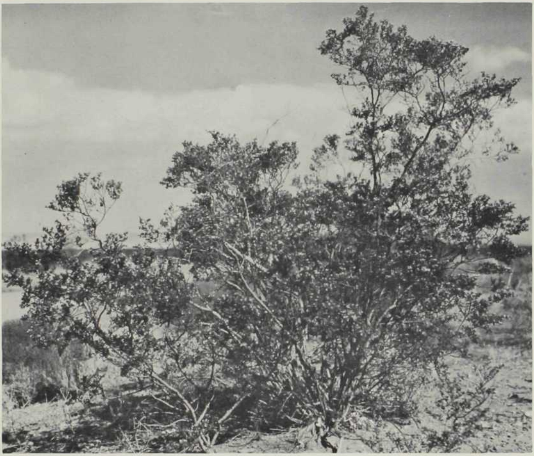
Life-History Characteristics of the Creosotebush, *Larrea tridentata*



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CONTENTS

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Life-History Characteristics of the Creosotebush, *Larrea tridentata*

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Creosotebush (*Larrea tridentata* (DC.) Coville) aggressively invades desert plains grassland in Arizona, New Mexico, and western Texas. Gardner (10) recorded invasion of grassland along the Rio Grande Valley in southern New Mexico and pointed out that it takes the form of frontal advances along the margins of the larger creosotebush communities and of single plants and then small outlier stands at varying distances from the main bodies of the larger communities. Yang (21) recorded invasions of grassland on upland plains adjacent to the Rio Grande Valley. Buffington and Herbel (2), using 1858 General Land Office survey records and recent observations, reported increase of creosotebush on the Jornada Experimental Range in southern New Mexico from 644 acres of moderately invaded range (creosotebush comprising 15 to 55 percent of the perennial vegetation) in 1858 to 12,388 acres of heavily invaded range (55 to 100 percent of the vegetation) in 1963. Dick-Peddie (8) found from these early General Land Office survey records that level and gently rolling land in southern New Mexico generally was covered with grama grass and that creosotebush was restricted to foothills and outlying well-drained knolls.

Damage to grassland range following invasion by creosotebush takes the form of reduced perennial grass cover and yield and increased erosion of soil (Cooperrider and Hendricks, 6; Gardner, 10; Leithead, 14). Jardine and Hurtt (12) reported extensive areas of black grama (*Bouteloua eriopoda* (Torr.) Torr.) grassland on the Jornada Experimental Range, as shown by range survey in 1915. These areas were entirely replaced by creosotebush by 1934, a scant 20 years later. Canfield (4) recorded basal cover of black grama of 1,127 square centimeters per square meter (11.27 percent) for the period 1925-27 on a remnant of this grassland. Average herbage yield of black grama, clipped to stubble heights of one and two inches, was 768 pounds per acre for the same years. By 1940, the last of this remnant stand had disappeared, leaving the site dominated by creosotebush with little or no herbaceous ground cover. Thus the shift from productive and protective perennial grass cover to the creosotebush type may be rapid and extreme.

Accompanying the reduction in perennial grass cover is a great loss in grazing capacity of the range. Paulsen and Ares (15) reported a decrease in capacity from 7.1 to 3.7 animal-unit years per section over a 25-year period in a creosotebush-tarbush (*Flourensia cernua* DC.) pasture on the Jornada Experimental Range. They attributed

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the loss in capacity to continuous encroachment of the brush. While this was a large loss in capacity, it does not represent the loss which generally accompanies the full development of the creosotebush community. This commonly attained development brings about the loss of practically 100 percent of original grazing capacity.

The capacity of any noxious plant species to invade and dominate a range and the time and spatial patterns involved are in large part related to the autecological characteristics of that species, especially its fruiting, dissemination, establishment, growth, and competitive characteristics. The susceptibility to control, whether by grazing management or other range management practices, and the choice of control methods also depend, or should depend, upon these same and other autecological characteristics. The work reported here was designed to determine certain of these characteristics which have a bearing on the invasion of grassland range by creosotebush and on the control of creosotebush on invaded rangeland. More specifically, the objectives of the work were to determine fruit and seed production, viability, establishment, and growth characteristics of creosotebush. These are, of course, only a few of the many characteristics which constitute the complete autecology of the species.

Methods

Description of Experimental Areas

The field work was done on or near New Mexico State University's Agricultural Experiment Station Ranch in Dona Ana County. The ranch lies on the southern part of the Jornada Plain and in the bordering hills and mountains between the plain and the Rio Grande River on the west. This part of the plain is nearly level to gently undulating and varies in elevation between 4300 and 4400 feet (20).

The climate of the area is arid. Paulsen and Ares (15) report the 38-year average annual precipitation at the Jornada Experimental Range headquarters, representative of the central southern part of the plain, to be 9.02 inches. An average of 4.74 inches, slightly over half the annual total, falls during July, August, and September, the main growing season on the range. An average maximum temperature of 97°F is reported for June, and an average maximum of 56°F is reported for January. Extremes of —20° and 109°F have been recorded at the Jornada Experimental Range headquarters (16, 17). Departures from mean annual and mean growing season precipitation are frequent and marked, and drought is common.

Soils of the southerly part of the plain on which the experiment station ranch is located are mainly sandy loams underlain by indurated calcium carbonate at depths varying from a few inches to 30 inches and more.

The vegetation of the lower Jornada Plain consists of grass and brush types. The grass types consist in the main of the black grama-mesa dropseed (*Sporobosus flexuosus* (Thurb.) Rydb.) climax and various successional stages of this climax indirectly resulting from the extremely damaging drought of the early 1950's. Tobosa (*Hilaria mutica* (Buckl.) Benth.)-burro-grass (*Scleropogon brevifolius*

Phil) types dominate the more restricted lowland swales on the plain. The brush types consist in the main of separate stands of mesquite (*Prosopis juliflora* (Swartz) DC. var. *glandulosa*) and creosotebush, but over limited areas these two species occur in mixed stands.

Fruit Production

Fruit production was determined on plants in the creosotebush vegetation type and in grassland, both on the station ranch. Groups of 10 full-grown plants each were delineated at three locations in each of these vegetation types. Each fall from 1955 to 1962, except 1956, a typical branch was collected from each plant, the fruits were removed and counted, and the branch was oven-dried and weighed. Fruit production is reported as number per 100 grams of branch weight. Upon completion of these determinations, all leaf-bearing branches and portions of branches of each plant in the several groups were clipped, oven-dried, and weighed for an estimate of fruit production per plant.

Carpel Fill

Carpel fill, or seed set, was determined by examination of carpels used in the germination tests after these tests were completed and by direct examination of carpels of fruits collected for the fruit production study.

Viability

Viability was determined through germination tests of material collected on the ranch in November, each year from 1955 to 1961. In 1954, material was collected near the University campus, about 20 miles south of the ranch. After collection, all material was dusted with DDT to control insects and stored in the laboratory in paper bags. Tests were conducted in the New Mexico State Seed Laboratory, in 17°C constant-temperature, humidified germinators. Four lots of 50 carpels each were used in each test. The carpels were placed in petri dishes on standard germination blotter paper moistened with distilled water. The carpels were dusted with Spergon to control fungus growth. The tests were run for 60-day periods. After each test, the carpels with no germinated seed were opened to determine whether any seed was present. Germination percentage was computed on the basis of the filled carpels.

