# DROUGHT EFFECTS ON A SEMIDESERT GRASSLAND RANGE[1]

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*Abstract.* A vegetational survey on the Jornada Experimental Range in southern New Mexico, taken annually from 1941 through 1957, is the basis for a study of the effects of the great drought of 1951 through 1956. Both cover and yields were studied. Observations were stratified into seven classes based on a consideration of landform and soil characteristics. Seasonal and annual precipitation during the drought averaged 55% of the pre-drought average. The most severe drought years were 1951, 1953, and 1956.

Both the cover and yield of *Bouteloua eriopoda* (Torr.) Torr., the dominant species on the upland sandy soils, were greatly reduced by drought. However, drought damage was much more severe on the deep than on shallow sands. When the impermeable caliche layer occurred at shallow depths, moisture relations during drought were apparently much better than when caliche occurred at greater depths.

Another result of drought was the invasion of *Prosopis juliflora* (Sw.) DC. in areas where grass stands have been thinned by drought.

*Sporobolus* spp. and *Aristida* spp., minor components of the climax, were more susceptible to drought damage than *Bouteloua eriopoda.*

Yields of perennial grasses per unit cover were as great during the drought as prior to the drought. Both winter–spring and summer precipitation are important in preventing death losses of black grama. In arid areas it seems necessary to consider both cover and species composition in arriving at a potential for a site.

## INTRODUCTION

"Drought is unique among spells of weather; it creeps upon us gradually, almost mysteriously, but its consequences are a terrible reality" (Tannehill 1947). In some instances the damaging effects of drought on the vegetation are not fully realized until it is over. The semiarid and arid lands which make up the greater part of the grazing areas of the world are subjected to protracted periods of deficient precipitation and hence decreased production of forage. If the drought persists for two seasons or more, there may also be a marked decline in the plant cover, even in the absence of grazing (Paulsen and Ares 1962). The deterioration of many grazing lands begins during prolonged drought periods. The years of less than average precipitation set the pattern of land use, and must be anticipated and planned for safe utilization of the range (Forsling 1951).

From 1951 through 1956, the southwestern United States experienced a prolonged drought. Although dry periods are not uncommon in the Southwest, the drought of the 1950's was considerably more severe than any other in the region's recorded history. McDonald (1956) and Schulman (1956) both concluded that the drought of 1951–56 was one of the most severe in the past 350 years, and perhaps exceeded in severity only by the Great Drought of the late thirteenth century. Their findings would also apply to southern New Mexico and extreme west Texas. Lohmiller (1963) used the 1851–1962 precipitation records for the Las Cruces area to study cumulative moisture deficiencies. He found that the July through September precipitation (mean is 126 mm) was below average each year from 1947 through 1957 and that the cumulative deficiency was 483 mm. The second driest period was 1906 through 1911 when the cumulative moisture deficiency for the growing season was 249 mm. There were 8 other periods when the cumulative deficiencies for the growing season were at least one-half the mean; but none was greater than 155 mm.

Droughts occur more frequently in areas that have minimal than in those that have optimal precipitation. However, even a slight reduction from normal precipitation may lead to severe reductions in plant yields in the areas of minimal precipitation, while significantly greater reductions from the average rainfall may have no material influence on plant growth in areas of optimal precipitation (Klages 1942). Arid zones are border regions of possible survival by the various species. Therefore, the smallest change in environmental factors, especially precipitation, plays a decisive role in plant survival (Boyko 1952).

The semidesert grassland is one of the major plant associations of west Texas, southern New Mexico, southeastern Arizona, and northern Mexico. Since

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detailed weather and vegetation records are available at the Jornada Experimental Range, it is possible to record the effects of the catastrophic drought of 1951–56. Since the semidesert grassland is of major importance to the livestock industry, a study of the behavior of the native vegetation during droughts is of paramount importance. These studies will lead to a better understanding of plant-soil-climate relations.

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## Literature Review

A drought is a period of deficient rainfall which seriously injures vegetation (Tannehill 1947). Carpenter (1956) defined drought as a period of interrupted precipitation or a reduction of water supply hindering plant growth. Klages (1942) suggested that the term "drought" should be applied to moisture deficiencies deviating sufficiently from the phenological mean to interfere with the normal life processes of plants. While the term "drought" may be readily defined in the descriptive sense, its precise meaning in the quantitative sense is not easily defined. Water deficits in plants and the cause for such reductions may be numerous and varied, depending on environmental conditions and differences in the reactions of plants during the various stages of development.

Nelson (1934) studied the effects of two droughts on the vegetation on the Jornada Experimental Range. During the first drought (1916–18) the basal cover of black grama (*Bouteloua eriopoda*) gradually declined to 41.5% of the original predrought cover. It practically recovered its original stand during two favorable growing seasons (1919-20), then dropped very suddenly in the following two years of drought to the extremely low point of 10.9% of the original cover. The black grama cover remained low for the remainder of the second drought period (1921–26), then increased markedly during the succeeding favorable years. Nelson (1934) found that from one fall to the next the status of the black grama cover is mainly influenced by the vigor of the plants at the start of the current growing season, as determined by the previous summer's precipitation. Current seasonal rainfall had no significant effect on the change in basal cover during the current year.

Canfield (1939) stated that in 1934, a severe drought year, no new growth occurred on any of the black grama quadrats that he was studying on the Jornada. Campbell (1936) reported that the basal cover of black grama on that conservatively grazed area declined 77% between 1933 and 1935 as a result of the 1934 drought. Paulsen and Ares (1961), reporting on trends in carrying capacity and vegetation on the Jornada Experimental Range, found that the basal area of black grama was reduced to approximately the same point during a series of dry years irrespective of grazing treatment.

