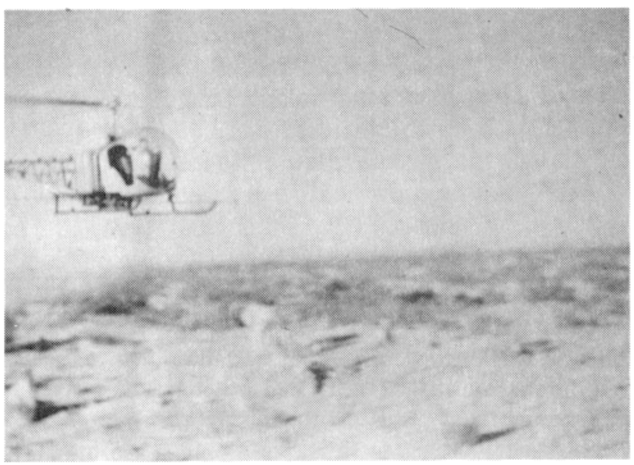

Fig. 5. Aerial spraying of honey mesquite with a helicopter.

Table 5. Rootkills (%) of honey mesquite treated with 0.6 kg/ha 2,4,5-T applied with a helicopter and fixed-wing aircraft.

Year	Helicopter	Fixed-wing
1961	4	15
1962	23	16
1963	28	40
Average	18	24

Determination of Volume of Aerial Spray

The standard recommendation for mesquite control in the 1950s and early 1960s was to use a total volume of 37 to 47 l/ha in aerial sprays. In an effort to reduce application costs, we compared various volumes of aerial sprays.

These studies were conducted on the Jornada Experimental Range from 1961 to 1971. The herbicide, 2,4,5-T, at 0.6 kg/ha was used on each plot. Plot sizes were a minimum of 5 ha.

For 3 years we compared total volumes of 28.0, 46.8, and 93.5 l/ha (table 6). Average rootkills of honey mesquite were 22, 18, and 23%, respectively. Because there were no or very little increased rootkills from the high volume of herbicidal spray, we eliminated the total volume of 93.5 l/ha from our trials. For 6 years, we compared volumes of 28.0 and 46.8 l/ha. The respective rootkills averaged 25 and 22%. For 4 applications, we compared volumes of 9.4 and 46.8 l/ha, the average rootkills were 30 and 22%, respectively (table 6). The results of the trials with a total volume of 46.8 l/ha prompted us to drop this volume from these studies. Thirteen aerial applications compared total volumes of 9.4 and 28.0 l/ha. The average rootkills of honey mesquite were 39 and 33%, respectively. There were six comparisons between 2.3 and 9.4 l/ha, with average rootkills of 28 and 38%, respectively. These results and others indicate a total volume of 9.4 l/ha gave comparable or higher rootkills of honey mesquite than other volumes.

Effects of Repeat Sprayings on Rootkills of Honey Mesquite

Some land managers wish to plan their herbicidal spray applications on honey mesquite before growth conditions are known. The purpose of this study was to determine whether repeat applications

Table 6. Rootkills (%) of honey mesquite aerially sprayed with various volumes.

Year(s) applied	2.3 l/ha	9.4 l/ha	28.0 l/ha	46.8 l/ha	93.5 l/ha
1961			12	19	12
1962			18	12	17
1963			37	24	41
1965			33	33	
1966		9	16	13	
1967		18		9	
1966 + 1967		39		33	
1968		52	36	34	
1966 + 1968	46	40	34		
1969	5	16	16		
1966 + 1969		40	21		
1968 + 1969	35	45	42		
1966 + 1968 + 1969	40		42		
1966 + 1970		40	24		
1968 + 1970	47	52	41		
1969 + 1970	23	46	44		
1968 + 1969 + 1970		64	54		
1968 + 1971		27	27		
1969 + 1971	12	29	22		
1969 + 1970 + 1971		44	46		

of herbicidal sprays should be applied indiscriminately without considering precipitation or plant condition.

The herbicide, 2,4,5-T, was aerially applied in June at 0.6 kg/ha on the Jornada Experimental Range. The sprays were applied two or three times, 1–4 years apart on 5–20 ha plots. The spray mixture in 1958 to 1965 was 7:1 water to diesel oil at 47 l/ha. The spray mixture in 1966–70 was 1.1 l/ha 2,4,5-T (0.5 kg/l), 1.1 l/ha diesel oil, and 7.1 l water/ha for a total volume of 9.4 l/ha. A minimum 50% honey mesquite rootkill is the acceptable level of control for these repeat applications.

Results (table 7) show that with two treatments in successive years, the observed rootkill exceeded the predicted rootkill calculated from data in table 3 except in the treatments applied in 1958 + 1959. With two treatments applied in alternate years, observed rootkills exceeded predicted rootkills in three of six years, but the difference between observed and predicted rootkills was larger than 10% only in the treatments applied 1966 + 1968. With two treatments applied three or more years apart, observed rootkill was

Table 7. January through May precipitation (mm) during the year of spray treatment and rootkills (%) of honey mesquite aerially sprayed with 0.6 kg/ha 2,4,5-T with various repeat applications.

Years of treatment	January–May precipitation (mm)	Predicted rootkills (%)[1]	Observed rootkills (%)
1958 + 1959	92 + 8	47	32
1966 + 1967	51 + 21	29	33
1967 + 1968	21 + 121	51	58
1968 + 1969	121 + 143	64	68
1969 + 1970	143 + 77	53	64
Av. Successive Years		49	51
1958 + 1960	92 + 18	25	22
1959 + 1961	8 + 20	43	49
1961 + 1963	20 + 13	63	64
1966 + 1968	51 + 121	58	74
1967 + 1969	21 + 143	39	30
1968 + 1970	121 + 77	62	60
Av. Alternate Years		48	50
1958 + 1961	92 + 20	29	37
1966 + 1969	51 + 143	48	39
1967 + 1970	21 + 77	36	31
1966 + 1970	51 + 77	45	32
Av. 3 or more Yr.		40	35
1966 + 1967 + 1968	51 + 21 + 121	62	78
1967 + 1968 + 1969	21 + 121 + 143	66	63
1968 + 1969 + 1970	121 + 143 + 77	75	60
1966 + 1967 + 1969	51 + 21 + 143	52	52
1967 + 1968 + 1970	21 + 121 + 77	66	69
1966 + 1967 + 1970	51 + 21 + 77	50	43
1966 + 1968 + 1970	51 + 121 + 77	71	72
Av. 3 Treatments		63	62

[1]Predicted rootkills are calculated from rootkills obtained from treatments applied in those individual years (47% = 18% + [35% x 82%]), (29% = 22% + [9% x 78%]), etc. The 18%, 22%, etc., are from table 3, and the 82% is 100%–18% and the 78% is 100%–22%.

greater than predicted in only one of four treatments. When three applications were made, the observed rootkill exceeded or was equal to the predicted rootkill in four of seven treatments. Overall, differences between predicted and observed rootkills were within 10% for 16 of the 22 treatments, indicating considerable additive effects. Table 7 also illustrates the low rootkills that were obtained when the vigor of honey mesquite was low because of drought conditions. Five of 11 treatments with two applications in successive or alternate years had <50% rootkill of honey mesquite. The major exception was the rootkill of 64% obtained in the 1961 + 1963 treatments. Plant condition of mesquite was particularly susceptible to herbicidal spray applications in both 1961 and 1963 because of available soil water during the early spring of both years from fall precipitation.

