SEEDING, FURROWING, BRUSH REMOVAL, AND RABBIT EXCLUSION EFFECTS ON CREOSOTEBUSH-INFESTED SITES

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by

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"Seeding, Furrowing, Brush Removal, and Rabbit Exclusion Effects on Creosotebush-Infested Sites," a thesis written by Edward Jay Korzdorfer in partial fulfillment of the requirements for the degree Master of Science, has been approved and accepted by the following committee:

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VITA

Edward Jay Korzdorfer was born February 19, 1945, at Somerville, New Jersey. He attended school in Somerville, New Jersey, Ogden and Delta, Utah, Westboro, Massachusetts, and was graduated from William Fleming High School, Roanoke, Virginia, in June 1963. He entered Utah State University in September 1963 and received a Bachelor of Science Degree in Natural Resources in June 1967, with a major in Range Science. He began graduate work at New Mexico State University in June 1967, and completed the requirements for the Master of Science Degree in June 1968.

ABSTRACT

Creosotebush (*Larrea tridentata* (DC) Cov.) dominates much of the formerly productive rangelands of the southwest. A successful and practical method of eradicating this shrub, followed by revegetation of the area by desirable forage plants, would greatly improve these creosotebush-infested areas for livestock use. The purpose of this factorially designed experiment was to study the effects of seeding, furrowing, brush removal, and rabbit exclusion on three creosotebush-infested sites on the Jornada Experimental Range, Las Cruces, New Mexico.

Brush removal consistently decreased the canopy cover of creosotebush and total shrubs, regardless of other treatments. The brush removal alone or the brush removal x rabbit exclusion treatment significantly increased the grass species at the Ragged and Parker Tank sites. The rabbit exclusion fence was present in the treatment applications that significantly increased the grass cover at the Dona Ana site. This treatment was significant in increasing the grass cover due to its soil retaining and soil depositional effects on this site with the steeper slope and the more severe erosion and runoff condition.

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INTRODUCTION

Creosotebush (<u>Larrea tridentata</u> (DC) Cov.), a common desert shrub found throughout the Southwest, is aggressively invading much of the presently productive rangelands. It occupies large areas which were once grasslands. A successful and practical method of eradicating this shrub, followed with revegetation of the area by desirable forage plants, would greatly improve the creosotebush-infested rangelands, at present mostly unproductive. The purpose of this study was to determine the value of seeding, furrowing, brush removal, and rabbit exclusion, separately and in combination for the improvement of creosotebush-infested sites.

Creosotebush dominates an estimated 18.8 million hectares of sparsely vegetated, arid lands from western Texas to California and from Nevada to north central Mexico (Platt 1959). This shrub also occupies extensive areas in the arid regions of Argentina and Chile (Duisberg 1952). Part of the creosotebush region occurs in semidesert grasslands dominated by grama (<u>Bouteloua</u> sp.), threeawn (<u>Aristida</u> sp.), and tobosa (<u>Hilaria mutica</u> (Buckl) Benth.) from the short grasses and bush muhly (<u>Muhlenbergia porteri</u> Scribn.) from the mid grasses.

LITERATURE REVIEW

In reviewing the journals of a number of the early explorers, I found that little or no mention was made of creosotebush. Gregg's (1845) description of the area between Juarez, Chihuahua and Socorro, New Mexico made no mention of creosotebush, but he did mention the vast acres of grama grass and the occurrence of mesquite (Prosopis juliflora (Swartz) DC). Wislizenus's (1848) account of his trip through this same general area, also, has no mention of creosotebush, though when his botanical collection was turned over to Engelmann a specimen of this shrub was found.

J.W. Abert (1848) and W.H. Emory (1848) were the earliest of the explorers to mention the presence of creosotebush in their narratives. The narratives of the numerous explorers to follow them made little mention of this shrub. From the descriptions of the occurrence of creosotebush by the early explorers its presence was confirmed, but none of these men defined its abundance as anything more than sparse. From these observations, one can reasonably assume that it has been during the last one hundred years that creosotebush has increased in abundance and taken over the lush grama grasslands that the early explorers described.

Chew and Chew (1965) stated that creosotebush has always existed in limited amounts in the grassland type, but that a reduction in grass cover, due to overgrazing, reduced the frequency of the fires which had prevented the shrub from becoming established. Humphrey (1958) stated that cessation of fires initiated a "self-perpetuating irreversible vegetation change." Wright (1960) stated that fires were not a factor in keeping the Jornada plain free from brush. He found no record of past fires in the area and believed the sparse cover had been unable to carry a fire.

The expansion of creosotebush in the Chihuahuan Desert follows two general patterns. The first is the invasion of creosotebush into the grasslands, and the second is the gradual displacement of mesquite in the subgrasslands. Yang (1961) suggests that in the Chihuahuan Desert the trend of vegetation change in historical time has been from desert grassland to dominance by creosotebush, with or without a subgrassland transition. In 1961 Yang stated:

> "The aggressive expansion of *Larrea* is principally the outcome of the interaction between a changing climate on one hand and the physiological adaptability of creosotebush on the other hand. A complex of environmental factors operating within historical time (within the general framework of the much longer secular trend) has brought about an ever increasing degree of aridity and fluctuating climatic extremes to the desert environment. *Larrea divaricata*, more than any other contemporary North American desert species, has evolved a genetic system which enables it to meet more successfully these climatic adversities through an exceptional elastic range of physiological amplitude and ecological tolerance."

The climate of the creosotebush region is arid. The annual rainfall ranges from 58 to 470 mm, two-thirds of which falls between April 1 and September 30. The summer rainfall is spotty and often torrential in nature, while the winter rainfall is marginal and less intense. The evaporation rate varies from 122 to 240 cm annually. July is the hottest month of the year with a mean temperature of 25°C, or above. The winter temperatures are mild and infrequently below -17°C, with the mean at 4°C.

The soils on which creosotebush occurs are frequently covered with a surface pavement and range from clay to localized areas of dune sand. The older strata of the Rio Grande Valley found at the deeper soil depths are of the Sante Fe formation of the Pliocene age overlain by Pleistocene sands and gravels (Gardner 1951). The gravelly soils predominate on the ridges and slopes between the swales and valleys. These soils range from gravelly sands to gravelly loams underlain by caliche. The caliche can be a mere impregnation of the soil to a layer of compact limestone 0.6 to 4.6 m thick (Bryan 1938). Nichol (1952) reported that the occurrence of caliche started at a depth of 10 to 50 cm and ranged from 0.5 to 4.5 m in depth.

Shreve and Mallery (1933) concluded that the formation of caliche was primarily due to the interrupted penetration of rain water under arid conditions. These examiners found that even thin layers of caliche greatly retarded upward or downward movements of water and that roots were unable to penetrate the silicified hard layers of caliche. In pot tests, creosotebush made its best growth where caliche made up half or more of the soil mixture.

The best development of creosotebush occurs on eroding gentle slopes. Spalding (1909) and Gardner (1959) confirm that creosotebush is better developed on transported soils than on soils developed on the site, and in eroding rather than depositing situations. Gardner (1951) stated that creosotebush is rarely found on areas that are not well drained. Yang (1950) and Livingston (1910) concurred on this point by saying that these soils are porous, have better internal drainage and aeration than the soils of adjacent areas. Livingston went even further to say that an oxygen deficiency may keep creosotebush out of the lower slopes which have better, denser, deeper, and well watered soils, but Buffington and Herbel (1965) found creosotebush to be invading all soil types on the Jornada Experimental Range.

Tarbush (Flourensia cernua DC), a common member of the creosotebush community, seems to have an inverse relationship with creosotebush in regard to density---determined by a combination of soil factors. In the soils that are shallow with a thick caliche layer creosotebush dominates the tarbush. This condition is reversed when the soil is deep and the caliche layer is thin or non-existant (Chew and Chew 1965).

According to Spalding (1904) creosotebush is able, through its absorbing cells, to abstract a certain amount of water continuously, even from the driest of the desert soils. Therfore, it is able to maintain transpiration through many months of excessive drought. Creosotebush is capable of living, and does live as an ordinary mesophyte when given a suitable supply of water, and Ashby (1932) found that the leaves of creosotebush have as many stomata per unit area as privet (Ligustrum sp.), and that the stomata do not have any special anatomical adaptations. Runyon (1934) concurred, and added that as a rule leaves are persistant throughout the driest seasons. The leaves that successfully endure the most prolonged and severe droughts are only partially grown. These leaves are in a partial state of dormancy and resume growth and activity when more favorable conditions occur. Runyon (1936) found that during growth the water content of the foliage was not lower than that reported for any other seed plant measured. He also observed that three types of leaves are produced: (1) high water content, very little drought resistance, (2) intermediate, and (3) low water content, resistant to drought, and a long life span. Warskow (1965) showed that the moisture content of creosotebush leaves varied directly with relative humidity and inversely with air temperature and light intensity.