When an area experiences a severe drought, the question arises: Has the climate changed? Friedman (1957) concluded that there is little statistical evidence of the existence of trends, cycles, or even year to year persistence of rainfall in Southwest Texas (including El Paso). Most of the movements of the time series of annual rainfall can be explained on the basis of random fluctuations; therefore, there is no evidence that the climate is getting drier. Paulsen (1956) studied the long-time precipitation records for the Las Cruces area from 1851 to 1955 and concluded that there is no evidence of a general long-time upward or downward trend. Thomas (1962) and Friedman (1957) discussed some of the meteorological anomalies of the drought of the 1950's and Tannehill (1947) gave a comprehensive exposition on the causes of drought.

## Materials and Methods

This study describes the effects of drought on the vegetation of the major upland soil types of the Jornada Experimental Range from 1941 to 1957, with emphasis on cover and yield of the major species.

### *Description of the area*

The semidesert grassland lies primarily in southeastern Arizona, southern New Mexico, western Texas, and northern Mexico (the desert grassland of Shreve 1917, and Shantz and Zon 1924, the desert plains of Clements 1920, and the grama-tobosa shrub-steppe of Kuchler 1964). The semidesert grassland does not occupy the entire area given above but occurs as local grasslands rather widely interspersed with other types. It occupies extensive plains areas, but it also typically lies as broad belts around the base of many of the southwestern mountain ranges.

The study herein reported was conducted at the Jornada Experimental Range north of Las Cruces, New Mexico. The experimental range is in a gently undulating basin with no surface outlets. The elevation varies from 1,190 to 1,372 m. The average annual precipitation for 1915–1959 was 227 mm. The low recorded was 77 mm in 1953 while the high, recorded in 1941, was 451 mm. An average of 55% of the annual precipitation occurs during July–September. Summer rainfall comes from convectional thunderstorms which are frequently localized and of high intensity. Winter precipitation usually occurs as low intensity rainfall and occasionally as snow.

Temperatures are moderate with an annual mean of 15°C. Temperatures above 38°C in the summer are not uncommon, and temperatures below −18°C occasionally occur in the winter.

The average annual wind movement at the experimental range is 17,346 km. The highest monthly movement occurs during March–June. The average annual evaporation from a Weather Bureau pan is 231 cm (about 10 times the average precipitation).

The soils of the nearly level uplands, characteristic of the greater part of the experimental range, are sands or loamy sands. Gravelly loams are found in the foothill areas and clay loams on the flood plain sites.

The nearly level sandy areas are dominated by black grama. Dropseeds (*Sporobolus* spp.) and threeawns (*Aristida* spp.) generally are a minor part of the association. Depleted ranges, whether by drought or overgrazing, are readily invaded by broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby). Tobosa (*Hilaria mutica* (Buckl.) Benth.) and burrograss (*Scleropogon brevifolius* Phil.) types occur on the heavier soils. Tarbush (*Flourensia cernua* DC.) has invaded the heavier soils. The foothills are dominated by creosotebush (*Larrea tridentata* (DC.) Coville).

Mesquite (*Prosopis juliflora* (Sw.) DC. var. *glandulosa* (Torr.) Cockerell) has invaded the entire area. It is a serious problem on sandy sites where mesquite invasion ultimately results in the formation of mesquite sand dunes. Buffington and Herbel (1965) analyzed vegetation changes from 1858 to 1963.

### *Stratification*

The vegetation data were placed into seven strata based on landform and soil characteristics. The following information is taken from a soil survey conducted on the Jornada Experimental Range (Soil Conservation Service 1963). The names are tentative, pending final correlation. Each stratum contains more than one closely related soil. The dominant soils of each stratum are discussed.

*Deep sandy stratum.*—Soils of this unit have loamy sand textures to depths of 12 cm, moderately well developed textural B horizons, and strong $C_{ca}$ horizons. They generally are noncalcareous to a depth of about 76 cm and caliche occurs at depths of 91–127 cm. The dominant soil types in this unit have been tentatively identified as Berino and Sonoita loamy sands, 1–3% slopes. They are classified as Typic Haplargids, fine-loamy, mixed, thermic.

*Sandy flats stratum.*—These are moderately deep soils with moderately sandy textured surface horizons and weakly developed textural B horizons usually noncalcareous to depths of 38 to 51 cm. Indurated caliche occurs at depths of 64–76 cm. The soils of this stratum occur on sloping breaks adjacent to the deep sandy units. These soils are closely associated with the shallow sands but differ in having a more developed profile. The shallow sands will normally occur on a convex surface, whereas these soils occur on a sloping plane surface. The major soil type has been tentatively identified as Cacique loamy sand, 1–3% slopes. They are classified as Petrocalcic Paleargids, fine-loamy, mixed, thermic.

*Shallow sandy stratum.*—These soils have sandy surfaces over weak to moderate lime zones that may be discontinuously indurated. They are calcareous to very near the surface and are underlaid by indurated caliche at depths of 25–46 cm. The surfaces are level to convex. The major soil type in this stratum is Simona loamy sand, 0–2% slopes. They are classified as Typic Paleorthids, loamy, mixed, thermic, shallow.

*Low hummocky stratum.*—These soils are similar to those in the deep sandy stratum, except that they are extremely susceptible to wind erosion. Mesquite has invaded in the last 30 years. This has resulted in a depletion of perennial grass stands, with the subsequent deposition of the surface soil at the base of the mesquite plants. These soils have been tentatively named Berino soils, hummocky, 1–3% slopes, and they have the same classification as shown in the deep sandy stratum.