Influence of Site on Creosotebush Establishment

This experiment was conducted to determine the influence of site characteristics on establishment of creosotebush. Three sites were included in the study: one a calcareous variant of Palma loamy sand with caliche outcrops at the top of a gently sloping ridge, occupied by a fully developed creosotebush community; the second, Simona sandy loam on an upland plain, occupied by good condition black grama grass cover; and the third, a deep clay loam in an intermittently lightly flooded swale, occupied by fair to good tobosa grass cover. Five one-yard-square grids were established on each site in June or early July in 1956 to 1959, inclusive. Two carpels were planted at depths of 1/4 to 3/8 inch at each of 100 points (10 rows of 10 points each) on each grid. The planted carpels were the heavier ones remaining after light carpels were separated by flotation on water. Grids were examined for seedling emergence and survival each fall from 1956 to 1963, except 1961.

Influence of Soils on Emergence and Early Growth of Creosotebush Seedlings

This was a pot test conducted in the greenhouse. Soils from six sites on and in the vicinity of the station ranch were used. These soils are representative of sites which are presently occupied by creosotebush or subject to invasion by creosotebush.

One hundred carpels from a collection averaging 43.3 percent fill and 91.1 percent viability were spot-seeded in a gridiron pattern in each of two five-gallon buckets of each soil. Damping-off of emerged seedlings reached very high levels, all seedlings being affected in some buckets. This necessitated replanting, which was done after drenching the soil in each bucket with a 1:10,000 water solution of Panogen (methyl mercury dicyandimide, 2.2 percent). Thus, five seedlings were obtained in each bucket, one centrally and four peripherally located. After eight months' growth, the four peripheral seedlings in each bucket were clipped at soil level, dried, and weighed. (Three of the four peripheral seedlings in one bucket of stable sandy loam soil died before reaching the age of eight months. The cause was not apparent.)

At the end of 12 months, the central seedling in each bucket was clipped at soil level, dried, and weighed.

Influence of Range Condition on Creosotebush Establishment

From 1956 to 1958, this experiment was conducted at one location on the ranch, and from 1959 to 1961, it was expanded to include two additional locations. At each location in each year, 10 transects were established—five in very poor condition range and five in adjacent good condition range. Condition was determined by basal cover of desirable perennial grasses—0.15 percent on the very poor condition range and 1.71 percent on the good condition range. Each transect consisted of a 200-foot line marked by stakes at each end. Seed planting spots were located at two-foot intervals along the transect, from 2 to 200 feet. Spots were marked with nails for future observation.

In June or July each year, four carpels were planted at each spot at depths of 1/4 to 3/8 inch. Only the heavier carpels separated by water flotation were planted.

At the time of planting, perennial grass cover values were obtained by observation of the surface condition for presence of perennial grass under each foot mark along the transects from 1 to 200 feet. After the summer growing season each year, emergence and survival of all creosotebush seedlings on the transects were recorded.

Natural Field Establishment

This experiment was designed to determine how the number and proximity of seed-bearing plants and the soil stability affect the rate of natural establishment. In 1956, plots representing three variations of these conditions were established, and in 1962 plots representing a fourth variation were added. Circular plots 400 feet in diameter were used where creosotebush plants were scattered. In moderate to heavy stands of creosotebush, 200-foot diameter plots were used. All creosotebush plants on the plots were located from a central hub by means of azimuth and radial tape readings.

Repeat observations were made in 1962 and 1965.

Growth and Maturation

This experiment had as its objective the determination of the rate of growth and maturation of creosotebush seedlings. Three groups of 20 plants each of naturally established seedlings were delineated at each of two locations in the vicinity of the experiment station ranch. One location was on the adjacent Jornada Experimental Range and the other was on the A. L. Winder ranch, also adjacent to the experiment station ranch. Height measurements were recorded for each plant each fall from 1956 to 1965 at the Winder location and from 1957 to 1965 at the Jornada location. Record of fruit production was made for the plants as they came into fruiting.

Death Loss and Borer Damage

This study was made in mature stands. Temporary plots were laid out on the experiment station ranch and at several outlying locations in Sierra, Luna, Dona Ana, and Otero counties. Dead creosotebush plants were counted on these plots. Insect larvae were observed to be responsible for damage to some of the dead plants, so additional dead plants and unthrifty and thrifty live plants were dug, and the crowns were split and examined for larval channelling.

Results and Discussion

Fruit Production

Results of the fruit production study are presented in table 1. The unusually low production in 1962 is attributed to the extremely low temperature which occurred on January 11 of that year. The Jornada Experimental Range headquarters recorded a near-record low of —19°F for this date (18). Other extreme lows were recorded at numerous stations in south-central New Mexico on this date. Following this, the leaves of creosotebush plants over wide areas on and near the experimental ranch turned brown and dropped, and many plants exhibited split stems and sloughed bark. Few if any plants were killed, however, and most plants produced vigorous basal sprouts. Flower buds are thought to have been severely damaged by the cold, because flowering and fruiting were greatly reduced in heavily damaged creosotebush stands.

These effects of cold were similar to those reported by Fosberg (9) for creosotebush near St. George, Utah in 1937. Here damage to stems was heavy, and all plants exhibited greatly reduced fruit production, but no plants were killed.

In 1956, fruit production on that part of the ranch where the fruit production study groups were located was exceedingly low. Although rainfall was low from January through September, it did not appear to have been low enough to account for the extreme deficiency of production. Low temperature may have been partially responsible. A minimum of 5°F was recorded for February 3, 1956 at the Jornada Experimental Range headquarters. No stem, twig, or leaf damage was observed following this low temperature, however.

Variance analysis of the data of table 1, excluding that for 1962, revealed significant differences between plants in the creosotebush type and those in the grassland type and between those on certain of the locations in the grassland type. Fruit production in the creosotebush type was between two and eight times that in open grassland. The difference in fruit set in the two vegetation types was easily seen in the field. It appeared to be related in large part to difference in clipping and trampling damage.

Isolated plants were commonly clipped by small rodents and rabbits and trampled and horned by cattle and other larger animals, presumably antelope, in the study area. Rabbits clipped the stems of isolated plants at heights ranging from 4 to 18 inches above ground level, apparently at irregular intervals. Cattle commonly trampled and horned the larger isolated plants, breaking the stems back to one- or two-foot stubs. Rabbits appeared to be responsible for the greater part of the total damage. Few mature isolated plants escaped this damage; in fact, close observations commonly revealed a series or sequence of damage events on older plants. Apparently, as a result of this clipping and trampling, the shrubs were kept in a vigorous, vegetative, non-fruiting condition. Typical rabbit clipping and the low-fruiting condition are contrasted with the unclipped, high-fruiting plants in figure 1.

The clipping and trampling of grassland plants also had some influence on their size, and this, in turn, affected fruit production per plant. Size of plants, expressed as dry weight of branches, and calculated average fruit production per plant are shown in table 1. Plants in the Powerline and Pasture 2 grassland groups produced much less fruit than those in the creosotebush vegetation type. The greater size of the plants in the Selden group compensated largely for the lower production per unit of branch weight, with the result that plants in this grassland group produced almost as much fruit as the smaller plants in the creosotebush type.

The difference in production between the Selden group and the other grassland groups was indirectly a result of more numerous creosotebush plants at the Selden group location. The greater number of plants had the effect of reducing clipping and trampling each plant, and this allowed the plants to reach a larger size and more mature condition. This, in turn, caused further reduction in clipping and trampling. The production of the plants in the Powerline and Pasture 2 groups was more representative of plants in lightly invaded grassland.