Effects of Mesquite Control on the Environment

As mesquite becomes established, the lateral roots grow rapidly (Fisher et al. 1973) and utilize soil water that would otherwise be available to herbaceous plants. In arid regions, this causes large areas of bare soil around mesquite plants. The potential for wind erosion on a bare soil surface is greater than on surfaces with vegetational cover. The vegetation on large areas of rangelands has changed from domination by herbaceous plants to domination by honey mesquite (Buffington and Herbel 1965), and dunes have formed on sandy soils. During windy periods, particularly in the spring, these sites are a major source of air pollution from blowing dust. This study was conducted to quantify the environmental effects occurring on areas infested with honey mesquite treated with herbicide and untreated areas.

An area on the Jornada Experimental Range measuring about 550 x 1200 m was aerially sprayed with 0.6 kg/ha 2,4,5-T in June, 1968. The rootkill of honey mesquite was 46% (table 3). The surface soils are Typic Haplargids, coarse, mixed, thermic of the Onite series. Sand traps were installed in February, 1973, at the west boundary of the treated area, and 90 and 180 m into the treated and untreated areas because the high velocity winds in the spring are from the southwest. The sand traps were metal boxes, 30 x 30 x 15 cm, with a perforated tray 3 cm deep filled with marbles and set flush with the soil surface. The traps were removed in May, 1973.

During 1975–79, 3,634 ha was aerially sprayed twice with 2,4,5-T at 0.56 kg a.e./ha in 1:7 diesel oil to water emulsion at a total volume of 9.4 l/ha. An adjacent untreated paddock was the check area. Studies were conducted on the control of honey mesquite; herbicide residuals; soil microorganisms; insect, small mammal, and bird populations; and cattle weights, time budgets, and diets.

The average dry weight of soil collected in the sand traps in a 12-week period during spring 1973 at the boundary and untreated area was 4266 g (table 8). At a distance of 180 m into the sprayed area, the soil weight was reduced to 231 g or 5% of the soil movement in untreated areas and the boundary (fig. 6). For details of this study, see Gould (1982).

Table 8. Soil weight (g) in sand traps over a 12-week period.

Distance from spray boundary (m)	Soil weight (g)
180 - untreated	4616
90 - untreated	4165
0 - boundary	4016
90 - treated	675
180 - treated	231

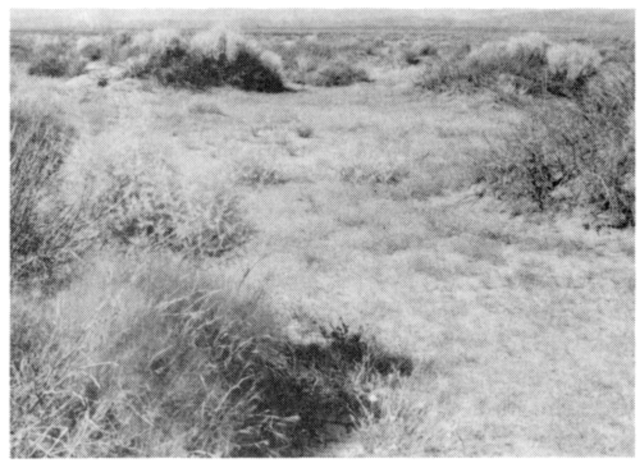

Fig. 6. A stand of forbs developed during the summer after spraying honey mesquite in the spring. These forbs reduced wind erosion.

Comparisons between the large area sprayed with 2,4,5-T 1975–79 and the adjacent unsprayed area showed 1) herbicide residuals in soils and plant tissue on the treated area disappeared in a single year, 2) microbial populations were not different between paddocks but dehydrogenase activity and CO_2 evolution were greater in dunal than interdunal areas, 3) numbers of small mammals and tenebrionid beetles did not differ, 4) there were more mesquite leaf tiers on the sprayed area, 5) a few more bird species were present on the unsprayed area, 6) cattle weights and time budgets did not differ, and 7) the sprayed area supported over twice as many animal-unit-months (AUMs) of cattle grazing as the untreated area in the first 3 years after the herbicidal treatments. For details of this study, see Gibbens et al. (1986).

Vegetation Response to Herbicides in Southern New Mexico

The invasion and increase of honey mesquite have caused a decrease in cover and production of the perennial grasses that once dominated these areas. As mesquite plants become established, an area devoid of herbaceous vegetation develops around the maturing mesquite plants. Wind erosion from the soil depleted of herbaceous plants results in a further decrease of the desirable perennial grasses and an increase of dunes. This study was conducted to determine whether control of honey mesquite on depleted rangelands in southern New Mexico would restore them to a more productive condition.

This study was conducted on the Jornada Experimental Range and at several locations in southeastern New Mexico. The soils of the Jornada site are in the Simona-Harrisburg association of sands (Bulloch and Neher 1980). The vegetation on the Jornada is dominated by honey mesquite, broom snakeweed, and mesa dropseed. The deep soils of the study sites in southeastern New Mexico are in the Kermit-Maljamar-Berino association and the shallow sands are in the Upton-Simona association (Maker et al. 1970). The vegetation on the deeper sands is dominated by honey mesquite, sand shinnery oak, and sand sagebrush with tall and mid-grasses. The more shallow sands have honey mesquite and broom snakeweed with short and mid-grasses. The average annual precipitation in southeastern New Mexico ranges from 258 mm at the Ochoa Weather Station to 313 mm at Roswell.

The basal cover and yield of perennial grasses and the canopy cover of live mesquite were measured on adjacent sprayed and unsprayed areas approximately 150 m apart. The line intercept for the cover measurements was 30.5 m long. The perennial grasses on a belt transect, 5.1 cm x 30.5 m, were clipped to ground level, the old growth discarded, and the current season's growth air-dried and weighed. The same line was used to measure plant cover and to form one side of the belt transect. Fourteen to 25 of these observations were made on each sprayed area and also on an adjacent unsprayed area. The observations were made from 1963 to 1976 on the Jornada and 1965 to 1967 in southeastern New Mexico. The spray treatment consisted of 2,4,5-T applied in June.

The average rootkill of honey mesquite was 36% on three areas on the Jornada (table 9). The average annual production of perennial grasses for 1963–76 was 183 kg/ha while the adjacent unsprayed area yielded 32 kg/ha. The mesquite canopy cover was 2.9% on the sprayed areas and 12.6% on the control. The basal cover of mesa dropseed averaged 0.207% on the sprayed areas and 0.019% on the adjacent unsprayed control (table 9). The production of perennial grasses was more than five-fold greater on the sprayed areas, and the difference would have been even greater had the estimates in the unsprayed area been taken further into the untreated area. However, the observations were taken relatively close together to minimize environmental differences (fig. 7).