*Flood plains stratum.*—These soils are clay loams with an average of 5 cm of sand deposited on the surface. They are deep and slowly permeable, and have strong $C_{ca}$ horizons. This stratum receives runoff water from adjacent slopes. These soils normally support tobosa and burrograss, but the deposition of sand permits establishment and growth of black grama, dropseeds, and threeawns. This stratum, as considered in this paper, has the sand deposition on the surface. However, by far the greatest area does not have the sand deposition and supports excellent stands of tobosa and burrograss, two species little affected by the drought. These are Reakor soils, 0–1% slopes. They are classified as Typic Calciorthids, fine-carbonatic, thermic.

*Heavy sandy flats stratum.*—The soils of this unit are deep to moderately deep, light-colored, calcareous soils with sandy surfaces over weakly developed, moderately permeable, sandy clay loam textural B horizons. A prominent lime zone usually occurs below 50 cm. The sandy surface soils are subject to wind erosion. This soil has been tentatively identified as Headquarters sandy loam, 1–3% slopes. They are classified as Typic Haplargids, fine-loamy, mixed, thermic.

*Slopes stratum.*—These are deep, calcareous soils with a moderately sandy surface over grayish subsoils of sandy clay loam. They occur on gentle slopes of playas or depressional areas, usually on the leeward side. The major part of this area has been identified as Wink sandy loam, 0–7% slopes. These soils are classified as Typic Calciorthids, coarse-loamy, mixed, thermic.

### *Sampling methods*

Grass cover was estimated each autumn by 50-ft (15.25 m) line-intercept transects (Canfield 1941). Approximately 4 observations per section were taken on the black grama type. The sample areas were randomly located on a map for annual guidance of the examiner. Grass plants with basal portions beneath the line, and all upright culms touching either side of the line, were measured for basal cover. When the line passed through a grass clump the portion of the clump intersected by the line was measured in hundredths of a foot. A single culm rooted under the line was considered to occupy 0.01 ft (3 mm).

Yield estimates were obtained by clipping to ground level all perennial grass herbage from a strip 4 inches (10 cm) wide along one side of the line-intercept transect used for obtaining estimates of cover. The species were placed in separate bags and air-dried for about 4 weeks. Herbage yields were obtained each year during the study period except for 1947.

Black grama, threeawns, and dropseeds were the only species considered in the data analyses because they are the major species occurring on the sandy soils of the semidesert grassland. The threeawn species is largely *Aristida longiseta* Steud. but with minor amounts of *A. divaricata* Humb. & Bonpl., *A. glauca* (Nees) Walp. and *A. purpurea* Nutt. The dropseed species is largely *Sporobolus flexuosus* (Thurb.) Rydb. with minor amounts of *S. cryptandrus* (Torr.) A. Gray and *S. contractus* Hitchc.

TABLE 1. Average precipitation, basal cover, and yields for the deep sandy, sandy flats, shallow sandy, and low hummocky strata[1]

| | No. of Veg. Obs. | YEAR 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 |
|---|---|---|---|---|---|---|---|---|
| DEEP SANDY | 35–70 | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 218 | 129 | 138 | 117 | 55 | 151 | 95 |
| Annual | | 435 | 195 | 207 | 233 | 110 | 230 | 158 |
| *Cover (%)* | | | | | | | | |
| Black grama | | $0.38^{fg}$ | $0.45^{efg}$ | $2.06^{a}$ | $0.57^{def}$ | $0.76^{d}$ | $1.06^{c}$ | $0.65^{de}$ |
| Total[2] | | $0.55^{hi}$ | $0.67^{h}$ | $2.48^{a}$ | $1.00^{fg}$ | $1.12^{efg}$ | $1.52^{bd}$ | $0.92^{g}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | $250^{c}$ | $312^{c}$ | $451^{b}$ | $468^{b}$ | $331^{c}$ | $432^{b}$ | — |
| Total[2] | | $326^{f}$ | $447^{e}$ | $547^{cd}$ | $717^{ab}$ | $471^{de}$ | $644^{b}$ | — |
| SANDY FLATS | 26–46 | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 227 | 140 | 130 | 123 | 62 | 165 | 120 |
| Annual | | 449 | 211 | 205 | 245 | 123 | 249 | 186 |
| *Cover (%)* | | | | | | | | |
| Black grama | | $0.48^{fgh}$ | $0.57^{efg}$ | $2.64^{a}$ | $0.64^{ef}$ | $1.04^{cd}$ | $1.54^{b}$ | $0.77^{de}$ |
| Total[2] | | $0.55^{ghi}$ | $0.64^{gh}$ | $3.17^{a}$ | $0.80^{fg}$ | $1.35^{cd}$ | $1.95^{b}$ | $0.99^{ef}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | $335^{g}$ | $451^{f}$ | $743^{ab}$ | $817^{a}$ | $538^{def}$ | $574^{de}$ | — |
| Total[2] | | $401^{f}$ | $609^{e}$ | $880^{b}$ | $1078^{a}$ | $682^{de}$ | $823^{bc}$ | — |
| | No. of Veg. Obs. | YEAR 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 |
| DEEP SANDY | | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 30 | 116 | 115 | 26 | 79 | 33 | 81 |
| Annual | | 138 | 212 | 162 | 91 | 161 | 81 | 142 |
| *Cover (%)* | | | | | | | | |
| Black grama | | $1.34^{b}$ | $1.04^{c}$ | $1.20^{bc}$ | $1.15^{bc}$ | $0.29^{g}$ | $0.32^{g}$ | $0.01^{h}$ |
| Total[2] | | $1.54^{bc}$ | $1.24^{cef}$ | $1.36^{cde}$ | $1.23^{ef}$ | $0.32^{ijk}$ | $0.33^{ijk}$ | $0.07^{k}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | $266^{c}$ | $470^{b}$ | $634^{a}$ | $166^{d}$ | $131^{d}$ | $85^{de}$ | $31^{e}$ |
| Total[2] | | $293^{fg}$ | $560^{c}$ | $740^{a}$ | $166^{hi}$ | $136^{hij}$ | $90^{ij}$ | $58^{j}$ |
| SANDY FLATS | | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 31 | 112 | 110 | 30 | 100 | 33 | 86 |
| Annual | | 148 | 208 | 162 | 99 | 170 | 81 | 141 |
| *Cover (%)* | | | | | | | | |
| Black grama | | $0.87^{de}$ | $1.27^{bc}$ | $0.96^{d}$ | $1.30^{bc}$ | $0.33^{ghi}$ | $0.49^{fgh}$ | $0.25^{hi}$ |
| Total[2] | | $1.08^{def}$ | $1.46^{c}$ | $1.11^{de}$ | $1.34^{cd}$ | $0.33^{hi}$ | $0.49^{hi}$ | $0.36^{hi}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | $489^{ef}$ | $624^{cd}$ | $704^{bc}$ | $208^{h}$ | $204^{h}$ | $170^{hi}$ | $126^{hi}$ |
| Total[2] | | $574^{e}$ | $737^{cd}$ | $789^{bcd}$ | $209^{gh}$ | $204^{gh}$ | $174^{h}$ | $174^{h}$ |