Ashby (1932) stated, "...possibly the power of protoplasm to endure desiccation and to recover from it unharmed is the most effective 'adaptation' of creosotebush to a shortage of water." The drought resistant leaves have cells 38 to 78% smaller than the other leaves of the plant. This cell size possibly avoids the fatal mechanical distortion of their protoplasm as they dehydrate and shrink (Iljin 1953).

As the dry season progresses, the mature leaves and some stems are shed thereby reducing the evaporative surface of the plant. Only the smaller, immature leaves remain during the extreme drought periods. These particular leaves can survive a reduction in water content to less than 50% of their dry weight (Runyon 1936, Killian and Lemee 1956).

The leaves of creosotebush are coated with a resinous secretion, that is particularly noticeable on the younger leaves. This resinous secretion probably does not reduce transpiration or absorb any significant amounts of short infrared wave lengths to enable it to act as a type of radiation sheild (Duisberg, et al 1949). Schratz (1931) showed that the transpiration rate of the leaves of creosotebush is low in comparison to some of the other common desert plants.

Spalding (1904) described the root system of creosotebush as having a strong development of secondary roots. The tap root does not continue vertically downward; but turns off at a small angle from the horizontal until at a distance of approximately 80 cm, it turns directly downward. The lateral roots continue near the surface for only a short distance then turn downwards reaching depths of greater than 45 cm, in spite of the rocky nature of the substratum.

The roots of adjacent creosotebush plants do not intermingle. Cannon (1911) found that the lateral roots tend to be superficial, even when they could easily have penetrated to a greater depth. The root hairs are most abundant on those plants in soils with the least soil moisture; and Spalding (1904) suggests that there is possibly an extensive regeneration of root hairs after a damaging dehydration.

Dalton and Humphrey (1962) reported that, "...flowering occurs where daily minimum-maximum temperatures reach $4^{\circ}C$ and $26^{\circ}C$, respectively; also, that after drought flowering occurs before vegetation growth is resumed." These researchers also reported that creosotebush renews flowering and vegetative growth with each new supply of available moisture. Chew and Chew (1965) found that plant growth was largely independent of rainfall and soil moisture, but began when the soil temperature was above $16.9^{\circ}C$, regardless of whether or not the soil was below the standard wilting point.

Livingston (1910) noted that the driest period of the year occurred just before the summer rains, and that germinating seedlings of the desert plants produce their roots rapidly and tops slowly. The loss of water by evaporation from the soil was reduced by the formation of a natural mulch in the surface soil.

In 1952 Went explained the wide, regular spacing of most of the desert shrubs by the fact that these plants give off their own particular chemical inhibitors. Precipitation was described as a key to the degree of effectiveness of these inhibitors. The chemical inhibitors remain in the immediate area of their source plant until a rainfall occurs and disperses the chemical compounds or dissipates their effective inhibitory actions. Went (1952) stated:

> "After summer rains, it was observed that a large number of _Larrea_ seedlings developed, partly under and between existing shrubs. A few weeks later, the seedlings under the old plants shriveled and died. This was not due to a lack of water, because all other seedlings in that neighborhood remained perfectly healthy. A month later, all the _Larrea_ seedlings about half a meter away from the old plants had died too, and the radius of death progresses further and further until only the seedlings furthest removed from any other existing shrub were left. Because of this, _Larrea_ are very regularly spaced, and the less frequent the rain the wider the spacing."

Singh (1964) stated that, "The uniform distribution of creosotebush appeared to be due to a passive 'competition' of roots for water on a first-come, first-served basis, rather than due to the production of toxic substances." Dalton and Humphrey (1962) also believed that the distribution was a result of water competition rather than a toxic substance.

Knipe and Herbel (1966) concluded that aqueous extracts from creosotebush plant material prepared in high concentrations significantly reduced the germination of black grama (_Bouteloua eriopoda_ (Torr.) Torr.) caryopses, but not bush muhly or creosotebush seeds, removed from their carpels. The less concentrated aqueous extract---possibly more comparable to actual field conditions---did not significantly reduce germination of any species tested. Plumule and radicle growth of black grama and bush muhly were significantly reduced by all extracts. The delay and reduction of creosotebush seed germination apparently was caused by either a structural carpel characteristic or a non-water soluble chemical compound in the carpel itself. These researchers concluded that the effects of the creosotebush extracts on the initial growth of black grama and bush muhly plus the reduction in infiltration rates observed in the potted soils treated with these extracts could be contributing factors in the degeneration of grassland area where creosotebush is invading.

Yang (1967) has recently published an article on the ecotypical variation in creosotebush that states:

> "Data on the rate of germination, rate of growth, and temperature and moisture responses of creosotebush (*Larrea divaricata* Cav.) seedlings from the Sonoran Desert and Chihuahuan Desert suggest that the species as it occurs in North America is comprised of at least two major genetic population systems or ecotypes. Compared to the Chihuahuan Desert ecotype, that of the Sonoran Desert is characterized by a taller, more erect and open growth form, more slender and less incurved leaflets, slower germination rate, slower initial growth rate of the seedlings, less tolerance for low temperature, and greater tolerance for low moisture."

Yang found that the Sonoran Desert ecotype could withstand one-third to one-fourth less water than the Chihuahuan Desert ecotype. It was also discovered that a temperature drop for a period of a week between 5° and 10°C during the night would cause a significant increase in the mortality rate of the newly emerged seedlings of the Sonoran Desert ecotype, but not for the seedlings of the Chihuahuan Desert ecotype.

DESCRIPTION OF AREA

General Area

The Jornada Experimental Range, approximately twenty-five miles northeast of Las Cruces, New Mexico, is part of the lower Sonoran Life Zone as described by Merriam (1898), and is classified as Desert Plains Grassland by Clements (1934). It is situated on the Jornada del Muerto Plain, which is bounded by the Rio Grande Valley and the Fra Cristobal-Caballo Mountain complex on the west and by the San Andres Mountains of the east. The area ranges in elevation from 1,000 to 1,500 m.

The climate of the Jornada Experimental Range has been described as arid by Thornthwaite (1941). Winters are mild, summers are hot, and both are characterized by a wide range between day and night temperatures. The temperature is favorable for plant growth for approximately 200 days, but moisture conditions are such that normally growth occurs for only 90 to 100 days per year. The average maximum temperature is highest in June when it averages 36° C; it is lowest in January when the average maximum is 13° C (Buffington and Herbel 1965). The record temperature extremes are -29° C and 43° C. The mean daily average for the coldest month is 4° C in January, while the mean daily average for the hottest month is 26° C in July. The annual mean temperature recorded at the headquarters of the Jornada Experimental Range is 15° C.

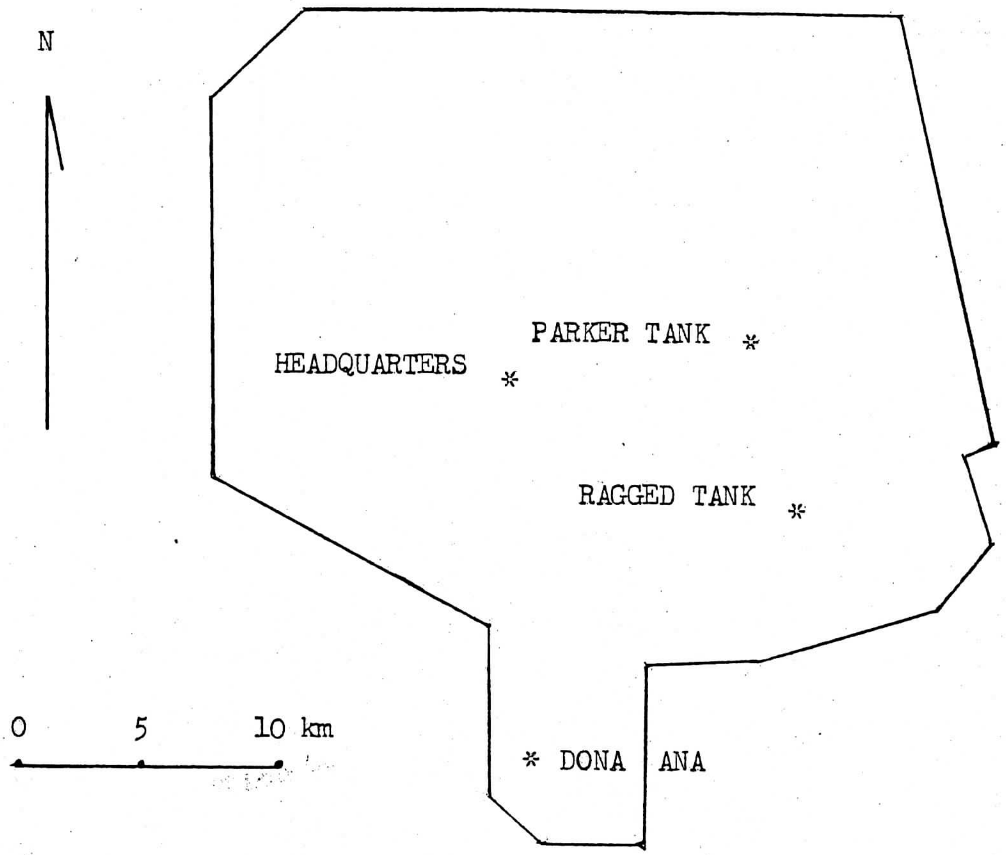
The average annual precipitation is 228 mm (1915-1967), with slightly more than half falling during the growing season (July 1 to September 30). The growing season precipitation is the result of convectional storms that are erratic in nature and of high intensity. Frequently precipitation resulting from these localized thunderstorms is of such high intensity that much of the water is lost as runoff.