Table 9. Average cover and yield, 1963–76, on areas sprayed for mesquite control and an adjacent unsprayed area on the Jornada Experimental Range.

Vegetation attribute	Av. mesquite rootkill (%)			
	0[1]	23[2]	37[3]	49[4]
Dropseed basal cover (%)	0.02	0.20	0.22	0.20
Other grasses basal cover (%)	0.00	0.01	0.01	0.02
Mesquite canopy cover (%)	12.64	3.01	2.99	2.83
Perennial grass yields (kg/ha)	32	154	226	170

[1]Adjacent unsprayed area.
[2]Sprayed 1958 plus 1960.
[3]Sprayed 1958 plus 1961.
[4]Sprayed 1959 plus 1961.

Fig. 7. Mesa dropseed developed on an area on the Jornada Experimental Range where none occurred prior to control of honey mesquite.

At the Bates allotment in southeastern New Mexico, two areas were sprayed with 2,4,5-T for control of honey mesquite (table 10). The area sprayed in 1959 had a mesquite rootkill of 38%. The major perennial grass was black grama. The average yield of perennial grasses for the three years was 2,101 kg/ha on the sprayed area and 1,463 kg/ha on the adjacent unsprayed area. Another part of the Bates allotment was sprayed in 1964 with a mesquite kill of only 7% (table 10). This area was in poorer condition than the area sprayed in 1959. Plains bristlegrass was the major perennial grass on the area treated in 1964. The average production of perennial grasses for 1965–67 was 450 kg/ha on the treated area and 410 kg/ha on the adjacent untreated area.

The major perennial grass on the Brinnenstool allotment sprayed in 1965 was also plains bristlegrass, however, the rootkill of mesquite was 50%. While the average yield of perennial grasses on the treated area was only 269 kg/ha, it had increased from 77 kg/ha in 1965 to 519 kg/ha in 1967. Mesa dropseed was a co-dominant perennial grass in 1967 (fig. 8). The production on the untreated area remained relatively stable at 80 kg/ha (table 10).

Table 10. Average cover and yield, 1965–67, on areas sprayed for mesquite control and an adjacent unsprayed area in southeastern New Mexico[1].

Allotment, year(s) of herbicidal spray, and vegetation attributes[2,3]	Average s[4]	Average u[5]
Bates, 1959		
Mesquite rootkill (%)	38	0
Mesquite c.c. (%)	2.67	7.19
Perennial grass b.c. (%)	1.64	1.00
Perennial grass yields (kg/ha)	2101	1463
Bates, 1964		
Mesquite rootkill (%)	7	0
Mesquite c.c. (%)	4.07	9.53
Perennial grass b.c. (%)	1.08	0.90
Perennial grass yields (kg/ha)	450	410
Brinnenstool, 1965		
Mesquite rootkill (%)	50	0
Mesquite c.c. (%)	2.26	15.13
Perennial grass b.c. (%)	0.28	0.08
Perennial grass yields (kg/ha)	269	80
Daniels, 1962 plus 1965		
Mesquite rootkill (%)	48	0
Mesquite c.c. (%)	1.44	6.32
Perennial grass b.c. (%)	1.87	1.22
Perennial grass yields (kg/ha)	456	327
James, 1961		
Mesquite rootkill (%)	42	0
Mesquite c.c. (%)	0.94	6.64
Perennial grass b.c. (%)	0.62	0.25
Perennial grass yields (kg/ha)	308	148
Snyder, 1963		
Mesquite rootkill (%)	30	0
Mesquite c.c. (%)	2.12	8.83
Perennial grass b.c. (%)	0.46	0.31
Perennial grass yields (kg/ha)	261	218

[1]In cooperation with the Bureau of Land Management.
[2]b.c. = basal cover.
[3]c.c. = canopy cover.
[4]s = sprayed with 2,4,5-T.
[5]u = unsprayed control.

Fig. 8. Grasses increased rapidly on the Brinnenstool allotment following aerial spraying for control of honey mesquite.

Mesquite rootkill was 48% on the Daniels allotment sprayed with 2,4,5-T in 1962 and again in 1965. The principal perennial grass was ring muhly. The average production of perennial grasses was 456 kg/ha on the sprayed area and 327 kg/ha on the untreated control (table 10).

The portion of the James allotment sprayed in 1961 had a mesquite rootkill of 42% (table 10). The major perennial grasses were threeawns and black grama. The average production of perennial grasses for the 3-year period was 308 kg/ha on the area sprayed for control of honey mesquite and 148 kg/ha on the adjacent check.

Principal perennial grass species on the portion of the Snyder allotment sprayed in 1963 were threeawns. The rootkill of honey mesquite was 30%. The average yield of perennial grasses was 261 kg/ha on the sprayed area and 218 kg/ha on the adjacent unsprayed area (table 10).

Production of perennial grasses was greater on all of the areas sprayed for honey mesquite control. The average production on the nine areas sampled in southern New Mexico was 488 kg/ha, while the adjacent unsprayed area yielded 383 kg/ha (tables 9 and 10). At some locations, notably the Jornada, the Brinnenstool allotment, and the James allotment, the production of perennial grasses was 2 to 7 times greater on the treated area. At one location, the Bates allotment treated in 1959, controlling 38% of the honey mesquite increased perennial grass production from 1463 to 2101 kg/ha, or an average annual increase of 638 kg/ha (Herbel and Gould 1970, Gould and Herbel 1971, Herbel et al. 1983, and Gibbens et al. 1986).

Treating Individual Mesquite Plants with Dry Herbicides

Mesquite plants become established on a site in response to specific environmental conditions. The effects of mesquite on site deterioration could be alleviated if small plants could be removed. The purpose of this study was to study the efficacy of dry herbicides on small honey mesquite plants.

These trials were conducted from 1958 to 1967 on the Jornada Experimental Range. Rates of 2, 4, 6, or 8 g/plant active ingredient (a.i.) were applied to plots 29 x 45 m in late June or early July. Herbicides were applied around the base of individual plants. The most effective herbicides were applied on larger areas averaging about 100 ha. Pellets were applied from horseback (fig. 9) and powder was applied by individuals on foot at the rate of 1 g a.i./0.3 m canopy diameter. A system of swaths, 10 m wide for applications on foot and 20 m wide for each horseback rider, was used to treat individual plants over the entire treated area.

Monuron powder (80% a.i.) was the most effective dry herbicide, and fenuron pellets (25% a.i.) were the second most effective over the 10-year period (table 11). The next most effective were monuron TCA granules (11% monuron) and fenuron TCA granules (11% fenuron). The granular form of 2,3,6-TBA and dicamba was less effective at rates of 2, 4, 6, and 8 g a.i./plant of honey mesquite than monuron and fenuron. Because variable rates of dry herbicides were applied at different dates to different sized mesquite plants, the following recommendation was developed: Use 1 g a.i. monuron or fenuron/0.3 m canopy diameter for honey mesquite up to 2.0 m canopy diameter growing on sands or loamy sands on arid rangelands and applied just prior to, or the early part of, an expected rainy period (June and July in south-central New Mexico).