Table 1.—continued

| | YEAR 1955 | 1956 | 1957 | Average[2] Predrought | Drought |
|---|---|---|---|---|---|
| **DEEP SANDY** | | | | | |
| *Precip. (mm)* | | | | | |
| Jul.–Sep. | 98 | 62 | 102 | 116 | 63 |
| Annual | 157 | 76 | 173 | 208 | 118 |
| *Cover (%)* | | | | | |
| Black grama | 0.02$^{h}$ | 0.02$^{h}$ | 0.01$^{h}$ | 0.86 | 0.11 |
| Total[3] | 0.35$^{ij}$ | 0.11$^{jk}$ | 0.18$^{jk}$ | 1.12 | 0.23 |
| *Yield (kg/ha)* | | | | | |
| Black grama | 14$^{e}$ | 39$^{e}$ | 35$^{e}$ | 402 | 72 |
| Total[3] | 92$^{ij}$ | 119$^{ij}$ | 221$^{gh}$ | 527 | 126 |
| **SANDY FLATS** | | | | | |
| *Precip. (mm)* | | | | | |
| Jul.–Sep. | 100 | 67 | 140 | 122 | 69 |
| Annual | 144 | 84 | 257 | 228 | 120 |
| *Cover (%)* | | | | | |
| Black grama | 0.28$^{hi}$ | 0.19$^{i}$ | 0.26$^{hi}$ | 0.94 | 0.30 |
| Total[3] | 0.53$^{ghi}$ | 0.28$^{i}$ | 0.45$^{hi}$ | 1.13 | 0.41 |
| *Yield (kg/ha)* | | | | | |
| Black grama | 71$^{i}$ | 240$^{gh}$ | 154$^{hi}$ | 586 | 168 |
| Total[3] | 153$^{h}$ | 307$^{fg}$ | 347$^{f}$ | 730 | 224 |

| | No. of Veg. Obs. | YEAR 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 |
|---|---|---|---|---|---|---|---|---|
| **SHALLOW SANDY** | 28–54 | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 246 | 132 | 135 | 140 | 133 | 128 | 90 |
| Annual | | 478 | 189 | 195 | 263 | 194 | 194 | 137 |
| *Cover (%)* | | | | | | | | |
| Black grama | | 0.74$^{ef}$ | 0.59$^{efg}$ | 2.78$^{a}$ | 0.69$^{ef}$ | 1.17$^{d}$ | 1.75$^{b}$ | 0.63$^{efg}$ |
| Total[3] | | 0.82$^{fgh}$ | 0.73$^{gh}$ | 3.28$^{a}$ | 0.84$^{fg}$ | 1.64$^{d}$ | 2.42$^{b}$ | 0.82$^{fgh}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | 448$^{fg}$ | 502$^{ef}$ | 719$^{abc}$ | 816$^{a}$ | 597$^{de}$ | 643$^{cd}$ | — |
| Total[3] | | 503$^{c}$ | 699$^{b}$ | 907$^{a}$ | 1015$^{a}$ | 760$^{b}$ | 987$^{a}$ | — |
| **LOW HUMMOCKY** | 8–27 | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 239 | 121 | 144 | 133 | 106 | 135 | 84 |
| Annual | | 472 | 179 | 203 | 254 | 167 | 202 | 128 |
| *Cover (%)* | | | | | | | | |
| Black grama | | 0.39$^{ef}$ | 0.49$^{def}$ | 2.19$^{a}$ | 0.80$^{cde}$ | 0.78$^{cde}$ | 0.84$^{cde}$ | 0.65$^{cde}$ |
| Total[3] | | 0.59$^{de}$ | 0.58$^{de}$ | 2.66$^{a}$ | 0.99$^{cd}$ | 1.11$^{cd}$ | 1.51$^{bc}$ | 1.11$^{cd}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | 178$^{de}$ | 384$^{c}$ | 592$^{ab}$ | 731$^{a}$ | 386$^{c}$ | 363$^{c}$ | — |
| Total[3] | | 230$^{d}$ | 529$^{c}$ | 760$^{b}$ | 923$^{a}$ | 561$^{c}$ | 626$^{bc}$ | — |