The similarity in production between the Selden group and the creosotebush-type groups was also caused by the larger size of plants in the Selden group, which compensated for the lower production per unit weight of branch in this group. The larger size of plants in the Selden group as compared with the creosotebush-type plants probably results from the more favorable site conditions in the grassland and the much lower interplant competition.

Census figures on jackrabbits in the study areas in recent years reflect low populations. These have in the main not damaged the desirable forage grasses. The cattle stocking rate has been relatively light, averaging 3.77 animal unit years per section yearlong before the drought of the early 1950's and somewhat lower since. Thus, relatively low numbers of both

TABLE 1. Fruit production of creosotebush plants in the creosotebush vegetation type and in grassland, Agricultural Experiment Station Ranch, 1955 and 1957-62

Vegetation Type and Group	1955	1957	1958	1959	1960	1961	1962	Group Average[1,2]	Type Average[1,2]	Average Weight of Branches per Plant[3]	Calculated Average Annual Fruit Production per Plant
	Number of fruits per 100 grams of branch									Gram	Number
Creosotebush											
Parker	518	278	136	200	280	160	1	278 x		615	1709
Blackstrike	390	394	116	170	332	216	2	269 x		637	1714
Pasture 13	385	426	130	228	213	72	0	242 x	263 m	695	1682
Grassland											
Selden	375	145	93	103	78	108	0	150 y		1081	1621
Powerline	144	92	26	13	27	57	0	59 z		431	254
Pasture 2	90	28	50	50	10	11	0	39 z	83 n	306	119
Annual Average[1]	317	227	92	127	173	104					
	a	b	c	c	bc	c					

[1] Means associated with the same letter are not significantly different at the .05 probability level.
[2] Averages do not include 1962 values.
[3] The branches were oven-dried and weighed at the end of the study.

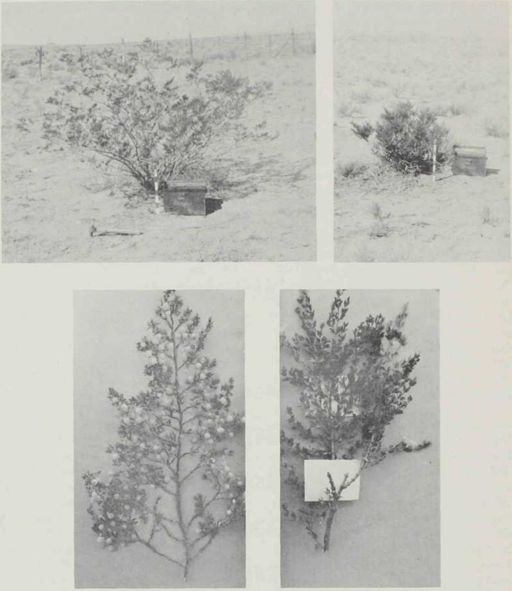


Fig. 1. **Upper left.** Normal creosotebush plant which was protected from clipping and trampling. **Upper right.** Plant in a highly vegetative, low fruiting condition, because of repeated clipping by rabbits. **Lower left.** Branch from unclipped plant showing abundant fruit production. **Lower right.** Branch from clipped plant.

cattle and jackrabbits produced the degree of trampling and clipping damage observed.

The correlation of fruit production in the creosotebush type and precipitation for the preceding January-September period suggests a trend in the direction of reduced production with increased precipitation at the .10 level of probability (figure 2). This is

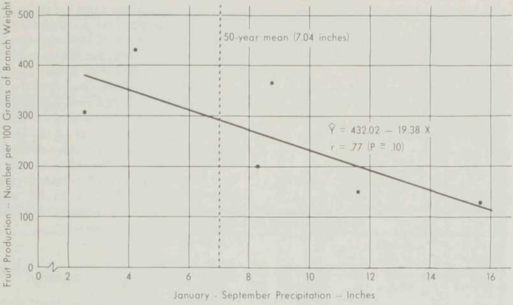


Fig. 2. Relationship between January-to-September precipitation and creosotebush fruit production, Agricultural Experiment Station ranch, 1955 and 1957-61.

consistent with Dalton's (7) observations that the least watered plants produced the most flowers and that frequent watering induced flower drop. Over a long period, fruit production might be a little higher than that observed in the present study, since the long-time average January-September precipitation as recorded for the Jornada Experimental Range headquarters (19) is 1.48 inch lower than the average for this period observed in this study. Annual fruit production may also exceed the values found in the current study because of biseasonal fruiting. Creosotebush plants commonly carry nearly mature fruit early in the summer preceding the main growing season. It was not determined in this study whether such plants produce additional fruit later in the year. Chew and Chew (5) reported spring and fall seed production near Portal, Arizona to be approximately proportionate to rainfall before blooming in spring and fall, with fall production being between 9 and 10 times spring production. General observations indicate that a similar response to spring and main growing-season precipitation prevails in the area of this study, and that the fall fruit production is several times as great as the early season production.

Carpel Fill

Fill of carpels is presented in table 2. Fill varied from 12.50 to 61.75 percent and averaged 35.26 percent. This

TABLE 2. Average carpel fill of creosotebush fruit from plants in the creosotebush vegetation type and in grassland, Agricultural Experiment Station Ranch, 1955 and 1957-61

Vegetation Type	Fruit Collection	1955	1957	1958	1959	1960	1961	Vegetation Type Average[1]
				percent				
Creosotebush	General Fall Collection	36.50	39.75	33.50	61.75	38.00	38.25	41.29 m
Creosotebush	Fruit Production Study	25.50	45.25	22.00	37.00	29.33	40.00	33.16 n
Grassland	Fruit Production Study	26.25	44.50	12.50	32.50	36.00	37.50	31.34 n
Year average[1]		29.41 ab	43.16 d	22.67 a	43.75 d	34.42 bc	38.58 cd	35.26

[1] Means associated with the same letter are not significantly different at the .05 probability level.

average is much less than the 60.6 percent (3.03 mature seed per fruit of five carpels) reported by Chew and Chew (5). Their value was for the year 1958 only, however, and may simply represent fill in a single favorable year. Variance analysis revealed significant differences among years and between the two collection sources in the creosotebush site. Correlation analysis failed to reveal a relationship between seed set and January-September precipitation. No difference in fill was found between the creosotebush vegetation type and the grassland.

Seed Viability and Longevity

Results of germination tests with seed collected each year are presented in table 3. Germination percentages varied from 54.8 to 89.6 and averaged 73.9. Variance analysis revealed significant differences among years. Correlation analysis failed to reveal a relationship between viability and precipitation for the January-September period preceding collection.

Germination values for the 1954, 1955, and 1956 collections from collection to January, 1962 are presented in table 4. A number of significant differences are indicated within each collection. The November-to-January increase in germination percentage of the 1954 crop may reflect an after-ripening process in this lot. The lower values for the 1956 crop in the latter part of the test period may reflect a decline in viability. Other differences are thought to have resulted from inadvertent variations in water, light, and fungal infection during the tests (Gerard, 11). The average germination percentages varied little for two years and then tended to decline. Six of the last nine values in the last column of table 4 fell below the overall average more than the margin of tol-

TABLE 3. Average germination percentage of creosotebush seed collected on the Agricultural Experiment Station Ranch, 1954-61[1,2]

1954	1955	1956	1957	1958	1959	1960	1961	Avg.
82.5 cd	89.6 d	75.9 bcd	79.7 bcd	69.4 bc	66.3 ab	73.2 bc	54.8 a	73.9

[1] Means associated with the same letter are not significantly different at the .05 probability level.
[2] The percentage for each year is an average of 13 tests run from November 15 to May 15 on each year's collection.