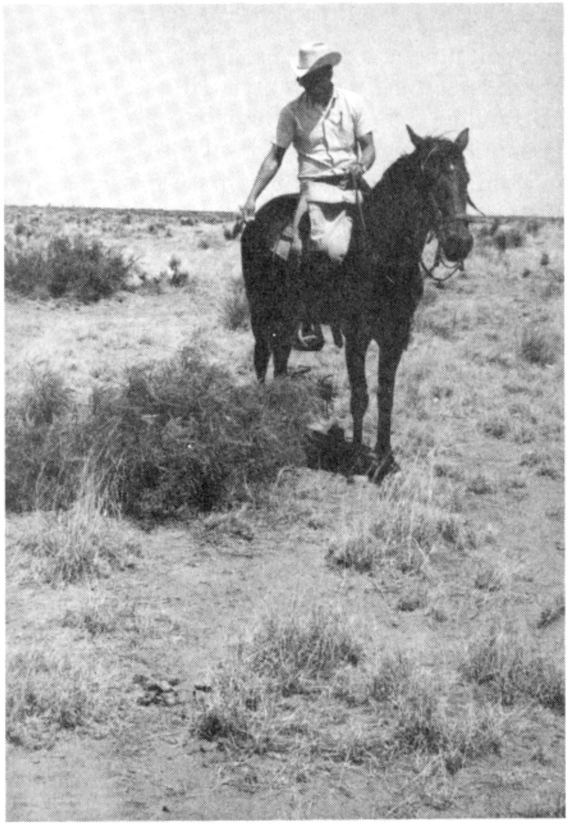

Fig. 9. Applying fenuron pellets on individual plants of honey mesquite.

Table 11. Rootkills (%) of honey mesquite with an individual plant treatment of dry herbicides on small plots.

Herbicide	Mesquite rootkill (%)
Fenuron	71
Monuron	78
Fenuron TCA	61
Monuron TCA	65
2,3,6-TBA	23
Dicamba	42
Picloram	60
Bromacil	58

The average rootkill of honey mesquite for field-scale applications of fenuron pellets for 1958–67 was 66% (table 12). The average for monuron powder and fenuron pellets for four of those years was 63%. Fenuron pellets were preferred because they are easier to apply than powder. Highest rootkills were obtained in a dry year (1960), while the lowest rootkill of honey mesquite treated with fenuron pellets was in 1962, a year with relatively high precipitation (table 12).

Table 12. Rootkills (%) of honey mesquite with an individual plant treatment of dry herbicides at the rate of one g a.i./0.3 m canopy diameter on field-scale areas.

Year applied	Herbicide	Precipitation (mm) date of application through October	Rootkill (%)
1958	Fenuron pellets	176	82
1959	Fenuron pellets	184	80
1960	Fenuron pellets	76	94
	Monuron powder	76	95
1961	Fenuron pellets	140	67
	Monuron powder	140	53
	Fenuron TCA	140	61
1962	Fenuron pellets	206	20
	Monuron powder	160	36
1963	Fenuron pellets	164	70
	Monuron powder	77	67
1964	Fenuron pellets	102	79
1965	Fenuron pellets	90	74
1966	Fenuron pellets	142	38
1967	Fenuron pellets	129	54

Aerial Application of Tebuthiuron Pellets

It became apparent in the mid-1970s that 2,4,5-T and some other herbicides would not be available to land managers. As tebuthiuron is effective for chemical control of several woody plants in the Southwest, this study was initiated to determine the efficacy of tebuthiuron on honey mesquite and associated plants.

This research was conducted on the Jornada Experimental Range after tebuthiuron became available for our trials in 1977. From 1977 to 1980, we applied tebuthiuron pellets (20% a.i.) aerially at various rates to loamy sands infested with honey mesquite. The plots were 4.9 ha, and applications were made in early summer each of the four years. The equipment on a fixed-wing aircraft was calibrated with the pellet formulations available because the flow rates of the formulations provided by the manufacturer differed each year. Beginning and ending weights determined amounts of tebuthiruon applied to each plot. Observations indicated that applications were uniform across the 4.9 ha plot.

All treatments except the 0.48 kg treatment applied in 1977 killed 55% or more of the honey mesquite plants (table 13). The rates of 1.48 kg/ha or more applied in 1977 and 1978 on areas dominated by mesquite sand dunes prevented the establishment and growth of mesa dropseed common on sandy range sites. Plots treated in 1979 and 1980 had a scattered stand of mesquite, some on sand dunes, intermingled with black grama and mesa dropseed. Established grass plants in 1979 and 1980 treatment plots were not affected by tebuthiuron, but rates in excess of 2 kg a.i./ha killed the mesa dropseed seedlings. These results indicate that adequate control of honey mesquite growing on coarse-textured soils could be obtained with an aerial application of tebuthiuron pellets at 0.9–1.2 kg a.i./ha. Herbel et al. (1985) and Gibbens et al. (1987) provide additional information.

Table 13. Rootkill (%) of honey mesquite treated with tebuthiuron pellets applied aerially.

Year of treatment	Precipitation 7/1–10/31 treatment year (mm)	Tebuthiuron rate (kg a.i./ha)	Mesquite rootkill (%)
1977	155	0.48	23
		1.02	60
		1.67	93
1978	196	0.58	55
		1.48	74
		2.24	81
1979	135	1.48	95
		2.16	98
		2.96	99
1980	107	0.31	55
		1.03	64
		1.27	77

CREOSOTEBUSH

Evaluation of Liquid Herbicides Applied with Ground Equipment

Some preliminary research in Arizona indicated 2,4,5-T may be effective on creosotebush (Schmutz et al. 1957). Our early trials were not able to duplicate these results; therefore, research was initiated to examine the effects of various liquid herbicides on creosotebush.

This research was conducted on 6.4 m^2 plots at the Jornada Experimental Range. Liquid herbicides were applied at the rate of 1.1 kg a.e./ha at various times throughout the year. For the first 6 years of the 10-year study, the herbicide mixture was applied with a paint sprayer (fig. 10); during the last 4 years, the herbicides were applied with a hand-carried boom equipped with nozzles (fig. 11).

The optimum time of year for spraying herbicides on creosotebush was found to be August 21-September 14. The highest rootkills of creosotebush were obtained with a picloram spray treatment of 1.12 kg/ha and a 1:1 mixture of 2,4-D and picloram at a rate of 1.12 kg/ha (table 14). When applied alone, the phenoxy herbicides (2,4-D, dichlorprop, 2,4,5-T, and silvex) and amitrole

Fig. 10. Spraying creosotebush with a paint sprayer.