| | No. of Veg. Obs. | YEAR 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 |
|---|---|---|---|---|---|---|---|---|
| **SHALLOW SANDY** | | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 40 | 97 | 97 | 36 | 93 | 49 | 86 |
| Annual | | 137 | 187 | 127 | 92 | 167 | 105 | 171 |
| *Cover (%)* | | | | | | | | |
| Black grama | | 0.95$^{de}$ | 1.60$^{bc}$ | 1.30$^{cd}$ | 1.60$^{bc}$ | 0.24$^{hi}$ | 0.80$^{ef}$ | 0.34$^{ghi}$ |
| Total[3] | | 1.21$^{ef}$ | 2.01$^{c}$ | 1.52$^{de}$ | 1.84$^{cd}$ | 0.27$^{ij}$ | 0.87$^{fg}$ | 0.47$^{hij}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | 363$^{gh}$ | 689$^{bcd}$ | 757$^{ab}$ | 293$^{hi}$ | 219$^{ijk}$ | 260$^{hi}$ | 141$^{k}$ |
| Total[3] | | 469$^{cd}$ | 919$^{a}$ | 887$^{a}$ | 305$^{e}$ | 236$^{ef}$ | 281$^{ef}$ | 233$^{ef}$ |
| **LOW HUMMOCKY** | | | | | | | | |
| *Precip. (mm)* | | | | | | | | |
| Jul.–Sep. | | 39 | 93 | 105 | 30 | 87 | 46 | 78 |
| Annual | | 139 | 192 | 131 | 89 | 166 | 103 | 158 |
| *Cover (%)* | | | | | | | | |
| Black grama | | 1.26$^{bc}$ | 1.35$^{b}$ | 1.00$^{b}$ | 0.95$^{bcd}$ | 0.04$^{f}$ | 0.15$^{f}$ | 0.18$^{f}$ |
| Total[3] | | 1.58$^{bc}$ | 1.78$^{b}$ | 1.13$^{cd}$ | 1.12$^{cd}$ | 0.04$^{e}$ | 0.18$^{e}$ | 0.22$^{e}$ |
| *Yield (kg/ha)* | | | | | | | | |
| Black grama | | 359$^{cd}$ | 532$^{b}$ | 456$^{bc}$ | 144$^{e}$ | 42$^{e}$ | 71$^{e}$ | 93$^{e}$ |
| Total[3] | | 513$^{c}$ | 699$^{b}$ | 522$^{c}$ | 150$^{de}$ | 42$^{e}$ | 87$^{de}$ | 117$^{de}$ |

TABLE 1.—continued

| | YEAR | | | Average[2] | |
|---|---|---|---|---|---|
| | 1955 | 1956 | 1957 | Predrought | Drought |
| SHALLOW SANDY | | | | | |
| *Precip. (mm)* | | | | | |
| Jul.–Sep. | 84 | 58 | 168 | 124 | 68 |
| Annual | 139 | 108 | 299 | 210 | 130 |
| *Cover (%)* | | | | | |
| Black grama | $1.31^{cd}$ | $0.15^{i}$ | $0.51^{fgh}$ | 1.10 | 0.56 |
| Total[3] | $1.73^{cd}$ | $0.17^{j}$ | $0.60^{ghi}$ | 1.39 | 0.69 |
| *Yield (kg/ha)* | | | | | |
| Black grama | $152^{jk}$ | $252^{hij}$ | $276^{hi}$ | 615 | 228 |
| Total[3] | $173^{f}$ | $280^{ef}$ | $346^{de}$ | 794 | 265 |
| LOW HUMMOCKY | | | | | |
| *Precip. (mm)* | | | | | |
| Jul.–Sep. | 89 | 49 | 172 | 120 | 63 |
| Annual | 141 | 93 | 297 | 207 | 125 |
| *Cover (%)* | | | | | |
| Black grama | $0.02^{f}$ | $0.02^{f}$ | $0.02^{f}$ | 0.85 | 0.07 |
| Total[3] | $0.08^{e}$ | $0.02^{e}$ | $0.09^{e}$ | 1.15 | 0.11 |
| *Yield (kg/ha)* | | | | | |
| Black grama | $6^{e}$ | $57^{e}$ | $34^{e}$ | 442 | 64 |
| Total[3] | $14^{e}$ | $64^{de}$ | $75^{de}$ | 596 | 78 |

[1]Superscripts on the same line containing the same letter are not significantly different (.05 level).
[2]Predrought average for precipitation is 1941–50; for cover, 1941–51, exc. 1943; anf for yield, 1941–50, exc. 1947. Drought average for precipitation is 1951–56; for cover, 1952–57; and for yield, 1951–57.
[3]Total = black grama + dropseeds + threeawns.

The statistical analyses consisted of variance analyses separating individual degrees of freedom for linear, quadratic, and cubic effects by the use of orthogonal polynomials. The multiple range test for correlated and heteroscedastic means developed by Duncan (1957) was used to establish significance among years. Black grama observations and the combined observations of black grama, dropseeds, and threeawns were analyzed separately. It was necessary to use the combined observation of black grama, dropseeds, and threeawns rather than dropseeds and threeawns alone, because in many instances neither of the latter two species were observed.

There was a network of eleven rain gauges associated with the vegetational observations over the seven strata. Each observation, taken in the same general area each year, was related to the precipitation recorded at the nearest rain gauge.

## RESULTS

The following classes of data were analyzed for each stratum: (1) black grama cover; (2) total cover of black grama, dropseeds, and threeawns; (3) black grama yield; and (4) total yield of black grama, dropseeds, and threeawns. Table 1 shows the average precipitation, basal cover, and yields for the four major sandy strata for the study period, 1941–57. Both seasonal (July–September) and annual precipitation for the 1951–56 period were about 55% of the 1941–50 averages. The most severe drought years were 1951, 1953, and 1956.