TABLE 4. Average germination of creosotebush seed from 1954, 1955, and 1956 crops, from dates of collection to January, 1962

Test Date	1954 Crop[1]	1955 Crop[1]	1956 Crop[1]	Average Age of Seed		Average Germination
	percent	percent	percent	yr.	mo.	percent
	(1954)	(1955)	(1956)			
Nov. 16	63.7 a	85.1 c	77.9 efg	..	..	75.5
Dec. 1	72.4 c	87.9 de	87.5 i	0	1	82.5
Dec. 16	79.9 d	87.1 cd	68.5 c	..	..	78.4
	(1955)	(1956)	(1957)			
Jan. 1	84.9 fgh	91.0 fgh	60.6 b	0	2	78.8
Jan. 16	77.8 d	97.3 i	80.1 gh	..	..	85.0
Feb. 1	88.5 ijk	88.1 de	63.5 b	0	3	80.0
Feb. 16	87.0 ghijk	82.6 b	75.3 def	..	..	81.6
Mar. 1	72.2 c	89.6 defg	83.8 hi	0	4	81.8
Mar. 15	87.4 hijk	89.7 efg	73.7 de	..	..	83.5
Apr. 1	85.0 fgh	95.0 i	83.7 hi	0	5	87.8
Apr. 15	93.9 l	88.6 def	74.4 def	..	..	85.5
May 1	96.6 l	92.0 gh	77.0 defg	0	6	88.4
May 16	84.0 fg	91.4 gh	80.7 gh	..	..	85.3
June 1	94.3 l	92.7 h	50.2 a	0	7	79.0
July 1	93.6 l	87.3 cde	74.4 def	0	8	85.0
Aug. 1	85.5 fghi	92.8 h	74.8 def	0	9	84.3
Sept. 1	83.9 fg	91.6 gh	76.6 defg	0	10	83.9
Oct. 1	90.0 k	81.5 b	87.9 i	0	11	86.4
Nov. 1	84.4 fgh	96.2 i	77.0 defg	0	12	85.8
	(1956)	(1957)	(1958)			
Feb. 1	85.0 fgh	....	78.7 fg	1	3	81.8
May 1	85.0 fgh	87.6 de	....	1	6	86.3
Aug. 1	94.0 l	....	72.9 d	1	9	83.4
Nov. 1	80.5 de	97.3 i	....	2	0	88.9
	(1957)	(1958)	(1959)			
Apr. 1	89.4 jk	....	63.4 b	2	5	76.4
Dec. 1	86.8 ghijk	....	....	3	1	86.8
	(1958)	(1959)	(1960)			
June 1	67.4 b	....	77.8 efg	3	7	72.6
Dec. 1	....	85.2 c	59.9 b	4	1	72.6
			(1962)			
Jan. 1		....	61.5 b	4	2	61.5
	(1959)					
June 1	71.1 c	....	....	4	7	71.1
Dec. 1	82.9 ef	....	....	5	1	82.9
	(1962)	(1962)				
Jan. 1	....	61.0 a	....	5	2	61.0
Jan. 1	89.5 ghij	....	....	7	2	89.5
Average[2]	84.0	88.6	73.7			82.1

[1] Means associated with the same letter are not significantly different at the .05 probability level.
[2] Differences between these annual averages and those in table 3 are due to differences in number of tests used to compute the averages.

erance allowed in official seed testing (1). Indications are that viability holds up fairly well for four or five years, and the 1954 data suggests that it may, in some instances, continue to remain up for as long as seven years. Viability under natural conditions, involving exposure on or near the soil surface, cannot be projected from the present study.

If germination of seed in the carpels brought about a reduction in germination percentage, it was not nearly as great as that reported by Knipe and Herbel (13)—90.5 percent with the seed removed from the carpels and 34 percent with seed remaining in the carpels.

Influence of Site on Creosotebush Seedling Emergence

Analysis of variance revealed no significant differences in average seedling emergence among sites or years (table 5). Some differences within sites and years were revealed. At the ridgetop and upland sites, emergence was low in 1956 because of very low rainfall. At the swale site, emergence was highest in 1956 because of reduced interference from excessive moisture and flooding. At the ridgetop and upland sites in 1958, growing-season rainfall was about three times the long-time average; however this was not reflected in increased emergence. No seedlings survived at any site in 1963. All planting grids were located in plant cover normal to the sites. The extent to which the biotic factors of microclimate and competition influenced the outcome is unknown. It cannot be concluded from the results obtained over the short period of study that there are no differences in seedling emergence and establishment among the sites.

Influence of Soil on Emergence, Damping-off, and Growth of Creosotebush Seedlings

Emergence, damping-off and growth data for the creosotebush seedlings grown in the several soils are

TABLE 5. Average emergence of creosotebush seedlings at three sites on the Agricultural Experiment Station Ranch, 1956-59[1]

Site	Vegetation Type	1956	1957	1958	1959	Site Average
		seedlings per 100 viable seed planted				
Shallow loamy sand; ridgetop	Creosotebush	1.83a x	10.48b y	5.28ab xy	11.00b y	7.15
Sandy loam; upland	Black grama grass	4.84ab x	13.71b y	8.05b xy	6.00ab x	8.15
Deep clay loam; swale	Tobosa grass	11.11b y	3.05a x	.76a x	2.14a x	4.26
Annual average[1]		5.93	9.08	4.70	6.38	6.52

[1] Means associated with the same letter are not significantly different at the .05 probability level. No significant differences among averages for years or sites were revealed by variance analyses.

shown in table 6. Emergence values exhibited significant differences among soils.

Emerged seedlings showed varying degrees of infection by damping-off organisms, and most were either dead or heavily damaged. The low emergence probably reflected highly damaging infection in early germination stages. Death and damage values, which also differed significantly among soils, were very likely influenced by emergence values; that is, the greater the number of emerged seedlings, the greater the number to exhibit death and damage. The number of seedlings sustaining only light damage, from which they might have recovered under favorable conditions, exhibited considerable variation. No seedlings fell in this category in two of the soils, and an average of six per bucket fell in this category in the one deep sandy loam soil. Emergence and damage in soils from the creosotebush types were not different from emergence and damage in soils from the other vegetation types.

Growth, as measured by weight, exhibited erratic values, and differences among soils were not significant for seedlings clipped at either 8 or 12 months of age (figure 3). All seedlings were dark green and thrifty. These results indicate that the soils tested are about equally capable of supporting growth of creosotebush seedlings, but they may differ some with respect to emergence and establishment. In one bucket of the sandy loam from the black grama grassland, three of the four peripheral seedlings were lost before they were eight months old.