Wind movement for the area is high, averaging approximately 16,900 km annually. Wind velocities are highest in March through June, when they average more than 1,610 km per month. The average annual evaporation is nearly ten times the average annual precipitation, or approximately 225 cm of evaporation per year (1929-1965). The months of May and June have the highest evaporation rates, June having the highest rate of evaporation with 330 mm.

Some of the major plants found on the Jornada Experimental Range are: gramas, muhlys, dropseeds (*Sporobolus* sp.), burrograss (*Scleropogon brevifolius* Phil.), soapweed yucca (*Yucca elata* Engelm.), threeawns, witchgrasses (*Panicum* sp.), mormon tea (*Ephedra* sp.), mesquite, tarbush, and creosotebush. According to a 1963 survey, there is no vegetation type on the Jornada Experimental Range that does not also include either mesquite, tarbush, or creosotebush (Buffington and Herbel 1965).

Study Area

Three areas were selected for this study; they will be referred to as Ragged Tank, Parker Tank, and Dona Ana (figure 1). The average annual precipitation for the three sites from 1939 to 1967 was 209 mm, with 57.4% falling during the growing season (table 1). Ragged Tank had the highest average annual precipitation with 222 mm, while Dona Ana and Parker Tank had 212 and 192 mm of average annual precipitation respectively. The average seasonal precipitation was highest at Ragged Tank, but it had the lowest percentage of precipitation during the growing season. Figure 2



shows the average annual and seasonal site precipitation for the study period, while figure 3 illustrated the monthly distribution of precipitation.

Since Ragged Tank and Parker Tank occur on similiar sites on the ridge tops and foot-slopes of the San Andres Mountains, approximately five miles apart, I shall discuss their general characteristics as one. The entire area is characterized by rolling topography with numerous draws and an occasional area that is flat and open. The ridge tops are dominated by

Table 1 PRECIPITATION AT STUDY SITES FROM 1939 THROUGH 1967 IN MILLIMETERS.

	Ragged Tank		Parker Tank		Dona Ana	
Year	Annual	Seasonal*	Annual	Seasonal	Annual	Seasonal
1939	283	196	204	112	244	157
1940	246	79	226	94	289	105
1941	490	287	394	201	470	291
1942	293	179	203	130	190	110
1943	183	72	196	96	196	86
1944	262	148	213	123	275	124
1945	127	65	134	88	147	84
1946	220	144	211	105	190	78
1947	208	124	87	45	97	65
1948	274	88	186	70	153	18
1949	235	113	198	99	163	93
1950	176	130	165	135	186	146
1951	122	51	83	18	124	49
1952	188	90	146	65	237	149
1953	88	40	58	12	123	83
1954	166	114	136	101	126	64
1955	182	124	240	140	147	109
1956	123	81	96	68	106	70
1957	294	162	243	132	302	165
1958	343	176	267	132	358	193
1959	136	116	115	102	234	198
1960	139	56	99	34	177	89
1961	201	126	226	146	319	191
1962	219	155	309	226	229	170
1963	227	160	264	218	185	135
1964	200	123	180	120	161	111
1965	299	151	248	116	215	107
1966	321	199	245	152	186	121
1967	197	130	195	108	336	229
Mean:	222	127	192	110	212	124

Mean percent seasonal percipitation: 57.4%

For sites: 56.78% 57.28% 58.18%

Mean for all sites: Annual = 209 mm , Seasonal = 120 mm

* Seasonal : July 1 through September 30

FIGURE 2 AVERAGE ANNUAL AND SEASONAL PERCIPITATION FOR STUDY SITES.

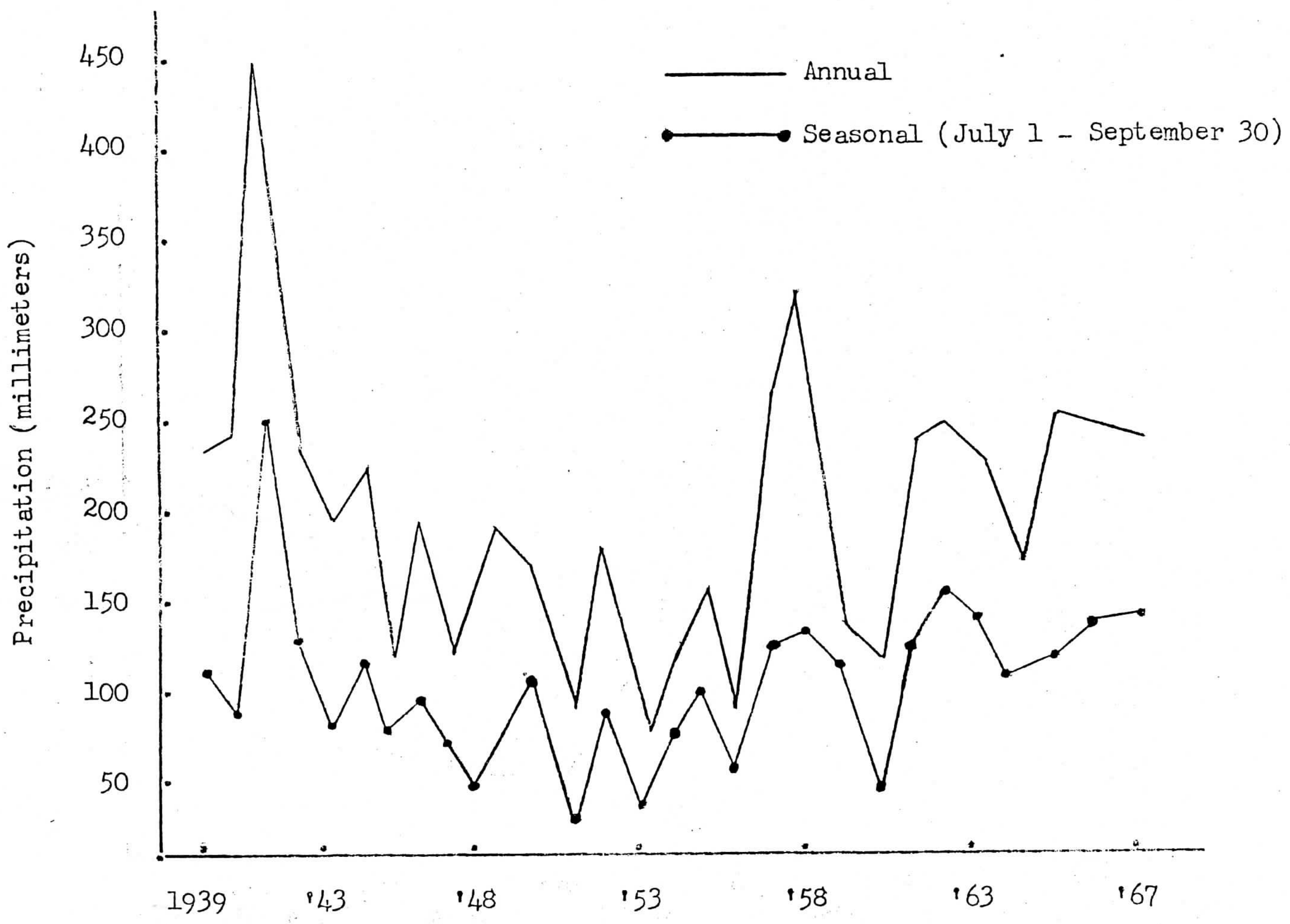
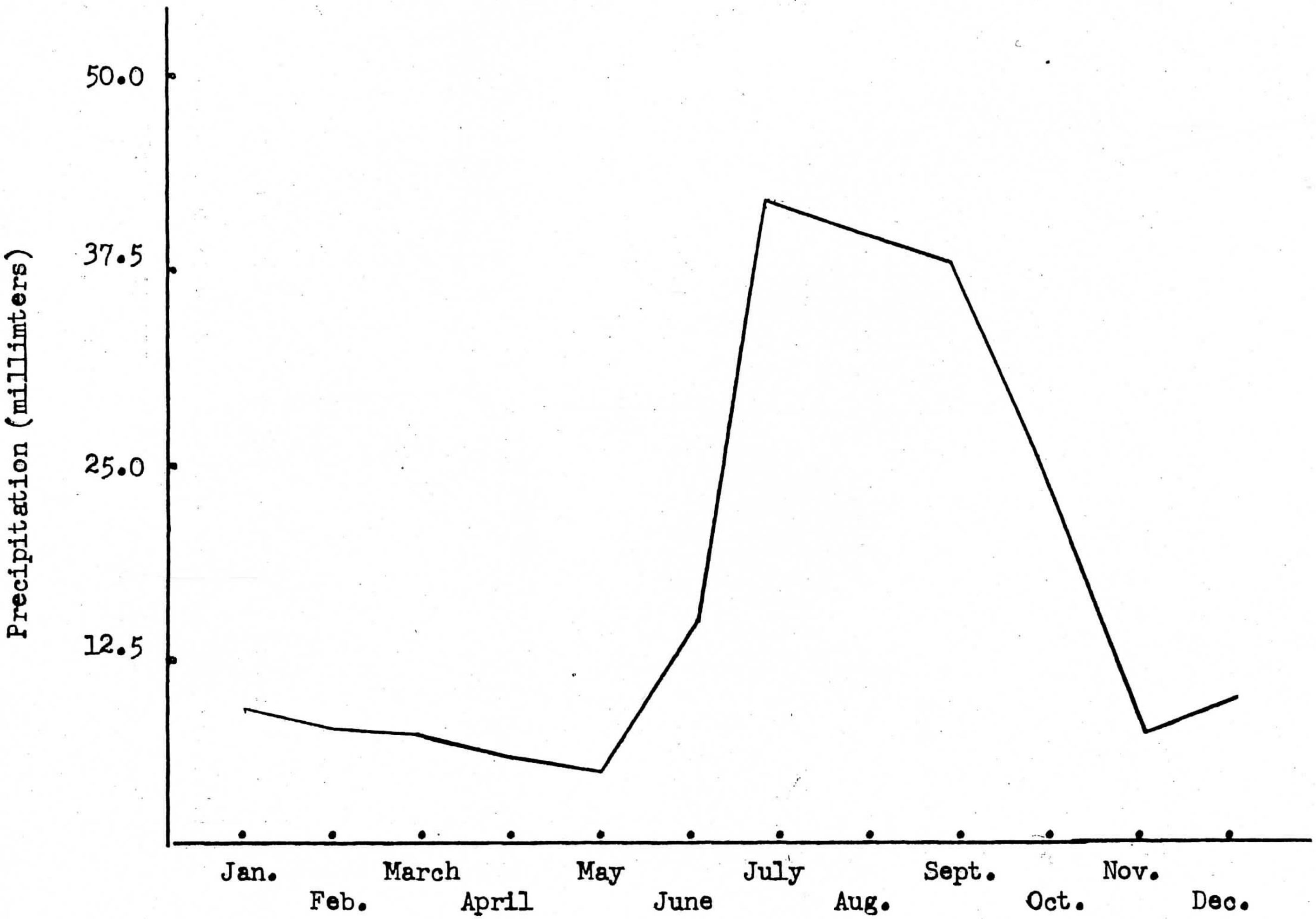