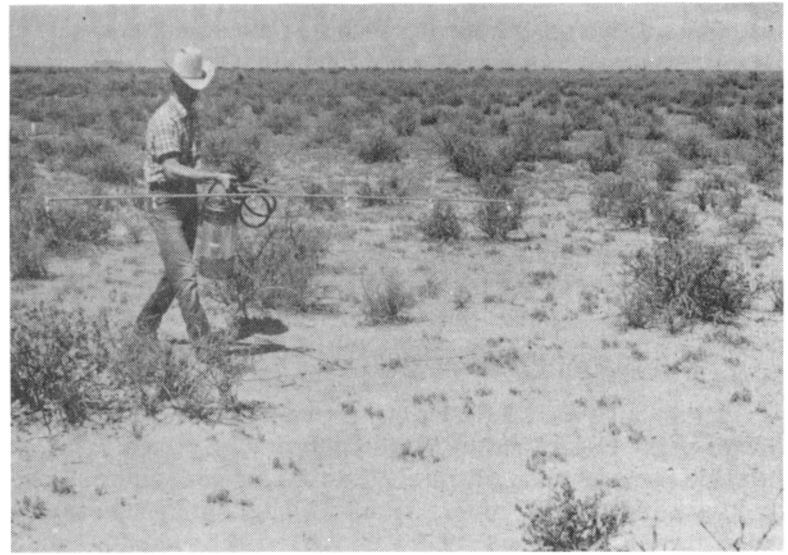

Fig. 11. Spraying tarbush with a boom sprayer to evaluate various herbicides.

Table 14. Rootkills (%) of creosotebush treated with liquid herbicides at rate of 1.1 kg/ha applied with ground equipment.

Herbicide	Creosotebush rootkill (%)
2,4-D	9
Dichlorprop	7
2,4,5-T	18
Silvex	6
Amitrole	2
2,3,6-TBA	37
Dicamba	49
Picloram	69
2,4-D + 2,4,5-T	25
2,4-D + 2,3,6-TBA	21
2,4-D + dicamba	43
2,4-D + picloram	60
2,4,5-T + dicamba	52
2,4,5-T + picloram	54
2,3,6-TBA + dicamba	55
2,3,6-TBA + picloram	49
Dicamba + picloram	50
2,4-D + dicamba + picloram	39
2,4,5-T + dicamba + picloram	54

were ineffective on creosotebush. Beside picloram, other liquid herbicides showing efficacy on creosotebush were 2,3,6-TBA and dicamba. Some of the earlier trials were summarized by Gould and Herbel (1969a).

Evaluation of Liquid Herbicides Applied Aerially

Aerial applications are necessary because rangelands of the northern Chihuahuan Desert are extensive. This study was initiated to evaluate the response of creosotebush to aerial application of spray materials that had appeared promising in small plot tests (see table 14).

This research was conducted on the Cuchillo Community Allotment, about 15 km northwest of Truth or Consequences, New Mexico, in cooperation with the Bureau of Land Management. The plots were 61 m x 797 m for a total of 4.9 ha. Aerial applications were made in early September with a fixed-wing aircraft with a total volume of 46.8 l/ha. The oil-soluble herbicide, 2,4-D, was mixed with 6.7 l/ha diesel oil before water and the water-soluble herbicides (2,3,6-TBA, dicamba, or picloram) were added to the spray mixture.

The highest rootkills of creosotebush were obtained with 3.3 kg/ha 2,3,6-TBA or dicamba, or mixtures of 2,3,6-TBA, dicamba, or picloram with 2,4-D at rates of 2.2 + 2.2 or 4.4 kg/ha (table 15). These treatments are relatively expensive.

Effects of Repeat Sprayings on Rootkills of Creosotebush

Repeat treatments of liquid herbicides were evaluated because it was necessary to apply relatively high rates of 2,3,6-TBA, dicamba, or picloram in a single treatment to obtain about a 50% rootkill of creosotebush (see table 15).

This study was also conducted on the Cuchillo Community Allotment. The plots were about 2.5 ha in size. Applications were made in early September with a fixed-wing aircraft at a total volume of 46.8 l/ha.

The rootkills of creosotebush were greatest when dicamba or 2,3,6-TBA were applied at rates of 1.1 kg/ha or more at least one of the treatment years (table 16). Adding 2,4-D to the spray mixture to reduce costs was effective in some years but reduced rootkills in

Table 15. Rootkills (%) of creosotebush treated with liquid herbicides applied with fixed-wing aircraft.[1]

Herbicide	Rate (kg/ha)	Creosotebush rootkill (%)
2,3,6-TBA	1.1	4
	2.2	17
	3.3	55
Dicamba	0.6	5
	1.1	20
	2.2	38
	3.3	78
Picloram	0.6	8
	1.1	15
	1.7	26
2,3,6-TBA + 2,4-D	2.2 + 2.2	52
Dicamba + 2,4-D	2.2 + 4.4	54
Picloram + 2,4-D	0.6 + 0.6	3
	0.6 + 1.1	5
	1.1 + 1.1	16
	1.1 + 2.2	20
	2.2 + 4.4	49

[1]In cooperation with the Bureau of Land Management.

Table 16. May through August precipitation (mm) during the year of spray treatment and rootkills (%) of creosotebush aerially sprayed at various rates and with various herbicides.[1]

Years of treatment and herbicides	Rate of herbicide (kg/ha)	May-August precipitation (mm)	Rootkills of creosotebush
1964 + 1967		88 + 254	
Dicamba + 2,4,5-T - dicamba	2.2 + 1.1 - 1.1		57
Picloram + 2,4,5-T - dicamba	1.7 + 1.1 - 1.1		76
1965 + 1966		86 + 136	
2,3,6-TBA	2.0 + 2.2		51
Dicamba	1.1 + 1.1		54
	2.2 + 2.2		62
Picloram	1.7 + 1.7		29
2,4-D + 2,4,5-T - dicamba	1.1 + 1.1 - 1.1		56
1965 + 1967		86 + 254	
2,3,6-TBA + 2,4,5-T- dicamba	2.0 + 1.1 - 1.1		63
Dicamba + 2,4,5-T - dicamba	2.2 + 1.1 - 1.1		62
Picloram + 2,4,5-T - 2,3,6-TBA	1.7 + 1.1 - 1.1		55
Picloram + 2,4,5-T - dicamba	1.7 + 1.1 - 1.1		53
1966 + 1967		136 + 254	
2,4,5-T - dicamba	1.1 - 1.1 + 1.1 - 1.1		50
2,3,6-TBA	2.2 + 2.2		44
Dicamba	1.1 + 1.1		47
	1.1 + 2.2		72
	2.2 + 2.2		93
1966 + 1968		136 + 102	
2,4-D - dicamba + dicamba	0.6 - 0.6 + 2.2		55
	1.1 - 0.6 + 2.2		53
Dicamba	0.6 + 2.2		69
	1.1 + 1.1		49
	2.2 + 0.6		55
	2.2 + 2.2		65

Table 16. Continued.