TABLE 6. Average emergence, damping-off damage, and growth of creosotebush seedlings in greenhouse tests with soils from various sites and vegetation types on Agricultural Experiment Station Ranch

Soil	Site and Vegetation Type	Emergence[1]	Dead and Heavy to Moderate Damage[1]	Light Damage	Weight of Oven-Dry Seedlings[2] 8 mo.	12 mo.
		percent of viable seed planted			gm	gm
Clay loam	Swale tobosa grass	31.6a	31.6mn	0.0	1.0	5.8
Eroded Simona sandy loam	Plain Snakeweed-fluffgrass	8.9a	8.9m	0.0	1.5	8.1
Shallow stoney silt loam	Hillside Creosotebush	32.9a	30.4mn	2.5	1.1	3.9
Shallow loamy sand	Low ridge Creosotebush	63.3b	57.0no	6.3	1.8	5.8
Deep sandy loam	Plain Snakeweed-dropseed	82.3b	67.1o	15.2	1.4	4.1
Stable Simona sandy loam	Plain Black grama grass	72.2b	65.8o	6.3	1.0	4.1

[1] Means associated with the same letter are not significantly different at the .05 probability level.
[2] Weight data are from second planting after soil was drenched with Panogen solution.

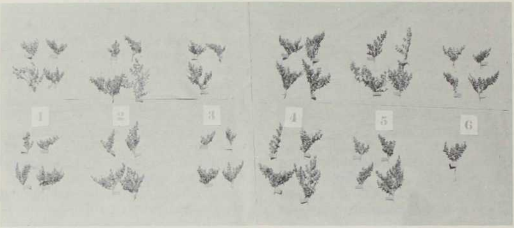


Fig. 3. Eight-month-old creosotebush seedlings grown from various sites on and near the Agricultural Experiment Station ranch. 1. Clay loam. 2. Eroded Simona sandy loam. 3. *Shallow stoney silt loam.* 4. *Shallow loamy sand.* 5. *Deep sandy loam.* 6. *Stable* Simona sandy loam.

Influence of Range Condition on Creosotebush Establishment

Results of this experiment are presented in table 7. Variance analysis of the six-year emergence values at the Pasture 15 location revealed significant differences between the two range condition classes and among years. Analysis of the 1959-61 results at the three locations revealed a difference between the condition classes at the 10 percent level of significance and highly significant differences among years. The slight drop in significance level between condition classes resulting from the three-year location analysis appears to be due to the fact that two of the three years were quite abnormal with respect to rainfall. In 1960 the growing-season rainfall was 46 percent of average and in 1961 it was 213 percent of average, so that the differences due to condition classes in more nearly average years may have been largely eliminated.

The greater emergence in the good condition range is attributed to two factors. First, microclimate of range in this condition class appears to be more favorable. Campbell (3), working under similar climatic conditions on the Jornada Experimental Range with Livingston atmometers, observed that the average daily evaporation rate from a tobosa grass vegetation cover was 19 percent below that from barren soil. Second, a greater degree of soil stability prevailed within the good condition cover. As a result, the carpels remained in the soil about as they had been planted. On the very poor condition range, wind scoured the surface and the carpels were blown out at some spots along the transects and deeply buried at others.

Actual establishment results were very erratic, but indications are that there is little if any difference between the two condition classes. It is possible that competition of the better perennial grass cover acted to eliminate many of the emerged seedlings in the good condition range. The artificial planting procedure used in the experiment may have had some influ-

TABLE 7. Average emergence and survival of planted creosotebush seed on very poor condition and good condition black grama grass range, Agricultural Experiment Station Ranch, 1956-61 and 1965

Plant Characteristic	Range Condition	Pasture	1956	1957	1958	1958	1960	1961	Pasture Average	Condition Average
			seedlings per 100 viable seed planted							
Emergence	Very poor; .15	3	....	....	....	5.14	.14	17.48	7.59	
	percent cover	4 & 5	....	....	....	5.43	.00	17.27	7.57	
	of perennial	15	.59	3.52	3.58	1.79	.41	36.40	7.71g	
	forage grasses	Average	.59	3.52	3.58	4.09	.18	23.72		7.64m
	Good; 1.71	3	....	....	....	7.07	.68	29.42	12.39	
	percent cover	4 & 5	....	....	....	9.00	.00	31.44	13.48	
	of perennial	15	2.74	7.81	11.83	11.21	.68	25.23	9.92h	
	forage grasses	Average	2.74	7.81	11.83	9.09	.45	28.63		11.43n
	Three-year, three-location average[1]					6.59	.31	26.17		
						xy	x	y		
	Six-year, pasture 15 average[1]		1.66	5.66	7.70	6.50	.54	30.82		
			a	a	a	a	a	b		
Final Survival, 1965	Very poor; .15	3	....	....	....	.00	.00	.00	.00	
	percent cover	4 & 5	....	....	....	.00	.00	.00	.00	
	of perennial	15	.00	.00	.00	.00	.00	.36	.06	
	forage grasses	Average	.00	.00	.00	.00	.00	.12	.03	.03
	Good; 1.71	3	....	....	....	.00	.00	.00	.00	
	percent cover	4 & 5	....	....	....	.00	.00	.07	.02	
	of perennial	15	.20	.10	.00	.07	.00	.07	.06	
	forage grasses	Average	.20	.10	.00	.02	.00	.02		.04

[1] Means associated with the same letter are not significantly different at the .05 probability level.

ence on the outcome, but the direction and magnitude of this influence, if any, is unknown. The results are consistent with general observations on and in the vicinity of the experimental ranch; no evidence has been seen of a relationship between range condition and establishment of creosotebush. The plants seem about as likely to appear on good condition range as on poor condition range, provided that a comparable source of seed is available. Neither the time covered by the present study nor the total number of seed involved was great. Results covering a considerably longer period and involving many times as many seed, all under fully natural conditions, might be different.

In the good condition range, two of the six creosotebush seedlings became established in openings in the perennial grass cover. One of these was six or eight feet across, and the other was considerably larger—50 or 60 feet across and centered on an active kangaroo rat den. Such openings as these, although representing a small proportion of the total area, are not at all uncommon in good condition black grama range (figure 4).

The five seedlings which became established in the very poor condition range all emerged in 1961 when the excellent growing-season rainfall may have tended to offset the microclimatic adversity. Five of the six seedlings which became established in the good condition range emerged in years other than 1961.

The very low rate of establishment seems noteworthy in view of the fact that creosotebush, when mature, is so well adapted to xeric conditions. From the 7,740 viable seed (number estimated from fill and germination data) planted in each of the two condition-class ranges in Pasture 15, only five seedlings became established in each. In Pasture 3, none of the estimated 3,570 viable seeds planted under each condition produced established seedlings. In Pasture 4 and 5, planting of the same number of seeds under each class resulted in the establishment of one plant. The overall rate of establishment at the three locations was about .37 seedling plant per thousand viable seed planted.

When the surviving seedlings were counted in the fall of 1961, the causes of stress and damage to surviving seedlings and of death of seedlings were observed (table 8). Drought caused most of the stress and loss, although damping-off was responsible for a small proportion of the loss. It is possible that loss was actually brought about by a combination of damping-off damage and late-season drought. The soil influence study revealed that creosotebush seedlings may become severely infected by damping-off organisms. Exceptionally good rainfall of the early and middle part of the 1961 growing season may have been quite favorable for infection in the field, which may have produced undetected losses (losses before emergence). The slightly greater percentage of drought-stressed seedlings in the good condition range may reflect the greater competitive strength of the perennial grasses.

The influence of the year on seedling emergence is chiefly a matter of growing-season rainfall, figure 5. This relationship was curvilinear; average and below-average rainfall brought about little emergence. Average emergence (about 10 percent of the viable seed planted) was reached only when growing-season rainfall reached about eight inches, nearly 60 percent above the long-time growing-season rainfall. According to the 50-year record (1916-65) at the Jornada Experimental Range headquarters, eight inches or more of growing-season rainfall was received in only seven years. Thus,

Very poor condition range. Eroding soil and harsh microclimate are adverse to seedling establishment.