FIGURE 3 AVERAGE MONTHLY DISTRIBUTION OF PRECIPITATION (1939-1967).



creosotebush with lesser amounts of tarbush and a few scattered mesquite plants. Mariola parthenium (Parthenium incanum HBK) and knifeleaf condalia (Condalia spathulata Gray) appear to be more abundant on the tops of the ridges than on any of the slopes. Bush muhly is the major perennial grass on the ridge tops, but there is a sparse scattering of fluffgrass (Tridens pulchellus (HBK) Hitchc.).

On the slopes of the ridges creosotebush still dominates, but there is a change in the abundance of the other species, and some new species occur. Fluffgrass is plentiful on the north facing slopes, nearly to the crest of the ridges. As one progresses down the north slope plants such as threeawn, black grama, and bush muhly are found with a little spike dropseed (Sporobolus contractus Hitchc.). At the bottom of the draw there is usually a gully that has eroded down to the limestone or caliche layer. The borders of the gully are lined with perennial grasses such as threeawn, black grama, bush muhly, spike dropseed, and, in an occasional area, some sideoats grama (Bouteloua curtipendula (Michx.) Torr.). All the grasses bordering the gully seem to be quite robust compared with their counterparts on the slopes and ridge tops.

The south slopes are nearly void of grasses. Creosotebush seems to be the only shrub which can maintain any dominance over the area. Near the very bottom of the south slope grass plants will appear, but only at the borders of the gullies, except for a few localized areas.

The wide flats are quite different from the rest of the area, creosotebush and tarbush are present, but not necessarily as the dominants. If the soil is not stabilized, creosotebush dominates the area and there is an abundance of tarbush. These localized unstable areas in the flats are usually quite sandy, with a distinct and servere series of erosion patterns. Few grass plants exist, but those species present are threeawn, burrograss, sand muhly (Muhlenbergia arenicola Buckl.), and lesser amounts of showy chloris (Chloris virgata Swartz.).

If the soils of the flats are stabilized, then there are only limited amounts of tarbush and creosotebush. Mesquite and knifeleaf condalia are usually represented by a few very large plants. The flats are dominated by large and robust grass plants. Alkali sacaton (Sporobolus airoides (Torr.) Torr.) is usually the dominate grass, with considerable spike dropseed, mesa dropseed (Sporobolus flexuous (Thurb.) Rydb.), and tobosa, and lesser amounts of plains bristlegrass (Setaria macrostachya HBK).

Soapweed yucca plants are scattered throughout the creosotebush community. This plant seems to frequent all the diverse habitats in the creosotebush community except the south facing slopes. Fourwing saltbush (Atriplex canescens (Pursh.) Nutt.) is dispersed throughout the community in very limited amounts, but gains in abundance as one approaches the mountains. Cactus (Opuntia sp.) plants are also found throughout the creosotebush community.

The Dona Ana site is separated from the other sites by general topography, slope, and type of vegetation, as well as distance. The slope is greater at the Dona Ana site. Due to this slope, the area is subjected to severe periods of flash floods which cause extreme damage to the soil, as well as the vegetation.

From records available in the form of photographs and a bulletin by Canfield (1939), I have found that this area, presently entirely dominated by creosotebush, formerly had a good stand of black grama yielding approximately 780 kg per hectare per year during the 1925 through 1935 period. Under the present conditions there are few , if any, black grama plants in the area. The other plant species found in this creosotebush community are soapweed yucca, tarbush, mormon tea, cactus, and fourwing saltbush. Except for bush muhly and fluffgrass, perennial grasses are practically non-existant.

The soils of these sites have been described by the Soil Conservation Service (1968). The soil at Ragged Tank and Parker Tank is Upton gravelly loam derived from parent material of limestone and sandstone. They are situated on old alluvial fans at an elevation of approximately 1,400 m. The surface is 50-60% covered with semiangular limestone gravel, creating a weak desert pavement. The subsoil is described as having moderate permeability, with roots extending to a depth of 33 cm. The depth to hardpan varies from 40 to 50 cm at Ragged Tank, but is approximately 8 cm deeper than at Parker Tank.

The soil on the Dona Ana site has been described as Canutio gravelly sandy loam derived from parent material of mixed igneous rocks. The site is located on an old alluvial fan at an elevation of approximately 1,300 m. The surface is 50% covered with mixed igneous rounded gravel. The roots penetrate to a depth of 45 cm through a subsoil described as having rapid permeability. The depth to hardpan varies from 85 to 100 cm. Although the subsoil at the three sites is described as being either rapid or moderately permeable, water penetration in the upper 7 cm of the surface soil is extremely slow due to its platy nature. The permeability of the surface soil is increased if pre-wetting occurs.

METHODS AND PROCEDURES

Experimental Design

The study was designed for the purpose of evaluating the effects of four primary treatments, seeding, furrowing, brush removal, and rabbit exclusion, for the improvement of creosotebush-infested areas. The study was initiated at Ragged Tank and Parker Tank in July and August of 1938 and in September of 1939 at Dona Ana, and then continued until September 1967 with periodic retreatment and sampling. The study was factorially designed with two levels of four treatments. At each site there was a check plot, four single factor plots, and eleven plots with varying degrees of interaction (table 2).

Plot Establishment

At each site, selected for uniformity, a block 146.3 m on a side was established, which was divided into sixteen 21.3 m^2 plots. These plots were arranged in four rows of four so that each was surrounded by a buffer zone 7.6 m wide. A fence was built around the block in order to exclude livestock.