Years of treatment and herbicides	Rate of herbicide (kg/ha)	May-August precipitation (mm)	Rootkills of creosotebush
1967 + 1968		254 + 102	
2,4-D - dicamba	0.6 - 0.6 + 1.1 - 0.6		63
2,4-D - dicamba + 2,4,5-T - dicamba	0.6 - 0.6 + 0.6 - 0.6		57
2,4-D - dicamba + dicamba	0.6 - 0.6 + 2.2		77
2,4,5-T - dicamba + 2,4-D - dicamba	0.6 - 0.6 + 1.1 - 0.6		56
2,4,5-T - dicamba	0.6 - 0.6 + 0.6 - 0.6		56
2,4,5-T - dicamba + dicamba	0.6 - 0.6 + 2.2		81
Dicamba + 2,4-D - dicamba	0.6 + 1.1 - 0.6		52
	2.2 + 1.1 - 0.6		78
Dicamba + 2,4,5-T - dicamba	0.6 + 0.6 - 0.6		51
	2.2 + 0.6 - 0.6		71
Dicamba	0.6 + 2.2		57
	2.2 + 0.6		58
	2.2 + 2.2		84
1967 + 1969		254 + 152	
2,4,5-T - dicamba + dicamba	0.6 - 0.6 + 2.2		59
Dicamba + 2,4-D - dicamba	2.2 + 1.1 - 0.6		67
Dicamba + 2,4,5-T - dicamba	2.2 + 0.6 - 0.6		78
Dicamba	2.2 + 0.6		78
	2.2 + 2.2		57
1968 + 1969		102 + 152	
2,4-D - 2,3,6-TBA + 2,4-D - dicamba	2.2 - 2.2 + 2.2 - 1.1		68
2,4-D - 2,3,6-TBA + dicamba	2.2 - 2.2 + 1.1		53
2,4-D - dicamba	0.6 - 0.6 + 1.1 - 0.6		70
	0.6 - 0.6 + 2.2 - 1.1		79

Table 16. Continued.

Years of treatment and herbicides	Rate of herbicide (kg/ha)	May-August precipitation (mm)	Rootkills of creosotebush
	4.4 - 2.2 + 2.2 - 1.1		69
2,4-D - picloram + 2,4-D - dicamba	4.4 - 2.2 + 2.2 - 1.1		58
2,4-D - picloram + dicamba	4.4 - 2.2 + 1.1		74
2,3,6-TBA	2.2 + 2.2		71
2,3,6-TBA + dicamba	2.2 + 1.1		52
	3.3 + 1.1		74
2,3,6-TBA + 2,4-D - dicamba	2.2 + 1.1 - 0.6		61
Dicamba + 2,4-D - dicamba	0.6 + 2.2 - 1.1		62
Dicamba + 2,4,5-T - dicamba	0.6 + 1.1 - 1.1		64
Dicamba	3.3 + 1.1		76
1969 + 1970 + 1971		152 + 54 + 81	
Dicamba	0.6 + 0.6 + 0.6		23
	2.2 + 2.2 + 2.2		40
1970 + 1971		54 + 81	
2,4-D - dicamba + dicamba	1.1 - 0.6 + 0.6		18
Dicamba + 2,4-D - dicamba	0.6 + 1.1 - 0.6		23

[1]In cooperation with the Bureau of Land Management.

other years. Rootkills were reduced in the drought summers of 1964, 1965, 1970, and 1971 (table 16), but repeat sprays in September following a wet summer gave reasonably good rootkills of creosotebush when dicamba or 2,3,6-TBA were applied at rates exceeding 1.0 kg/ha. Some of the treatments involving 2,4-D and 2,4,5-T, and the lower rates of 2,3,6-TBA, dicamba, and picloram were omitted from table 16 because those treatments had a creosotebush kill of <50%. Additional information on the effects of liquid herbicides on creosotebush can be obtained from Gould and Herbel (1969a, c) and Herbel and Gould (1970).

Treating Individual Plants with Dry Herbicides

Creosotebush is the most xerophytic of the three shrubs considered in this report and is invading sites that are presently dominated by honey mesquite and tarbush (Buffington and Herbel 1965). Generally, a grass stand in the northern Chihuahuan Desert is initially invaded by mesquite or tarbush, followed by creosotebush. As creosotebush begins to dominate, the site deteriorates further. Sites dominated by creosotebush have degraded from the original site dominated by grasses. The purpose of this research was to determine the efficacy of herbicidal pellets, powders, and granules on creosotebush.

These trials were conducted in 1958–67 on the Jornada Experimental Range. Rates of 1, 2, 4, or 6 g/plant (a.i.) of the various herbicides were applied in late June or early July around the base of individual plants. The plots averaged 30 x 30 m and the soil was a sandy loam. Some of the early research showed the highest rootkills were obtained when dry herbicides were applied just prior to, or in the early part of, an expected rainy season (Herbel and Gould 1970).

Bromacil powder (80% a.i.) was the most effective dry herbicide on creosotebush (table 17). Fenuron pellets (25% a.i.) and the fenuron derivative, fenuron TCA granules (11% fenuron), were also effective. High plant kills were obtained when bromacil, fenuron, or fenuron TCA were applied at the rate of 2 g a.i./m canopy diameter. The granular form of 2,3,6-TBA and monuron compounds (powder and monuron TCA granules) were less effective at the rates used in these trials.

Table 17. Rootkills (%) of creosotebush with an individual plant treatment of dry herbicides on small plots.

Herbicide	Creosotebush rootkills (%)
Bromacil	94
Dicamba	72
Fenuron	85
Monuron	68
Picloram	73
2,3,6-TBA	51
Fenuron TCA	84
Monuron TCA	68

Aerial Application of Tebuthiuron Pellets

Several dry herbicides were effective in creosotebush control (table 17). When tebuthiuron pellets became available for field testing in the mid-1970s, this study was initiated to determine the effective rate of tebuthiuron. Aerial applications were used because of the extensive areas dominated by creosotebush.

This research was conducted on the Jornada Experimental Range. During 1977–80, tebuthiuron pellets (10 or 20% a.i.) were aerially applied annually at various rates to sandy loams infested with creosotebush. The plots were 4.9 ha, and tebuthiuron was applied in early summer. The equipment on fixed-wing aircraft was calibrated with the pellet formulations available, as the flow rates of various formulations differed. Beginning and ending weights determined amounts of tebuthiuron applied to each plot. Observations indicated applications were uniform across the 4.9 ha plot (fig. 12).

In 1981 tebuthiuron pellets were applied aerially on 130 ha at 0.4 kg/ha a.i. The area was dominated by creosotebush, but honey mesquite and tarbush were present. Both efficacy on shrubs and herbage responses were determined.

All treatments except the light rate applied in 1978 killed in excess of 60% of the creosotebush plants (table 18). Similar rates were applied in 1977 and 1980, but creosotebush rootkills were above 60%. This suggests the high rainfall of July through October of 1978 affected the 0.29 kg/ha a.i. of tebuthiuron pellets adversely.