The mean squares for the individual degrees of freedom for linear, quadratic, and cubic effects were all highly significant for both cover and yield data for the four strata shown in Table 1. For the cover data among the four strata, 13–28% of the variation among years was a linear regression of cover on years. Quadratic effects removed an additional 7–23% of the variability in the years sum of squares for the four strata while cubic effects removed an additional 2–5% of the variability. However, a large and highly significant amount, 46–78%, was not included in the third degree polynomial. For the yield data, linear effects removed 43–51% of the variability in the years sum of squares among the four strata. Quadratic effects removed an additional 5–15% of the variability while cubic effects removed an additional 8–22% of the variability. However, 17–35% of the variability among years was not included in the third degree polynomial. Both the linear and quadratic effects were negative in all the analyses on cover and yields for the four strata.

Table 1 shows that none of the 1943 figures for cover agree with the other years. Although precipitation for the two years prior to 1943 was average or above, the authors assume that there was some observational error. Therefore, the 1943 cover data are excluded from consideration.

### *Deep sandy*

Black grama cover dropped to 0.29% in 1952 when it showed the effects of the low 1951 precipitation. In 1954 it dropped to 0.01%. When considered as a percentage of the combined cover of black grama, dropseeds, and threeawns, the black grama cover was remarkably stable at about 70% for 1941–47, increased to 97% by 1953, and then declined to 20% and less for the last years of the study period.

The black grama yields were between 250 and 634 kg/ha during 1941–50. The yields for 1954–57 ranged from 14–39 kg/ha of air-dry herbage. The combined yield of dropseeds and threeawns fluctuated from 76 to 249 kg/ha of air-dry herbage during 1941–50 except for 1948 when it was 27 kg. In 1951 the yields dropped to 0.2 kg. In 1954 the dropseeds and threeawns yield was 27 kg, and it increased to 186 kg/ha in 1957.

### *Sandy flats*

The black grama cover was about 0.50% in 1941–42, then fluctuated between 0.64 and 1.54% during the 1944–51 period. In 1952, it dropped to 0.33%, increased to 0.49% in 1953, then dropped to 0.25% in 1954, and stayed at about that level for the remainder of the study period. The combined cover of dropseeds and threeawns fluctuated between 0.07 and 0.41% during the 1941–50 period. It dropped to 0.04% in 1951 and to zero in 1952. The dropseeds and threeawns cover increased from zero in 1953 to 0.25% in 1955. The black grama cover varied from 77 to 89% of the combined cover of black grama, dropseeds, and threeawns during 1941–50. During 1954–57, it was about 70% of the combined cover.

The black grama yield varied from 451 to 817 kg/ha for 1942–50. In 1951 the yields decreased sharply to 208 kg and then steadily decreased further to a low of 71 kg by 1955. The combined yield of dropseeds and threeawns averaged from 66 to 261 kg/ha of air-dry herbage during 1941–50. During 1951–53 it was between 0 and 4 kg/ha and then the yields of dropseeds and threeawns began increasing until 1957 when it was 193 kg/ha.

### *Shallow sandy*

The black grama cover in this stratum fluctuated more from year to year than it did in any of the other strata; 1952, 1954, and 1956 it was 0.15–0.34%, and in the remainder of the study period, 0.51–1.75%. The cover of dropseeds and threeawns dropped to 0.03 and 0.02% in 1952 and 1956, respectively. The black grama cover varied between 71 and 92% of the combined cover of black grama, dropseeds, and threeawns.

Black grama yields varied from 597 to 816 kg/ha for 1943–50 except for 1948 when it was 363 kg. It fluctuated from 141 to 293 kg/ha for 1951–57. The combined yield of dropseeds and threeawns fluctuated from 55 to 344 kg/ha of air-dry herbage during the 1941–50 period, while during the 1951–57 period it ranged between 12 and 92 kg. When considered as a percentage of the combined yield of black grama, dropseeds, and threeawns, the black grama yield varied from 61 to 96% during the study period.

### *Low hummocky*

The black grama cover followed the same general trend in this stratum as it did in the deep sandy stratum. It varied from 0.39 to 1.35% between 1941 and 1951. The black grama cover dropped to 0.04% in 1952 and 0.02% in 1955. The combined cover of dropseeds and threeawns varied between 0.09 and 0.67% during 1941–51, dropped to zero in 1952, and then was 0.002–0.07% for the remainder of the study period.

The black grama yields varied from 359 to 731 kg/ha for 1942–50. In 1951 the yields decreased sharply to 144 kg/ha and then varied from 6 to 93 kg/ha for 1952–57. The combined yields of dropseeds and threeawns varied from 145 to 263 kg/ha during 1942–49. It varied from zero to 41 kg/ha for 1951–57.

### *Flood plains, heavy sandy flats, and slopes*

Due to the limited area in each of these strata, there were only 4–9 observations in each stratum each year. Figure 1 shows the July–September precipitation, black grama yields, and black grama cover for the three strata averaged for 1941–50 and for each year during 1951–56. The average seasonal

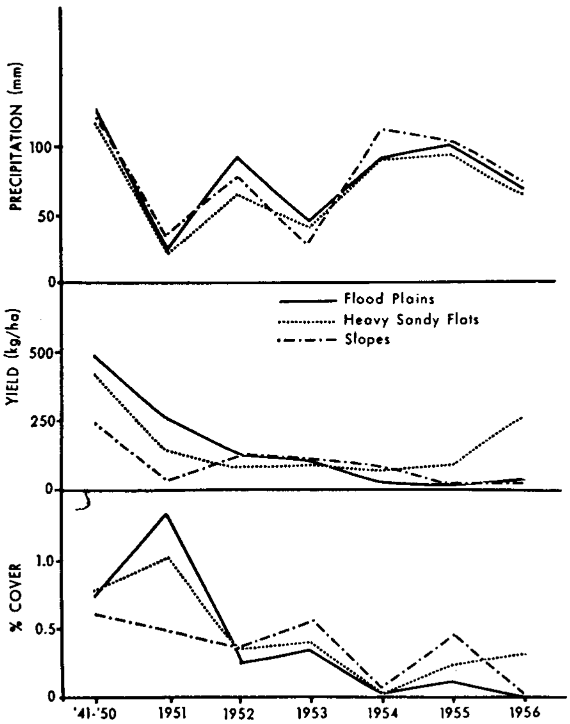


FIG. 1. July–September precipitation, black grama yields, and black grama cover for 1941–56 for the flood plains, heavy sandy flats, and slopes strata.