Treatment Application

Each of the sites were treated in their respective year of establishment, preceded by their initial sampling. A mixture of mesa dropseed, spike dropseed, and fourwing saltbush was used for the seeding treatment. The seed was hand broadcasted and then raked into the soil. The seeding treatment was repeated in 1947 at all sites due to the lack of response. After each of the periodic samplings, all the creosotebush, tarbush,

TABLE 2 LIST OF TREATMENT COMBINATIONS APPLIED AT EACH SITE.

Check	No Treatment	(1)
Single Factor	Seeded	S
	Furrowed	F
	Brush Removal	B
	Rabbit Exclusion	R
1st. Order Inter-action	Seeded x Furrowed	SF
	Seeded x Brush Removal	SB
	Seeded x Rabbit Exclusion	SR
	Furrowed x Brush Removal	FB
	Furrowed x Rabbit Exclusion	FR
	Brush Removal x Rabbit Exclusion	BR
2nd. Order Inter-action	Seeded x Furrowed x Brush Removal	SFB
	Seeded x Furrowed x Rabbit Exclusion	SFR
	Seeded x Brush Removal x Rabbit Exclusion	SBR
	Furrowed x Brush Removal x Rabbit Exclusion	FBR
3rd. Order Inter-action	Seeded x Furrowed x Brush Removal x Rabbit Exclusion	SFBR

mesquite, and cactus plants on those plots receiving the brush removal treatment were hand grubbed. Two rolls of galvanized poultry were used to enclose each rabbit exclusion plot. Approximately 20 cm of the wire were buried in the ground to prevent rabbits from burrowing under the wire. The furrows were made with a rake, in such a manner as to form a partial half-circle. The soil was raked down the slope into the half-circle in order to construct a dam along the arc of the half-circle. The furrow was approximately 2.5 m from tip to tip with a width of about one meter. The dam along the arc was highest in the center, reaching a height of nearly 25 cm, and then decreased in height toward the tips of the half-circle. There were approximately 25 furrows per plot, located in such a manner as to impede soil erosion and runoff.

Sampling Procedure

The plots (21.3 x 21.3 m) were sampled by the line intercept method of Canfield (1941). Recordings were made in hundredths of a foot for basal intercept of perennial grass and canopy intercept of shrubs. The vegetation was sampled in late August and early September of 1939, 1947, 1960, and 1967 for all sites. Ragged Tank was also sampled in September 1956.

The plot was divided into an east and a west subplot, each of which had fourteen permanent 10.65 m transects located at random running east to west across each subplot. Parallel tape measures were stretched along the east and west sides of a subplot. The tapes were located in such a manner as to have the 15.2 cm mark placed on the north border of the subplot in order to have 70 possible transect positions, at 30.4 cm intervals, from which to randomly select the fourteen permanent transects. After the permanent transects for a subplot were determined, a wire was stretched across the subplot between the two parallel tapes in order to locate the proper transect position. After all the transects for a subplot were recorded, the tape measure bordering the west side of the plot was relocated on the east border of the plot to locate the fourteen transects in the east subplot.

All shrubs and perennial grasses were recorded. The shrubs were divided into two categories, creosotebush and total shrubs. Total shrubs include such species as creosotebush, mesquite, tarbush, knifeleaf condalia, mariola parthenium, fourwing saltbush, and broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt.). The perennial grasses are divided into five categories: black grama, bush muhly, dropseed, fluffgrass, and total useful perennial grasses. Dropseed includes all of the species of this genus, such as spike dropseed, mesa dropseed, and alkali sacaton. Total useful perennial grasses includes all perennial grass species present except fluffgrass which has very little value as a grazing species. The species included in this category are black grama, bush muhly, dropseed,tobosa, threeawn, and plains bristlegrass.

RESULTS

A mixed model, with years randon and treatments fixed, was used as the statistical model for this experiment. The year x treatment interactions were pooled and used as the error term to test significance of the treatments. If a third order interaction was significant, it took precedence in the interpretation of all other significant treatment effects. Similarly, if a second or first order interaction was significant, it took precedence in the interpretation of all lower order interactions that had the same treatments and any of the four primary treatments that occurred in that interaction.

The 5% probability level was used to test significance among treatment means. When the analysis of variance indicated a significant interaction, the means were shown in two, three, or four way tables and compared using Duncan's Multiple Range Test (Duncan 1955). Appendix 1, 2, and 3 show the results of the analysis for all sites.

Ragged Tank

Appendix 4 lists the average percent cover of the major species and groups of species for all plots at the Ragged Tank site. Each number is an average of twenty-eight observations over the five years the vegetation was sampled.

Significant treatment effects occurred in the creosotebush canopy cover in the second order interaction SFR, SBR, and FBR (refer table 2 for symbols). Since all primary treatments are represented, the interpretation was based on the SFBR interaction (table 3). The brush removal treatment significantly reduced the canopy cover of creosotebush regardless of other treatments being present. The rabbit exclusion and furrowing treatments tended to increase the canopy cover. The canopy cover of creosotebush was reduced by seeding alone and when seeding was added to the furrowing, brush removal, and rabbit exclusion treatment.

TABLE 3 MEAN CANOPY COVER (%) OF CREOSOTEBUSH FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	17.117	15.382	4.500	7.125
Furrowing	16.958	21.920	6.641	11.199
Seeding				
No Furrowing	15.743	19.629	4.159	6.114
Furrowing	19.397	21.289	6.162	5.565

LSR = 1.296

Since all the primary treatments were present in the significant second order interaction of SFR and SBR, the third order interaction, SFBR, was used to interpret the data for total shrubs at Ragged Tank (table 4). The brush removal treatment significantly reduced the total shrub canopy cover regardless of other treatments being present. The furrowing and rabbit exclusion treatments tended to increase the canopy cover of the total shrubs. When seeding was added to furrowing and rabbit exclusion or furrowing, brush removal, and rabbit exclusion the canopy cover of the total shrubs was significantly reduced.

TABLE 4 MEAN CANOPY COVER (%) OF TOTAL SHRUBS FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	21.033	22.594	6.242	9.366
Furrowing	22.493	30.256	7.903	15.616
Seeding				
No Furrowing	18.941	26.300	4.980	8.496
Furrowing	22.120	25.039	8.379	8.867

LSR = 1.676

The significant third order interaction, SFBR, (table 5) for black grama indicated that a number of treatments significantly increased the basal cover. Although brush removal alone gave the greatest improvement, the addition of brush removal and rabbit exclusion to a treatment usually increased the basal intercept of black grama. The mean basal intercept of black grama for the brush removal treatment was more than twice as large as the value for the next highest treatment.

The third order interaction, SFBR, (table 6) took precedence in the interpretation of the data for the basal intercept of bush muhly. Bush muhly cover increased significantly only with brush removal alone or when brush removal was added to the seeding, furrowing, and rabbit exclusion treatment.

TABLE 5 MEAN BASAL COVER (%) OF BLACK GRAMA FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	0.004	0.056	0.433	0.089
Furrowing	0.002	0.009	0.015	0.138
Seeding				
No Furrowing	0.058	0.002	0.018	0.100
Furrowing	0.016	0.018	0.113	0.195

LSR = 0.048

TABLE 6 MEAN BASAL COVER (%) OF BUSH MUHLY FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	0.166	1.236	1.729	1.099
Furrowing	0.242	0.369	0.335	1.321
Seeding				
No Furrowing	0.573	0.396	0.332	1.280
Furrowing	0.556	0.498	1.100	1.890

LSR = 1.109

In the BR interaction (table 7), only when both treatments were present did the basal intercept of dropseed increase significantly. The same type of interaction took precedence in the interpretation of fluffgrass (table 8). In this case only brush removal alone significantly increased the basal intercept of fluffgrass.

TABLE 7 MEAN BASAL COVER (%) OF DROPSEED FOR THE BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Rabbit Exclusion	Rabbit Exclusion
No Brush Removal	0.000	0.014
Brush Removal	0.005	0.400

LSR = 0.208

TABLE 8 MEAN BASAL COVER (%) OF FLUFFGRASS FOR THE BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT RAGGED TANK.

	No Rabbit Exclusion	Rabbit Exclusion
No Brush Removal	0.056	0.636
Brush Removal	0.434	1.342

LSR = 0.157

Significant differences occurred in two primary treatments and one interaction for total useful perennial grasses, all perennial grasses except fluffgrass, at Ragged Tank. Brush removal (table 9) and rabbit exclusion (table 10) acted as independent factors that significantly increased the basal intercept of total useful perennial grasses. The SF interaction (table 11) was a complete reversal. No treatment increased the basal intercept of the total useful perennial grasses above the

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TABLE 9 MEAN BASAL COVER (%) OF TOTAL USEFUL PERENNIAL GRASSES FOR BRUSH REMOVAL AT RAGGED TANK.

No Brush Removal	0.529
Brush Removal	1.494

LSR = 0.705

TABLE 10 MEAN BASAL COVER (%) OF TOTAL USEFUL PERENNIAL GRASSES FOR RABBIT EXCLUSION AT RAGGED TANK.