Barren opening in good condition black grama range adjacent to a kangaroo rat den. Such openings are not uncommon in generally good condition range. Although microclimate is harsh, rodent-induced soil instability may be favorable for planting of seed.

Good condition black grama range. Here relative stability of soil may be unfavorable for planting of seed, but microclimate induced by the grass cover appears to favor germination and emergence.

Fig. 4. Effect of range condition and microclimate on creosotebush seedling establishment.

TABLE 8. Stress, damage, and death of creosotebush seedlings under poor and good range condition, average all locations planted in 1961, Agricultural Experiment Station Ranch

Range Condition	Condition of Seedlings	Live Seedlings	Dead Seedlings	Total
		———percent of all seedlings———		
Poor	Drought-stressed	71.0	20.1	91.1
	Damped-off	.4	3.1	3.5
	Trampled	.2	.1	.3
	Shaded out	.0	.2	.2
	Unknown	.0	.2	.2
	Thrifty	4.7	.....	4.7
				100.0
Good	Drought-stressed	57.6	40.1	97.7
	Damped-off	.0	1.2	1.2
	Thrifty	1.1	.....	1.1
				100.0

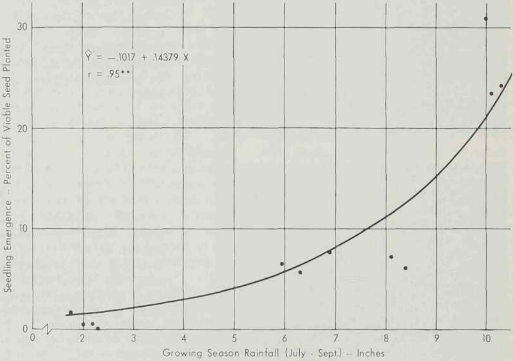


Fig. 5. Relationship between growing-season rainfall and emergence of planted creosotebush seedlings, Agricultural Experiment Station ranch.

emergence of any considerable proportion of seed planted would occur in relatively few years. The Jornada headquarters record also reveals erratic or irregular spacing of these rains. This rainfall characteristic and the actual emergence values observed in the present study suggest an irregular time pattern of seedling establishment, rather than the gradual increase pattern postulated by Chew and Chew (5). Gardner's findings (personal communication) of no seedlings on any of the observation plots in his survey of 172 miles (one plot per mile surveyed) in the creosotebush type in 1947, 1948, and 1949 and numerous seedlings along about half the distance surveyed in 1951 are similar to the results of this study.

Natural Establishment of Creosotebush as Influenced by Proximity and Number of Seed Source Plants and Soil Stability

Results of this study are presented in table 9. These results are erratic, but they reveal a general pattern of change.

The plots without creosotebush at the outset remained free of the species through the period of observation. This is probably chiefly a result of the low rate of transport of carpels to any particular location far removed from seed-bearing plants and the low rate of establishment of plants from carpels actually appearing at a particular location. Chew and Chew (5) pointed out that seed dispersion is relatively limited in creosotebush. The crescent-shaped carpels tend to collect in depressions in the soil surface not far from the seed-producing plants.

The plots with a single mature plant in open grassland and stable soil varied from no change to slight increase, figure 6. From 1956 to 1965, the average annual rate of increase for the five plots was .06 plants per acre. Annual observations of fruit production on the single mature plants on the plots were not made. On the basis of the calculated fruit production from the Powerline and Pasture 2 grassland groups, which were near these plots, and the average carpel fill and viability value, it is estimated that these mature plants produced 30 to 70 viable seeds per plant per year. From this low fruit production and the low rate of establishment observed in the experiment with range condition, one would expect a low rate of establishment around single mature plants.

The plots with single seed-bearing plants and unstable soil appear to represent a critical point in creosotebush invasion of range, figure 6. Although these plots were actually established in 1962, the size of the young plants and the size-age relationship brought out in the growth and fruit production study indicate that they were about five or six years old at this time. They probably were five years old, starting in 1957, because 1956 was a very dry year on the experimental ranch. If they started in 1957, the average annual rate of increase on these plots was about one plant per acre over the eight-year period. The soil instability of these plots may have contributed much to the establishment of seedlings by planting the seed. The similar sizes of the young plants on these plots gives further support to the view of irregular occasional establishment of seedlings rather than regular or steady rate of establishment.

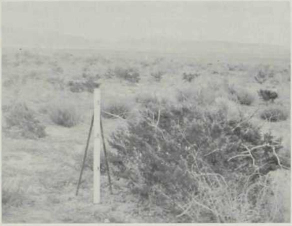
The loss of young plants on the plots adjacent to the creosotebush type is noteworthy, although no cause can be suggested to account for it. At the time of the 1962 observations, the

TABLE 9. Natural establishment of creosotebush under various conditions of seed availability and soil stability, Agricultural Experiment Station Ranch

Seed Source and Soil Condition	Plot No.	1956	1962 Survival of 1956 Plants	1962 Reproduction 1956-1962	1962 Total 1962	1965 Survival of 1956 Plants	1965 Survival of 1956-62 Plants	1965 Reproduction 1962-1965	1965 Total 1965	Change 1956 to 1965
		creosotebush reproduction—plants per acre								
Open grassland; seed source distant; soil stable.	1	.00	....	.00	.00	....	....	.00	.00	.00
	2	.00	....	.00	.00	....	....	.00	.00	.00
	3	.00	....	.00	.00	....	....	.00	.00	.00
	Average	.00	....	.00	.00	....	....	.00	.00	.00
Open grassland; single mature plant; soil stable.	1	.36	.36	.00	.36	.36	....	.00	.36	.00
	2	.00	....	.00	.00	....	....	.00	.00	.00
	3	.36	.00	.00	.00	....	....	.69	.69	.33
	4	.36	.36	1.73	2.09	.36	1.73	.69	2.78	2.42
	5	.00	....	.00	.00	....	....	.00	.00	.00
	Average	.22	.24	.35	.49	.24	1.73	.28	.77	.55
Light mesquite invasion; single mature plant; soil unstable.	1[1]		....[1]	16.78	16.78	....[1]	16.78	.00	16.78	16.78
	2		....	6.22	6.22	....	6.22	.00	6.22	6.22
	3		....	2.19	2.19	....	2.19	.00	2.19	2.19
	Average		....	8.40	8.40	....	8.40	.00	8.40	8.40
Adjacent to creosotebush type; soil unstable.	1	18.04	8.31	13.85	22.16	8.31	13.85	.00	22.16	4.12
	2	587.26	292.24	85.87	378.11	292.24	84.49	8.31	385.04	—202.22
	3	78.95	36.01	41.55	77.56	36.01	41.55	4.15	81.71	2.76
	Average	228.08	112.19	47.09	158.94	112.19	46.63	4.15	162.97	—65.11

[1] The size of the young plants on these plots and the relationship between size and age brought out in the growth and fruit production studies indicate that the young plants probably became established in 1956 or 1957. The plots were not laid out until 1962.

The single plant here was repeatedly clipped by rabbits and trampled by livestock. It is in a thrifty vegetative condition and produces little fruit. The soil, although exhibiting much open surface, is relatively stable. Two young plants became established near this plant over a nine-year period.



Here the single mature plant was subject to less clipping and trampling. Soil is moderately stable. Forty-six young plants became established in the vicinity of this plant over a period of 8 to 10 years.