TABLE 2. Seasonal precipitation–black grama relationships: drought years as a percentage of the predrought years

| Soil Type | July–Sept. Precip. | Cover | Yield | Cover/ Precip. | Yield/ Precip. | Yield/ Cover |
|---|---|---|---|---|---|---|
| Deep Sandy | 54 | 13 | 18 | 19 | 30 | 140 |
| Sandy Flats | 57 | 32 | 29 | 43 | 43 | 90 |
| Shallow Sandy | 55 | 51 | 37 | 64 | 55 | 73 |
| Low Hummocky | 52 | 8 | 14 | 10 | 21 | 175 |
| Flood Plains | 56 | 18 | 20 | 22 | 32 | 112 |
| Heavy Sandy Flats | 54 | 35 | 32 | 45 | 49 | 110 |
| Slopes | 58 | 46 | 32 | 62 | 47 | 69 |
| Average | 55 | 29 | 26 | 38 | 40 | 110 |

precipitation for the three strata for 1941–50 was 121 mm. For 1951–56 it was 66 mm.

Black grama yields for 1941–50 averaged 478, 410, and 238 kg/ha, respectively, for flood plains, heavy sandy flats, and slopes. For 1951–56 it averaged 96, 119, and 66 kg/ha for the same respective sites. The average black grama cover for 1941–51 ranged from 0.59 to 0.82% for the three strata while the 1952–57 means ranged from 0.15 to 0.28%. The 1941–51 averages for the combined cover of dropseeds and threeawns (not shown in Fig. 1) were 0.18–0.36% for the three strata while the 1952–57 averages were 0.06–0.10%.

Table 2 shows some relationships among the precipitation, black grama cover, and black grama yield data for the seven strata. The various relationships are shown as the average of the drought years as a percentage of the average of the predrought years. The years of data for the averages are shown in footnote 2 of Table 1. Both seasonal and annual precipitation during the drought averaged about 55% of the predrought average. Black grama cover in the low hummocky and deep sandy strata during the drought years was 8 and 13%, respectively, of the predrought average. These two strata also had the greatest yield reductions. The least reduction in black grama cover during the drought years occurred in the shallow sandy and slopes strata. Black grama yields were less affected by the drought on the shallow sandy stratum. Since precipitation over the seven strata was similar, cover and yield per unit seasonal precipitation had about the same rankings as cover and yield. Yields per unit of precipitation were less efficient in the drought period, averaging only 40% of the predrought period. When calculated separately for each period, the yields per unit precipitation were lowest in the slopes stratum and highest in the shallow sandy stratum.

The yields per unit cover were greater on four of the strata during the drought than prior to the drought. The percentages obtained when the total of black grama, dropseeds, and threeawns was used, or when annual precipitation was used, were similar to the values shown in Table 2.

## DISCUSSIONS AND CONCLUSIONS

This paper is concerned with the effects of the 1951–57 drought on plant cover and herbage yields of semidesert grassland. Plant cover is closely related to weather cycles while herbage yields are good indicators of growing conditions within a year.

Precipitation during 1951–56 was about 55% of the predrought average. The driest years were 1951, 1953, and 1956. In 1957, there was essentially no precipitation until July, but for the remainder of 1957 precipitation was above average except at rain gauges associated with the deep sandy stratum. The severe drought year of 1948 had seasonal precipitation varying from 18 to 40 mm over the various strata. However, the perennial grass cover was affected very little by this one year drought. This is apparently due to the approximately average precipitation recorded during the remainder of 1948. On the other hand, 1951 seasonal precipitation was similar to that of 1948 but the precipitation for the remainder of 1951 was also below average. This resulted in a great loss of vegetation reflected in the yield data of 1951 and the cover data of 1952. Nelson (1934) considered seasonal precipitation as the major influence on perennial grasses. However, in this instance, precipitation during the other nine months of the year seems to be the major influence. Again, in 1953–54, the seasonal precipitation for 1953 was very low; the fall-winter-spring precipitation of 1953–54 was also very low; but the seasonal precipitation for 1954, while below average, was only moderately so, yet, the drought period of 1953 through July 1954 resulted in a further loss of vegetation. A winter-spring period with no effective precipitation may be very detrimental to black grama. Black grama has a solid culm which remains green during the winter. This indicates some respiration with a probable loss of stored carbohydrates.

Prior to the drought, black grama cover and yield did not differ greatly among the seven strata, although it was somewhat higher on the shallower sands. No stratum was particularly favored by precipitation during the drought. Yet, effects on the vegetation were not the same over all sites. The cover and yield

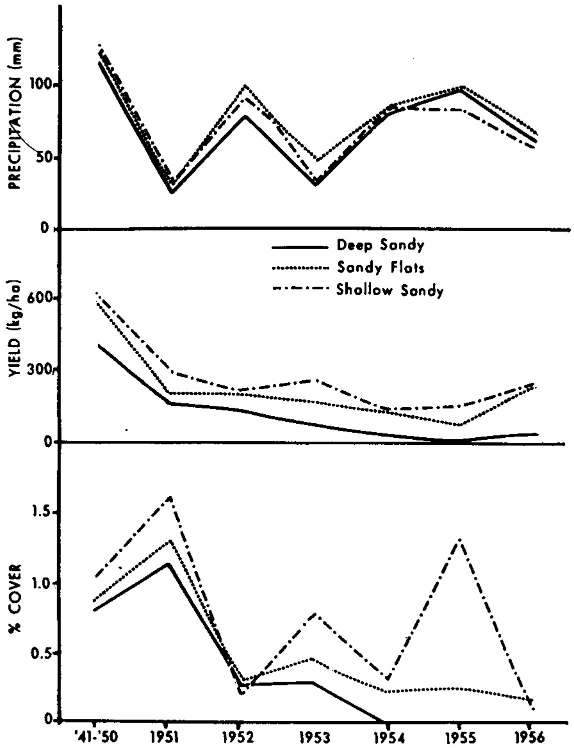


FIG. 2. July–September precipitation, black grama yields, and black grama cover for 1941–56 for the deep sandy, sandy flats, and shallow sandy strata.