No Rabbit Exclusion	0.593
Rabbit Exclusion	1.299

LSR = 0.705

TABLE 11 MEAN BASAL COVER (%) OF TOTAL USEFUL PERENNIAL GRASSES FOR THE SEEDING X FURROWING INTERACTION AT RAGGED TANK.

	No Furrowing	Furrowing
No Seeding	1.310	0.636
Seeding	0.755	1.342

LSR = 0.705

Table 12 list the mean percent cover of each species and group of specices at Ragged Tank every year the vegetation was sampled. The cover of creosotebush and total shrubs was highest in the initial year, but decreased in 1947 and again in 1956. The cover of these two categories then started to increase, but did not attain their former cover. Black grama decreased consistently through the years. Bush muhly, fluffgrass, and total useful perennial grasses decreased after the initial year, but the decrease was not consistent. The decrease varied with the precipitation conditions. Only dropseed increased when compared to 1939.

TABLE 12 MEAN COVER (%) FOR ALL SPECIES AND GROUPS OF SPECIES AT RAGGED TANK.

Year	1939	1947	1956	1960	1967
Creosotebush	18.73	12.10	9.59	9.86	11.81
Total Shrubs	23.90	16.62	12.49	12.66	15.16
Black Grama	0.16	0.12	0.07	0.03	0.01
Bush Muhly	2.42	0.16	1.31	0.20	0.06
Dropseed	0.00	0.08	0.29	0.12	0.03
Fluffgrass	0.31	0.06	0.33	0.11	0.02
Total Useful Perennial Grasses	2.59	0.36	1.67	0.35	0.09

Parker Tank

Apprendix 5 lists the average percent cover of the major species and groups of species for all plots at the Parker Tank site. Each number is an average of twenty-eight observations over the four years the vegetation was sampled.

The interaction of all primary treatments (table 13) was the significant interaction that took precedence in the interpretation of the effects on creosotebush cover at Parker Tank. In every case the addition of brush removal significantly reduced the cover of creosotebush. Creosotebush cover indreased significantly when the rabbit exclusion treatment was added to seeding or furrowing-brush removal treatments. Seeding alone significantly decreased the creosotebush cover, but it was still significantly higher than if brush removal and/or rabbit exclusion were also present.

TABLE 13 MEAN CANOPY COVER (%) OF CREOSOTEBUSH FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	20.315	18.857	5.901	6.219
Furrowing	18.851	23.860	5.191	7.356
Seeding				
No Furrowing	14.752	19.884	5.400	8.317
Furrowing	20.424	19.136	4.564	6.413

LSR = 1.931

Significant treatment effects on total shrub cover were noted in the SFR and SBR interactions. Since all of the primary treatments were included, the SFBR interaction (table 14) was used in the interpretation. Regardless of the presence of other treatments, brush removal significantly reduced the total shrub cover in all cases. The furrowing and rabbit exclusion treatments tended to increase the total shrub cover, while seeding tended to decrease the total shrub cover.

TABLE 14 MEAN CANOPY COVER (%) OF TOTAL SHRUBS FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	22.848	22.653	10.445	9.402
Furrowing	23.783	26.243	5.964	10.459
Seeding				
No Furrowing	16.743	26.654	6.331	11.616
Furrowing	22.909	24.060	5.561	7.971

LSR = 1.696

The basal intercept of black grama increased significantly with brush removal alone in the significant BR interaction (table 15). No single factor increased cover with this same type of interaction for bush muhly (table 16), but the addition of brush removal to the rabbit exclusion treatment did significantly increase bush muhly cover. For dropseed in the BR interaction (table 17), only the presence of both of these primary treatments significantly increased the basal intercept.

TABLE 15 MEAN BASAL COVER (%) OF BLACK GRAMA FOR THE BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Rabbit Exclusion	Rabbit Exclusion
No Brush Removal	0.102	0.174
Brush Removal	0.193	0.121

LSR = 0.090

TABLE 16 MEAN BASAL COVER (%) OF BUSH MUHLY FOR THE BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Rabbit Exclusion	Rabbit Exclusion
No Brush Removal	0.246	0.097
Brush Removal	0.132	0.202

LSR = 0.098

TABLE 17 MEAN BASAL COVER (%) OF DROPSEED FOR THE BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Rabbit Exclusion	Rabbit Exclusion
No Brush Removal	0.012	0.012
Brush Removal	0.009	0.188

LSR = 0.027

The SFBR interaction (table 18) showed that if rabbit exclusion was present in the treatment it must be accompanied by either brush removal or brush removal-furrowing to significantly increase the basal intercept of fluffgrass. No single treatment or treatment interaction significantly affected the basal intercept of the total useful perennial grasses.

TABLE 18 MEAN BASAL COVER (%) OF FLUFFGRASS FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT PARKER TANK.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	0.311	0.826	0.603	0.119
Furrowing	0.428	0.625	0.544	0.751
Seeding				
No Furrowing	0.640	0.456	0.642	0.536
Furrowing	0.122	0.459	0.755	0.444

LSR = 0.594

The variation of shrub cover and basal intercept of the grasses for each year the vegetation was sampled, all plots combined, at Parker Tank is shown in table 19. Creosotebush and total shrubs were highest the first sampling year, but gradually decreased until 1967 when it increased slightly. Black grama, bush muhly, and the total useful perennial grasses decreased progressively through the years. Dropseed increased in 1947 and 1960 but then dropped back to its 1939 level in 1967. Fluffgrass dropped sharply after the initial year and then remained at the lower level.

TABLE 19. MEAN COVER (%) FOR ALL SPECIES AND GROUPS OF SPECIES AT PARKER TANK.

Year	1939	1947	1960	1967
Creosotebush	18.759	10.372	9.536	12.694
Total Shrubs	22.434	13.926	11.621	14.715
Black Grama	0.418	0.136	0.027	0.006
Bush Muhly	0.581	0.049	0.040	0.009
Dropseed	0.028	0.044	0.120	0.027
Fluffgrass	2.005	0.016	0.040	0.004
Total Useful Perennial Grasses	1.026	0.231	0.188	0.043

Dona Ana

Appendix 6 list the average percent cover of the major species and groups of species for all plots at the Dona Ana site. Each number is an average of twenty-eight observations over the four years the vegetation was sampled.

Creosotebush cover was significantly decreased in the SFBR interaction (table 20) by the presence of brush removal except when the treatment was combined with rabbit exclusion alone or the seeding-furrowing-rabbit exclusion treatment. If seeding was added to a treatment of furrowing-rabbit exclusion these was a significant decrease in the cover of creosotebush.

The SFBR interaction (table 21) reacted on total shrub cover in nearly the same manner as for creosotebush cover. The presence of seeding with furrowing, with or without rabbit exclusion, significantly decreased the total shrub cover. If seeding was added to brush removal-rabbit exclusion there was a significant decrease in total shrub cover. The addition of brush removal to any treatment combination significantly reduced the total shrub cover except when added to rabbit exclusion alone or the seeding-furrowing-rabbit exclusion treatment. The addition of rabbit exclusion to any treatment combination that had brush removal, except for the seeding-brush removal, significantly increased the total shrub cover.

TABLE 20 MEAN CANOPY COVER (%) OF CREOSOTEBUSH FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT DONA ANA.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	9.156	7.592	4.994	5.766
Furrowing	11.775	14.928	6.370	4.247
Seeding				
No Furrowing	8.040	8.545	5.130	3.836
Furrowing	9.713	7.263	4.406	5.535

LSR = 1.978

In the SFR interaction (table 22) the treatment combinations of furrowing-rabbit exclusion and seeding-rabbit exclusion significantly increased the basal intercept of black grama. Bush muhly and dropseed were significantly increased by the independent action of rabbit exclusion (table 23 and 24 respectively).

TABLE 21 MEAN CANOPY COVER (%) OF TOTAL SHRUBS FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT DONA ANA.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	13.920	11.494	6.550	9.244
Furrowing	15.208	19.652	7.454	10.056
Seeding				
No Furrowing	12.478	12.296	6.761	6.496
Furrowing	11.322	11.461	6.883	9.853

LSR = 2.456

TABLE 22 MEAN BASAL COVER (%) OF BLACK GRAMA FOR THE SEEDING X FURROWING X RABBIT EXCLUSION INTERACTION AT DONA ANA.

	No Rabbit Exclusion	Rabbit Exclusion
No Seeding		
No Furrowing	0.000	0.013
Furrowing	0.000	0.036
Seeding		
No Furrowing	0.001	0.042
Furrowing	0.001	0.002

LSR = 0.025

TABLE 23 MEAN BASAL COVER (%) OF BUSH MUHLY FOR RABBIT EXCLUSION AT DONA ANA.

No Rabbit Exclusion	0.007
Rabbit Exclusion	0.026

LSR = 0.018

TABLE 24 MEAN BASAL COVER (%) OF DROPSEED FOR RABBIT EXCLUSION AT DONA ANA.