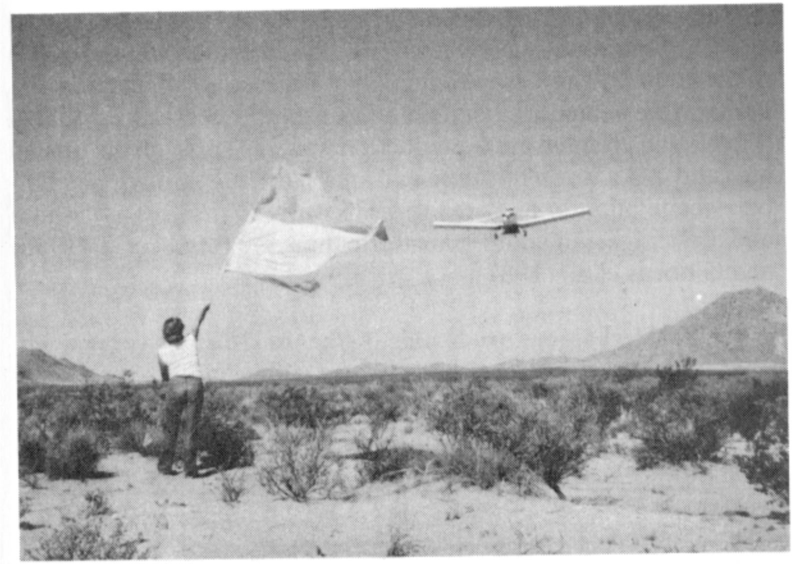

Fig. 12. Aerial application of tebuthiuron pellets on rangeland infested with brush. The airplane is flying at a height of 15 m. Note the flagger in the foreground.

Table 18. Rootkills (%) of creosotebush treated with tebuthiuron pellets applied aerially.

Year of treatment	Precipitation 7/1–10/31 of treatment year (mm)	Tebuthiuron rate (kg a.i./ha)	Creosotebush rootkill (%)
1977	86	0.20	62
		0.56	95
		1.28	91
1978	211	0.29	37
		0.38	88
		1.34	98
1979	118	0.57	93
		1.14	97
		3.28	99
1980	109	0.28	80
		0.34	75
		0.62	76
		1.14	96

The larger area treated with 0.4 kg a.i./ha in 1981 had a rootkill of 48% of the honey mesquite, 87% of the creosotebush, and 100% of the tarbush. The 1985 production of herbaceous plants was 791 kg/ha on the treated area and 89 kg/ha on the adjacent untreated area (table 19). Perennial grass production was 519 kg/ha on the treated area and 49 kg/ha on the untreated area. The July through September precipitation in that area in 1985 was 180 mm, about 54 mm above average. For additional information, see Herbel et al. (1985) and Gibbens et al. (1987).

Table 19. Herbaceous production (kg/ha) in 1985 on an area dominated by creosotebush treated with tebuthiuron pellets in 1981 and an adjacent untreated area.

Plant category	Treated area (kg/ha)	Untreated area (kg/ha)
Perennial grasses	519	49
Perennial shrubs	54	50
Annual forbs	272	40
Total herbs	791	89

TARBUSH

Evaluation of Liquid Herbicides Applied with Ground Equipment

No previous research on tarbush management was found, so studies were initiated to determine the efficacy of various herbicides and the optimum time of year for treatment.

This research was conducted on 6.4 m^2 plots dominated by tarbush on the Jornada Experimental Range, 1961–1971. Treatments were applied semi-monthly in the summer and early fall using a simulated aerial application (a volume of 47 l/ha). Herbicides were applied at rates of 0.6, 1.1, 1.7, and 2.2 kg a.e./ha (figs. 10, 11).

The optimum time of year for spraying herbicides on tarbush was found to be August 16-September 21. The highest rootkills of tarbush were obtained with 1.7 kg a.i./ha of dicamba (table 20). Herbicidal costs were reduced by using 0.6 kg/ha 2,4-D plus 1.1 kg/ha dicamba but with some reduction in plant kill (table 20). Less effective herbicides were dichlorprop, 2,4,5-T, silvex, amitrole, 2,3,6-TBA, and picloram. Some of the earlier trials were summarized by Gould and Herbel (1969b).

Table 20. Rootkills (%) of tarbush treated with liquid herbicides applied with ground equipment.

Herbicide	Tarbush rootkill (%)
2,4-D	53
Dichlorprop	4
2,4,5-T	38
Silvex	14
Amitrole	28
2,3,6-TBA	10
Dicamba	73
Picloram	32
2,4-D + dicamba	58
2,4-D + picloram	51

Treating Individual Plants with Dry Herbicides

Tarbush originally occurred on relatively dry slopes but in the last half century it has increased on flooded plains where it competes with tobosa (Buffington and Herbel 1965). If tarbush could be controlled before it begins to dominate a site, considerable grass production could be maintained. The purpose of this research was to determine the efficacy of dry herbicides on tarbush.

These trials were conducted from 1958 to 1967 on the Jornada Experimental Range. Herbicides were either granules, pellets, or powder. Rates of 0.5, 1, 2, or 4 gm/plant a.i. were applied in late June or early July around the base of individual plants approximately 1 m high. The plots averaged 12 x 12 m and the soil was a clay loam.

The most effective herbicides on tarbush were bromacil powder, fenuron TCA granules or pellets, fenuron powder or pellets, monuron TCA granules, and monuron powder (table 21). High plant kills were obtained when these herbicides were applied at the rate of 1 gm a.i./m canopy diameter. Less effective herbicides were granules of dicamba, TBA, and picloram. Information on this study is also available in Herbel and Gould (1970).

Table 21. Rootkills (%) of tarbush with an individual plant treatment of dry herbicides.

Herbicide	Tarbush rootkill (%)
Bromacil	94
Dicamba	76
Fenuron	91
Monuron	87
Picloram	54
2,3,6-TBA	59
Fenuron TCA	93
Monuron TCA	91

Aerial Application of Tebuthiuron Pellets

Some of the plots dominated by creosotebush also had a scattering of tarbush plants (see tables 18 and 19 and the accompanying discussion for details). All treatments killed more than 75% of the tarbush plants (table 22).

Table 22. Rootkills (%) of tarbush treated with aerial applications of tebuthiuron pellets.

Year of treatment	Tebuthiuron rates (kg a.i./ha)	Tarbush rootkills (%)
1977	0.20	76
	0.56	98
	1.28	98
1979	0.57	100
	1.14	100
	3.28	100
1981	0.40	100

ECONOMIC CONSIDERATIONS

What is the value of a stand of grass on a semidesert range? If the stand is replaced by unwanted shrubs and renovated using herbicides, the cost may be higher than the original cost of the land. However, the spread of shrubs such as mesquite, creosotebush, and tarbush is accompanied by soil erosion, sedimentation problems, degradation of wildlife habitat, impaired recreational values, and the loss of forage resources. The manager is concerned with all these problems, but the primary source of income for the livestock manager is the forage resource. Some of the problems accompanying the spread of these shrubs are societal costs, because the entire society benefits from reducing sedimentation and improving wildlife habitat and recreational opportunities. Political issues can also affect the economics of renovating or maintaining herbaceous cover. For example, 2,4,5-T was an effective and economical means of managing mesquite while maintaining or improving herbaceous plants but because of pressures from several groups, the manufacturers of 2,4,5-T decided it was not in their best interest to maintain this herbicide on the market. It is possible to renovate brush-infested rangelands with herbicides, but some of the practices are costly.