Former grassland which was invaded by large numbers of young creosotebush plants. The young plants here are 11 or 12 years old and number up to 20,000 or 25,000. Soil surface is open and unstable. Seed source for this stand is an older creosotebush type immediately adjacent.

Fig. 6. Natural invasion of creosotebush into rangeland representing varying conditions with respect to seed availability and soil stability.

plants had disappeared, leaving no indication as to cause. It is possible that merging of enlarging plants may account for some reduction in apparent plant numbers, but this process probably does not account for more than a small fraction of the missing plants. The loss however, had no real effect on the character of the plant cover, the plots remained lightly to heavily invaded by vigorous, growing young creosotebush plants. While there are no evaluations of the amount of seed coming to the brush margin plots or degree of soil instability, general observations indicated that both seed supply and soil movement prevailed at high levels. Both probably contributed greatly to the production of the young shrub stand observed in 1956 and the reproduction observed in the course of the study (figure 6).

The type of soil instability which appeared to favor seedling establishment was deposition on the surface. The soil may have originated only a few feet from the area of deposit or at a distance of several hundred feet or more. Establishment took place at a very low rate on wind-scoured eroding surfaces.

Practically all seedlings near isolated pioneer plants in grassland were to the leeward and within a few hundred feet of the pioneer plants. This relatively short distance conforms with the short dispersal distance reported by Chew and Chew (5). Extension of young plants from older stands was also downwind, and again for only a relatively short distance from the older stands. Thus, control efforts can be confined to relatively restricted areas.

Although this study did not involve systematic sampling of extensive areas, the results obtained are believed to apply to such areas. They are consistent with Gardner's (10) and Yang's (21) observation of continuing encroachment of creosotebush into grassland range. No contrary observations have been made.

Growth and Fruit Production of Naturally Established Creosotebush Seedlings

Height growth and fruit production data from the naturally established seedlings are presented in table 10. Analysis of the height growth and age data revealed highly significant correlations of height with age for seedlings from both locations for the period of observation (figure 7). It is to be expected that as the plants approach full size the relationship will become curvilinear.

Plants at the two locations exhibited minor differences in height growth. The essentially static heights of 9- and 10-year-old plants at the Jornada location probably was due in part to increased competition among the creosotebush plants themselves, because density of the young plants at this location was much above average. The decrease in height in the eighth year at the Winder location is a result of freeze damage in January, 1962. Most stems were killed back to or near ground level, and the height growth measured for the eighth year was made for the most part during the 1962 growing season. This single year's growth, although from an established root system, was not quite sufficient to restore the full pre-freeze height. The Jornada location plants, situated on a gentle slope which promotes drainage of cold air, sustained some freeze damage to leaves and twigs, but only light damage to stems. If the Winder location plants had not been damaged, their height growth would probably have been very similar to that of the Jornada plants. The 10- and 11-year-old plants of these two

TABLE 10. Average height growth and fruit production of naturally established creosotebush seedlings under field conditions, 1956-65

Plant Characteristic and Location	Age in Years 2	3	4	5	6	7	8	9	10	11
Height (inches) Jornada Experimental Range	4.41	7.62	9.62	9.60	12.20	15.77	17.31	17.79	17.81	
Winder's Ranch	2.79	5.78	9.42	10.67	11.30	13.25	11.72	13.59	15.13	15.80
Fruit (number per plant) Jornada Experimental Range	0	0	1	0	1	1	44	40	98	
Winder's Ranch	0	0	0	0	5	25	0	7	72	171

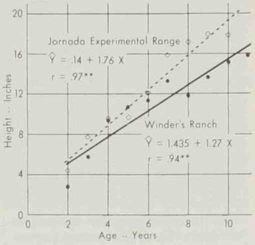


Fig. 7. Relationship between height and age of naturally established creosotebush plants at two locations.

groups attained 50 to 56 percent of the average height reported by Gardner (10) for mixed-age plants of mature stands on upland topography.

In addition to damage from freezing, a number of plants at both locations were subjected to varying degrees of rodent and rabbit clipping. Values for all such plants were included in computation of height averages, because such damage appears to be normal to all naturally occurring young creosotebush plants.

Fruit production began at a very low level in the fourth and fifth years at the Jornada and Winder locations, respectively. By the tenth and eleventh years, the plants were fruiting abundantly for their size. The decrease in production at the Winder location in the eighth and ninth years was caused by the freezeback of stems of 1962. Almost all stems in 1962 were from new basal sprouts, which were very thrifty. This thrifty, highly vegetative condition carried over into 1963.

Chew and Chew (5) found no fruit production on plants estimated to be younger than 13 years near Portal, Arizona. Site differences may account in part for the difference in time required to attain fruiting size or condition. Soil at the Winder location is a deep sandy loam with almost optimum water-supply characteristics under arid climatic conditions. Topography is very gently sloping, with an east exposure. Soil at the Jornada location is a deep gravelly sandy loam. Although the site is gently sloping, inducing some runoff, the seedlings themselves were in a very shallow slowly-draining trench. This microtopography may have operated to offset normal runoff. It is possible, too, that differences in age at first fruiting as found in the present study and as found by Chew and Chew are accounted for by differences in observed stands. In the present study, the stands consisted entirely of young plants not in competition with an established community of older plants; the observations of Chew and Chew were within established stands of older plants. Results obtained in the present study appear to be applicable to other comparable sites in the area of the study.

Death, Borer Damage, and Crown Decay in Creosotebush

Results of this study are presented in table 11. Dead creosotebush plants are rarely conspicuous in the creosotebush type, but a few were found at each of the locations (figure 8). Most of these dead plants were medium-size to full-grown, and most had been dead for several years, judging from the degree of weathering and termite attack. Smaller plants may undergo some death loss, but they may decay and disappear more rap-

TABLE 11. Death and borer channelling of creosotebush plants from the creosotebush vegetation type and from open grassland

Vegetation Type	Location	Dead Plants	Degree of Borer Channelling in— Dead Plants	Unthrifty Plants	Thrifty Plants
		no/A	percent of plants examined		
Creosotebush	Stover	40	100	100	95
	Winders	42	100	95	95
	Cuchillo	42	100	95	100
	Nunn	20	60	85	80
	Nutt	52	100	95	75
	Blackstrike	42	100	100	75
	Pasture 13	52	50	75	85
	Average	41.4	80.0	92.0	86.5
Grassland	Pastures 2 and 14	0[1]	0[1]	0[1]	20
	Past. 1 and Powerline	0	0	0	15
	Selden	0	0	0	10
	Average				15

[1] No dead or unthrifty plants were found in the grassland type.

Fig. 8. Dead creosotebush plants (indicated by markers) in the creosotebush type. The area occupied by these dead plants is approximately two-fifths of an acre. Such plants, although generally inconspicuous, are consistently present in the creosotebush type.

idly than the larger, woodier plants, leaving no evidence of death in their size class. Dead plants generally represent only a small proportion of the total population on any given area. Counts of creosotebush plants at the four locations listed first in the table averaged 1,122 per acre. The average number of dead plants indicated a low percentage of loss. The annual death rate is much lower. Such losses do not alter the vegetation type of the ranges in this study.

Gardner (personal communication) states that he observed no dead creosotebush plants in the extensive sampling of the type over the four-year period of his study. Dead plants observed in the present study considerably exceed the one plant per hectare (.4 plant per acre) reported by Chew and Chew (5).