No Rabbit Exclusion	0.000
Rabbit Exclusion	0.034

LSR = 0.032

Two second order interactions were significant for fluffgrass at the Dona Ana site, SBR and SFR. Since all of the primary treatments occurred in these two interactions the third order interaction, SFBR, was used for the interpretation (table 25). The cover of fluffgrass increased with the seeding-rabbit exclusion, seeding-furrowing-rabbit exclusion, and the furrowing-brush removal-rabbit exclusion treatments. Rabbit exclusion was the only factor common to all the treatments that increased the cover of fluffgrass.

The total useful perennial grasses were significantly increased in the SF interaction (table 26), only for the single factors acting alone. Rabbit exclusion (table 27) acted independently to significantly increase the basal intercept of total useful perennial grasses.

TABLE 25 MEAN BASAL COVER (%) OF FLUFFGRASS FOR THE SEEDING X FURROWING X BRUSH REMOVAL X RABBIT EXCLUSION INTERACTION AT DONA ANA.

	No Brush Removal		Brush Removal	
	No Rabbit Exclusion	Rabbit Exclusion	No Rabbit Exclusion	Rabbit Exclusion
No Seeding				
No Furrowing	0.001	0.000	0.001	0.001
Furrowing	0.000	0.003	0.004	0.078
Seeding				
No Furrowing	0.005	0.340	0.000	0.005
Furrowing	0.003	0.001	0.038	0.006

LSR = 0.030

TABLE 26 MEAN BASAL COVER (%) OF TOTAL USEFUL PERENNIAL GRASSES FOR THE SEEDING X FURROWING INTERACTION AT DONA ANA.

	No Furrowing	Furrowing
No Seeding	0.024	0.071
Seeding	0.082	0.035

LSR = 0.044

TABLE 27 MEAN BASAL COVER (%) OF TOTAL USEFUL PERENNIAL GRASSES FOR RABBIT EXCLUSION AT DONA ANA.

No Rabbit Exclusion	0.008
Rabbit Exclusion	0.098

LSR = 0.044

The variation of shrub canopy cover and basal intercept of grasses for each year the vegetation was sampled, all plots combined, at Dona Ana is show in table 28. The canopy cover of creosotebush and total shrubs increased in 1947. The canopy of total shrubs decreased slightly in 1960 and again in 1967 when compared to 1947. The creosotebush cover increased again in 1960 but then decreased in 1967, nearly falling as low as the cover for the initial year the vegetation was sampled. All the grass species and groups of species increased through the years when compared to the initial cover.

TABLE 28 MEAN COVER (%) FOR ALL SPECIES AND GROUPS OF SPECIES AT DONA ANA.

Year	1939	1947	1960	1967
Creosotebush	6.220	7.680	8.808	6.459
Total Shrubs	8.603	12.113	11.740	10.078
Black Grama	0.000	0.008	0.033	0.006
Bush Muhly	0.003	0.048	0.003	0.013
Dropseed	0.000	0.010	0.046	0.012
Fluffgrass	0.000	0.020	0.017	0.002
Total Useful Perennial Grasses	0.003	0.072	0.092	0.044

DISCUSSION AND CONCLUSIONS

Brush removal was the only treatment that consistently decreased the cover of creosotebush and total shrubs at Ragged and Parker Tank, regardless of whether or not it was combined with any other treatment. The furrowing and rabbit exclusion treatments or both tended to increase the canopy cover of creosotebush and total shrubs, but seeding would usually decrease shrub cover when used as the only treatment applied or when added to the furrowing-rabbit exclusion treatment.

At the Dona Ana site brush removal decreased the cover of creosotebush, except when added to either the rabbit exclusion treatment or the seeding-furrowing-rabbit exclusion treatment. The addition of seeding to the furrowing-rabbit exclusion treatment decreased the cover of creosotebush and total shrubs. If rabbit exclusion is used as part of a treatment combination it must be accompanied by furrowing to decrease the canopy cover of total shrubs.

Only two treatments increased the basal intercept of black grama at Ragged Tank, brush removal alone and a combination of the four primary treatments. The brush removal treatment resulted in a mean cover of 0.433% compared to only 0.195% for the combination of the four primary treatments. Black grama cover increased at the Parker Tank site by applying the brush removal treatment alone. At the Dona Ana site the interaction of all primary treatments took precedence in the interpretation of cover changes for black grama. In this treatment interaction only the furrowing-rabbit exclusion and the seeding-rabbit exclusion treatments increased the cover of black grama.

Bush muhly cover was increased in only two treatment combinations at Ragged Tank where the interaction of all primary treatments took precedence. In each case the treatment included brush removal. At Parker Tank the brush removal x rabbit exclusion interaction took precedence, and only when both primary factors were present did bush muhly cover increase. The independent action of rabbit exclusion was the only treatment that increased bush muhly cover at Dona Ana.

Dropseed cover increased only when brush removal and rabbit exclusion were combined at the Ragged and Parker Tank sites. Rabbit exclusion alone increased the basal cover of dropseed at the Dona Ana site.

Brush removal was the major factor increasing fluffgrass at Ragged Tank. At Parker Tank the treatment combinations of brush removal-rabbit exclusion and furrowing-brush removal-rabbit exclusion increased the basal cover of fluffgrass. Seeding-rabbit exclusion, seeding-furrowing-rabbit exclusion and the furrowing-brush removal-rabbit exclusion treatment combinations increased the basal cover of fluffgrass at Dona Ana.

There were no significant differences among treatments for total useful perennial grasses at Parker Tank. Brush removal and rabbit exclusion acted as independent factors that increased the cover of total useful perennial grasses at Ragged Tank. At the Dona Ana site rabbit exclusion acted as an independent factor to increase the total useful perennial grasses. Both seeding and furrowing, separately but not in combination, increased the cover of the total useful perennial grasses at the Dona Ana site.

The physical presence of the rabbit exclusion fence at the Dona Ana site was of great importance. The fence reduced the effects of the severe conditions imposed on the vegetation as well as the soil, by retaining the soil already present and causing the deposition of soil during periods of runoff. The soil was deposited on the downhill side of the plots that had the rabbit exclusion fence. Approximately one-fourth of the area of each of these plots had a soil depositional zone. In these areas very little, if any, creosotebush was present. Also, these areas were the only sections of the plot at the Dona Ana site that maintained any of the perennial grasses. The absence of creosotebush in these depositional zones concurs with the findings of Spalding (1909) and Gardner (1951). They stated that this species is found in eroding rather than depositing situations.

The brush removal treatment was consistently the best treatment to clear the plots of creosotebush and other shrubs at all of the study sites. Brush removal proved to be the best treatment for increasing black grama, bush muhly, and fluffgrass at Ragged Tank and black grama at Parker Tank. For dropseed at Ragged Tank and for bush muhly and dropseed and Parker Tank the best treatment was a combination of brush removal and rabbit exclusion. The treatment combination of furrowing-brush removal-rabbit exclusion increased fluffgrass at Parker Tank. Brush removal and rabbit exclusion acted as independent factors to give the best cover of total useful perennial grasses at Ragged Tank, but no treatment combination improved total useful perennial grasses at Parker Tank. Rabbit exclusion alone improved the cover of bush muhly and dropseed at the Dona Ana site. Seeding-rabbit exclusion and furrowing-rabbit exclusion increased the cover of black grama at the Dona Ana site. The basal cover of fluffgrass was improved by treatment of brush removal-rabbit exclusion and furrowing-rabbit exclusion. Rabbit exclusion, seeding, and furrowing increased the basal cover of total useful perennial grasses when allowed to act as independent factors at the Dona Ana site.

SUMMARY

Three study sites were located on the Jornada Experimental Range, 25 miles north of Las Cruces, New Mexico, to investigate the effects of seeding, furrowing, brush removal, and rabbit exclusion in a factorially designed experiment on creosotebush-infested areas. The climate of the area is characterized by mild winters and hot summers, with great variations between day and night temperatures. The growing season occurs from July 1 to September 30, the period when both temperatures and moisture conditions are ideal for plant growth. Nearly 60% of the mean annual precipitation (209 mm) occurs during these months, but it comes as a result of convectional storms that are erratic in nature and of high intensity. Frequently precipitation resulting from these localized thunderstorms is of such high intensity that much of the water is lost as runoff. The average annual evaporation is nearly ten times the average annual precipitation, and the wind movement is high, especially for March through June.

The study was initiated in July and August of 1938 and September of 1939 and continued until September of 1967 with periodic retreatment and sampling. At each site sixteen 21.3 m square plots were established and the treatments were randomly assigned to the plots. Each plot was then

divided into an east and a west subplot from which 14 line-transects were selected at random to sample each subplot.