on the shallow sandy stratum remained higher but there were great losses in the low hummocky and deep sandy strata (Fig. 2). There is a direct relationship between drought damage and depth of soil. Grass plants obtain moisture more readily from the surface 30 cm of soil. On deeper soils the roots become more extended and thus more susceptible to drought damage during years when there is only enough moisture in the surface area. Another important point is that the indurated caliche under these soils is almost impermeable and therefore holds moisture, even above field capacity, until the plant uses it. Therefore, on shallow soils, moisture is held at a more readily obtainable depth. This moisture is not lost by evaporation through capillary movement because there is limited capillary movement in these sands.

Vegetation on the low hummocky stratum was also severely affected by drought. However, a contributing factor was the rapid invasion of mesquites. Mesquites are favored at the expense of perennial grasses during drought periods. Furthermore, with their well-developed lateral and tap-root systems, the mesquites are able to increase moisture stress on the remaining live grass plants. Drought may be a contributing factor in the spread of shrubs on other sites, too (Buffington and Herbel 1965).

Only a few vegetational observations were obtained on the three remaining strata. None of these strata occupy a very large area on the Jornada Experimental Range. Cover and yield on the slopes stratum were reduced 60 and 70% by the drought. They were reduced 65 and 68% on the heavy sandy flats stratum. It seems feasible to assume that the heavier textured soils may have retained more moisture, released it to plant use more slowly, and thus permitted the perennial grasses to live. Another factor is that on the slopes stratum, occasional flooding occurs when there is sufficient precipitation. This latter factor applies to the flood plains stratum, but the vegetational observations reported in this paper were taken in disturbed areas with recent deposits of wind-blown sand. There was a great loss of black grama, dropseeds, and threeawns during the drought on the flood plains stratum because these species are not well adapted to this stratum even though there is a thin mantle of sand. Tobosa and burrograss on the flood plains site were little affected by the drought. Although tobosa and black grama occur primarily on different soils, tobosa seems to have much higher drought-resistance than black grama. It was also found to be the most drought resistant of the grasses in the Barnhart, Texas area (Thomas and Young 1954). Apparently tobosa has the capacity to become completely dormant as soil moisture approaches the wilting point. However, with black grama the solid culms remain green and there is probably a measure of respiration. This becomes serious during a prolonged drought because the stored carbohydrates are probably reduced to a low level.

The dropseeds and threeawns were even more susceptible to drought than black grama. In some of the strata none, or essentially none, was observed in the drought years. In the less severe drought years of 1954 and 1955, the dropseeds made a partial recovery from seedlings. These were subsequently reduced by the severe drought year of 1956. The threeawns were essentially eliminated by the drought.

The yield per unit precipitation during the drought was only 40% of the predrought average, primarily because cover was reduced during the drought. Prior to the drought, black grama yields per unit precipitation were 35% greater on the shallow sandy and sandy flats strata than on the deep sandy, low hummocky, flood plains, and heavy sandy flats strata. They were 150% greater than on the slopes stratum. This indicates that black grama on the shallow sandy and sandy flats strata was able to make more efficient use of precipitation. Generally, maximum yields per unit precipitation on each stratum were obtained when the cover was about one per cent.

The yield of black grama per unit cover was greater during the drought on the heavy sandy flats, flood plains, deep sandy, and low hummocky strata. It was considerably lower during the drought only on the shallow sandy and slopes strata. With the higher level of standing dead during the drought, and since it was easily detected, it is conceivable that live cover was overestimated during the predrought years as compared to estimations during the drought. However, it is also conceivable that the live plants were able to make good use of the meager precipitation.

Black grama cover was reduced to such a low level in 1954 on the deep sandy and low hummocky strata that there was not enough residual live plants for it to increase in 1955 and 1956. Generally, black grama yields are closely related to seasonal precipitation. There was not a close relationship between seasonal precipitation and yield during the drought. This is a result of below average precipitation during all the drought years and a substantial reduction in cover. Thus, both cover and species composition are important in assessing site potential.

An attempt was made to fit the vegetational data over the 17-year period into a first, second, or third degree polynomial. However, the large amount of variation among years not explained by the third degree polynomial would indicate the population cannot be well described by polynomials. It seems that if a long vegetational record were available over several wet and dry cycles, this would be an excellent method to describe these cycles. With the present data, separating out the years differing significantly by Duncan's method gave the most useful interpretation of the data.

Air temperatures were higher during the drought. For example, the maximum temperatures for July and August, 1951 were 3.5 and 1.5°C higher than the 35-year average. There were 45 days during the summer of 1951 when the maximum temperature was 38°C or higher as compared to an average of 8 days. Higher maximum temperatures were observed in all the drought years except 1955, which was about average.

A discussion of the great drought would be incomplete without mention of the severe wind erosion as a result of drought damage to the perennial grasses. On the sandy soils, large areas left bare by the drought began to erode with the ever-present spring winds. The sand would drift until it reached fences, mesquite plants, buildings, or other obstacles. Many grass plants not killed by moisture stress were killed by sand deposition.

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