CONCLUSIONS

Mesquite, creosotebush, and tarbush can be managed with the judious use of herbicides to accommodate the objectives of the land manager. Ames and Gold (1990) and Gold et al. (1992) reported 99.99% of the pesticides in the human diet are natural. The low levels of herbicides used to control shrubs may not enter the human food chain, or if they enter the food chain, they would be present at low levels. The environmental impact of some of the herbicides presented in this bulletin was discussed by Bovey (1993). The following can be concluded from these studies:

1. The most cost-effective liquid herbicidal treatment on honey mesquite was a mixture of clopyralid, triclopyr or picloram, and a phenoxy herbicide (either 2,4-D, dichlorprop, or mecoprop) at a total of 0.6 kg/ha. While we did not use this specific mixture, our results indicated that it would be effective.

2. Spray materials on honey mesquite were ineffective unless the precipitation during January through May of the spray year was average or above, or the plant condition was susceptible to herbicidal sprays due to available soil water in the early spring from precipitation in the previous fall.

3. Herbicide applications from a fixed-wing aircraft gave as high rootkills of honey mesquite as applications from a helicopter.

4. A total volume of 9.4 l/ha of herbicidal spray applied aerially was sufficient for honey mesquite control.

5. Sand movement by winds was reduced 95% by partial control of mesquite growing on sand dunes. Mesquite control caused relatively minor effects on microbial populations; population dynamics of small mammals, insects, and birds; and individual cattle weights and time budgets.

6. Production and cover of perennial grasses and other herbaceous plants are increased with a reduction in shrubs. An area

sprayed to control honey mesquite supported twice as many cattle as an unsprayed area over a three-year period.

7. Individual plants of honey mesquite up to 2 m canopy diameter growing on sands or loamy sands on arid rangelands can be effectively treated with 3 g a.i./m canopy diameter of monuron powder or fenuron pellets applied just prior to, or during the early part of, an expected rainy season.

8. A high level of control of honey mesquite growing on arid rangelands on coarse-textured soils can be obtained with an aerial application of 0.9–1.2 kg a.i./ha of tebuthiuron pellets.

9. The highest rootkills of creosotebush by aerially applied liquid herbicides were obtained with a treatment of at least 1 kg/ha of dicamba or 2,3,6-TBA sprayed one or two spray years during August 21-September 14 following a wet summer to spray time.

10. Individual plants of creosotebush growing on sandy loams on arid rangelands can be effectively treated with 2 g a.i./m canopy diameter bromacil powder, fenuron pellets, or fenuron TCA pellets applied just prior to, or during the early part of, an expected rainy season.

11. Creosotebush growing on arid rangelands on sandy loams can be controlled with an aerial application of 0.35 kg a.i./ha of tebuthiuron pellets.

12. Highest rootkills of tarbush with liquid herbicides were obtained with 1.7 kg a.e./ha dicamba sprayed August 16-September 21.

13. Individual tarbush plants growing on clay loams on arid rangelands can be effectively treated with bromacil powder, fenuron TCA pellets, fenuron pellets, monuron TCA granules, or monuron powder at 1 g a.i./m canopy diameter applied just prior to, or during the early part of, an expected rainy season.

14. Tarbush plants growing on arid rangelands on clay loams can be controlled with an aerial application of 0.25 kg a.i./ha of tebuthiuron pellets.

15. The increase in populations of mesquite, creosotebush, and tarbush is accompanied by soil erosion, reduced wildlife numbers, and forage loss.

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APPENDIX A

Scientific Names of Plants and Insects Mentioned in Text

Common name	Scientific nomenclature
Black grama	*Bouteloua eriopoda* (Torr.) Torr.
Broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton and Rusby
Creosotebush	*Larrea tridentata* (Sesse & Mocino Ex DC.) Coville
Honey mesquite or mesquite	*Prosopis glandulosa* L.
Mesa dropseed	*Sporobolus flexuosus* (Thurb.) Rydb.
Plains bristlegrass	*Setaria macrostachya* H.B.K.
Ring muhly	*Muhlenbergia torreyi* (Kunth) A. Hitch. Ex Bush
Sand sagebrush	*Artemisia filifolia* Torr.
Sand shinnery oak	*Quercus havardii* Rydb.
Tarbush	*Flourensia cernua* DC.
Threeawns	*Aristida* spp. L.
Mesquite leaf tiers	*Tetralopha euphemella*
Tenebrionid beetles	*Coleoptera: Tenebrionidae*

APPENDIX B

Conversion from Metric to English Units

Metric unit	English equivalent
Centimeter (cm)	0.394 inch
Degrees Centigrade (°C)	(degrees Fahrenheit -32) x 0.556
Gram (g)	0.0022 pound
Hectare (ha)	2.47 acres
Kilograms per hectare (kg/ha)	1.12 pounds per acre
Kilograms per liter (kg/1)	0.12 pound per gallon
Kilometer (km)	0.6214 mile
Liter (l)	0.264 gallon
Liters per hectare (1/ha)	0.107 gallon per acre
Meter (m)	3.281 feet
Millimeter (mm)	0.0394 inch

APPENDIX C

Chemical Names of Herbicides Mentioned in Text

Common name	Chemical name
Amitrole	1 H-1,2,4-triazol-3-amine
Bromacil	5-bromo-6-methyl-3-(1-methylpropyl)-2,4 (1H,3H) pyrimidinedione
Clopyralid	3,6-dichloro-2-pyridinecarboxylic acid
Dicamba	3,6-dichloro-2-methoxybenzoic acid
Dichlorprop	2-(2,4-dichlorophenoxy) propionic acid
Diuron	N'-(3,4-dichlorophenyl)-N, N-dimethyl-urea
Fenuron	N, N-dimethyl-N'-phenylurea
Fenuron TCA	N, N-dimethyl-N'-phenylurea mono (trichloroacetate)
Mecoprop	2-(4-chloro-2-methylphenoxy) propionic acid
Monuron	N'-(4-chlorophenyl)-N, N-dimethylurea
Monuron TCA	N'-(4-chlorophenyl)-N, N-dimethylurea mono (trichloroacetate)
Picloram	4-amino-3,5,6-trichloro-2-pyridine-carboxylic acid
Silvex	2-(2,4,5-trichlorophenoxy) propionic acid
Tebuthiuron	N-[5-(1, 1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N, N'-dimethylurea
Triclopyr	[(3,5,6-trichloro-2-pyridinyl)oxy] acetic acid
2,4-D	(2,4-dichlorophenoxy) acetic acid
2,4,5-T	(2,4,5-trichlorophenoxy) acetic acid
2,3,6-TBA	2,3,6-trichlorobenzoic acid