Brush removal was the only treatment that consistently reduced the canopy cover of creosotebush and total shrubs at all three sites. At the Ragged Tank site the basal cover of black grama, bush muhly, fluffgrass, and total useful perennial grasses, all perennial grasses except fluffgrass, significantly increased with the brush removal treatment. The basal cover of total useful perennial grasses also increased significantly with rabbit exclusion, while the basal cover of dropseed increased when both brush removal and rabbit exclusion treatments were present.

Black grama basal cover increased significantly with brush removal alone, but bush muhly and dropseed increased significantly with the brush removal-rabbit exclusion treatment at Parker Tank. Fluffgrass basal cover increased significantly at Parker Tank with the furrowing-brush removal-rabbit exclusion treatment, but no treatment increased the total useful perennial grasses at Parker Tank.

The grass cover at the Dona Ana site was influenced greatly by the physical presence of the rabbit exclusion fence by retaining the soil, causing deposition of more soil, and reducing the effects of the severe runoff. The physical presence of the fence was of such importance that the rabbit exclusion treatment was present in every significant treatment combination for the grass species at the Dona Ana site. Seeding-rabbit exclusion and furrowing-rabbit exclusion significantly increased the cover of black grama. Rabbit exclusion alone increased the cover of bush muhly and dropseed significantly. Fluffgrass cover increased significantly by three treatment combinations, all of which included rabbit exclusion, while the cover of the total useful perennial grasses increased significantly with seeding, furrowing, and rabbit exclusion separately.

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APPENDICES

APPENDIX 1 RESULTS OF ANALYSIS OF VARIANCE FOR SPECIES AND GROUPS OF SPECIES AT RAGGED TANK.

Source of Variation [a]	Degrees of Freedom	Creosote-bush	Total Shrubs	Black Grama	Bush Muhly	Drop-seed	Fluff-grass	Total Useful Perennial Grasses
Total	2239							
Year	4	*		*	*	*	*	*
S	1							
F	1	*	*					
B	1	*	*	*	*	*	*	**
R	1	*	*			*	*	**
SF	1	*	*	*	*			**
SB	1	*						
SR	1							
FB	1							
FR	1			*				
BR	1					**	**	
SFB	1			*				
SFR	1	**	**					
SBR	1	**	**	*				
FBR	1	**		*				
SFBR	1			**	**			
Treatment X Year	60							
Error	2160							

(*) Significant (0.05) F test
(**) Significant (0.05) F test that takes precedence
a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion

APPENDIX 2 RESULTS OF ANALYSIS OF VARIANCE FOR SPECIES AND GROUPS OF SPECIES AT PARKER TANK.

Source of Variation[a]	Degrees of Freedom	Creosotebush	Total Shrubs	Black Grama	Bush Muhly	Dropseed	Fluffgrass	Total Useful Perennial Grasses
Total	1791							
Year	3	*	*	*	*	*	*	*
S	1	*	*					
F	1	*						
B	1					*		
R	1					*		
SF	1							
SB	1	*						
SR	1		*					
FB	1	*	*					
FR	1							
BR	1			**	**	**		
SFB	1							
SFR	1	*	**					
SBR	1		**					
FBR	1							
SFBR	1	**					**	
Treatment X Year	45							
Error	1728							

(*) Significant (0.05) F test
(**) Significant (0.05) F test that takes precedence
a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion

APPENDIX 3 RESULTS OF ANALYSIS OF VARIANCE FOR SPECIES AND GROUPS OF SPECIES AT DONA ANA.

Source of Variation[a]	Degrees of Freedom	Creosotebush	Total Shrubs	Black Grama	Bush Muhly	Dropseed	Fluffgrass	Total Useful Perennial Grasses
Total	1791							
Year	3	*	*	*	*		*	
S	1	*	*					
F	1	*	*					
B	1		*					
R	1		*	*	**	**		*
SF	1			*				**
SB	1							
SR	1							
FB	1	*					*	
FR	1		*					
BR	1							
SFB	1	*	*					
SFR	1			**			**	
FBR	1						**	
SFBR	1	**	**					
Treatment X Year	45							
Error	1728							

(*) Significant (0.05) F test
(**) Significant (0.05) F test that takes precedence
a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion

APPENDIX 4 MEAN PERCENT COVER FOR ALL PLOTS AND SPECIES OR GROUPS OF SPECIES AT RAGGED TANK.

Plot[a]	Creosote-bush	Total Shrubs	Black Grama	Bush Muhly	Drop-seed	Fluff-grass	Total Useful Perennial Grass
(1)	17.12	21.03	0.00	0.17	0.00	0.01	0.01
S	15.74	18.94	0.06	0.57	0.00	0.10	0.64
F	16.96	22.49	0.00	0.24	0.00	0.03	0.24
B	4.50	6.24	0.43	1.73	0.02	0.58	2.18
R	15.38	22.59	0.06	1.24	0.01	0.13	1.30
SF	19.40	22.12	0.16	0.56	0.00	0.08	0.57
SB	4.16	4.98	0.18	0.50	0.00	0.59	0.52
SR	19.63	26.30	0.00	0.40	0.00	0.02	0.40
FB	6.64	7.90	0.02	0.34	0.00	0.16	0.35
FR	21.92	30.26	0.00	0.37	0.00	0.01	0.38
BR	7.12	9.37	0.09	1.10	0.33	0.18	1.59
SFB	6.16	8.38	0.11	1.10	0.00	0.41	1.21
SFR	21.29	25.04	0.02	0.50	0.02	0.02	0.54
SBR	6.11	8.50	0.72	1.28	0.12	0.14	1.47
FBR	11.20	15.62	0.14	1.32	0.11	0.76	1.57
SFBR	5.56	8.87	0.20	1.89	0.10	0.13	3.05

a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion, (1)-control

APPENDIX 5 MEAN PERCENT COVER FOR ALL PLOTS AND SPECIES OR GROUPS OF SPECIES AT PARKER TANK.

Plot[a]	Creosote-bush	Total Shrubs	Black Grama	Bush Muhly	Drop-seed	Fluff-grass	Total Useful Perennial Grass
(1)	20.32	22.84	0.07	0.29	0.00	0.31	0.37
S	14.75	16.74	0.12	0.11	0.01	0.64	0.24
F	18.85	23.78	0.09	0.35	0.02	0.43	0.44
B	5.90	10.44	0.12	0.06	0.02	0.60	0.19
R	18.86	22.65	0.21	0.02	0.01	0.83	0.24
SF	20.42	22.91	0.12	0.24	0.02	0.12	0.38
SB	5.40	6.33	0.17	0.13	0.01	0.64	0.32
SR	19.88	26.65	0.28	0.18	0.01	0.46	0.47
FB	5.19	5.96	0.20	0.16	0.00	0.54	0.36
FR	23.86	26.24	0.10	0.11	0.00	0.62	0.22
BR	6.22	9.40	0.11	0.21	0.12	0.12	0.43
SFB	4.56	5.56	0.27	0.18	0.00	0.76	0.46
SFR	19.14	24.06	0.10	0.08	0.02	0.46	0.20
SBR	8.32	11.62	0.12	0.22	0.23	0.54	0.57
FBR	7.36	10.46	0.14	0.18	0.21	0.75	0.53
SFBR	6.41	7.97	0.11	0.21	0.19	0.44	0.52

a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion, (1)-control

APPENDIX 6 MEAN PERCENT COVER FOR ALL PLOTS AND SPECIES OR GROUPS OF SPECIES AT DONA ANA.

Plot[a]	Creosote-bush	Total Shrubs	Black Grama	Bush Muhly	Drop-seed	Fluff-grass	Total Useful Perennial Grass
(1)	9.16	13.92	0.00	0.00	0.00	0.00	0.00
S	8.04	12.48	0.00	0.01	0.00	0.00	0.01
F	11.78	15.21	0.00	0.01	0.00	0.00	0.01
B	4.99	6.55	0.00	0.02	0.00	0.00	0.02
R	7.59	11.49	0.01	0.01	0.00	0.00	0.05
SF	9.71	11.32	0.00	0.00	0.00	0.00	0.00
SB	5.13	6.76	0.00	0.01	0.00	0.00	0.02
SR	8.54	12.30	0.05	0.01	0.15	0.34	0.23
FB	6.37	7.45	0.00	0.00	0.00	0.00	0.00
FR	14.93	19.65	0.00	0.34	0.00	0.00	0.41
BR	5.77	9.24	0.02	0.01	0.00	0.00	0.03
SFB	4.41	6.89	0.00	0.01	0.00	0.04	0.01
SFR	7.26	11.46	0.00	0.06	0.00	0.00	0.06
SBR	3.84	6.50	0.03	0.01	0.02	0.00	0.08
FBR	4.25	10.06	0.07	0.07	0.04	0.08	0.23
SFBR	5.54	9.85	0.00	0.01	0.05	0.01	0.06

a S-seeding, F-furrowing, B-brush removal, R-rabbit exclusion, (1)-control