The scarcity of dead plants at the Nunn location may be related in part to age of stand. Chew and Chew (5) concluded that high mortality was associated with young populations which had reached a stage when density-dependent factors were causing losses; however, it is possible that the population at the Nunn location represented a stage prior to one in which stress was causing losses. Plant counts at the Nunn location averaged 2,010 per acre, many of which were small plants. Tarbush was also present in greater density at the Nunn location than the average for the four locations, 1,048 and 361 plants per acre, respectively. This also indicates relative recency of creosotebush invasion according to Gardner (10) who concluded that early invasion stages of creosotebush were evidenced by the presence of tarbush, the earlier invader of the sites.

The present study was made only a few years after the very severe drought period which prevailed in south-central New Mexico in the 1950's. It is possible that this period of drought contributed to the death loss observed, and may account in part for the differences between Gardner's and Chew and Chew's observations and those of the present study.

No dead plants were observed among the isolated plants, even though many of these were large and evidently old. Also, all of the isolated plants exhibited a relatively high degree of thrift.

As shown in the table, borer channels were generally present in plants occurring in the creosotebush type, but crowns of isolated plants exhibited little channelling. It appears too, that in the creosotebush type, the borers must have attacked fairly young plants, because the thrifty plants, most of which were a little less than full grown, exhibited as high a proportion of channels as the unthrifty and dead plants. Unthrifty and dead plants commonly exhibited a number of channels, suggesting that they are subjected to repeated attack by borers. The degree of channelling was generally much less in the thrifty plants. This was especially true of isolated plants; channels, when present, were usually single and unbranched (figure 9). Most of the channelling observed was old rather than recent, and very little current channelling was noted.

Very few larvae were found in the plant crowns. Of those which were in condition to be submitted for identification, three were buprestids (Acmaeodera sp.), one was a cerambycid (Cerambycinae—not determined to genus) and one was the larva of a leaf cutting bee (Megachilidae—Ashmeadiella sp.). The beetle larvae are members of families well known as destruc-

Fig. 9. Crowns of live creosotebush plants taken from open grassland (upper row) and from the creosotebush type (lower row). Crowns of open grassland plants generally exhibit little channelling by beetle larvae and are relatively free from decay. One borer channel, surrounded by sound wood, is pointed by arrow in second crown from left. Crowns of plants from the creosotebush type generally exhibit more channelling and death, and decay of wood is more extensive.

tive wood borers of both cultivated and native plants. The bee larva is considered to have been present because of oviposition in an exposed part of a channel made by a wood-boring species.

Crown specimens from a number of unthrifty creosotebush plants were taken for determination of fungal infection. About half were infected by common saprophytes associated with soil and decaying vegetative material. The unthrifty condition did not appear to be due to attack by virulent fungi. Crowns of the borer channelled plants of the creosotebush type were generally conspicuously decayed; while comparatively little decay was associated with the channelled crowns of isolated plants (figure 9).

It seems probable that the extensive channelling and decay of crowns, which affected the sapwood as well as heartwood, would accentuate water stress in the tops of the plants during drought. This might materially increase drought loss in affected populations.

Another cause of death of creosotebush is clipping of roots by pocket gophers; however, very few plants have been observed to have been killed in this manner, even under conditions in which damage to ground cover by gopher mounding has been very heavy. Generally the few plants clipped were so heavily damaged that they died quickly and were subject to removal by wind because of total loss of anchorage. Gophers are not generally present in the creosotebush type, however, and damage from this source is infrequent and highly localized, when it does occur.

Summary and Conclusions

Several characteristics in the autecological life history of creosotebush were studied on the New Mexico State University Agricultural Experiment Station ranch in Dona Ana County and at other locations in south-central New Mexico, from 1954 to 1965. These characteristics were: 1. fruit production and seed production and viability, 2. site and soil influences on establishment of creosotebush, 3. Influence of range condition on establishment, 4. natural invasion and establishment, 5. growth and maturation, and 6. damage and death.

In normal years, fruit production of plants in the creosotebush vegetation type varied from 72 to 518 fruits per 100 grams of oven-dry branch. The average was 263 fruits. In one year, characterized by extremely low temperature in January, fruit production dropped to an average of 1 per 100 grams of branch. In contrast to plants in the creosotebush type, plants occurring as scattered individuals in grassland produced from 10 to 144 fruits per 100 grams of branch and averaged 49 fruits. This lower fruit production of the scattered plants was associated with a highly vegetative plant condition induced mainly by rabbit clipping and some livestock trampling. The rabbit and livestock numbers responsible for damage to creosotebush have generally not been damaging to the more desirable forage grasses. Fruit production per plant in the creosotebush type averaged about 1700 annually, and on scattered plants it averaged 665 annually. A trend in the direction of reduced fruit production with increased January to September precipitation was indicated.

Fill of carpels, or set of seed, varied from 12.50 to 61.75 percent of carpels, and averaged 35.26 percent, less than two filled carpels each in the five-carpellate fruit. Fill varied among years but was not associated with rainfall of the January-September period.

Germination percentages on a filled carpel basis averaged 73.9 percent and varied from 54.8 to 89.6 percent. Significant differences among years were revealed, but these were not found to be associated with January-September precipitation. Germination at the end of seven years in storage showed no marked drop below values obtained in earlier tests.

No differences in emergence of planted creosotebush seed was revealed among a sandy loam ridgetop site supporting a developed stand of creosotebush, a sandy loam upland carrying a black grama grass cover, and a deep clay loam swale carrying a tobosa grass cover. Further, no seedlings survived at any of these sites four years after the last planting. Pot tests revealed very high levels of damping-off of creosotebush seedlings in all soils tested, including those from creosotebush types. No significant differences in growth, expressed in weight of seedlings, at 8 and 12 months, was found on any of the soils.

Emergence of creosotebush seedlings from planted seed was significantly higher under good condition than under very poor condition black grama range, 11.43 and 7.64 percent of viable seed planted, respectively. The greater emergence under good condition was presumably due to beneficial microclimate and greater soil stability of the good condition range. Range condition had no differentiating influence on final survival. The overall rate of establishment of young plants was extremely low—0.37 plant per thousand viable seed planted—and essentially the same for very poor and good condition range. Emergence, although generally low, was found to be related to growing-season (July to September) precipitation. Average growing-season precipitation would be expected to bring about emergence of about five percent of viable seed planted.

Natural establishment of creosotebush was found to be associated with proximity and number of mature seed-bearing plants and degree of soil instability.

Range areas at distances from seed-bearing plants may remain uninvaded for extended periods of time. With the establishment of a single plant, the immediate area may still remain free from further invasion, pending the attainment of seed-producing size of the pioneer plant. This may be delayed by rabbit clipping and trampling by livestock. Following seed production by the pioneer plant, seedlings appear at irregular intervals, apparently dependent to a large degree on infrequent favorable rainfall years and in some measure on degree of soil instability. Indications are that the isolated pioneer plants should be destroyed before they attain seed-producing size.

Along the leeward margins of established creosotebush types, particularly if soil is unstable, young plants may become established and develop at such rapid rates as to bring about the conversion of brush free-range to the creosotebush type in 12 to 15 years. Control along such expanding margins is strongly indicated where feasible.

Dead creosotebush plants may be found in most older stands, but the rate of loss is apparently so low that no significant effect is produced in the stand; creosotebush remains as the dominant cover species. Cause of death may be a combination of borer attack of crowns, secondary damage by wood-decaying fungi, and drought stress.

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